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ISCRAM Asia Pacific 2022: Dealing with the Unexpected

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The second Information Systems for Crisis Response and Management (ISCRAM) Asia Pacific regional conference took place on 7-9 November 2022. This conference was originally planned for November 2021 but was postponed until 2022 due to the ongoing impact of COVID-19. The conference was delivered online via Zoom as a result of the pandemic, although there were in person venues in Melbourne for the three days of the conference at the RMIT Storey Hall and at Auckland University of Technology on the second day of the conference, Tuesday 8 November.

This event follows the first ISCRAM Asia Pacific conference that was held in Wellington New Zealand in November 2018. The conference theme was "Dealing with the Unexpected" and this has been the lived experience for everyone recently as a result of the COVID-19 pandemic.

Similar to other ISCRAM conferences, ISCRAM Asia Pacific 2022 accepted three types of papers: Completed Research (CoRe), Work in Progress (WiPe) and Practitioner Abstracts. CoRe papers are generally 8-12 pages in length and describe completed research including a description of methods, results and validation. WiPe papers are shorter, 4-6 pages, and presented work in earlier stages, outlining concepts and discussing initial results. Practitioner abstracts were sought from those who are active in all aspects of emergency management, such as practitioners or developers, so they can share their insights and knowledge. To achieve this, Practitioner Abstracts were limited to one or two pages that outlined, for example, tools, work practices, lessons learned, experience reports, case studies, known issues and so on.

There were a total of 34 accepted papers: 21 research papers, 5 insight papers and 8 practitioner abstracts. All papers were rigorously reviewed by at least 2 reviewers. There were also 11 posters. In terms of the conference programme, we tried to have a balance in terms of the time given to these different presentation categories by having parallel CoRe and WiPe paper sessions but not doing this for the Practitioner Abstracts and posters. The conference programme also included 3 keynote speakers, 3 panel sessions and 8 workshops. A field trip was planned to the Emergency Management Victoria State Control Centre for those attending in Melbourne, but unfortunately it had to be cancelled due to their activation status in response to the ongoing Victorian flood emergency.

Overall, there were 87 people registered from various countries, mostly Australia and New Zealand, but also people from 8 other countries including the United States, Mexico, Germany, Spain, Saudi Arabia, France, Sri Lanka and Ecuador.

The organizers would like to thank all participants, sponsors, authors, reviewers and the committee members. Although we were not able to hold the conference as an in-person event as originally planned, the virtual event was a success in terms of fostering the exchange of knowledge and expertise in the field of Information Systems for Crisis Response and Management.

All recorded material is available online at:
https://www.dropbox.com/sh/i34cs0h3uyd11jj/AAB6mN1sbIwEF1boLl7r8PKpa?dl=0 .

Rapid Geospatial Processing for Hazard and Risk Management using the Geostack Framework

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ABSTRACT

Operational predictive and risk modelling of landscape-scale hazards such as floods and fires requires rapid processing of geospatial data, fast model execution and efficient data delivery. However, geospatial data sets required for hazard prediction are usually large, in a variety of different formats and usually require a complex pre-processing toolchain. In this paper we present an overview of the Geostack framework, which has been specifically designed for this task using a newly developed software library. The platform aims to provide a unified interface for spatial and temporal data sets, deliver rapid processing through OpenCL and integrate with web APIs or external graphical user interface systems to display and deliver results. We provide examples of hazard and risk use cases, particularly Spark, a Geostack based system for predicting the spread of wildfires. The framework is open-source and freely available to end users and practitioners in the hazard and geospatial space.

Keywords

Hazards, modelling, simulation, data processing

INTRODUCTION

Hazard and risk models are an essential tool in planning, mitigation and operational management of environmental threats and disasters (Newman *et al.*, 2017). These generally take a broad range of forms from use of long-term climate projections for spatial predictions of local impact, to predictive natural hazard models for cyclones, floods, fires or earthquakes (Ward *et al*. 2020). Despite the breadth of domains these models cover there are commonalities between all of these applications. Specifically, these are the requirement for observed or modelled geospatial data as an input into the model, along with various parameters required, the ability to rapidly execute the model based on this input data, and the ability to provide model outputs to a downstream service or as standardized data. The requirement for rapid execution of a model can serve different purposes dependent on the model. For hazard predictions during live events, such as a wildfire or flood, the ability to rapidly understand the behavior of the hazard can guide short timescale operational management strategies such as evacuation (Simpson *et al.*, 2016). For risk predictions (including operational risk predictions) the faster a model can be executed allows both higher spatial fidelity for the model, providing greater detail, as well as allowing more scenarios to be evaluated for a more statistically complete understanding of the risk from a set of uncertain possibilities.

A number of large, well-maintained and extensively utilized open-source libraries and frameworks exist for reading and processing geospatial data. Some prominent examples are GDAL, GeoPandas, Shapely and Pangeo. Typical workflows for hazard and risk data processing usually involve these, or similar, libraries in some form (Zhu *et al.*, 2021). Geostack augments these tools by adding mid-level functionality to simplify geospatial data processing by internally managing local data resources, removing the explicit need for geospatial reprojection and spatial sampling of data. Furthermore, Geostack also maintains a small set of dependency-free data readers and writers for the most common geospatial data types, allowing minimal overhead if only these data types are used. Such libraries also usually do not provide general-purpose processing of data, for example the ability to express a given formula over the data sets, and are usually separate custom or proprietary modules.

One of the main features of Geostack is the ability to express general-purpose functional processing as *scripts* within the system. These scripts are compiled at run-time to either computer processing unit (CPU) code or graphics processing unit (GPU) code which are then run on targeted hardware. This allows data processing to take full advantage of the latest multi-core CPUs or GPU graphics cards, which typically have hundreds to thousands of times the potential computational ability of CPUs. This functionality is provided by OpenCL, which is supported by all major hardware manufactures. All scripts, expressions and solvers are run using OpenCL in Geostack, making the computation scalable over a wide range of hardware. The typical performance improvement for processing in Geostack is dependent on the exact algorithm or functions used, but our trials have found some processing can be improved from tens to hundreds of times faster than native Python implementations. Details and examples of these scripts are given in a later section.

The requirement for rapid execution of models is similarly covered by the use of OpenCL in Geostack. A number of models are provided with the framework, including hydraulic networks, level sets and particle modelling. Here we provide an example of a complete natural hazard workflow for Spark using Geostack data processing and the internal level set solver.

ARCHITECTURE

Geostack operates on three data types:

- Raster data layers, these are gridded two- or three-dimensional data sets with uniform cell spacing and optional information such as the geospatial projection system for the data.
- Vector data layers, these are sets of point, linestrings and polygon geometry elements with associated properties assigned to each element and optional information such as the geospatial projection system for the data.
- Series data, these are one-dimensional data sets composed of ordered pairs of abscissa and ordinate values.

Raster layers

The internal processing workflow for raster layers is shown in Figure 1. The input data here are two raster layers called *A* and *B*. Once named, the raster layers can be referenced in scripts using this given name. In the example show, the script simply specifies the output raster cell value as equal to the value of *A* plus the value of *B*. The language used in scripts is C90 with a wide range of additional mathematical and vector functions provided by OpenCL. Scripts can be as complex as needed and depend on any number of input layers and variables. These are compiled using OpenCL into native vectorized CPU or GPU instructions then run in parallel over all cells of the output raster. Internally each raster is broken into tiles that are loaded in memory as required and cached to local disk once user-specified memory limits are reached.

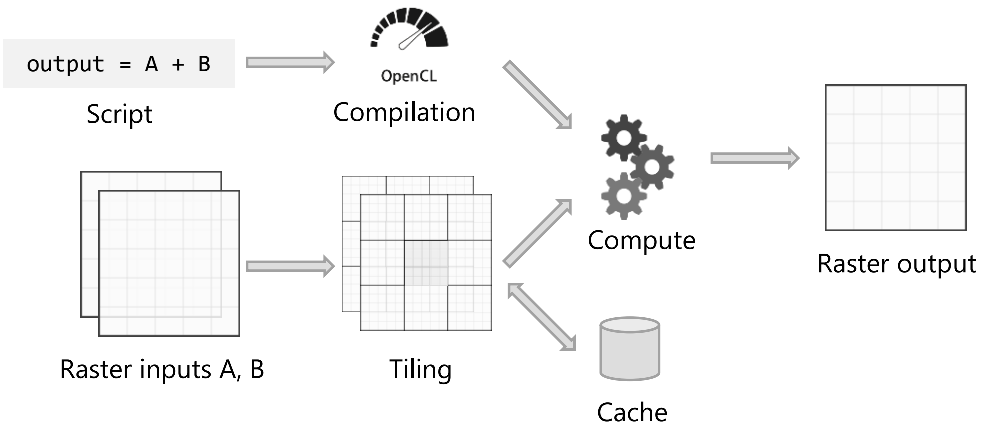
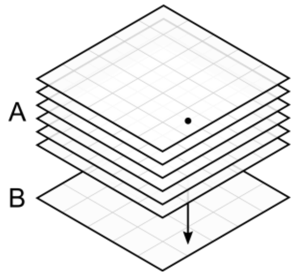


Figure 1. Internal processing workflow for raster script operations. Scripts are compiled on-the-fly by OpenCL and applied on a per-tile basis to compute a raster output.

The input rasters *A* and *B* can be any resolution or geospatial projection, with re-projection and sampling between the layers transparently handled. There are multiple options for how the output layer is created, although by default it is created to be identical in size, resolution and geospatial projection to the first raster named in the scripting function. Similarly, there are a range of options for the sampling method such as nearest-neighbor or bilinear interpolation. Outputs layers, as in the above example, do not have to be created and rasters can read and write to other rasters during processing, for example, A could be set equal to B using a script of the form $A = B$. One further feature of raster scripting is the ability to define a reduction to be carried out over each of the rasters. This performs operations including *maximum*, *minimum*, *mean*, *standard deviation* and *summation* of all values in the raster into a single value. These operations are carried out using parallel algorithms implemented in OpenCL.

Raster layers in Geostack can be three-dimensional. In this case special handling and functions can be applied over the third dimension to simplify many common operations. Figure 2 shows a 3D raster *A* and a 2D raster *B*. The minimum value can be found by looping over all layers of *A* and updating the minimum value in *B*, as in the inset script, where cell values in the third dimension can be referenced using a square bracket operator. Alternatively, Geostack contains a *sortColumns* function as well as an option to sort every column of *A* (by value in ascending order) before or after a script is run, so limits and quartiles over the column can easily be found. Testing has found that this OpenCL sort operation can be around 10-100 times faster than native sort operations. The third dimension is dependent on the application. For example, in gridded climate data the third dimension can be time and a script could be used to find projected climate extremes within the dataset. For hyperspectral analysis the third dimension may be the frequency band and script operations for frequency analysis could be used find a dominant wavenumber.




```
for (uint k = 0; k < A_layers; k++)
    B = min(B, A[k]);
```

Figure 2. Three-dimensional raster A being reduced over columns into second raster B. This can either be carried out using a script (inset) or a dedicated sort operation.

The capabilities detailed above can be used in many risk and hazard applications. Some examples include:

- Determining quartiles for climate projections from three-dimensional NetCDF data. This involves simply reading the NetCDF file using the inbuilt Geostack raster reading function, sorting the data and writing the various sorted layers.
- Rapid processing of remote sensing optical data, for example, masking, noise reduction or terrain correction. Masking of different land types can use input data layers of different resolution and projection to the remote sensing data, but implemented without needing any reprojection step. Algorithms such as noise reduction or terrain correction can be implemented using a scripting function.
- Calculation of impact cost from a natural hazard. A script implementing loss functions can be implemented based on given spatial maps of impact from the hazard and a spatial cost layer. If needed the reduction over the entire domain can be performed resulting in a single cost value using a *summation* reduction.

The Geostack library natively supports GeoTIFF, NetCDF3, ascii and binary data formats. For other formats the Geostack Python library uses the GDAL, RasterIO or NetCDF libraries as backend readers. The ability to read from a remote server through thredds is also supported. All data reads are localized, where only the tiles requiring processing are read from the underlying data, ensuring IO is minimized.

Vector layers

Vector data layers contain point, linestring or polygon geometry elements, along with associated properties attached to each element. These properties can be numbers, strings or numeric arrays. A range of common geospatial operations are provided for operations on vectors, such as sub- regioning and joining vector data sets. Functionality is also provided to convert and self-intersect vector elements, such as the example shown in Figure 3, where two polygons (left) are processed to provide a set of non-intersecting polygons.

Geostack supports script operations on vectors, where any numeric properties can be read or written to in the script. For example, a set of polygons with properties *p* and *q* could have a new property *r* added, and a script $r = p + q$ applied to populate *r*. As with rasters, these scripts are compiled to CPU or GPU code and run over multiple geometry elements in parallel.

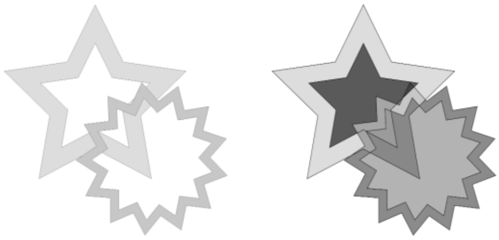


Figure 3. Example of polygon intersection using internal conversion function.

A key feature in Geostack is the ability to mix raster and vector datasets in vector scripts, allowing raster values to be sampled and written to properties in the vector. For example, if a raster *A* is used along with a vector containing a property *r*, the script *r = A* writes either a value or reduction of *A* into *r*. The rules for how the raster values of *A* are mapped to *r* are dependent on the data type of the geometry element:

- If the geometry is a point, *r* is the value of the enclosing cell of *A*.
- If the geometry is a linestring, *r* is the reduction over the cells of *A* touching the linestring.
- If the geometry is a polygon, *r* is the reduction over the cells of *A* within the polygon (that is, any cells where the central point of the cell is within the bounds of the polygon).

The reductions are the same as those for the raster scripting, and are passed as an argument to the scripting function. If the raster is three dimensional the reduction is carried out over all layers. If the reduction type is not specified, all data values are returned from each layer as a vector property.

An example use case for this type of scripting is shown in Figure 4, where the raster layer is a multi-dimensional data set containing weekly global temperature predictions for a year, and the vector data set is a set of country polygons, shown as the black outlines.

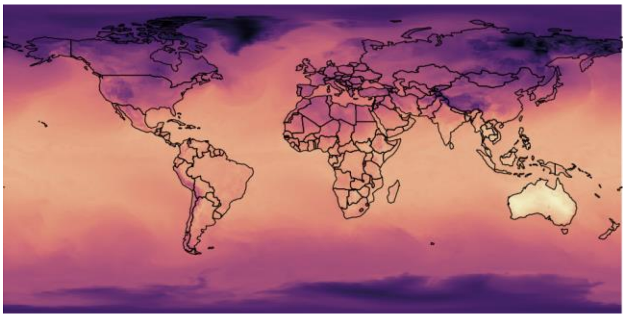


Figure 4. Slice of weekly global temperature prediction (colored layer) overlaid with country polygons. Reductions over each polygon can be carried out using a vector scripting command.

The maximum temperature over the year in each country can be found by loading the raster data for the temperature into a raster called *temp*, the vector data for the countries, adding a new property to hold the maximum temperature, *max_t*, and running a script of the form *max_t* = *temp*. The vector property for maximum temperature will then be populated for each country polygon. Altogether, the script for this in Geostack takes only a few lines of code due to the native interoperability of vector and raster data sets within the framework.

Type conversion

A range of conversion functions from raster data to vectors and vectors to rasters are also included in the framework, although a large number of tools already exist for these processes. However, Geostack provides some features of note for these operations.

To convert a vector to a raster a *rasterise* function is supplied. This takes a user-defined script as a parameter allowing the value written to the raster to be programmatically set from any numeric property. For example, a set of polygons with numeric properties *p* and *q* could be converted to a raster with the sum of *p* and *q* written at each cell within each polygon using the script *output* = *p* + *q*. Overlapping polygons can also be handled using the script and basic cumulative metrics, such as mean values or the count of polygons overlapping the cell, can be written. Another form of vector to raster conversion is a *distance mapping*, where each cell holds the Euclidian distance to the nearest geometry element. Again, an optional script allows users to determine the distance calculation and final output value in the distance map to allow more complex mappings such as spherical basis functions or inverse distance weightings to be implemented.

SPARK

Spark is a wildfire simulator, currently under development as the new national Australian prediction system. It is designed to be used for both operational wildfire simulation and management, with the requirement of much faster-than-real-time response, as well as offline risk mapping of potential fires under various climate and fire mitigation scenarios. Spark is detailed here as it is an example of a full geospatial hazard system developed using Geostack. Furthermore, the development of Spark has guided the development of Geostack at many levels, especially around the requirement for rapid data processing and the need for openness in model development and configuration. The system is built from Geostack components and comprises a set of Python scripts encapsulating the central model and a web API for interfacing with the system.

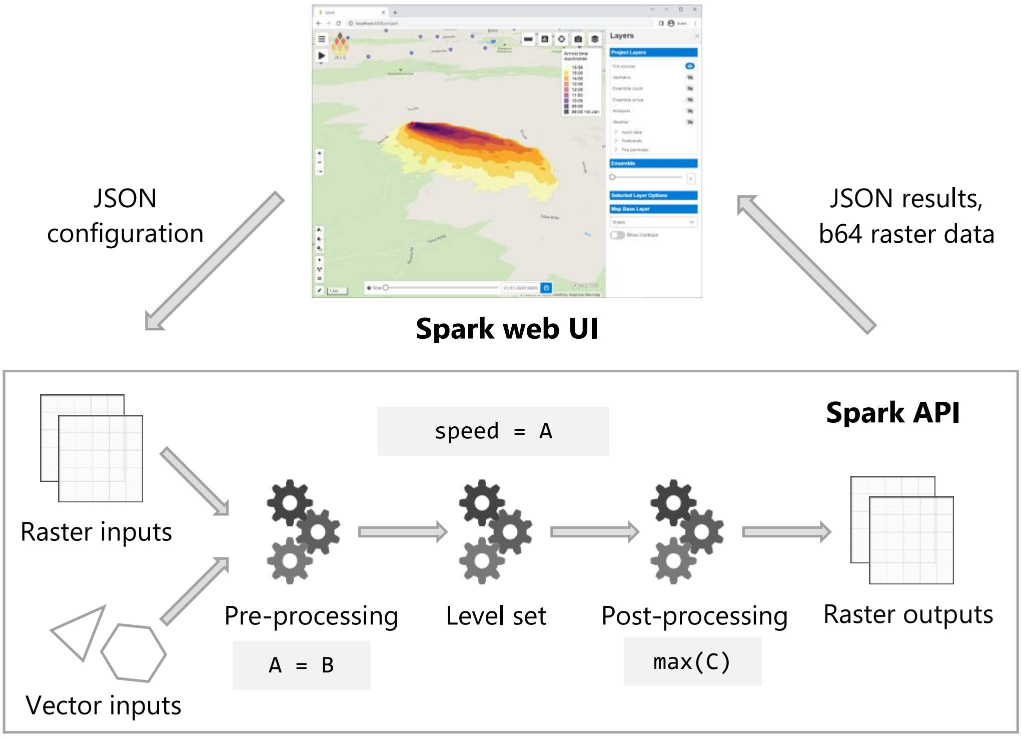


Figure 5.- Architecture of Spark configured for operational wildfire simulation and management. JSON configuration commands are sent to the Spark API, which processes data and models wildfire spread using Geostack. Output data is encoded and send back to the web UI for display.

A highly simplified architecture diagram of Spark is shown in Figure 5. configured for operational use through a web user interface (UI). The lower portion of the figure contains a schematic of the Spark API and Geostack workflow. One of the key differentiators of Spark is the ability to completely configure the simulator through plaintext configuration. All processing and wildfire spread models used for different vegetation types are defined in a JSON configuration file. This makes Spark high flexible in terms of only requiring the configuration JSON to be modified for entirely different regions (with different vegetation types and input data layers) as well as risk analysis (with different output requirements). This configuration is defined for the operational example through forms and inputs in the web UI, which are then encapsulated as a series of calls to the Spark API with JSON payloads. These define both the processing and models, though plaintext scripts, as well as data sources (raster inputs), wildfire sources and firebreaks (vector inputs), variables and time series. The input layers are used in a pre-processing step before being passed to a generic perimeter spread model based on a level set solver (Osher and Sethian, 1988). When the simulation is complete, an optional post-processing step is carried out such as finding maximum wildfire intensities or summing losses over affected areas. Finally, for the operation system, simulation information including the raster outputs are encoded as base64 text and send via the API for display in the web UI.

Basing Spark on Geostack provides several benefits, including:

- The accelerated geospatial data processing described in earlier sections. The transparent reprojection and sampling of spatial and temporal data places no data pre-processing requirements on the end user. In addition, the flexibility of the system allows any raster file formats to be used, and data sources can be swapped easily in the configuration from local files to remote data services.

- The ability to accelerate the computational modelling using OpenCL. The level set model is highly parallelizable and well-suited to OpenCL vectorization. The scripting paradigm described in the earlier sections are also applied to all solvers within the Geostack framework. For the level set solver, the calculation of the outward speed of the fire is defined using a script, allowing a record of the exact model run for each fire to be stored with the configuration for post-wildfire auditing and provenance. This also allows new wildfire spread models to be easily tested and deployed in the framework without the requirement of a full platform update, as the models are defined and encoded outside the Spark system. The Spark and Geostack framework also contain a Lagrangian particle model with a similar scripting system, used for firebrand and spot fires within Spark.
- The tile-based system. This is heavily utilized by the level set model, ensuring the model is run only within tiles spatially bounding the wildfire perimeter. This reduces computational costs and means a maximum domain size does not have to be determined in advance of the wildfire simulation. As previously discussed, the use of tiles also significantly saves data IO, which is a major bottleneck in such systems as IO time usually greatly exceeds the computational calculation times.
- The modular Python-based system, allowing common OS components to be used in the API.

The workflow and framework described above could be applied to many other hazards, and implementing such frameworks is a future focus for our group.

CONCLUSION

Geostack has been developed as an end-to-end geospatial data processing and modelling system. The emphasis in Geostack is on flexibility and ease of use for hazard modelers and data scientists in the geospatial domain, and to provide straightforward access to modern accelerated computer resources (such as graphics processing units and multi-core CPUs) though a transparent framework. All scripts expressed in the system are compiled into highly optimized and vectorized code, without user intervention or configuration, and run directly on these hardware units providing significant acceleration in some cases. The system also includes a growing range of geospatial models such as a perimeter spread level set model and Lagrangian particle model, both used in the Spark framework for wildfire prediction.

The system is currently under development as new use cases and models are explored. The library is available as an open-source project (Geostack, 2022), to which we freely welcome member of geospatial hazards community to use, trial and contribute. The library is also available as a Conda package for Python and has been developed to be interoperable with many common Python libraries including NumPy, GDAL, RasterIO, NetCDF and SpatialLite. We hope our contribution of this library is useful to the hazards community and helps the development of future systems to model, understand and mitigate natural hazards.

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SEEKER: A Web-Based Simulation Tool for Planning Community Evacuations

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ABSTRACT

Bushfires cause widespread devastation in Australia, one of the most fire-prone countries on earth. Bushfire seasons are also becoming longer and outbreaks of severe bushfires are occurring more often. This creates the problem of having more people at risk in very diverse areas resulting in more difficult mass evacuations over time. The Barwon Otway region in Victoria's Surf Coast Shire is one such area with evacuation challenges due to its limited routes in and out of coastal areas and its massive population surges during the tourist season and holiday periods. The increasing gravity of the bushfire threat to the region has brought about the Great Ocean Road Decision Support System (GOR-DSS) project, and the subsequent development of a disaster evacuation tool to support emergency management organisations assess evacuation and risk mitigation options. This paper describes the design and development of SEEKER (Simulations of Emergency Evacuations for Knowledge, Education and Response). The SEEKER tool adds another level of intelligence to the evacuation response by incorporating agent-based modelling and allows emergency management agencies to design and run evacuation scenarios and analyse the risk posed by the fire to the population and road network. Furthermore, SEEKER can be used to develop multiple evacuation scenarios to investigate and compare the effectiveness of each emergency evacuation plan. This paper also discusses the application of SEEKER in a case study, community engagement, and training.

Keywords

evacuation modelling, emergency management, decision support systems, agent-based simulation

INTRODUCTION

Bushfires cause widespread devastation in Australia, one of the most fire-prone countries on earth. The 2009 Black Saturday bushfires in Victoria burnt 430,000 hectares of land and resulted in the death of 173 people. Deloitte estimates the tangible costs of the Black Saturday fires to be AUD3.1 billion in 2015 dollars and the intangible costs at around AUD3.9 billion resulting in a total cost of AUD7 billion (Read and Denniss, 2020). The 2019-2020 Australian Black Summer bushfires, designated as a megafire, burned an estimated 18.4 million hectares, destroyed 9300 buildings and homes, and killed 34 people. During the ensuing firefighting operations, an air tanker, two helicopters and two fire trucks were involved in fatal incidents resulting in the death of three crew members and three firefighters. These fires, which burnt 25 times the corresponding area in the Black Saturday fires, is estimated to cost up to AUD88 billion making it Australia's costliest disaster. (Wikipedia, 2022).

Unfortunately, the bushfire risk for communities is increasing due to growing populations in high-risk, wildfire-urban interface (WUI) areas and a trend to higher daytime temperatures coupled with lower humidity and higher evaporation rates. Bushfire seasons are becoming longer, and outbreaks of severe bushfires are occurring more often (WFI, 2022). Studies have shown that natural disasters, in general, have been increasing in frequency and intensity over the past few years (Hooke, 2000; Newkirk, 2001). In addition, the increasing concentration of population in urban areas is exceeding the capacity of transport networks to move these people during times of disasters (Plowman, 2001; Barrett et al., 2000). The dynamic requirements of mass evacuation have caused research on evacuation and emergency management to receive more attention in recent years resulting in numerous evacuation models being developed (Xiongfei et al., 2010).

The Barwon Otway region in Victoria's Surf Coast Shire is one such area with evacuation challenges due to its limited routes in and out of coastal areas and its massive population surges during the tourist season and holiday periods. The increasing gravity of the bushfire threat to the region has brought about the Great Ocean Road Decision Support System (GOR-DSS) project to develop a disaster evacuation tool to support emergency management organisations assess evacuation and risk mitigation options. The delivery of this capability is expected to inform future policy and strategies on preparation and risk mitigation activities for emergencies in the entire state (Fairnie, 2017). This paper describes the design and development of the project's bushfire evacuation support tool SEEKER which stands for **S**imulations of **E**mergency **E**vacuations for **K**nowledge, **E**ducation and **R**esponse. This paper will also present and discuss results from the application of SEEKER in a case study, community events, and training.

SEEKER STRUCTURE AND COMPONENTS

SEEKER is a decision support system or DSS designed to help key people in emergency management to make safer and more informed decisions regarding evacuations. The ability to model different scenarios will assist emergency management organisations to develop robust community evacuation plans and evaluate risk mitigation options. The DSS is expected to allow trained emergency management to:

- Carry out a preliminary analysis of the potential impact of a predicted wildfire on a road network
- Design an evacuation scenario to be simulated
- Run an evacuation simulation; and
- Visualize the outcome of the simulated evacuation and produce summary results.

Transport and Behavioural Components

SEEKER uses an open-source transport simulation software called MATSim (Multi-Agent Transport Simulation) to simulate the evacuating traffic (Singh et al., 2019). In addition, a behavioural model called BDI (Belief-Desire-Intention) is used in conjunction with MATSim to provide the agents with a certain degree of "intelligence" intended to capture, in an idealised way, the complexity of human behaviour in an emergency situation and more specifically under the threat of a hazard. To implement this integration, each agent is split between two systems - the cognitive part in the BDI system, and a physical part in the agent-based modelling (ABM) system, as shown in Figure 1. The BDI component provides the "brain" where all decision making is performed while the ABM component provides the "body" where all actions are carried out. These two systems work synchronously as a single BDI-ABM engine passing information about actions, percepts and the status of actions (Singh et al., 2016).

The behavioural model for the individuals in the evacuating population is shown in Figure 2 and described in Singh et al. (2021). To represent and code these behaviours, we use the Belief-Desire-Intention (BDI) model of rational decision-making, underpinned in folk psychology, and for which several mature software implementations exist today (Bordini et al., 2020). A BDI agent is described by (a) its beliefs about its world, factual or assumed; (b) desires or goals, possibly even conflicting with one another, that it may care to achieve, and; (c) intentions, that are goals that it has committed to achieving using some plan of action.

Programmatically, for every conceivable goal (ovals in Figure 2), such as the high-level goal Response against bushfire threat, that an agent is designed to achieve, we supply one or more plan options (boxes), such as plan FullResponse. In this way, we say that a plan is *relevant* for achieving a goal by design, where each plan is a recipe, or steps to achieve the goal prescribed by the programmer based on domain knowledge. For instance, the FullResponse plan of the agent consists of the step InitialResp(onse) followed by the step FinalResp(onse). The acute reader will note that these steps are in fact goals! Each with its own plan options, structured in a hierarchical fashion (a goal-plan tree).

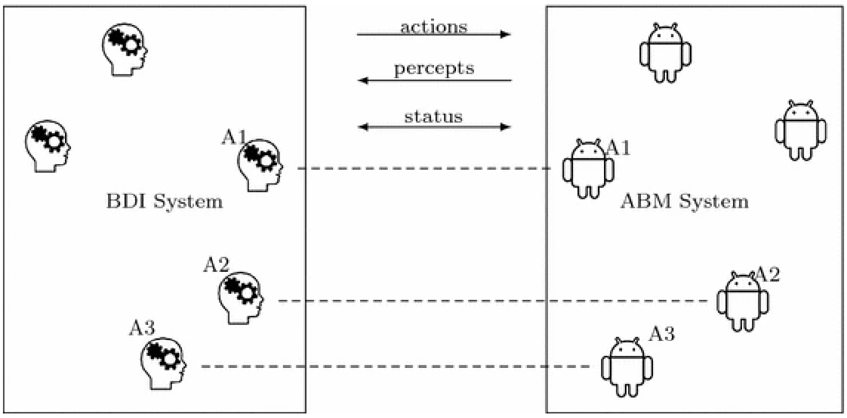

Figure 1. Conceptual BDI-ABM integration architecture

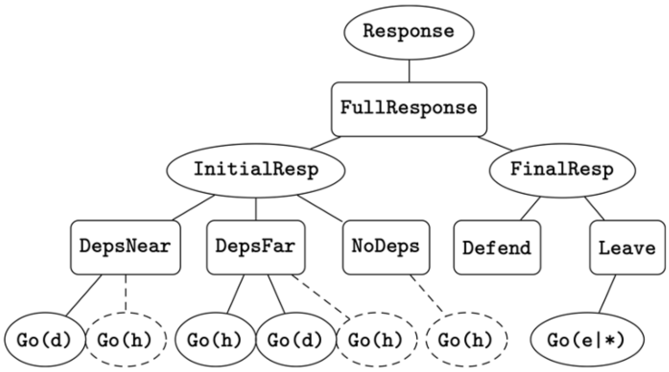

Figure 2. Sample goal-plan tree for evacuation response

To complete a plan, an agent must perform each step. In contrast, to achieve a goal, the agent need only select and complete one plan from the available plan options. Which of several relevant plans actually gets used by the agent to achieve the goal will depend on the run-time context at the moment of deliberation. Technically, relevant plans that can also be used in the moment are called *applicable*. For instance, to achieve its initial response (InitialResp), for an agent with dependents at a location (d) closer than its home (h) at the time of deliberation, the plan DepsNear (that requires going to that location (Go(d)) followed by possibly (dotted oval) going home (Go(h)) will apply, over plans DepsFar, that applies when home is closer than the dependent's location, and NoDeps, that applies if the agent has no dependents to attend to at all.

The goal-plan tree of Figure 2 offers a compact visual representation of behaviour that is relatively intuitive and easy for domain experts to follow and critique, but can also be directly translated to software code, and can serve as a common language between domain experts and programmers, minimising risk in translation of behaviours from knowledge to code. The goal-plan tree captures the deliberation process of an agent and therefore, the eventual observed actions of agents (performed as steps in leaf-level plans) over time can be *explained* by tracing them back to the thought process and the context in which those decisions were made.

Finally, the goal-plan tree while compact, captures a richness of variability in behaviour, depending on what path the agent takes down the tree toward eventual action. For instance, an agent at work who has no dependents (beliefs) may decide to wait-and-see (path Response::FullResponse > InitialResp::NoDeps) or go home (Response::FullResponse > InitialResp::NoDeps > Go(h)::driveTo(h)), then eventually (based on other triggers, such as perception of the fire or reception of official emergency warnings) decide to leave to the evacuation place (e) (Response::FullResponse > InitialResp::NoDeps > Go(h)::driveTo(h) > FinalResp::Leave > Go(e)::driveTo(e)), where driveTo() is the leaf-level observed action of the agent driving to a given location. Different reasoning pathways will apply to agents that have dependents to attend to.

One final source of variation is BDI's failure recovery reasoning. When, for instance, an agent that is driving to an evacuation destination encounters an unforeseen situation, such as a road overrun by fire and no longer passable, its driving plan *fails*. In this case, the agent, following new deliberation, may choose a different plan to reach the goal destination via an alternative route, or, failing that, choose a different destination altogether. Overall, then, the same compact goal-plan tree can produce very different heterogenous behaviours scattered over time.

Input Data

SEEKER is being developed to plan for evacuations resulting from a host of natural and man-made hazards, including bushfires, flooding, cyclones, storm surges, and terrorist events. The front-end of the SEEKER software has the ability to load, store and manipulate the inputs required to run a simulation. As illustrated in Figure 3, SEEKER assembles the inputs to produce all the information needed to define an evacuation scenario, then calls on the integrated BDI-ABM engine to run the simulation and produce outputs, which are then loaded into a map canvas for visualisation and analysis.

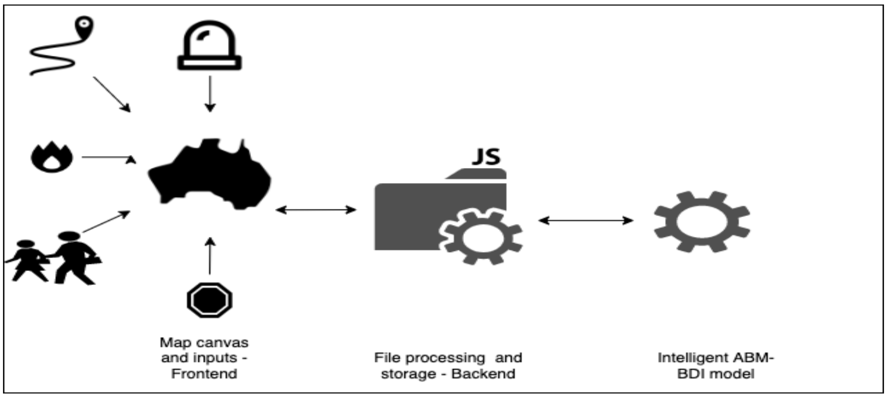

Figure 3. Map canvas and inputs used by SEEKER

SEEKER uses a map-based canvas to load and visualise the input data as vector layers. These vector layers can be in the form of Mapbox tiles or GeoJSON files. SEEKER needs the following data to define an evacuation scenario:

- Region – zoning and transport network data on the evacuation region to be simulated. Three regions are currently available (Surf Coast Shire, Mount Alexander Shire, Yarra Ranges Shire).
- Fire – spread data (location, intensity, direction) on the fire event to be simulated
- Population – description (location, demographics, activities) of the population to be evacuated
- Ignition time – time when the fire event starts
- Evacuation plan – description of messaging and time management options selected

From the selected region, SEEKER will set up the pre-defined activity zones. Fire and population files available for the selected region will then be loaded to the interface for the user to select. Evacuation messages and traffic points can also be added to the scenario set up using the client interface. The following sub-sections provide detail on the input data and output produced.

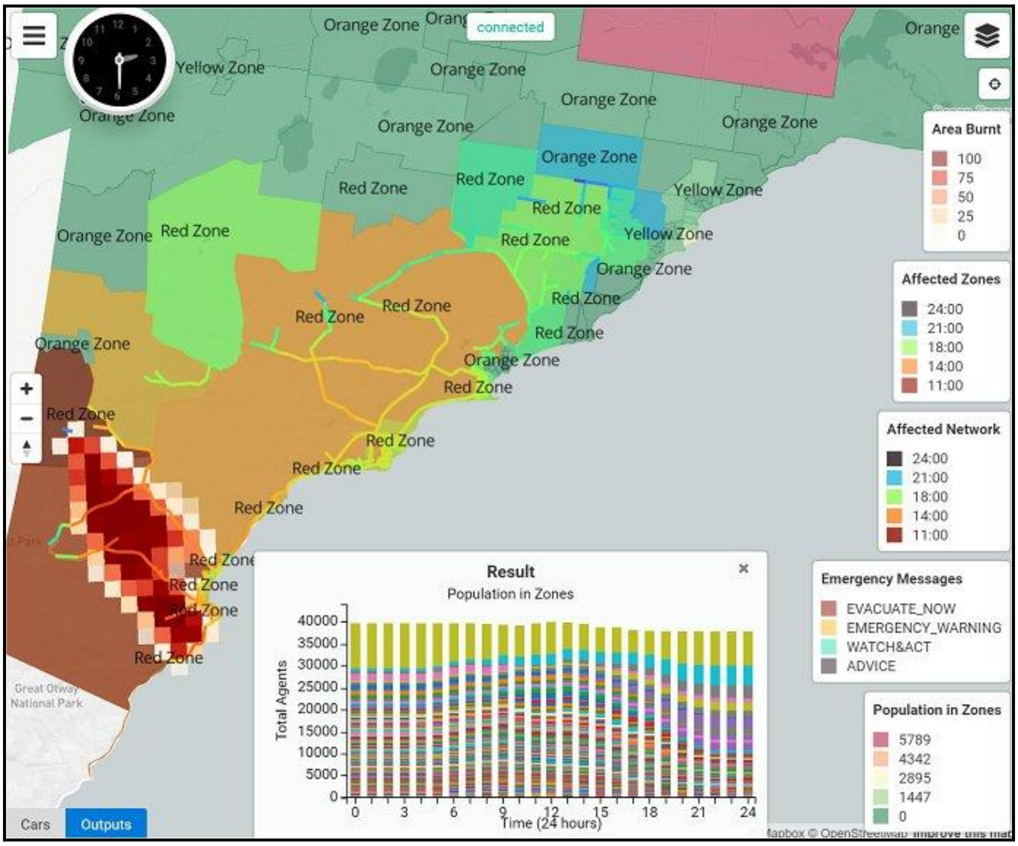

Figure 4. SEEKER window showing simulation status at 14:30

Fire

SEEKER takes as input, simulated fire progression outputs from Phoenix RapidFire (provided as ESRI shapefiles and converted into GeoJSON format for consumption), for an ignition point in a region of interest, for chosen weather parameters, and under certain fuel load assumptions. The Phoenix fire file (GeoJSON) contains a collection of features, where each feature has a polygon-type geometry (square) defined by a set of latitude and longitude coordinates. One feature represents one fire cell. Each fire cell is 180 m^2 in area. Time is denoted using a 24-hour format where, for example, 13:45 or 1345 HRS is used to refer to 1:45 pm.

In the map canvas, the colour of the fire is dependent on the intensity of each fire cell. The fire will be animated based on the time each fire cell was burnt. As the fire progresses, the burnt fire cells will stay on the map canvas to demonstrate the extent of the fire. The lower left section of the map in Figure 4 shows the extent of a fire event at 14:30 after it ignited at 11:00. The colour of the pixels indicates the intensity of the fire as shown in the legend for Area Burnt.

Road network

The road network is a graph representation of the roads, capturing the major and minor roads of interest for egress during evacuations. It is a connected graph, allowing agents in the simulation to find routes from any given location on the map to another, along the network links. Relevant road attributes like speed limits and number of lanes impact overall traffic flows, and contribute to estimates of traffic congestion in the network during mobility simulation performed using MATSim. The road network used by the SEEKER software is automatically extracted from Open Street Map, and adjusted based on local expert knowledge using JOSM (Java Open Street Map software). In the SEEKER web interface, the road network is presented using tiles, allowing the level of detail visible at different zoom settings to be automatically adjusted, giving an uncluttered and context aware experience to the end user. Figure 4 shows the major links in the road network displayed in the colour corresponding to the time of impact of the fire as shown in the legend for Affected Network.

Population

A synthesis algorithm is used to generate an example population dataset for each region (Robertson et al., 2021). This algorithm uses CENSUS, VISTA and region-specific population data to build the example population. The population is categorised into sub-groups (full time residents, overnight visitors, etc.), with locations classified based on their suitability for certain activities (home, work, beach, shop, etc.). SEEKER renders this data into the map canvas as a point layer where the points on the map will be coloured based on the activity an agent is expected to perform at a certain location and time. The layer for the population in zones is at the bottom of the map in Figure 4 so the distribution of the population among the zones is not visible from the window. However, the SEEKER window provides a bar chart of the population in zones by hour.

Evacuation zones and messages

SEEKER uses spatially defined zones to send out emergency messages to the synthetic population within each zone at specified times during the simulation. Such zones could represent population densities (e.g., Statistical Area Level 1 (SA1)), or represent administrative boundaries for the emergency services. SEEKER uses the unique zone ID to determine the spatial extent to send a given messages to. Agents within that extent at the time will receive the message. This aspect can also be configured, so that only a proportion of the agents in the area will actually become aware of the messaging, to more closely resemble real-world situations.

SEEKER identifies standard evacuation messages used by authorities in Victoria. These messages can be of type: ADVICE, WATCH AND ACT, EMERGENCY WARNING and EVACUATE NOW.

A single message must contain:

- A message type
- The time of the message
- Zone identification
- Message content (for EVACUATE NOW messages, this can include recommended evacuation destinations)

A single message can be sent to multiple zones. The zone identification can be a string or a number and will be defined in the model configuration file. These emergency messages will be saved as a JSON object and will be sent to the server at the time of the model execution. The scenario in Figure 4 includes the broadcast of the message EVACUATE NOW to all zones at 12:15. The thematic map of the messaging is not visible as it is under the other layers.

Traffic management points

In an event of an emergency evacuation, authorities may activate manned traffic management points at key intersections to direct traffic in certain directions and/or away from other directions. These are effectively implemented in SEEKER as time-sensitive changes to road conditions impacting speeds or flow rates on specified road links. Specified changes must contain a start time, end time and an identification number of the impacted network link. Traffic management points can be added to the map canvas and are coloured in red. The user is presented with a dialog box to enter details of each traffic management point. Similar to the emergency messages, these traffic management points will be saved as a JSON and sent to the server at the time of the model execution along with other configuration files. No traffic management options were used in the scenario in Figure 4.

Outputs Produced

The SEEKER backend outputs a file which contains details of activities performed by the agents from the start to the end of the simulation. The output files contain fields the describe the actions that were taken by agents, the time when each action was taken and where it was taken. SEEKER can process this data and produce a number of informative maps that can be used to evaluate the evacuation scenario. The thematic maps shown in Figure 4 illustrate some of these metrics. Furthermore, the model will output the routes taken by each agent along with their timestamps - SEEKER uses a third-party library called “DeckGL” to animate the agents on the map.

Car simulation

Currently in the model, people and vehicles are not separate, and effectively each agent represents a vehicle containing one person or household. In future work, we aim to add this separation using a pedestrian model, so that walking to/from vehicles as well as assignment of multiple persons to vehicles can be achieved.

As the main output, SEEKER demonstrates the routes taken by an agent during the evacuation. These agents will be rendered to the map canvas using the Trips layer provided by the DeckGL library. The output Trip files contain information of the path, the timestamps and traffic conditions that each agent faced during the evacuation. The Trip layer will render each agent on the map using their initial coordinates (in Latitude and Longitude format). Agents will be coloured in green, orange or red corresponding to the traffic conditions of go, slow or stop. A timer will be used to iterate the agents on the map whereby each agent will be moved to their next coordinate when the timer moves from the initial timestamp to the next timestamp. Figure 5 shows the animation window for viewing the simulated movement of vehicles along the road network for the selected evacuation scenario. The animation can be played, paused, moved forward or backward by using the controls at the bottom of the window.

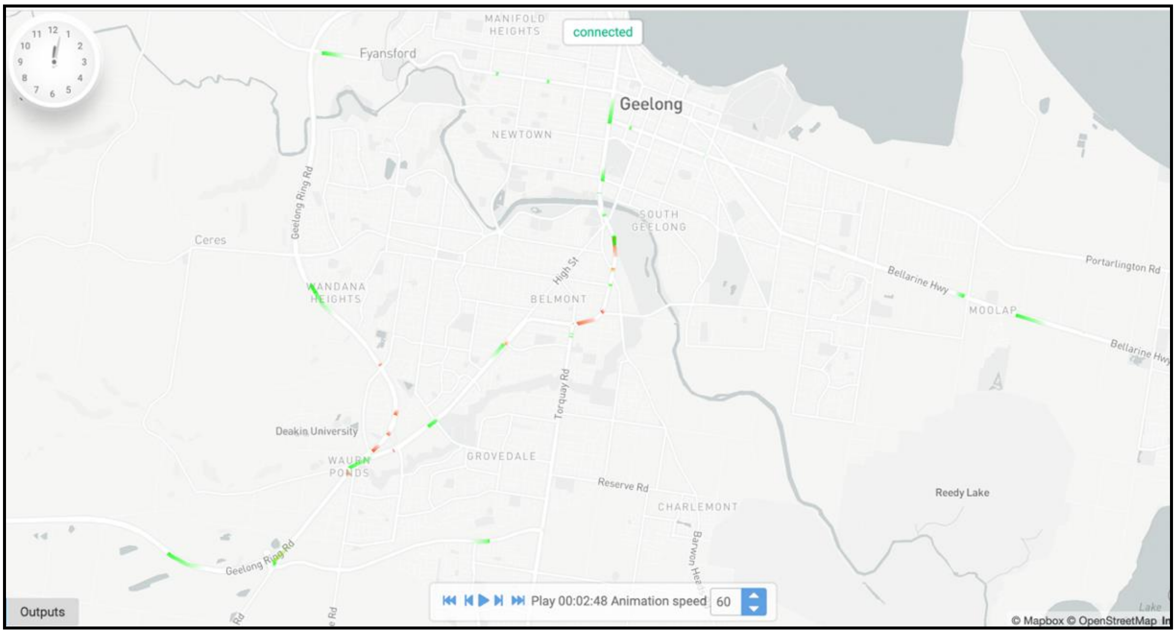

Figure 5. SEEKER car simulation example in Surf Coast Shire area

Affected Network

The main aim of this layer is to visualise the roads that were impacted by the fire. This is a basic intersection between Phoenix fire cells and the nodes of the road network. In addition, SEEKER provides further information about the affected network through this layer:

- The time that the road network gets overrun by the fire
- Total number of people on that road at the time of impact
- The number of people who received the emergency messages

Population in Zones

SEEKER software also has the ability to render geospatial data based on the user's selection of a time series. By default, the software will load the first timestamp data to the map canvas. Thereafter, the user is given control to change the time leading its respective data to change accordingly. Time will be displayed in both a digital and an analogue clock.

The population in a zone layer contains the number of people in each zone from the start of the evacuation to the end. This allows a user to investigate how the population of each zone reacts throughout the entire simulation. This data can be filtered based on aspects such as the total number of people in each zone, the number of people that were driving or the number of people engaging in other activities.

Network Traffic

This layer visualises the same information as the population in a zone layer but using the road network links as the primary indicator. This layer can be used to observe the traffic in different parts of the road network.

Reduced speeds due to poor visibility is an important concern in evacuations. Smoke modelling however is a complex task and not often provided with the fire progression model. If it were, then the progressing smoke front could directly be used to determine road links where speed reductions should be assumed over time. We have had several conversations with emergency stakeholders on whether sensible assumptions about visibility can be derived purely from the fire front information when smoke modelling is not included. Consensus had been that too many variables impact smoke progression cannot be derived from the fire front. Therefore, determination of where visibility is reduced should be made, judiciously, by end user experts when constructing the evacuation scenario. This understanding should then be entered into SEEKER as a relative degradation to maximum speeds on all roads to account for widespread smoke effects.

Area Burnt

This layer is similar to the input fire layer. The output area burnt by the fire is aggregated into grids of 1km^2 area to simplify the visualisation.

Moreover, all the outputs can be downloaded in JSON (JavaScript Object Notation) and CSV (Comma-separated values) format. These JSON files can be loaded to other available Geospatial data processing software and CSV files can be loaded to CSV viewers such as Microsoft Excel for further analysis and filtering.

SURF COAST SHIRE CASE STUDY

The communities in the Barwon Otway Region face a huge challenge in planning and managing large scale evacuations due to the large populations involved and limited infrastructure available. The Great Ocean Road (GOR) provides the main route in and out of the region making the population particularly susceptible in the event of a bushfire. The Great Ocean Road is a 243 km stretch of highway along the south-eastern coast of Australia, connecting the Victorian towns of Torquay and Allansford on both ends. The road is important for the tourism industry, as it provides access to the most popular attractions of the Surf Coast and the Shipwreck Coast including the London Arch, Twelve Apostles, Loch Ard Gorge and the Grotto. The heaviest traffic occurs at the height of the tourist season which is also the height of the bushfire season. Much of the road runs through forest, creating risks for people who travel through the area. The Great Ocean Road is also the only main road connecting several of the highest-risk towns in Victoria such as Anglesea, Lorne, and Aireys Inlet.

Evacuation Scenarios

The demographic, cultural and geographic characteristics of the Barwon Otway Region has made it one of the most visited areas of Australia featuring historic towns, popular festivals and events, and scenic attractions, while also remaining as one of the areas with the highest risk of bushfires in the country. In the Surf Coast Shire alone, the official population is 28,282 based on the 2016 census, but this swells to over 85,000 people during peak visitation periods. Adding to the complexity of evacuation planning, the location of people in the area varies depending on the time and day (i.e. weekend or weekday) and the bushfire threat may limit the availability of evacuation routes. The DELWP conducts fuel management activities enhanced by comprehensive traffic management plans for the area to reduce the risk of bushfires and other emergencies to road users. However, modelling by the Barwon Otway Risk Landscape Team shows that, in the Otway Fire District, the public land fuel management strategy (i.e. managed burns) can only mitigate risk by up to 40%, leaving a residual risk of 60% (DELWP, 2015). To mitigate this residual risk, it is crucial for emergency management organisations to possess the ability to model different scenarios for the Barwon Otway Region to develop robust community evacuation plans and to evaluate alternative risk mitigation options.

The scope of the GOR-DSS project provides for the application of SEEKER to explore different scenarios in order to investigate issues, such as:

- the impact on community evacuation times and options of different fire scenarios generated using third-party bushfire simulators;
- the impact of fire mitigation strategies on fire propagation and in turn community evacuations;
- the impact of infrastructure investments on improving evacuation performance; and,
- the potential impact of new developments or increases in population on evacuation preparedness.

The succeeding sections describe the results of a case study on the Barwon Otway Region where SEEKER simulation runs were completed for two evacuation scenarios described as follows:

1. S1 – A selected bushfire event is set to ignite at 11:00 on a representative summer weekday in the Barwon Otway Region. A synthetic population of 39500 people is generated for the 186 zones specified in the region. A representative road network is loaded for the Surf Coast Shire. The agents in the population are allowed to evacuate at their own discretion. There is no messaging or traffic management in place.
2. S2 – Identical to scenario S1 but with the "EVACUATE NOW" message sent to all regions at 12:15.

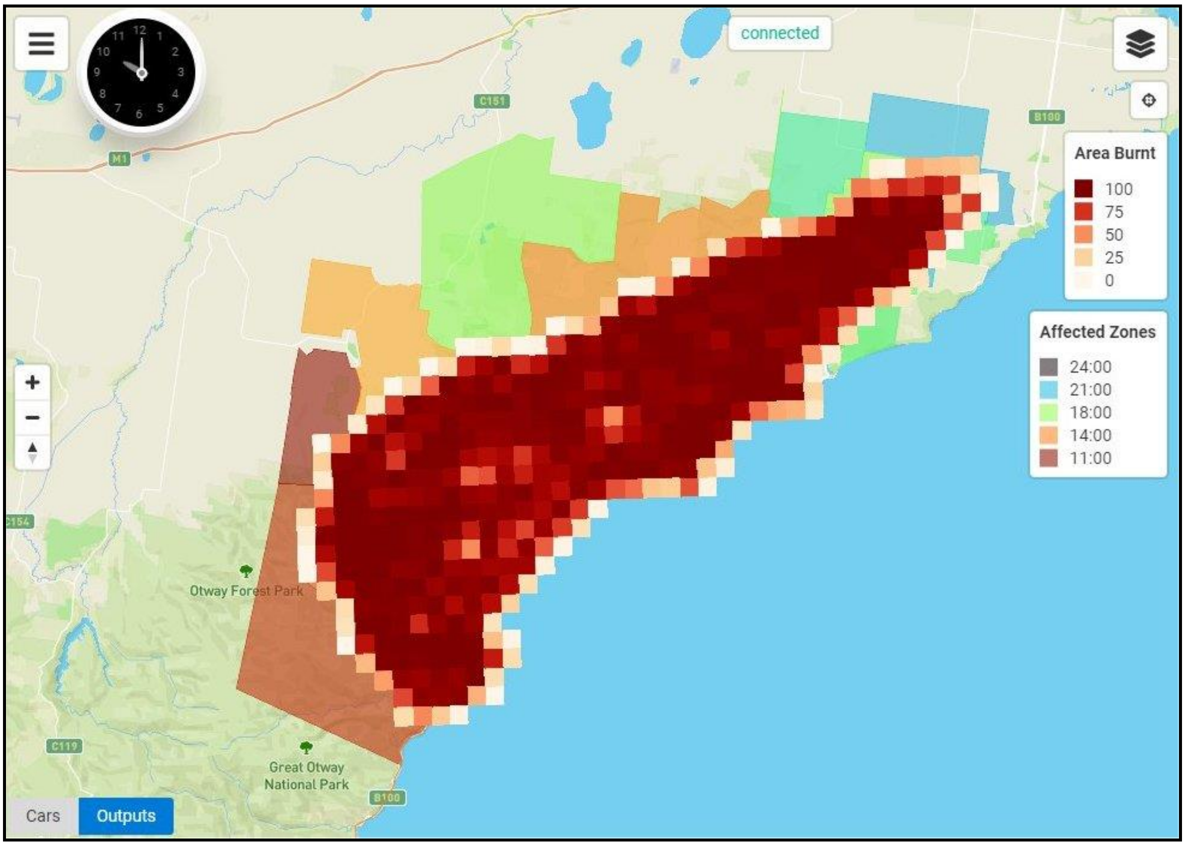

Figure 6. SEEKER window showing coverage of bushfire and time of impact on affected zones

Fire Simulation

Figure 6 displays the SEEKER window showing the timing and extent of the bushfire event while Figure 7 shows the location of the major towns and cities along the coastline.

The simulated bushfire event is loaded using the file DSSrun2_grid and starts at 11:00 from a point with coordinates longitude 143.881 and latitude -38.451. The bushfire burns for 12 hours and covers an area of around 366 sq. kms, as shown in Figure 6. The extent of the bushfire damage is mapped according to the percentage of the area burnt from no damage (0% burnt) to total damage (100% burnt)

Figure 6 also shows the time of impact of the bushfire on the different zones. The point of ignition is located in the zone impacted at 11:00 and the bushfire then moves south and then northeast. The town of Lorne is impacted at around 13:00 while Aireys Inlet and Anglesea are affected around 14:00. The towns of Bellbrae and Torquay are moderately affected by the bushfire at around 21:00.

Population in Zones

Figure 7 shows a SEEKER window with a map of the simulated population in the zones at 12:00 on a representative summer weekday. The brown-shaded areas represent zones with populations of 500 or more while the green-shaded areas represent zones with populations below 250. Aireys Inlet and Anglesea are surrounded by brown-shaded zones while Torquay and Bellbrae also have a number of high population zones close by. Note the large area of highly populated zones close to the ignition point of the bushfire. This ignition point, indicated by the burnt area on the map, is about 10 kms northwest of Lorne and less than 3 kms from the nearest brown-shaded zone.

Figure 7 also shows a map of the road network with the major links shaded according to the time when the link is cut off by the bushfire. Thus, the links close to the ignition point are mostly shaded brown (11:00) while those connecting Aireys Inlet and Anglesea are shaded close to orange (14:00). Links leading to Torquay and Bellbrae are shaded mostly in green (18:00) and blue (21:00).

Figure 7. Population in zones at 12:00 and time of bushfire impact on major road links

Congestion in Links

The simulation of traffic movement for scenario S1 was performed for the entire day, from 00:00 to 11:00 with regular everyday traffic, and from 11:00 to 24:00 with traffic impacted by the bushfire event. Figure 8 shows the maximum volumes observed on the links of the road network for 30-minute periods occurring between 11:00 and 24:00. As the legend shows, the colour and width of the links indicate the range where the maximum number of vehicles was observed. The highest volumes occur along the Great Ocean Road which is the coastal highway connecting Torquay with Lorne. The most significant points of congestion on the Great Ocean Road occur on links near Lorne and Anglesea. This means that the Great Ocean Road remains the principal corridor of evacuation for populations in the Surf Coast Shire and that serious traffic management issues need to be addressed in order to keep traffic flowing along this corridor during a disaster event.

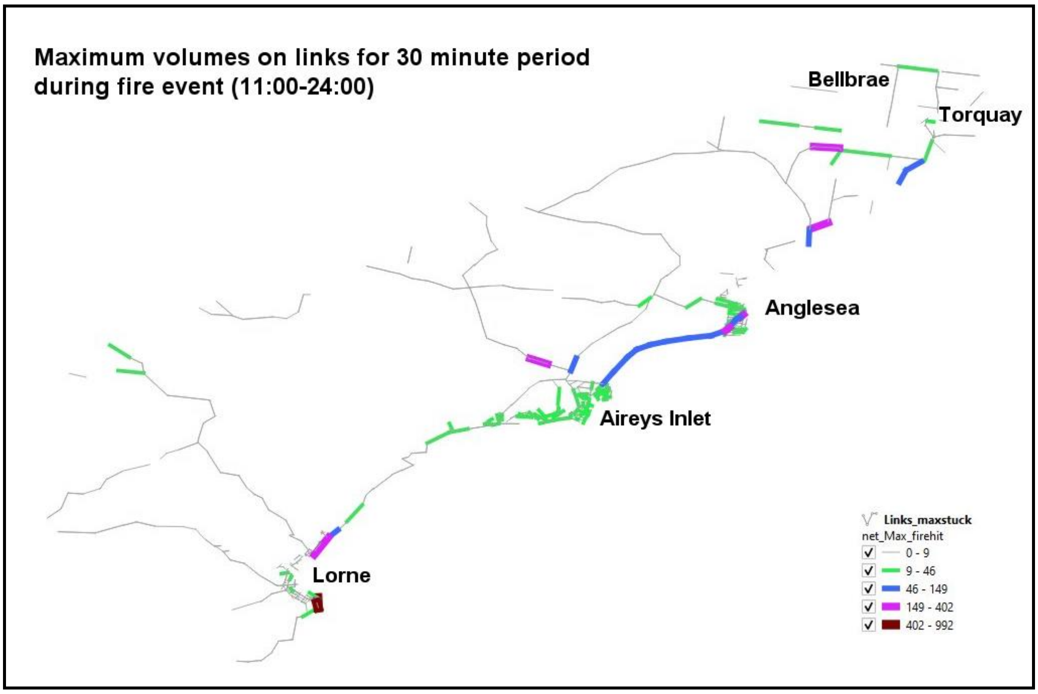

Figure 8. Potential points of congestion on the road network during the bushfire event

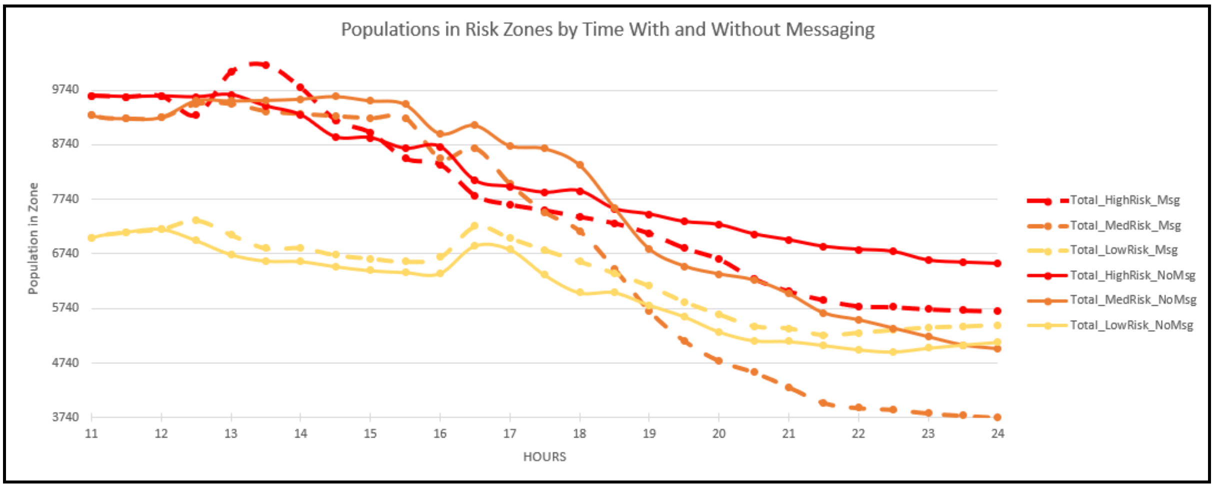

Figure 9. Total population in risk zones at each half hour during evacuation with and without messaging

Population at Risk

The movement of the population during the bushfire event means that there is a continuous change in the size of the population at risk. The change in the population in a risk zone comes from the departures from the zone and from arrivals or transients from other zones. SEEKER tracks the population in zones at half hour intervals so the aggregate population within the three risk categories can be compared and analysed.

Figure 9 shows a chart of the total messaged and non-messaged population in each of the three risk categories at half-hour intervals from 11:00 to 24:00. For the high-risk (Red) zones, the population declined from 9639 to 5688 for the messaged group and 6559 for the non-messaged group. For the medium-risk (Orange) zones, the population went down from 9290 to 3744 for the messaged group and 4995 for the non-messaged group while for the low-risk (Yellow) zones, the population decreased from 7029 to 5437 for the messaged group and 5123 for the non-messaged group. This means that the non-messaged group had at least 16500 at some level of risk during the bushfire event while the messaged group only had 14700.

The reasons for staying within the risk zones during the bushfire event are many and varied, and can include staying to defend the property, having insufficient time to leave safely, or being unable to leave because of transport or traffic problems. Whatever the reason for staying, there will be a significant portion of the population that will remain in the risk zones which means that emergency planning should include provisions for establishing and managing safety areas within the risk zones during a bushfire event. The results of scenario S1 shows that given an extremely large influx of visitors and transients to the Surf Coast Shire coupled with its unique geography and transport infrastructure, the complete evacuation of the population from risk zones during a bushfire event may be difficult to achieve which implies that alternative provisions for sheltering in place should be added to the emergency plan.

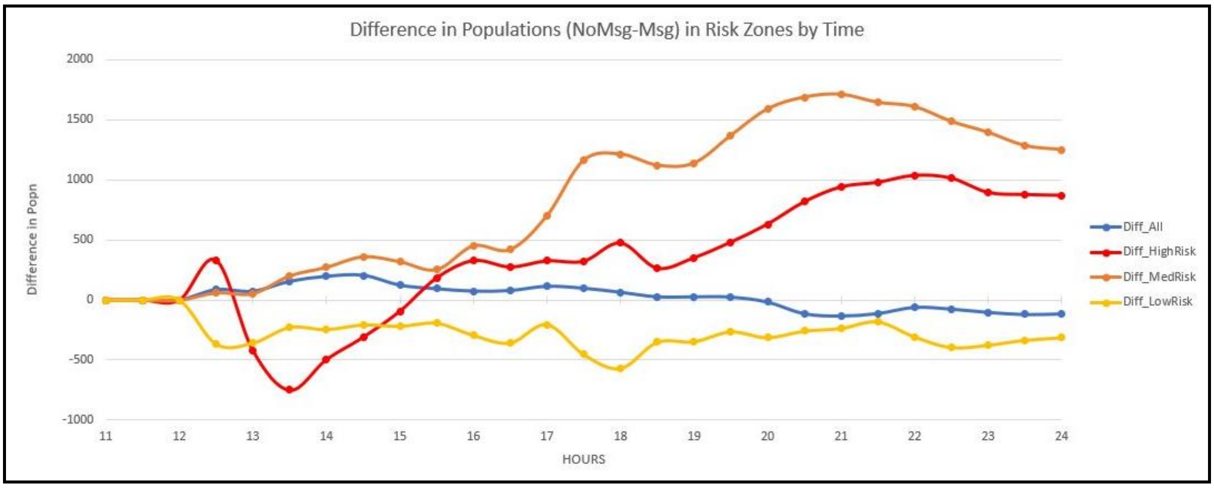

Figure 10. Differences in population in risk zones by time due to messaging

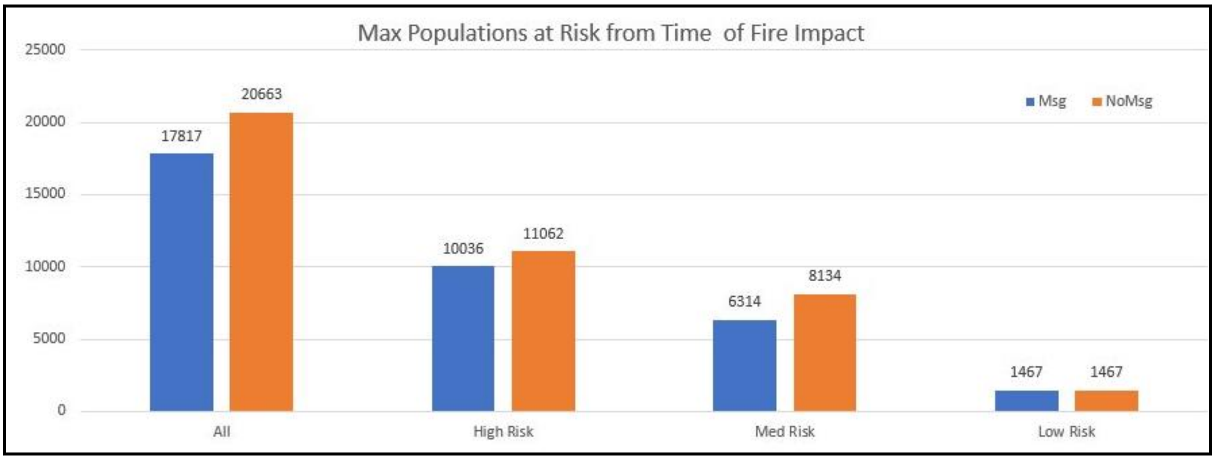

Figure 11. Comparison of total populations in risk zones after bushfire impact

Evacuation with Messaging

Scenario S2 is identical to scenario S1 except for the addition of messaging during the evacuation. Scenario S2 includes the sending out of the message "EVACUATE NOW" to all zones at 12:15, 75 minutes after the ignition of the bushfire. The distribution of the message can involve a number of technologies including SMS, social media, television and radio broadcast, as well as public and mobile address systems. The results from scenario S2 when compared to those from scenario S1 will show the impact of messaging on the level of population at risk during the bushfire event.

The flow of total populations within the risk zones in scenario S2 will follow similar curves for scenario S1 as shown in Figure 9. To evaluate the impact of messaging, Figure 10 charts the total difference (S1 minus S2) in population levels for each category of risk zone for each half-hour period from 11:00 to 24:00. Positive differences in the chart indicate times when no-messaging (S1) had a larger population at risk, while negative points indicate when messaging (S2) had a larger population at risk. Figure 10 shows that for the medium-risk (Orange) zones, messaging generally resulted in smaller populations at risk for the duration of the evacuation, while the opposite was observed for the populations in the low-risk zones. For the high-risk (Red) zones, there was a noticeable spike in the difference (332) at 12:30 as immediate response to the messaging at 12:15. The difference then favours no-messaging from 13:00 to 15:00 after which messaging produced less populations at high-risk for the remainder of the evacuation. Messaging put more people in high-risk zones between 13:00 and 15:00 since people started evacuating from all zones reached by the broadcast, resulting in some transiting through high-risk areas. In the no-messaging scenario, only the people who can see the fire front, who are already in high-risk areas, started the evacuation.

Figure 11 compares populations from the two scenarios that were actually impacted by the bushfire. The bars in the chart indicate the total of the maximum population in the risk zones after the zone has been overrun by the bushfire. For the low-risk regions, the population directly impacted by the bushfire was the same for S1 and S2. For the medium-risk zones, 29% more people were impacted in S1 compared to S2 while at the high-risk zones, 10% more people were impacted in S1 as compared to S2. Overall, the messaging scenario resulted in 16% less people being directly impacted by the bushfire.

The results from scenario S2 demonstrate the potential of messaging in improving the performance of an evacuation plan and in lowering the risk faced by a population during a disaster event. Messaging can be used to provide effective warnings and information, help the affected population understand risk, increase compliance with recommended actions, and establish order within an uncertain and chaotic environment. The framing and wording of a message, the timing and the sequencing of the messages, and the selection of recipients all contribute to an effective emergency response and in the mitigation of misinformation. More scenarios will be added to the case study in order to investigate various strategies in messaging, traffic management and evacuation planning.

COMMUNITY ENGAGEMENT, PLANNING, PREPAREDNESS AND TRAINING

SEEKER's development to date has followed an iterative improvement approach, in a process of co-production with emergency sector stakeholders. Through this process, SEEKER has been trialled for different use cases, towards improving understanding of risks to communities from bushfires, and informing planning, preparedness, community engagement, and training.[1] Feedback from uses has directly contributed to prioritisation of development of SEEKER features, refinement of its user interface to suit end user needs, and development of evacuation related metrics. The two regional areas where SEEKER has been trialled are Mount Alexander Shire and Surf Coast Shire in Victoria, Australia.

Emergency Response Training in Surf Coast Shire

As mentioned earlier, the Surf Coast Shire (SCS) is renowned for the picturesque Great Ocean Road and its quaint coastal townships but is also a high bushfire danger region. During summer months, the seasonal population in the Shire can swell to several times its full-time resident population, with many visitors often unaware of the risks and unprepared, posing a unique challenge for the emergency services in ensuring community safety. An important factor, therefore, in modelling evacuation was to first build a detailed representation of the population in the area on a typical summer (week)day, capturing the different subgroups (full and part-time residents, and regular, overnight, and daily visitors), their locations at different times of the day (home, work, shop, beach, etc.), and their commutes (background traffic on the roads). Established methods of building such activity-based synthetic populations rely on travel surveys to build a representative population (Both et al., 2021), however, these are not readily applicable due to the paucity of samples in regional areas such as SCS. Novel techniques were therefore developed (Robertson, 2019; Robertson et al., 2021; Singh et al., 2022), to allow such understanding of population behaviour to be elicited from local emergency experts in the form of tubular data on aggregated distributions of activities of sub-population at different times of the day. Robertson et al. (2021) presents the approach used to automatically output detailed synthetic populations, consisting of individuals, each with their individual daily travel itinerary that collectively represented the activities and travels of the real population on such a day.

In December 2021, SEEKER was used in a multi-agency training exercise to test live emergency response decision making in a rapid-onset bushfire event in SCS (Singh et al., 2022). The typical summer weekday population for the Shire was used as the population on the day, along with a simulated fire on a severe weather

[1] We note that SEEKER is the new name for the cloud-based evacuation modelling application as of 2022 and encompasses both the web-based user interface, as well as the underlying agent-based evacuation behaviour and traffic model. Previous iterations of the tool have been referred to as the Decision Support System. The underlying model is also known as Emergency Evacuation Simulator (EES) in earlier documents.

day. The Incident Management Team (IMT) responsible for evacuation decisions was briefed with SEEKER modelling results from a set of evacuation scenarios, including (a) evacuating the entire region as early as possible, (b) with or without activation of the traffic management points with manned emergency personnel directing traffic flow at key intersections, and (c) restricting evacuation to high fire risk areas only, or (d) staging the evacuation of high-risk areas over time, against (e) a base case of no response from the emergency services. In each scenario, synthetic persons self-evacuate based on their perception of the situation (sight of fire, embers), emergency messages received, and their behaviour persona as per Strahan's self-evacuation archetypes (Singh et al., 2021). While each managed evacuation scenario improved on the base case of no intervention, overall, the results showed that none of the managed evacuation scenarios were viable options in such a rapid-onset event, and that "too late to leave" messaging and related responses should be considered by the IMT. Post event debriefing on the day allowed participants to give feedback on SEEKER use in the training exercise. Overall, SEEKER was seen as a valuable tool to help with decision making. Participants also expressed a need for modelling to be re-run in real time to reflect IMT decisions, such as activation of traffic management points. As well, "ground-truthing" the typical population to match the actual population at the time, was highlighted as an important next step for SEEKER use during live events.

Planning and Preparedness in Mount Alexander Shire

The Mount Alexander Shire Municipal Fire Management Planning Committee has supported development of the evacuation modelling capability underlying SEEKER for several years. Through 2015-16, the committee, through a working group, contributed to the development of the first web-based version of SEEKER (Singh and Padgham, 2017). The tool was used to model the evacuation of the township of Maldon during the Twilight Dinner event that is held in the peak of summer and when the population in the town increases significantly from visitors attending the event. The modelling showed significant challenges to evacuation due to risk to major roads from the progressing fire and prompted considerations of improving traffic management and egress planning for these events. Evacuation modelling was similarly used to identify evacuation risk during an annual antique fair that was held in the township of Fryerstown during summer. The simulations showed a high level of risk to visitors in the event of a bushfire, due to the very limited egress options and high volumes of vehicles expected. Evacuation risk contributed to planning changes and the final decision to relocate the fair permanently to a new safer location.

In 2022, SEEKER is being used for modelling community response and possible consequences for the Chewton Bushlands region in the Shire. Through meetings and workshops, involving community members and local emergency agency personnel, inputs will be collected around a specific bushfire scenario. Assumptions about the population, its whereabouts, and behaviour will be recorded. The scenario will then be modelled in SEEKER, and results of the "what-if" scenario presented back to the community. This project is being undertaken under the Country Fire Authority's Community Based Bushfire Management initiative helping communities to become risk aware and more resilient against bushfire threats.

REVIEW OF LITERATURE

SEEKER is part of an emerging group of emergency management support tools whose main feature is the integration of the three important components of wildlife-urban interface (WUI) evacuation - fire spread, pedestrian behaviour, and traffic movement. Given the complexity of the issues involved in managing extreme events and the multitude of information required in the decision making, traffic simulations models have become indispensable in the analysis and planning of emergency evacuations (Barrett et al., 2000; Hardy et al., 2010). The current generation of traffic simulation models provide structure and integration to various layers of information from different sources, helping emergency management to obtain a better understanding of the disaster conditions and the effect of response strategies and control measures (Pel et al., 2012). These models enable authorities make better estimates or predictions of evacuation travel times, average speeds at different locations, traffic flow rates, congestion points and departure and arrival patterns. These models also help management to make evidence-based decisions on the latest possible time to start an evacuation, the best destination locations for each group of evacuees, the best travel routes to take and the most effective traffic management measures.

Before SEEKER, there have been four notable applications that demonstrated the coupling between bushfire and traffic models through case studies. The WUIVAC (Wildland Urban Interface Evacuation) model by Dennison et al. (2007) linked a simplified traffic modelling approach with the FLAMMAP fire model to establish trigger points around communities and transport links to initiate evacuations. The dynamic factors framework by Beloglazov et al. (2016), uses a workflow consisting of a wildfire simulator, warning generator, behaviour modeller, traffic simulator and an analytics engine to predict the outcome of wildfire evacuation scenarios, and calculate the exposure count, a new risk metric that quantifies the threat to a population. The approach has been implemented in a Software as a Service (SaaS) called IBM Evacuation Planner and applied to three independent evacuation scenarios in the Dandenong Ranges, a wildfire-prone area of Victoria in Australia.

The third application, GEO-SAFE (Veeraswamy et al., 2020), combines two established simulation tools, urbanEXODUS (Veeraswamy et al., 2018) for pedestrian modelling based on the well-known EXODUS software, and the agent-based traffic simulation model SUMO (SUMO, 2018). The integrated software tool estimates the impact of wildfire development on pedestrian and vehicle movement by linking to data produced by various wildfire simulation tools such as PHOENIX (Tolhurst et al., 2010), Prometheus (Tymstra, et al., 2010) or Wildfire Analyst (Monedero et al., 2019).

Finally, WUI-NITY (Ronchi et al., 2020) is a modelling platform that integrates different modelling layers (fire, pedestrian and traffic) to generate dynamic projections of the evacuation situation to enable responders and residents to generate similarly integrated and dynamic vulnerability assessment. WUI-NITY is built on the Unity game engine [https://unity.com/] which allows the application to be developed modularly with separate sub-models for key modelling components and the required data exchange with external components such as FARSITE (Finney 1998) for wildfire modelling and PERIL for trigger buffer generation.

Compared to previous evacuation models, the SEEKER tool adds another level of intelligence to the evacuation response by combining agent-based modelling with a BDI behavioural model specifically capturing human responses to bushfire disasters, and it allows emergency management agencies to design and run evacuation scenarios and analyse the risk posed by the fire to the population and road network. Furthermore, the SEEKER workflow was designed in close collaboration with emergency services and can be used to develop multiple evacuation scenarios to investigate the relative effectiveness of each emergency evacuation plan considered by emergency coordinators.

CONCLUSION

The increasing number of people choosing to live and work along the wildfire-urban interface, and the increasing frequency and intensity of natural disasters is making the task of evacuating mass populations during disaster events more complex. Emergency management organisations are turning to computer-based decision support tools to investigate potential disaster scenarios, develop robust evacuation plans and evaluate risk mitigation options. The GOR-DSS project has developed SEEKER as an evacuation support tool to assist communities faced with the challenge of evacuating large, diverse and highly variable populations from areas with the highest risk of bushfire using limited transport infrastructure. The application of SEEKER in a number of reality-based case studies and its engagement in live training exercises showed that it can provide valuable support to local emergency personnel.

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Creating trusted extensions to existing software tools in bushfire consequence estimation

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ABSTRACT

Bushfire modelling has advanced with wildfire simulators such as Spark and Phoenix Rapidfire that can generate plausible fire dynamics and simulations that decision-makers can easily explore. With extreme weather impacting the Australian landscapes through the onset of droughts and heatwaves, it is becoming more important to make decisions rapidly from fire simulations. An element of this decision-making process is trust, in which the decision-maker feels empowered to make decisions from models of complex systems like fire. We propose a framework for decision-making that makes use of a fire emulator, a surrogate version of Spark, to facilitate faster exploration of wildfire predictions and their uncertainties under a changing climate. We discuss the advantages and next steps of an emulator model using the mechanisms and conditions framework, a powerful vocabulary and design framework that builds in trust to allow users of a technology to understand and accept the features of a system.

Keywords

Wildfires; trustworthiness; optimal decisions; affordance analysis; emulation;

INTRODUCTION

Bushfires in Australia have caused substantial damages both in terms of human life, and in terms of the value of economic losses. The 2019-2020 ”Black Summer” fire season is the most recent severe fire season, occurring in drought conditions and resulting in multiple ‘megafires’. The consequences of this mega-event resulted in 14.3 million hectares had been burnt, over 2779 homes, and at least 34 people killed (Wittwer et al. 2021; SBS 2020; Ladds et al. 2017). More difficult to quantify are the indirect economic impacts of fires, including those impacts in vulnerable groups (Williamson and Quinn 2021; Gibbs et al. 2020; Whittaker et al. 2015) and those that emerge and persist over time (Gibbs 2021). Further to directly measurable impacts, bushfires have environmental impacts on landscapes, species, and ecosystems, both local to Australia and further afield due to smoke transport (Dockrill 2019; Readfearn 2020a; Dickman 2020; Gramling 2021; Readfearn 2020b). Reactively measuring consequences and damage in each of these contexts post-event is an important exercise; equally important can be using tools to *predict* potential impacts in these contexts to support anticipation of specific challenges that occur during and after hazard events to improve planning and response decisions.

With bushfires now a relatively common and expected occurrence in the Australian landscape, there is a long history of mathematical and computational tools to support understanding of bushfire hazards (Griffiths 1999; Noble et al. 1980; Keetch and Byram 1968; Cheney et al. 1998; Cruz, J. S. Gould, Kidnie, et al. 2015; Anderson et al. 2015; Burrows et al. 2009; McArthur 1967; Sharples 2008; Sullivan et al. 2014; Rothermel 1972; Cruz, J. S. Gould, Alexander, et al. 2015). This research encompasses understanding conditions associated with high fire spread; to physics type models describing spread of fires in different vegetation, landscape types and conditions; to tools used to assess and communicate fire risk. Much of the information and knowledge from this research has been incorporated into bushfire characteristic solvers used in Australia such as such as Spark (Miller et al. 2015) and Phoenix Rapidfire (Tolhurst et al. 2012). Based on this foundation of research and experience, such solvers aim to model and predict how a fire-front will spread through time. These characteristic fire models also have some well-established contexts in which they are used to inform decisions. Contexts where these computational tools are used to support decisions range from operational planning purposes by fire agencies, to understanding landscape-scale fire consequence risk caused by electricity distribution where the goal is targeting and assessing preventative measures(IGNIS 2021a; IGNIS 2021b; IGNIS 2019; SA Power Networks 2019; Dunstall, Huston, et al. 2017; Dunstall, Towns, et al. 2017).

While these characteristic fire modeling platforms run reasonably quickly given particular parameterisations through specific landscapes, explorations of hundreds, hundreds of thousands, or even millions of scenarios to pre-inform decisions relating fire spread and consequence can take time. Further, uncertainty is not automatically considered when assessing whether a fire-front will progress in a particular direction or through a particular location conditional on variable weather inputs.

Despite the value of existing tools and their ability to incorporate key information about our understanding of fire behaviour, the threat posed by bushfires is evolving and likely increasing due to factors such as climate change (Canadell et al. 2021). Our understanding of further contexts where being able to assess landscape-scale risk, or assess fire behaviour is also increasing as society begins to measure more, and more complex facets of fire consequence. As the threat of fire increases, and our understanding of contexts of consequence, so too can our tools for addressing and understanding the risk (Neale et al. 2021; Owen 2018; Begg et al. 2021).

In this paper we present work in progress of an *emulator* of characteristic fire behaviour which we hope is a next step in decision making toolsets used to understand and plan for bushfire hazards. While this emulator is currently under development, we recognise the importance of developing it collaboratively with planners and end users so that the opportunities provided by decision and AI tools based on it are understood and adopted broadly in the fire community. An emulation approach implicitly derives fire characteristic information in a different way to models like Spark which explicitly encode information about our current scientific and physical understanding of fire behaviour. As such, this paper will also explore how the emulator enables and constrains the types of outputs that can be created in different ways to the Spark predictive model on which it is based. There are challenges implicit in this, as emulated results are similar but not identical to those of the models on which they are based. At the same time, this emulator will 'afford' us new frameworks for application, especially if an efficient decision framework for it can be embedded as part of the overall artificial intelligence (AI) being developed.

Discussion to this point has been focused towards the development and understanding of an emulator as a fire characteristic solver. There is a decision making element to the development of such solvers that can often be overlooked at the development and research stage. At 'completion' the outputs are often left for decision makers like emergency services and first responders to determine how they should be used to act upon and make decisions.

Decision-making is tricky across all aspects of our working and personal lives and it is often challenged by how the circumstances present and how we interact with those circumstances. The same is true with the technologies we use and develop, like our emulator, and how we interact with those technologies to achieve an outcome and a corresponding decision. These decisions can be especially important and sensitive in a hazards context where lives and livelihoods can be at stake. In addition to introducing our emulator approach to fire characteristic estimation, this paper will focus on how Machine Learning and Artificial Intelligence (MLAI) can benefit decision-making. This is achieved through identifying smarter ways of characterising the physical processes that we wish to model and then connecting them with relevant formal *decisions* frameworks that enable optimal decisions. We consider this joint research path of emulator and decisions in the context of how AI technology 'affords' where the emulator provides information on which to make a choice. Such a principled approach to decision-making can take into account both the affordances of the model and decision making objectives. To demonstrate, we consider a toy scenario in which the reader explores the complexity of even a 'simple' decision-making problem and how decisions can change based on different model affordances, and can be improved through formal decision frameworks. Finally, we discuss improvements to existing decision-making methods for complex situations and provide a framework and pathway forward to enable better decisions to be formalised in the context of wildfire management using machine learning.

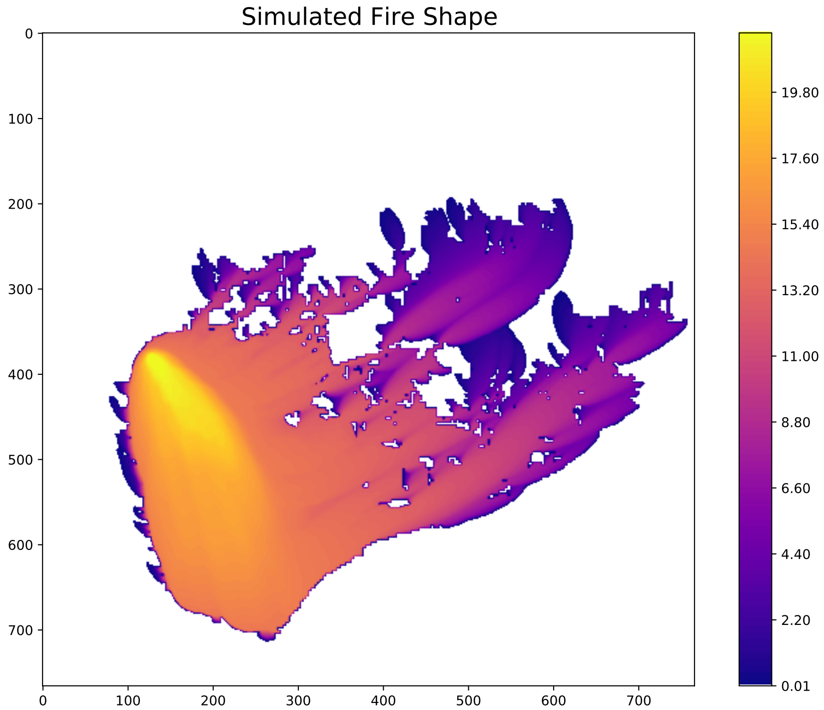

Figure 1. Fire arrival times as estimated in a Spark fire simulation. Yellow indicates earlier arrival times, purple, later arrival times.

METHODS

Wildfire modelling and emulation

As mentioned above, fire characteristic models such as Spark (Miller et al. 2015) and Phoenix Rapidfire (Tolhurst et al. 2012) are physics based in the sense that they incorporate our best understanding of fire spread. For example, much of the information about rate of spread is based on physical experiments of fire spread in different fuels, summarised in a resource like (Cruz, J. S. Gould, Alexander, et al. 2015). Basic physical knowledge and constraints such as fire not spreading in water is obviously also incorporated.

Fire characteristic solvers require an analogous set of inputs, including situational features that are consistent over a fire simulation such as topography and vegetation (with associated rates-of-spread). Other inputs, particularly related to meteorology can vary spatially and also temporally over the course of the fire. These include things such as wind-speed and direction inputs for different locations; temperature; relative humidity; drought estimates; fire danger estimates; and similar as needed.

We note that our list is not exhaustive of all inputs, particularly across different vegetation types. It merely provides an overview of some of the core types of spatial and spatio-temporal features that are used as inputs to the rate-of-spread and similar formulae that are used to inform fire characteristic solvers.

Collectively, such inputs that inform dynamics of our physical fire characteristic models are used as a basis for fire simulations at a start location. These solvers then create outputs such as arrival time maps. By selecting an arrival time, t, a characteristic fire perimeter, or active front at time t can be drawn. An example of arrival times taken from a set of Spark outputs is shown in Figure 1. This figure highlights the progression of a fire from its starting location (middle west, yellow) and progressing to the north east over the duration of the simulation and ending with the more recently burnt areas shown in purple.

Emulated Fire-Front

We propose an emulator of Spark, which creates spatial-temporal output of fire arrival times based on approximating the underpinning physics knowledge from Spark into the emulation system using machine learning. The emulator *learns* what a fire should look like based on the training data it is given. In this case, the training data comes from Spark simulation runs, but other training data could be created or sourced in future work and added to the library for training.

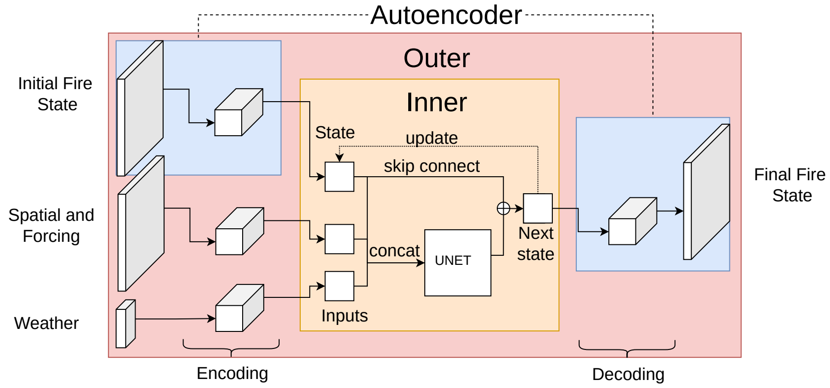

Figure 2. Overview of the emulator structure, highlighting the inner and outer components of the architecture that contributes to speedup of the emulated approach.

The basic structure of the emulator is visualized in Figure 2. This diagram shows two core learning steps termed the *outer* and *inner* components. The outer components comprise an *autoencoder* which encapsulates two key steps. First, it encodes input data into a lower dimensional latent (compressed) space. This is done to all of the inputs, including both explanatory variables, as well as fire arrival information taken from Spark outputs. It is this compression of information that can provide part of the computational speedup relative to the initial model. Balancing the encoding step is the decoding step. The purpose of the decoding step is to re-create an image in the same context and dimensionality as the original image. In this case, as our output of interest is the emulated fire arrival times, weather and spatial forcings are not decoded, just information about the final fire state.

The actual dynamics of fire are *learnt* in the inner portion of the emulator structure. This means that learning is taking place in the lower dimensional latent space. While not interpretable at a landscape-scale the way progression in Spark can be, this representation of fire dynamics is highly efficient and a source of speedup relative to the original model. Once learning/training is completed, the emulator can be used to create fast emulated fire results that can be interpreted in original spatial fire arrival time context once it is has been decoded. Further information about the neural net structure of the emulator can be found in (Bolt et al. 2022).

A comparison of an emulated fire-front taken at the end of a burn period, and a Spark fire-front simulated over the same time period is shown in Figure 3. Both methods for generating a fire- front give similar results, despite their different computational approaches. Additionally, the emulator has been able to learn and reproduce anticipated physical fire behaviours such as not burning through water bodies, fire fingering and capturing changes in spread rate as vegetation types change in the landscape.

Current work-in-progress for the emulator includes incorporating uncertainty into emulated outputs. We have considered two potential directions to achieve this. In early attempts, we have added variability to wind inputs to understand ways to visualize the output uncertainty for decision makers. This opportunity to create and demonstrate fast probabilistic emulations of fire-fronts through time will enable new uses for fire-front spread estimation that can be explored.

An Affordance Framework Applied To Fire-Front Emulators

All technologies enable and constrain in different ways, based on inbuilt features and how those features deploy in context. The opportunities and constraints of a technology are often referred to as 'affordances'–or how the features of a technology affect what we can do with it. (Davis and Chouinard 2016) and more recently, (Davis 2020) introduce the mechanisms and conditions framework of affordances, a design framework by which artefacts *request, demand, encourage, discourage, refuse and allow* certain outcomes. This framework can be applied to any technology as a way to examine and articulate how that technology operates in context. It is especially useful for grounding and organizing AI technologies with complex features, and for comparing technological systems to each other, as features and outcomes are mapped to a shared vocabulary (i.e., *request, demand, encourage, discourage, refuse, and allow*).

The mechanisms and conditions framework can thus productively apply to the wildfire emulator described above in order to explain its value vis-a-vis traditional predictive models. This clear articulation is vital, as uptake will require trust in the emulator system and understanding of the emulator's relative benefits. Specifically, we can discuss emulator trade-offs and explore the relationship between emulators and the models they emulate to understand the

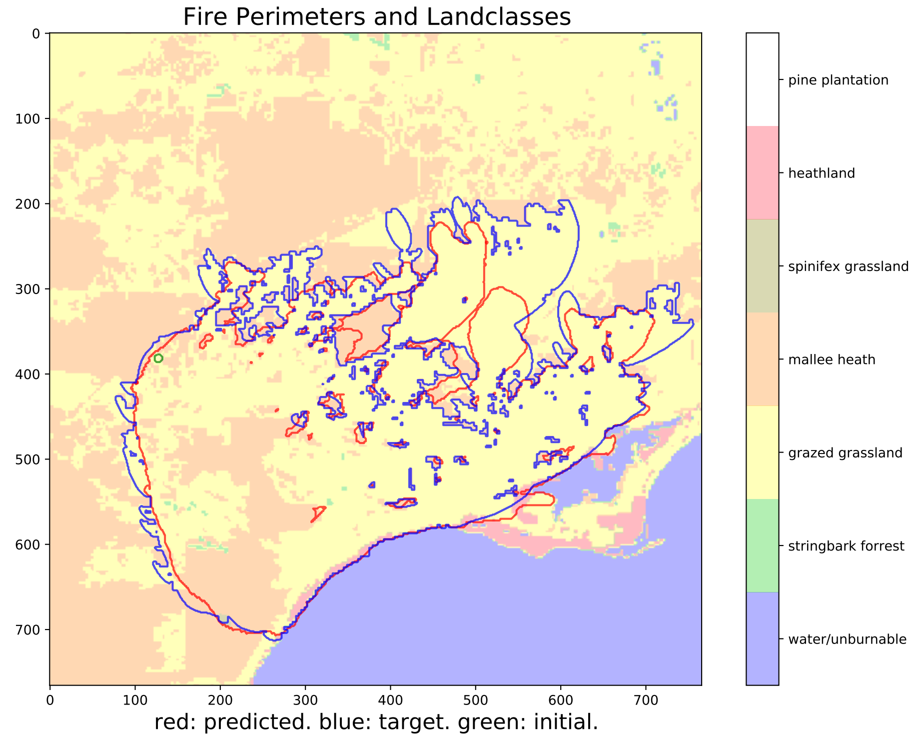

Figure 3. Comparison of Spark arrival time band (active fire-front) and emulator arrival time band at same simulated time point. Background is vegetation type which clearly impacts fire spread in both models. There are overall shape similarities between the Spark dynamic model and emulated results.

uses and benefits in certain types of situations. For example, the emulator *encourages* speed, operating system (OS) interoperability, and broad application, whereas the original wildfire model it was built on may be slower, *discourage* OS interoperability, and *demand* specific hardware and software. Of note, the emulator is not a replacement for the original model, but a supplement to it, such that trust in and reliance on the original model is a prerequisite, or *demand*, of a successful emulation. In short, this mechanisms and conditions framework helps clarify the utility of an emulator in the context of the original model and has the potential to bolster trust in the emulated version by showing its fidelity to the original model.

If emulators are embedded within a decision framework, this tech encourages optimal decision-making and allows more confident decisions to be made. This is particularly true where it is desirable to reflect uncertainty in outputs. This requires a faster, more efficient alternative to the original model as this decision framework demands flexibility and speed. In the context of the original model, they simply refuse or discourage the ability to connect with decisions and incorporate uncertainty in a timely or computationally feasible fashion and this may become unattractive to the decision-maker that wants decisions now.

EXPLORING DECISION-MAKING FOR WILDFIRES

There are many time scales to decisions that can be informed using results from fire-characteristic solvers like Spark or Phoenix Rapidfire, and, increasingly, by emulators like ours. The time scale and spatial scales of these decisions can vary depending on the application. For example, operational decisions are ones that are taken during the course of a fire. These can include firefighting suppression efforts, or decisions to evacuate suburbs or other communities.

Planning level decisions can occur well before a fire is experienced. Examples might include using simulations to understand potential financial consequence of fires to support better budget estimates and targeting of relief programs. Utility companies, who can be both causes and victims of wildfires, can use simulations to inform network planning for both preventative and protective actions.

Depending on the motivating problem, there are many complexities related to the decision making that can be supported with tools such a fire characteristic models, and emulators developed from them. Our work-in-progress emulator is at a point where it is a successful proof-of-concept around how, and that, fire characteristic models *can* be emulated relatively successfully. At this point we are exploring how to fine tune results of the current emulator

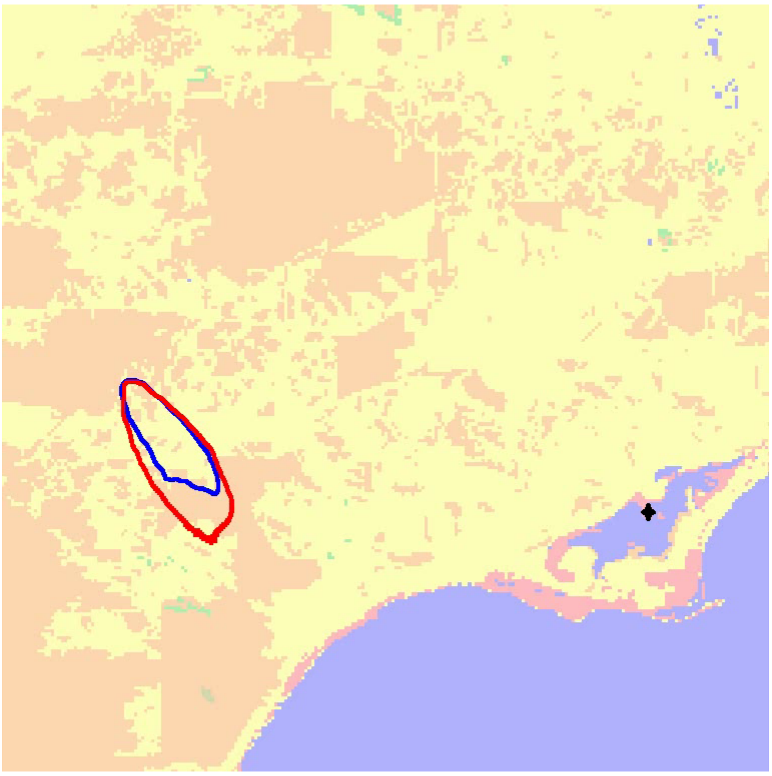

Figure 4. Early mapping of the fire threatening the holiday home (marked in black four-pointed star). Blue is Spark and red is emulator. Wind is traveling in a southerly direction.

and we are developing an extension that will allow results that better incorporate and report on uncertainty. There is a goal to make the emulator as useful a tool as it can be before either the single perimeter or uncertainty enabled versions are released for operational and planning purposes.

To facilitate thought and discussion around how our emulator, and its proposed uncertainty extensions will *afford* certain types of decisions, we explore emulated and original outputs using a simple motivating problem. While a relatively simple schema, we believe such an example can illustrate key decision processes and allow more complete understanding and articulation of some of the complexities related to decision making in a principled way.

For context, we posit that the reader has made a decision to go on an Australian beach vacation. The weather is balmy, and the forecast is for blue skies and no rain. After a few relaxing days, a bushfire starts nearby. The wind is coming from the north, and the most recent emergency prediction of the fire perimeter is as shown in Figure 4. There is a meteorology forecast that suggests the winds will change to a more westerly origin at some point in the next 12 hours. You, the holidaymaker, need to make a decision around whether to continue to enjoy your holiday, or whether to evacuate the area.

For the sake of simplicity when writing this paper, assume that you, the holiday maker have decided to stay in your beach house awaiting further information. The fire then progresses over the next 12 hours similar to what is shown in Figure 5.

Luckily the beach house you are sheltered in has not been directly impacted by the fire. We note that the location is currently cut off due to active fire front, and the holiday home could be at risk if there are further wind changes in the near future.

To understand the impact of incorporating uncertainty into decision making information, imagine the same scenario as above. However, instead of having one or two predicted fire perimeters on which to make a decision, there are a multitude. We create a toy set of emulations of this scenario in Figure 6. Here, the different emulated perimeters use the same base weather scenario, but small step changes in wind direction and wind-speed at each time point are introduced to loosely mimic uncertainty in real-world conditions.

Fortunately, the decision to shelter was fortuitous in that the beach house location was not directly impacted by fire in any of the simulations. Imagine an alternate scenario though, where evacuation was chosen rather than sheltering at the house. Would the optimal/preferred evacuation pathway individuals chose be impacted by more

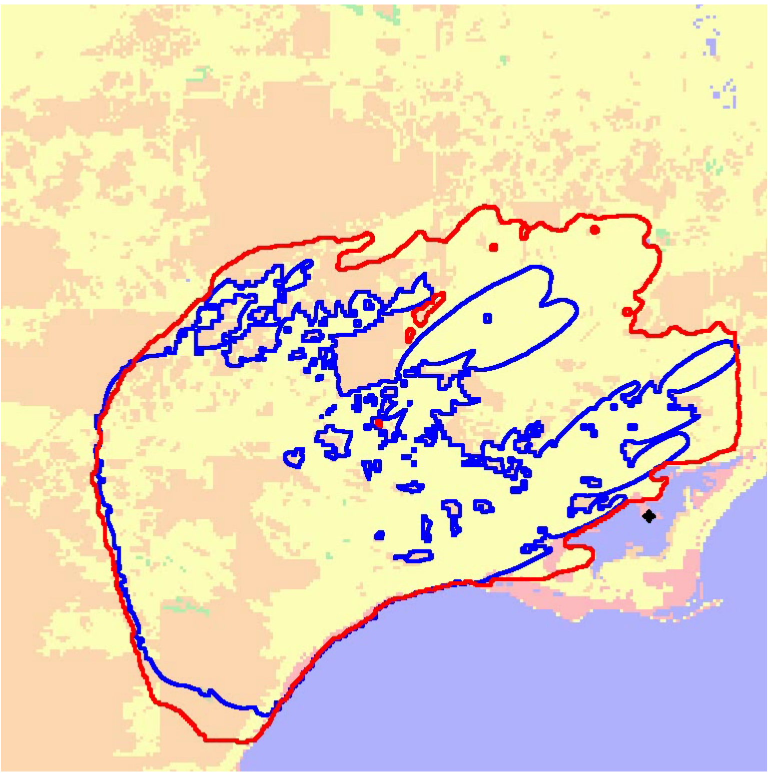

Figure 5. Final fire-front at midnight. Blue is Spark and red is emulator. Note that wind has changed to be a westerly, pushing the fire to the east. Beach house area is referenced by a black four-pointed star.

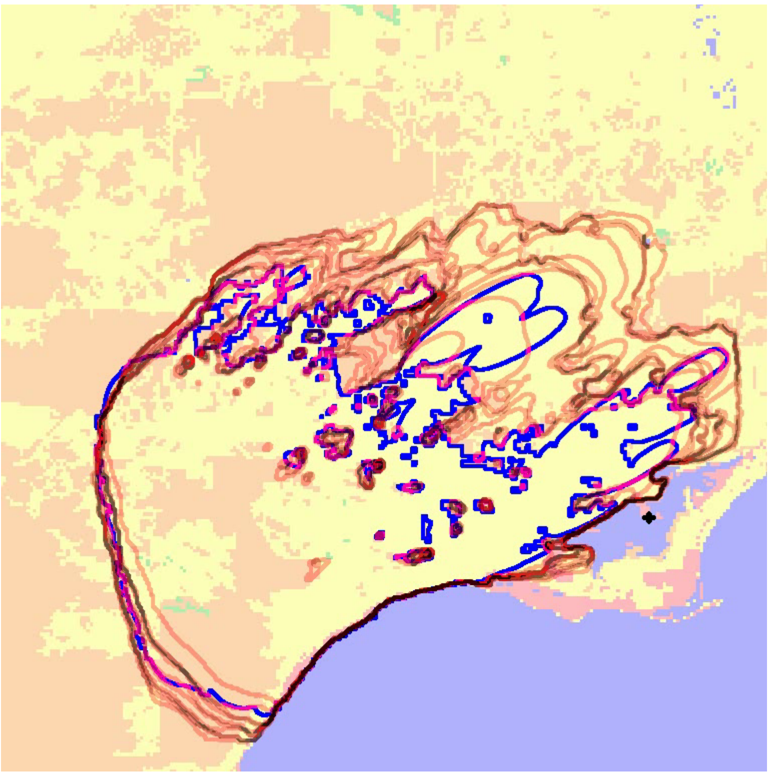

Figure 6. Ensemble emulator results with small uncertainty in wind and wind direction introduced. Blue is original Spark, various shades of translucent red are various emulated fires. The black four pointed star represents the location of the holiday beach-house.

information about potential uncertainty in the fire progression? Beyond being a holidaymaker who needs to shelter or escape, what other operational and planning decisions would/could be affected by what can be intuited from multiple emulated fire fronts instead of just one? In other words, what new types of decisions have been *afforded* by including uncertainty in our fireline reporting?

Meaningful discussions with emergency and hazard planning and response expertise would provide the best insight into how the different types of results (fire characteristic, single emulation, emulated uncertain ensemble) request, demand, encourage, discourage, refuse and allow certain decisions and uses. This is especially relevant because our Spark emulator is still in a developmental process. Now is the opportune time to have multiple structured and collaborative conversations about how the emulator could be used, considering viewpoints from many relevant decision making contexts. . On one hand, this creates opportunity to discuss and learn which emulator features and affordances are most useful in different decision making contexts. Having collaborative discussions with decision-makers who could be supported by the technology will also create a richer picture of the potential affordances provided by Spark and emulated versions of it. It can also lead to better trust and understanding of outputs from emulators and their advantages and disadvantages relative to the original Spark model.

CONCLUSION

In the broader context of climate change, risk and damages from natural hazards such as wildfires are increasing. Currently, there are a number of well established computational fire characteristic behaviour tools that embed physical and scientific knowledge about fire spread, such as fire-front rate-of-spread equations. Given the escalating risk of such events, we have built a prototype emulator of the Spark fire-front solver as an additional tool that can be used to explore potential fire consequence scenarios. A particular goal currently being progressed in the research and development of the emulator is more natural handling and reporting on potential uncertainty in fire-fronts at a given time.

Beyond establishment of the tool itself, we recognise the importance of conducting research to improve the uptake and understanding of the fundamental technology. This can involve a give and take in terms of understanding both what new types of decision emulation might afford, and how the emulator and its reporting can take feedback such that it permits desired interfaces and decisions. This is discussed in the context of the language of an affordance framework for AI as a structured path to facilitating this dialog between potential end-users and decision makers and AI and algorithm developers. To illustrate some of the affordances provided by the uncertainty being developed for the fire-front emulator, a simple example is discussed. Particular questions around how uncertainty might afford different decisions than one or two fire perimeter predictions were posed. We posit that facilitating such discussions with a shared affordance language and framework is an integral step to developing trusted AI systems for operational usage.

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Evaluating Flood-Related Decision-Making and the Role of Information Technologies

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ABSTRACT

The proposed research consists of an innovative research design and piloting to compare traditional and contemporary approaches to loss-related decisions, concerning flooding risk in particular. By developing and implementing the integration of multiple methods, the proposed research aims to provide detailed and compelling evidence of how disaster-related decisions can be evaluated using an out-of-frame (capacity) and out-of-sample (occurrence) criterion, i.e. instead of taking a more reductive approach to real world problems. Together with other research being conducted around the world, the current initiative will address the contemporary scientific problem of whether traditionally axiomatic or ecological rationality should be used for evaluating disaster-related decisions. Where ecological rationality is found to be more effective, the same research will inform how ecologically rational approaches to flood risk can be improved through promoting particular areas of an information display or interface under particular conditions.

Keywords

Risk perception, biases, decision support, research methods

INTRODUCTION

Many decision-makers facing perilous scenarios need to do so with a shortage of information and varying degrees of time constraints. Most of us have faced relevant scenarios, requiring rapid responses to highly limited information. They include deciding whether to socially distance and/or wear a mask when entering public places during the COVID-19 pandemic, or whether to visit a crowded hospital in order to meet COVID-19 testing requirements. The world has witnessed blatantly erroneous responses to these kinds of scenarios, exhibited in mask-less public gatherings to protest COVID restrictions or even religious ceremonies conducted in closely packed but poorly ventilated venues. Although it is easy to judge the individuals involved, these and other loss-related responses have been highly patterned across populations and certain demographic groups.

Other relevant patterns have been observed in a range of investment decisions researched by Tversky and Kahneman (1992), the selection of romantic partners, discussed by Todd and Gigerenzer (2007), and responses to natural hazards, reviewed by Hudson Doyle et al. (2019). These are a few of many risky scenario types where highly biased decisions, based on certain environmental cues, can have very negative consequences. In a world marked by ongoing pandemic risk, along with the worsening natural hazards, climate change and environmental degradation outlined by Huggins et al. (2018), it is time to extend relatively fundamental theories of erroneous responses to peril.

Relevant perils obviously include near and present hazards such as COVID-19. However, other hazards are just as destructive and are, arguably, even harder to manage. The current research focuses on flood disaster management in particular because flooding disasters are extremely common in many regions of the world. Flooding was the single most common type of natural hazard event from 1995-2015, accounting for 43% of all disasters caused by natural hazards over this period (CRED & UNISDR, 2016). Accelerating climate change and other factors outlined by Adnan and Kreibich (2016) and in the most recent Global Risk Assessment (UNDRR, 2019) means there is little hope that this is going to change. Flooding disasters are also exceedingly hard to manage because the decisions involved need to incorporate many types and sources of information. Much of this information tends to come too late, for the many hundreds of people that are affected by severe flooding every year.

The time and information constraints outlined above combine with cognitive limitations, to mean that decisions in loss-related scenarios typically depend on decision-making shortcuts. Gigerenzer et al. (1999) described these types of shortcuts as *cognitive heuristics*, focused on directly facilitating what a person wants to achieve instead of a more deliberative approach. This means that decision-making heuristics are typically *fast*, compared to responses that take too long to constitute an initial reaction.

The same heuristics tend to be *frugal*, meaning that they depend on a minimal amount of initial information. Frugal information requirements are particularly useful when decision-relevant information is incomplete, or when decision-makers do not have enough time to search for additional cues. Newell et al. (2003) and Bröder and Schiffer (2003) stated that frugality is most relevant in situations when information must be paid for, must be searched for, or when timeframes prevent accessing further information. Kozyreva and Hertwig (2019) reviewed a wide range of relevant research to illustrate how frugality is also common in situations that have no obvious time constraints. Even when a decision-maker decides to search for further information, this initial response is typically selected using cognitive heuristics (Huggins et al., 2018; Jayawardene et al., 2021).

Academic fields such as information science, cognitive psychology, management science, and behavioral economics have a long-running focus on how and why individuals make choices under different conditions. Their findings both diverge and coalesce around a cumulative science of decision-making, where the concepts of preference, utility, and value have been heavily studied alongside themes such as subjective probability, fuzziness, and the relevance of base-rate frequencies. All of these factors, and many others, have been applied to areas as diverse as business management, consumer marketing, and emergency management (Barberis, 2013). These applications have also naturally extended to the design and implementation of information systems for crisis response and management.

A narrative review by Fox et al. (2015) concluded that *prospect theory* and its iterations have become the predominant theory for describing decision-making about risk. This assertion led the current research to focus on contributions to decision-making science, concerning prospect theory in particular. As outlined below, prospect theory provides a broadly fundamental approach for evaluating the rationality of loss-related decisions. The question posed by the current paper is whether we can use evaluations from prospect theory to usefully evaluate the effectiveness of flooding-related decisions.

The current paper is divided into four parts: The current introduction; a summary and critique of basic theoretical assumptions, an innovative set of research methods, and a Conclusion section. Basic theoretical assumptions are outlined with a constructively critical approach to how criteria from prospect theory compare to criteria that may be much more relevant to flooding-related decisions. This is followed by a detailed approach to methods that aspects of prospect theory with alternative decision criteria and with innovative approaches to relevant data leveraging the type of cutting-edge technologies outlined by Liu et al. (2022). The Conclusion section reiterates and expands on the practical and theoretical relevance of the methods proposed.

BASIC THEORETICAL ASSUMPTIONS

Examples of heuristic-based responses to limited information can be as mundane as using an availability heuristic to choose the subway line that most recently took the decision-maker to work. Other examples can be as perilous as using a satisficing approach to dispatching firefighting crews to the first, minimally viable fire-ground. Although common to the point of being fundamental, these cognitive heuristics are often highly fallible - especially when compared to more deliberate decision-making processes. Over three decades of research into prospect theory has provided a vivid example of how heuristic approaches to financial and other risk are biased towards risk and loss aversion, risk seeking and other distortions (Barberis, 2013). Even when participants were given a well-defined probability, their responses tend to distort that probability, rather than systematically comparing prospective outcomes (Tversky & Kahneman, 1992). Their distorted responses create a set of deviations from axiomatically rational *expected values* (ev) of gains (x) and losses (p) shown by the straight diagonal in Figure 1, where:

$$ev = x \times p$$

Where decision weights, $\pi_i = \pi_{i^+}\ if\ i \geq 0\ and\ \pi_i = \pi_{i^-}\ if\ i < 0$, a generalizable description of the values (V) shown in Figure 1 is determined by:

$$V(f) = \sum_{i=-m}^{n} \pi_i v(x_i)$$

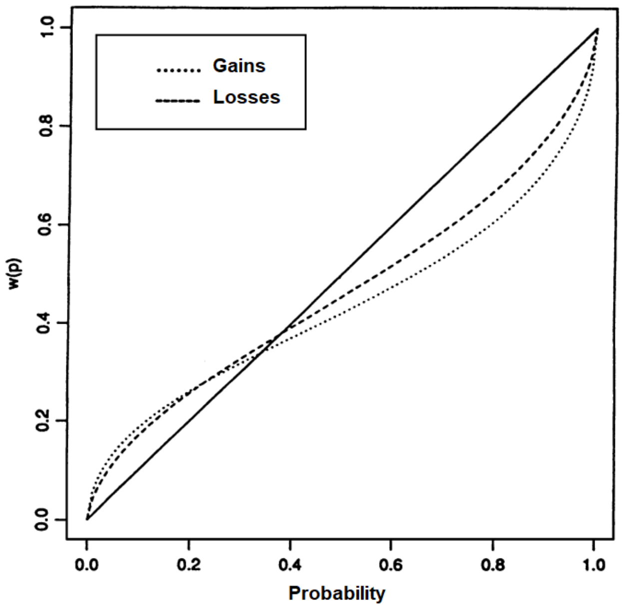

Figure 1. Deviation from Expected Values Shown on the Diagonal (adapted from Tversky & Kahnemann, 1992)

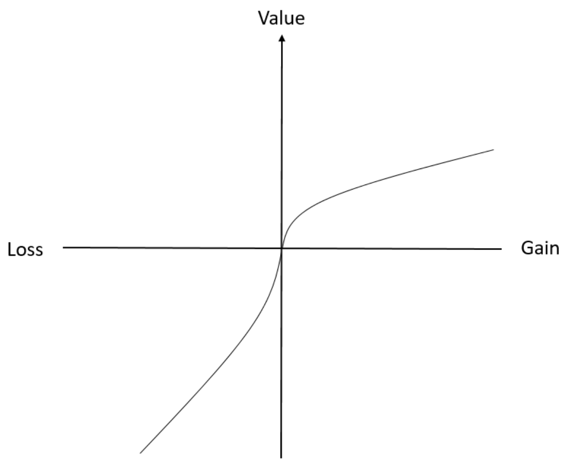

Figure 2. The Impact of Loss Aversion on the Perceived Value of Prospective Losses (adapted from Kahnemann & Tversky, 1983)

Along with a range of other descriptive findings reviewed by Chai et al. (2021), many decades of research into iterations of prospect theory has shown that participants tend to be averse to loss at low probabilities. At this level of probability, the value of a potential loss has a much larger impact on decisions, than equivalent gains (Tversky & Kahneman, 1992). The same loss aversion phenomena disrupts the s-shaped curve shown in Figure 2 and can be described as:

$$v0\ (x) < v0\ (-x) \text{ for } x \geq 0$$

Todd and Gigerenzer (2007) have been more optimistic about apparent flaws in heuristic decision-making. They queried whether decision-making heuristics can actually achieve *ecological rationality*, a match between heuristics and the surrounding environment that results in distinctly effective decisions. Examples include choosing the only recognizable option in a relatively novel environment, and searching for a single discriminating cue among information with highly mixed validity. Each of these fast and frugal approaches to decisions can be more effective than a more structured and sequential, algorithmic, approach. The latter example is generally just as accurate as decisions using a multiple regression (Todd & Gigerenzer, 2007).

This *ecological* approach to evaluating heuristic decision processes poses a challenge to the type of *axiomatic* rationality (Gigerenzer, 2019) that is traditionally used to evaluate loss-related decisions under the assumptions of prospect theory and other approaches. Rapidly heuristic decisions have usually been out-performed by steadily calculating and comparing an expected value (total loss or gain x probability) for each option (Barberis, 2013), based on Bayesian logic. This is shown in aspects of cumulative prospect theory, outlined above. However, the expected value of losses in these contexts excludes three other factors affecting cumulative disaster risk: *vulnerability* (V), or conditions increasing susceptibility to hazards; *exposure* (E), or assets situated in a hazard prone area; and reduced by *capacity* (C), i.e. to manage and reduce disaster risks (Huggins et al., 2020). Using these definitions, a more ecologically rational evaluation of disaster risk (DR) becomes:

$$DR = \frac{x\text{-} \ \times p \ \times V \ \times E}{C}$$

Capacity is particularly relevant, because it effectively reduces all other factors determining disaster risk (Huggins et al., 2020). It may also form a heuristic threshold for loss-related decisions, as indicated in pilot research by the current authors, which found that loss-related decisions deviated much more strongly from expected value once the potential loss reached 1,000,000 CNY. These highly tentative results were specific to female participants, partially replicating the several other studies into loss and risk aversion reviewed by Croson and Gneezy (2009). However, the central role played by disaster management capacities mean that these observed responses are not strictly irrational. The thresholds concerned may indicate attention to an amount of loss that participants simply do not have the capacity to face.

These kinds of contextual factors are not Strictly inconsistent with fundamental aspects of cumulative probability theory, shown in Figure 1. This is because responses in Tversky and Kahneman (1992) did not deviate from ev until prospects reached an identifiable threshold (>$200). Rather than treating thresholds as a simple issue of salience, or experimental realism, the innovative methods can focus on this threshold and its relationship with participants' decision context. Beyond the apparent simplicity of *framing effects*, where perceived values are affected by preceding experimental conditions (Tversky & Kahneman, 1986), there are additional, scientific questions to be asked and a growing body of research attempting to answer them.

Zeng (2007) previously found that loss aversion can be exaggerated in a Chinese cultural context. Like the responses of female participants in our own pilot research, this pattern of responses can labelled less-than-rational. However, and further to the relevance of capacities for disaster risk, previously axiomatic criteria for validating risk-related rationality are also limited to what Kozyreva and Hertwig (2019) called a *small-world* approach: characterized by restricted data sets and other, highly artificial, constraints. This means that axiomatic approaches to expected value or utility may result in poor criteria for decisions involving high levels of loss and low probabilities. For example, the historical frequency of catastrophic flooding is still relatively low in many cities that are nonetheless categorized as flood prone. Historical flooding data may provide a poor indicator of present-day conditions and future scenarios being impacted by accelerating climate and land use change. Recent urban development in China's Pearl River Delta provides one example, where the risk of storms, storm surge and riverine flooding has rapidly risen to the highest level faced by any metropolitan area in the world (SwissRE, 2019). Instead of relying on extended sets of semi-relevant longitudinal data, the current research takes an ecological approach to rationality. This assumes following priorities:

1. Formal models of heuristics, as opposed to vague labels.

2. Competitive testing of heuristics, as opposed to null hypothesis tests.

3. Tests of predictive power, such as in out-of-sample prediction, as opposed to data fitting.

(Gigerenzer, 2019, p. 3557).

Methods for addressing each of these priorities are outlined in the following section. They include the way that extant research procedures can be complemented through eye tracking and brain scanning apparatus. The simultaneous use of both apparatuses will help address the methodological difficulties of using brain activity to fully account for the heuristic role of visual attention, outlined by Moore and Zirnsak (2017). The proposed combination of methods, and the scientific questions they address, are important for understanding contemporary decision-making environments, such as worsening flood scenarios. Furthermore, once more ecologically rational, and therefore more effective, heuristic processes are identified, further research will be able to define how information formats and other environmental factors can promote the same processes. In the face of flooding risks worsened by rapid urban development and accelerating climate change, there may be few alternatives to taking these more innovative approaches.

PROPOSED METHOD

Relevant research can progress from a pilot set of laboratory-based methods, followed by one full set of fully refined methods. The first set will be used to pilot and refine the identification of risk aversion thresholds, as a proxy for loss aversion. Self-reported financial details can also be collected at this stage. The second set of methods generate additional data, collected using eye-tracking and brain scanning apparatus.

Table 1. Experimental Conditions for Initial Protocol

Condition	Pay (x)		Probability (p)		Damage ($-x$)
1	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-100,000 RMB
2	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-200,000 RMB
3	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-300,000 RMB
4	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-400,000 RMB
5	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-500,000 RMB
6	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-600,000 RMB
7	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-700,000 RMB
8	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-800,000 RMB
9	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-900,000 RMB
10	$(p \times -x)^{1.02}$	to avoid	[base-rate per year]	chance of	-1,000,000 RMB

Protocol 1

All data collection needs to be anonymized and assigned to serial numbers, rather than individual identifiers, to promote the ethical need for participant privacy and to encourage accurate responses. All prospective participants will be informed of these conditions, when being asked for informed consent. They can then be randomly allocated to one of several flooding scenarios and either ascending or descending levels of the damage prospects outlined in Figures 3 and 4 below.

The proposed research methods require a set of flooding frequencies, reduced to all but the most recent 5 years of a known sub-sample of historical flood occurrences, in several identifiable locations. The methods also require a single computer terminal operating under tightly controlled, laboratory conditions. The terminal needs to include a single monitor to display a sequence of prospect conditions, displayed using e-Prime software or similar. A single keyboard needs to be provided, allowing participants to select either "f" to accept the prospect displayed, or "g" to reject it. When they select f, the protocol will pause while participants complete a decision log: A brief description of why they selected the prospect in question. This participant interface follows option-based antecedents for testing prospect theory, outlined in Tversky and Kahneman (1992).

Following a very brief introduction to the decision context of flooding and a standard training procedure for using e-Prime, the laboratory procedure will be repeated at various levels of potential losses, i.e. using the conditions shown in Table 1. Among benefits for the transparency of data analysis, this procedure is short enough to avoid participant fatigue. Extended rest periods are not required, because the entire procedure is short enough to conduct in less than 20 minutes. Participants will be guided through the procedure by simply progressing through the conditions using e-Prime software under highly controlled and standardized laboratory conditions. A visual representation of this procedure is shown in Figure 3.

To counter the influence of order effects, or framing effects within prospect theory, participants will be randomly assigned to one order or another. One group of participants will proceed from condition 1 to condition 10, while the other group will proceed from condition 10 to condition 1. To help participants re-focus between conditions, small red crosses will be shown to participants for a standard maximum fixation period of 800 ms, between each prospect condition. The reversed order of conditions is shown in Figure 4.

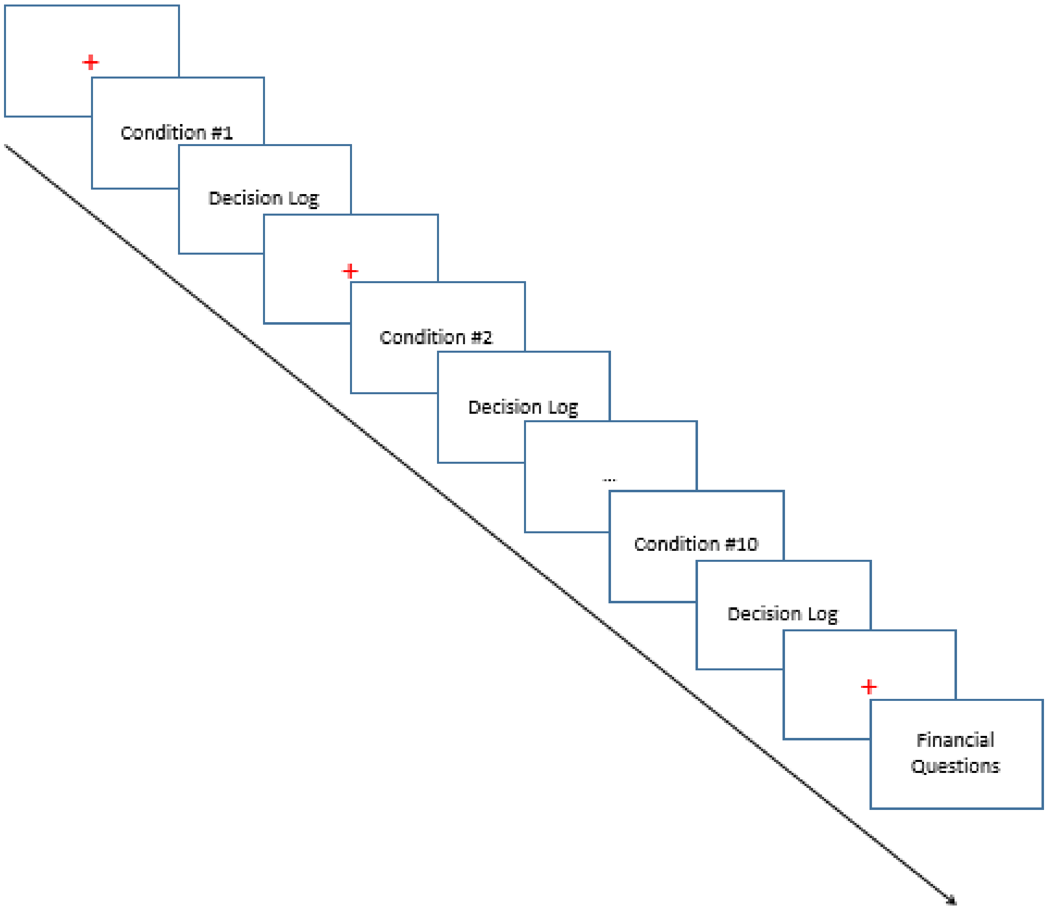

Figure 3. e-Prime Sequence of Decision-Making Prompts

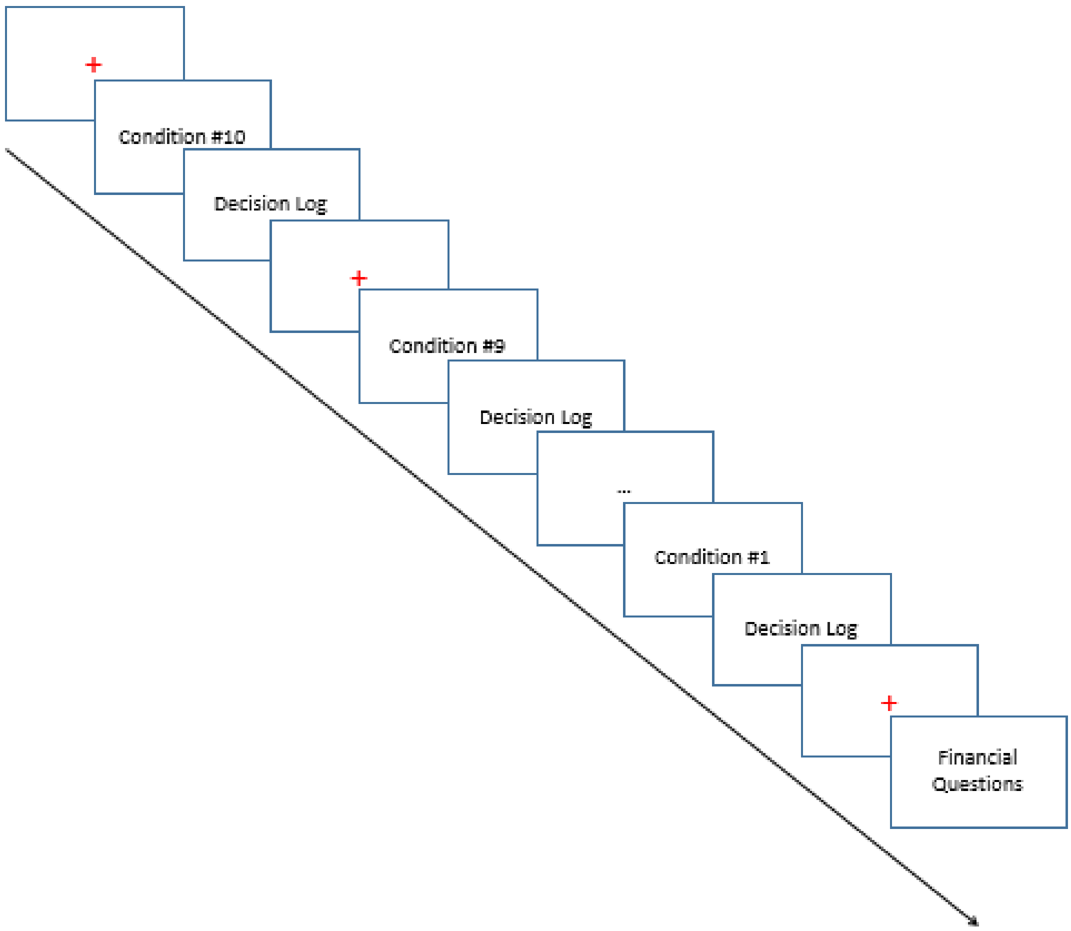

Figure 4. e-Prime Sequence of Reverse-Order Decision-Making Prompts

Conditions outlined above will be followed by another brief period of 800 ms. This will be followed by quantitative questions for respectively determining participants' financial net worth (nw) and available capital (ac):

1. Can you please estimate the total value of all financial and non-financial assets that you own?

2. What is the total amount of cash that you would have readily available in a crisis?

Analysis A: Threshold levels of loss will be determined by the lowest level of loss (-x) which is more heavily valued than savings from not buying insurance, i.e. where the decision is no longer axiomatically rational:

$$\theta(\text{-}x) = v\,(\text{-}x) > ev\,(\text{-}x)$$

Positive responses indicating a genuine loss (-x) threshold for risk averse responses will be accompanied by positive responses to options at all higher levels of damage. In other words:

$$\theta(\text{-}x) = v_{min}\,(\text{-}x) > ev\,(\text{-}x), \text{ if}$$

$$\left[v\,(\text{-}x)_{i-j} \geq \theta(\text{-}x)\right] > ev\,(\text{-}x)$$

Responses at the proxy threshold for loss aversion will then be evaluated for ecological rationality using the following criteria:

1. Mean distance between participants' damage thresholds and net worth (nw) that are significantly lower than the equivalent distance for sub-threshold levels of damage.

$$M|\theta(\text{-}x) - nw| < M|x_{max} < \theta(\text{-}x) - nw|$$

2. Mean distance between participants' damage thresholds and available capital (ac) that are significantly lower than the equivalent distance for sub-threshold levels of damage.

$$M|\theta(\text{-}x) - ac| < M|x_{max} < \theta(\text{-}x) - ac|$$

3. Correlation between losses at threshold level and out-of-sample losses (loss occurrence or -xo) that significantly exceeds correlation between losses at immediately sub-threshold level and out-of-sample losses.

$$r\ (\theta(\text{-}x), \text{-}xo) > r\ (x_{max} < \theta(\text{-}x), \text{-}xo)$$

Protocol 2

As at the time of writing we planned to recruit an equivalent sample of participants for the next set of laboratory protocols. Participants who have already participated in the initial protocol will be excluded. All materials piloted and adapted during the pilot phase will be used in the fully developed protocol. Additional equipment, including a Tobii eye tracking bar and software, Functional Near-InfraRed Spectography (fNIRS) sensors, a Nirsport2 cap and receiver unit, and two additional laptops will also be prepared for calibration with each participant. Data from the subsequent five years of flooding data samples used in Phase 1 will be used to constitute actual occurrence (-xo).

Before beginning data collection, all participants will be invited to help calibrate Tobii and fNIRS apparatus. Procedures successfully piloted and adjusted from the pilot research will then be replicated, together with the simultaneous collection of eye tracking and brain activity data.

A threshold level of loss will again be determined by the lowest level of loss (-x) which is more heavily valued than savings from not buying insurance, i.e. where the decision is no longer axiomatically rational. Equations (5), (6) and (7) in the Phase 1 protocol outline the criteria for determining this level. We can expect that eye tracking data collected during threshold conditions will reflect a heat map concentrated on the damage amount i.e. rather than any other element of the condition display. An example is shown in Figure 5. This use of eye tracking data will avoid many obstacles for using brain activity to accurately account for visual attention, outlined by Moore & Zirnsak (2017).

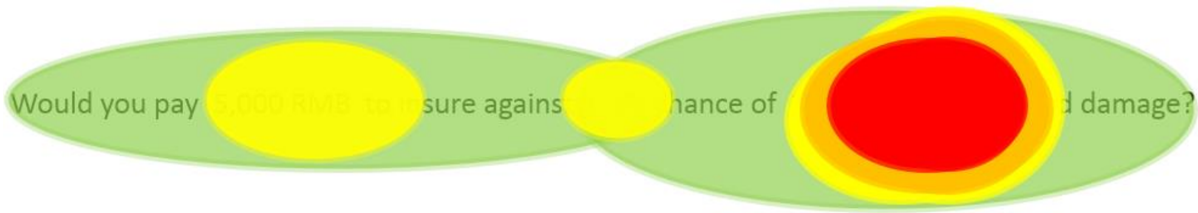

Figure 5. Synthetic Heat Map Focused on Damage Amount, Indicating Loss Aversion

Brain activity data can then be used to provide robust indications of mental processes used to process visual data. These mental processes can be observed through patterns of frontal lobe activity that are associated with mental arithmetic (Power et al., 2017). Using a standard sensor array, we expect to observe a reduction in blood flow, or hemodynamic response, within 10 seconds of an axiomatically rational response to particular prospect conditions. As shown in Figure 6, this hemodynamic response would usually indicate mental arithmetic required for estimating expected values. This response is expected to remain significantly more stable for prospect conditions eliciting the loss aversion heuristic. Hemodynamic responses during loss aversion may even increase, when loss aversion elicits a strong emotional response in certain participants.

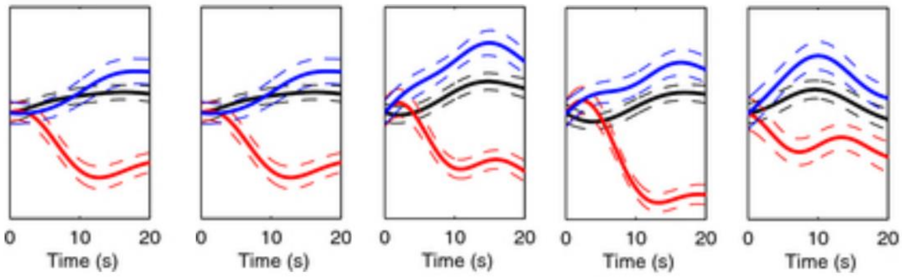

Figure 6. Typical Hemodynamic Responses to Mental Arithmetic in Red, Music in Blue, and Control Conditions in Black (adapted from Power et al., 2012, p.7)

CONCLUSION

Many decades of prior research, including examples outlined in the current paper, have identified how contextual factors affect risk-related decisions. The proposed research builds on these antecedents by studying conditions under which the axiomatic rationality implicit to prospect theory either occurs or does not, i.e. rather than simply noting the way that value and weight curves had to be marginally adapted. This is how the proposed research goes one big step further, by studying a heuristic response that deviates from axiomatic rationality (i.e. through referencing ev) but that may nonetheless lead to highly useful outcomes.

The proposed research will make a novel contribution to fundamental decision-making research, at the intersection of cumulative prospect theory and ecological rationality. The proposed research will also directly inform a very broad range of applied, disaster-related research. As part of a wider program of research into promoting ecologically rational heuristics for effective disaster management, the findings feed into important, real-world applications. These include innovative methods for optimizing public information systems and many other information system interfaces, towards optimizing user responses.

As outlined, the proposed research will help inform efforts to manage a range of natural hazards and potential disasters. However, the research remains most directly applicable to floods. In a world marked by the accelerating, and often interacting, impacts of intensifying rainfall patterns, sea level rise, urban development in coastal areas and flood plains, and both commercial and technological interdependencies that prior generations could barely imagine, the importance of this particular focus cannot be overstated.

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Assessing Climate Vulnerability Under Future Changes to Climate, Demographics and Infrastructure: A Case Study for the Chapel Street Precinct, Melbourne

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ABSTRACT

The Chapel Street Precinct is a busy commercial and residential corridor in the City of Stonnington Local Government Area (LGA) located in metropolitan Melbourne, Australia. Authorities and planners in the LGA are interested in understanding how the changing climate affects the socioeconomic environment of the region. By considering existing climate hazards (such as extreme heat, flood and water availability), infrastructure, and demographic information in the region together with future projections of climate change and demographic changes, a Socioeconomic Vulnerability Index (SVI) was created at a Mesh Block scale to better identify relatively high-risk Mesh Blocks in the region. The climate projections under medium and high future emission scenarios (i.e., representative concentration pathways (RCP)) as per IPCC (Intergovernmental Panel on Climate Change) fifth assessment report (AR5), RCP4.5 and RCP8.5 respectively for 30-year epochs around 2030, 2050 and 2070 were used in the SVI development. The current-day scenario is considered under Baseline conditions for demographic and asset information representing present-day conditions, whereas the baseline climate dataset considers the climate for the 30 year period 1991-2020 to best represent the present-day climate. The multi-model mean of the future climate projections from 6 different climate models were obtained from the Victoria's Future Climate tool (https://vicfutureclimatetool.indraweb.io), developed by CSIRO (Commonwealth Scientific and Industrial Research Organisation) Data61 together with the Department of Environment, Land, Water and Planning (DELWP) under Data61's INDRA framework (https://research.csiro.au/indra/). A version of INDRA is currently under development to allow map-based interactivity, experimentation and scrutiny of the vulnerability indices and their subcomponents across the study region.

The SVI was created using a weighted indicator approach utilising a range of indicators belonging to 3 categories, exposure, susceptibility, and baseline adaptive capacity. The indicators were first normalised and the final SVI was given a score between 0-1 for each Mesh Block. The worst levels of vulnerability were observed to be for the RCP8.5 2070 scenario. In general, the RCP8.5 scenarios indicated a worse outcome compared to the RCP4.5 scenario. The area along Chapel Street within the precinct which is a densely built-up area high in population was found to be the most vulnerable area in the study region. It is foreseen that decision makers will be able to use the holistic data-driven outcomes of this study to make better informed decisions whilst adapting to climate change.

Keywords

Climate change, heat, flood, vulnerability, risk, demographics

INTRODUCTION

The City of Stonnington, referred to as the city henceforth is a Local Government Area (LGA) located in the south-eastern suburbs of metropolitan Melbourne, Victoria, Australia which covers an area of 25.6 km^2 and is home to a population of 125,000 people. This population is expected to grow by 14.5% to over 143,000 people by 2036 (.id, 2022). Significant landmarks in Melbourne such as the Prahran Market and Jam Factory are located in the City of Stonington, particularly in the Chapel Street Precinct. The Chapel Street Precinct is a busy retail, entertainment, business and residential region consisting of the suburbs of South Yarra, Windsor and Prahran along Chapel Street that runs north to south (Figure 1). Given the high population density and the built-up nature of the region, it is important to understand how future climate change and changes in demographics could impact the precinct and prepare for additional climate risks that are involved. The purpose of this study is to develop an approach that can be applied to any geographical area to identify regions that are susceptible to both the combined and individual effects of climate hazards such as extreme heat and floods. Another key outcome of this work is that planners will be able to allocate limited resources in a prioritized manner at a granular scale to optimise climate change adaptation outcomes.

INDRA is a Climate and Hazard Risk Analytics and Visualisation Platform developed by CSIRO Data61 that integrates a range of climate, infrastructure, and demographic datasets (https://research.csiro.au/indra/). The platform improves accessibility to curated, relevant and actionable climate data for many end-users. INDRA also supports local governments, urban planners, and other interested parties in planning and to understand and develop climate adaptations for vulnerable regions. The outcomes of this study will be presented on an instance of INDRA termed INDRA Stonnington so that decision makers from the city will have the output datasets in an easily accessible web-based platform which integrates other geospatial analytics capabilities for more meaningful interpretation of the results whilst presenting the background data to better understand the climate and demographic inputs.

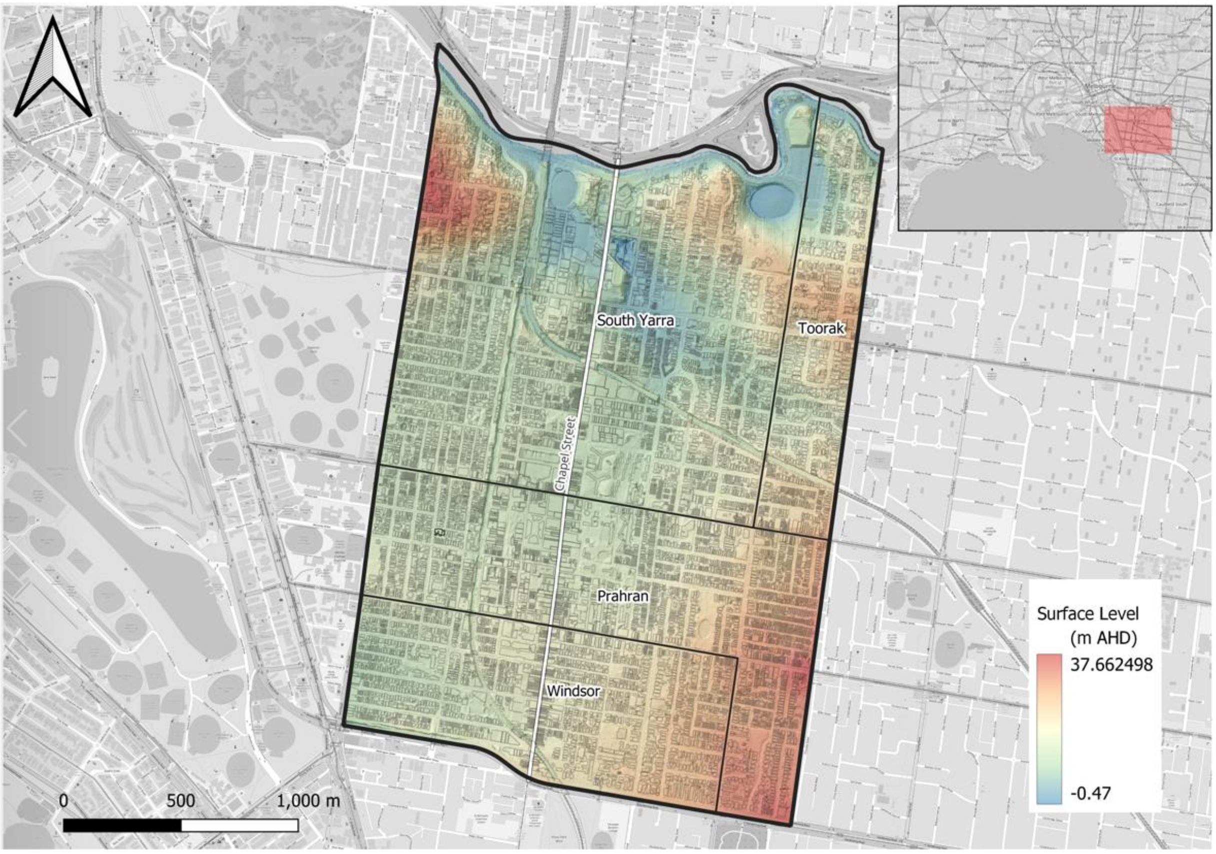


Figure 1 The Chapel Street Precinct with internal suburbs indicated and building footprints outlined in black. The coloured pattern indicates the surface level of the region (in m AHD). The inset map shows the relative location with respect to Melbourne

LITERATURE REVIEW AND LIMITATIONS OF PRESENT APPROACHES

A recent study done by Deakin University (Roös et al., 2020) attempted to identify highly sensitive and vulnerable populations prone to risk caused by heatwaves for the City of Greater Geelong in Victoria. The study explored the concept of Urban Heat Island (UHI), an indicator that represents the subsequent increase in surface and air temperature in urban environments due to the entrapment of heat in impervious surfaces (roads and buildings surfaces including roofs contribute to imperviousness). Upon modelling UHI over the years, the increase in the impervious surface ratio was identified as the key indicator. The study assumed that UHI does not change with future climate projections, where UHI represents the temperature difference between urban and rural zones. It was assumed that both urban and rural environments will equally rise in temperature, the temperature difference may remain the same (Roös et al., 2020). However, this assumption needs to be further investigated.

A study done by Sun et al. (2018) for DELWP presented a Heat Vulnerability Index (HVI) considering the 3 heat vulnerability components: heat exposure, sensitivity to heat and adaptive capability at an Australian Bureau of Statistics (ABS) Statistical Area Level 1 (SA1) scale. The HVI assessment combined nine demographic and geographic indicators to identify areas with high vulnerability to heat waves. A quintile approach was followed to give each SA1 area a HVI score between 1-5, where 1 indicated a low vulnerability and 5 indicated a high vulnerability. Most SA1 regions in the Chapel Street precinct have a low HVI score of 1, except for two SA1 regions that have a high SVI score of 4 and 5 respectively. The study recommends that the percentage of built-up area needs to be integrated into the index development, though was not included due to the lack of data.

For present-day conditions, Heat Vulnerability Indices for various cities have been proposed in Johnson et al. (2012), Wolf et al. (2013) and Rathi et al. (2022) whilst considering data for Land Surface Temperature (LST) and population to provide an overall idea of vulnerable areas and communities in their respective study region.

METHODOLOGY

The existing approaches mentioned earlier quantify the risk based on current day information and data. Though, the effects of extreme heat on the community are explored in detail, the effects of floods and water availability have not been explored. The City of Stonnington is keen to understand the vulnerability imposed by all aspects of heat, flood, and water availability in the socio-economic context. To identify the level of heat vulnerability at a local scale, a Socioeconomic Vulnerability Index (SVI) is developed at the Mesh Block scale, the finest statistical level described by the ABS (ABS, 2022) using a cohort of climate, demographic and infrastructure indicators. This scale was chosen to balance providing adequate spatial granularity to identify vulnerable communities whilst not singling out individual people or infrastructure. The first iteration of the study utilises diverse sources of data that includes climate data from the INDRA tool, publicly available data (Mesh Blocks and short-term demographic forecasts) and the data provided by the city (road data, building footprints, flood maps, etc.). The SVI is created for current day or "Baseline" and 3 future time periods centred on 2030, 2050 and 2070.

The three main types of spatio-temporally varying indicators are,

1. Exposure (Baseline, 2030, 2050, 2070) – climate hazards such as heat, flood and water availability
2. Susceptibility (Baseline, 2030, 2050, 2070) – components of the socioeconomic environment that are susceptible to the effects of climate change and climate hazards
3. Baseline adaptive capacity – the existing ability of the built environment to alleviate climate hazards and adapt to climate variability

Indicators

The indicators were chosen from an extensive literature search to assimilate various indicators that contribute to overall climate vulnerability. Additionally, local expertise from city officers was sought in integrating the various vulnerability indicators. It should be noted that certain indicators will have a higher contribution towards the overall vulnerability whilst others will not contribute much towards the vulnerability. To account for this, weights (low, moderate, and high) are assigned to the indicators. Finally, the availability of data dictated the final selection of indicators although extensive research was carried out to assimilate a vast collection of data relevant to the region. Indicators used to develop the SVI and the assigned weightings of the indicators are summarised in Table 1.

Exposure Indicators

To consider the combined vulnerability of Mesh Blocks to climate hazards, the exposure category of vulnerability combines heat, flood and water availability related datasets. Variables have been selected such that some variables provide spatial granularity regarding the climate hazards and the other variables provide temporal granularity into the future. For instance, climate projections on a 5 km spatial grid provide the temporal granularity in developing the indices. Application-ready gridded datasets for climate projections from an ensemble of climate models were obtained from the Victoria's future climate tool which sits within the INDRA framework developed by CSIRO's Data61 together with DELWP (https://vicfutureclimatetool.indraweb.io) (DELWP, 2021). The platform combines six future climate models ACCESS 1-0, CNRM-CM5, GFDL-ESM2M, HadGEM2-CC, MIROC5 and NorESM1-M to produce a multi-model mean climate dataset. The tool provides future projections for four 30-year epochs centred on 2030, 2050, 2070 and 2090, and for two representative concentrations pathways RCP4.5 (medium emissions) and RCP8.5 (high emissions). The platform also includes baseline historical data for the period 1986-2005, however, in this study, an updated baseline dataset for the period between 1991-2020 was developed to get a better representation of the current climate. The raw values for climate variables including maximum and minimum temperatures and rainfall volumes were utilised to produce processed climate extreme layers including projections of heatwaves, annual number of days above certain temperature thresholds, extreme value analysis of extreme rainfall (1 in 20-year daily rainfall volume) and the annual number of days above certain rainfall thresholds which are directly integrated as the relevant indicators.

The Urban Heat Island 2018 dataset published by DELWP (2019) has UHI data for metropolitan Melbourne at a fine Mesh Block scale based on remote-sensed Land Surface Temperature (LST) values. The difference in LST values with a standard rural temperature value provides the urban UHI value for each Mesh Block. The intensity of the UHI is the temperature difference expressed at a given time between the hottest sector of the city and the non-urban space surrounding this (Martin-Vide et al., 2015). The DELWP UHI dataset is used to provide spatial granularity for the heat variables. Furthermore, the number of days above 30, 35 and 40 C° are assigned low, moderate, and high weightings respectively to provide the temporal granularity to the heat vulnerability component in the exposure index. The total number of annual heatwaves are also considered in the indices and are assigned a high weighting as heatwaves are a severe climate hazard projected to increase into the future, moreover, extreme heatwaves have claimed more lives than any other natural hazard in Australia (Coates et al., 2014).

Table 1. Indicators used to derive the Socioeconomic Vulnerability Index (SVI) with low (L), moderate (M) and high (H) weightings indicated.

Exposure (Baseline, 2030, 2050, 2070)	Susceptibility (Baseline, 2030, 2050, 2070)	Baseline Adaptive Capacity
Heat Variables UHI 2018 map (H) Days above 30 deg C (L) Days above 35 deg C (M) Days above 40 deg C (H) Number of Heatwaves (consecutive days of above 35 deg C for 3 days) (H)	Population density (M) Elderly (older than 75 years) (H) Young children (0-4 years old) (H)	Street trees (H) Green (permeable) spaces (M) Drainage capability (pits and pipes) (M)
Flood Variables Flood maps (H) Increases in flood intensity due to climate change represented by change in 1 in 20-year rainfall volume (H) Terrain elevation range within a Mesh Block (L)	Homeless (H) People with disabilities (H) People with medical conditions (H)	Building footprints which negatively impacts adaptive capacity (H) Roads which negatively impacts adaptive capacity (M)
Water availability Variables Decrease in water availability due to climate change (represented by reduction in days with rainfall above 10 and 20 mm) (M)	Low-income households (H)	

Flood hazard is included in the exposure index by using flood extents maps to provide the spatial granularity for exposure index. The flood maps for 1 in 100, 1 in 50 and 1 in 20-year return period scenarios were modelled by

Melbourne Water and provided by the city. In the study region, the flood maps show detailed flood extents from the combined effects of extreme rainfall and subsequent catchment flooding. Furthermore, the terrain elevation range for each Mesh Block is derived from the 2.5-metre-high resolution Victorian Coastal Digital Elevation Model (DEM) (CRCSI, 2017). The terrain elevation range within a Mesh Block was calculated simply as the difference between the maximum elevation in a Mesh Block and the minimum elevation within each Mesh Block ($\boldsymbol{Terrain\ elevation\ range\ within\ a\ meshblock = elevation_{max} - elevation_{min}}$ Equation 1). If a Mesh Block has a larger terrain elevation range (proxy for steeper slope), flood water will tend to flow and drain out of the Mesh Block instead of stagnating. On the other, hand, flatter Mesh Blocks (smaller terrain elevation range) are assumed to entrap water without providing the elevation difference to water to flow, thus, pooling the water in that Mesh Block increasing the flood vulnerability. However, it should be noted that this approach only considers the potential depth of pooled water as an indicator of vulnerability and does not consider the added hazards of high velocity flood waters. Given the availability of hydrodynamic data, the combined effects of flood depth flood velocity can be incorporated into the methodology in future versions of the SVI.

$$\boldsymbol{Terrain\ elevation\ range\ within\ a\ meshblock = elevation_{max} - elevation_{min}} \quad \textbf{Equation 1}$$

The change in water availability into the future is a crucial aspect that would expose vulnerable populations to complex health related issues. The water requirements for Stonnington are served from Victoria's potable water system (10,831 ML/yr) for potable water, and rainwater (185 ML/yr) is mainly utilised for non-potable uses. Water consumption is further supplemented by the river water extracted (75 ML/yr) from the Yarra River and groundwater use (28 ML/yr) (E2DesignLab, 2022). Looking at the rainfall extremes data presented in the Victoria's future climate tool, the number of days with rainfall above 10 mm and 20 mm reduces into the future together with a reduction of annual rainfall volume indicating a hotter drier future. Since the overall rainfall is an indicator of the availability of potable water, a reduction of overall rainfall volume indicates an increase in vulnerability.

Susceptibility Indicators

Population and household forecasts for the City of Stonnington were prepared by informed decisions (id) (2022) and are available at suburb scale. These are based on 2016 census data and are spaced every 5 years up until 2036, thus giving data 5 different points in time (2016, 2021, 2026, 2031 and 2036) between 2016-2036. Present day population data and demographic breakdowns were available at a Statistical Area 1 (SA1) level which consists of multiple Mesh Blocks. This data was disaggregated further down to individual Mesh Blocks. To project the growth of population into the future, the suburb level growth forecasts were used for each Mesh Block. It is worth appreciating that population growth is dependent on a vast suite of complex factors which are specific in time and space for each region. However, identifying the complexities of population growth for the region was not the purpose of this study. Here, a logarithmic equation was fitted to the projections of population growth, and the fitted model was then used to predict the growth up to the year 2070. It was found that the change in population could be well represented by an exponentially decaying function. To account for differences in Mesh Block sizes, population density values were used in the susceptibility indices. Finally, high weightings were assigned to indicators that represented vulnerable communities such as the elderly, young children, people with disabilities and people from low socioeconomic backgrounds.

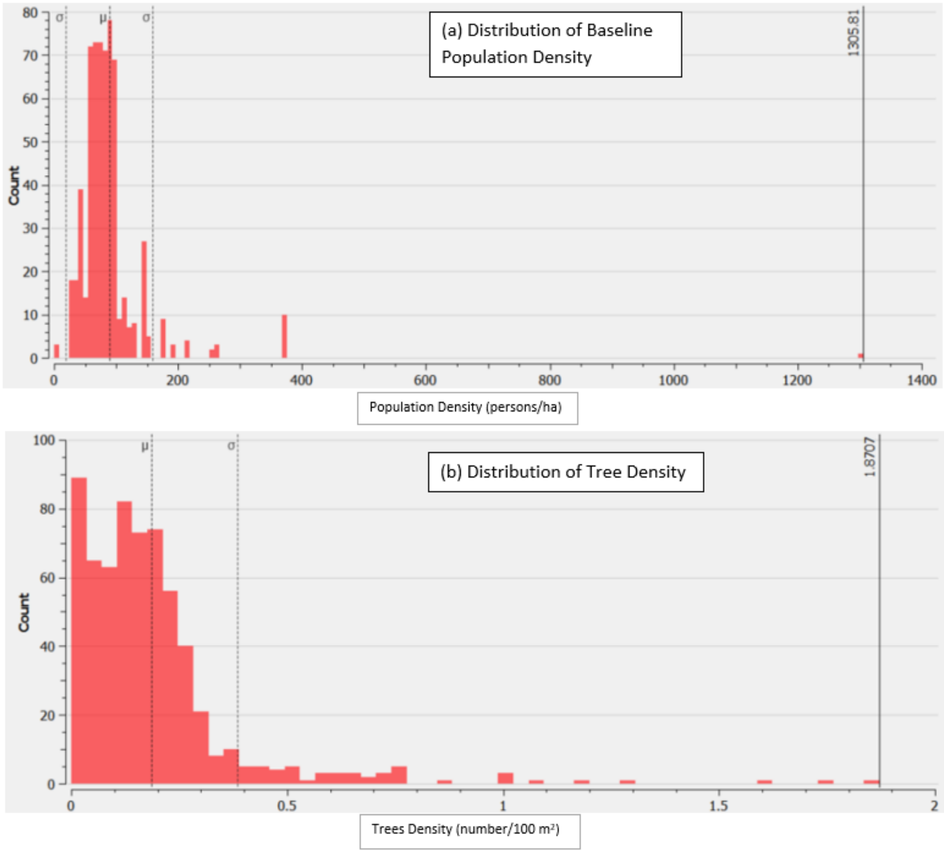
Baseline Adaptive Capacity Indicators

To engage the decision makers and subject experts in the city, the baseline adaptive capacity is considered using the present-day scenario of the built and natural environment. The changes in the built environment factors which support climate adaptation is entirely dependent on development standards that are introduced with the use of tools such as the one being developed in this study. Future phases of this study include steps such as workshops to engage with representatives in the city to discuss how future adaptive capacity indicators can be integrated into the methodology. The indicators included in the adaptive capacity category consist of elements in the physical environment that may have either a positive or negative impact in adapting to climatic hazards. Trees in urban environments are proven to provide benefits in reducing ambient air temperatures and to cool urban environments through evapotranspiration and shade (Kalkstein et al., 2022; Rahman et al.,2020 and DELWP, 2019). Furthermore, green spaces which include parks and sporting fields with permeable surfaces encourage infiltration of stormwater through ground infiltration. Additionally, evapotranspiration from grass may contribute to cooling the air temperature as well. To get an idea about a region's hydrodynamic drainage potential in present conditions which help manage stormwater, the quantities of pipe volumes and the number of volumes per unit area was included in the adaptive capacity indicators. Although, the inclusion of drainage assets might not be the best indicator of flood adaptive capacity as during heavy rainfall events these systems tend to get saturated, the assumption provides a basis for considering the existing adaptive ability of a region. Hard impervious surfaces in urban environments consist of roads and buildings. It is understood that impervious surfaces tend to entrap heat and exacerbate the impacts of heatwaves (Zhang et al., 2012). Furthermore, impervious surfaces cause water to run-off (rather than infiltrate) without leaving much moisture in the ground which reduces evaporative cooling. Moreover, high-density developments can have height and form that can trap heat at night. The existence of green infrastructure and vegetation reduces UHI (AECOM, 2013). Therefore, the area fractions of roads and building footprints are included in the adaptive capacity column as these factors act negatively and reduces the overall adaptive capacity.

Combination of Indicators

Vulnerability indices are inherently somewhat different from mathematical expressions of a conceptual model of vulnerability if they are not compared with observational data and tested (Bao et al., 2015). The approach undertaken in the study is summarised below.

1. Normalise each indicator to a value between 0-1 ($\boldsymbol{normalised\ indicator}=\frac{\boldsymbol{value-range_{min}}}{\boldsymbol{range_{max}-range_{min}}}$ Equation 2) by scaling to a range. When normalizing, for indicators which have temporal data from baseline until 2070, normalise based on the entire range including future values. It was found that each indicator exhibits a different form of distribution of values, with a common occurrence that included outliers on the maximum end of the range. As an example, there were a couple of Mesh Blocks with an extremely high population density due to the presence of high-rise apartment buildings. Additionally, certain Mesh Blocks representing parks had an unusually high number of trees compared to other Mesh Blocks. Since almost all of the indicators suggested a positive skew (a couple of examples of these distributions are shown in



2. Figure 2), the maximum of the range was clipped to two standard deviations from the mean. Since the actual minimum value did not extend too far beyond the mean implying an outlier for all indicators, the actual minimum value of the range is used as the lower limit.

$$\boldsymbol{normalised\ indicator} = \frac{\boldsymbol{value-range_{min}}}{\boldsymbol{range_{max}-range_{min}}} \quad \textbf{Equation 2}$$

$$\boldsymbol{range_{max}} = mean + 2\ standard\ deviations$$

$$\boldsymbol{range_{min}} = minimum(value\ range)$$

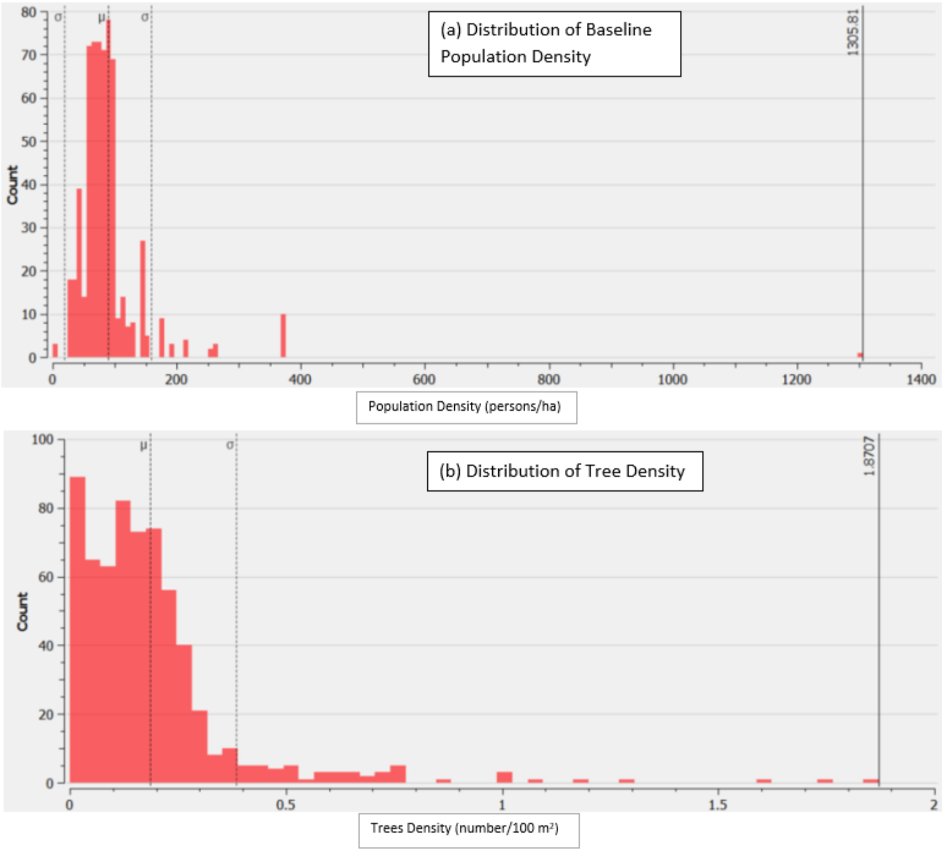


Figure 2 Distribution of values for Mesh Blocks highlighting the positive skew with outliers for the value distributions for (a) population density and (a) number of trees per 100 m^2. The standard deviation and mean of the distributions are marked with dotted lines

3. Calculate the indices for each vulnerability component –
   a. For the Exposure category, the temporally varying indicators for heat, flood, and water availability such as days above a certain temperature threshold are normalised and the weighted average for each hazard type is multiplied by the normalised spatially varying indicators, UHI for heat and flood maps for floods considering the weights.
   b. For Susceptibility, the weighted average of the normalised indicators.
   c. For Adaptive Capacity, the weighted average of the normalised indicators.
4. The final Socioeconomic Vulnerability Index is calculated using $\boldsymbol{SVI} = \frac{\boldsymbol{Exposure\ Index + Susceptibility\ Index + (1 - Adaptive\ Capacity\ Index)}}{\boldsymbol{3}}$ Equation 3

$$\boldsymbol{SVI} = \frac{\boldsymbol{Exposure\ Index + Susceptibility\ Index + (1 - Adaptive\ Capacity\ Index)}}{\boldsymbol{3}} \quad \textbf{Equation 3}$$

RESULTS AND DISCUSSION

The SVI was produced for 7 different scenarios including baseline (present-day) vulnerability and 6 future climate scenarios; for the years 2030, 2050 and 2070 under the future emission scenarios of RCP4.5 and RCP8.5. The SVI results and the individual indicators are presented on an instance of CSIRO Data61's geospatial visualization and analytics platform INDRA, INDRA Stonnington which is created for this study. Figure 3 includes the SVI results for four different climate scenarios; Baseline, 2030, 2050 and 2070 under the RCP8.5 future climate emissions scenario as presented on INDRA Stonnington. The figure shows all 630 Mesh Blocks in the study region coloured by the SVI which ranges between 0-1 with red colour indicating a high vulnerability and the lighter green and yellow colours indicate areas with a lower overall vulnerability. The baseline condition in Figure 3(a) shows higher vulnerability along Chapel Street (along the centre of the study region from north to south). As expected, densely built-up areas with high populations indicate a higher vulnerability while parks and other open space areas demonstrate a lower overall vulnerability. From Figure 3, it can be clearly seen that the overall SVI increases into the future, moreover, the Mesh Blocks which indicate a relatively higher socioeconomic vulnerability can be identified from the results.

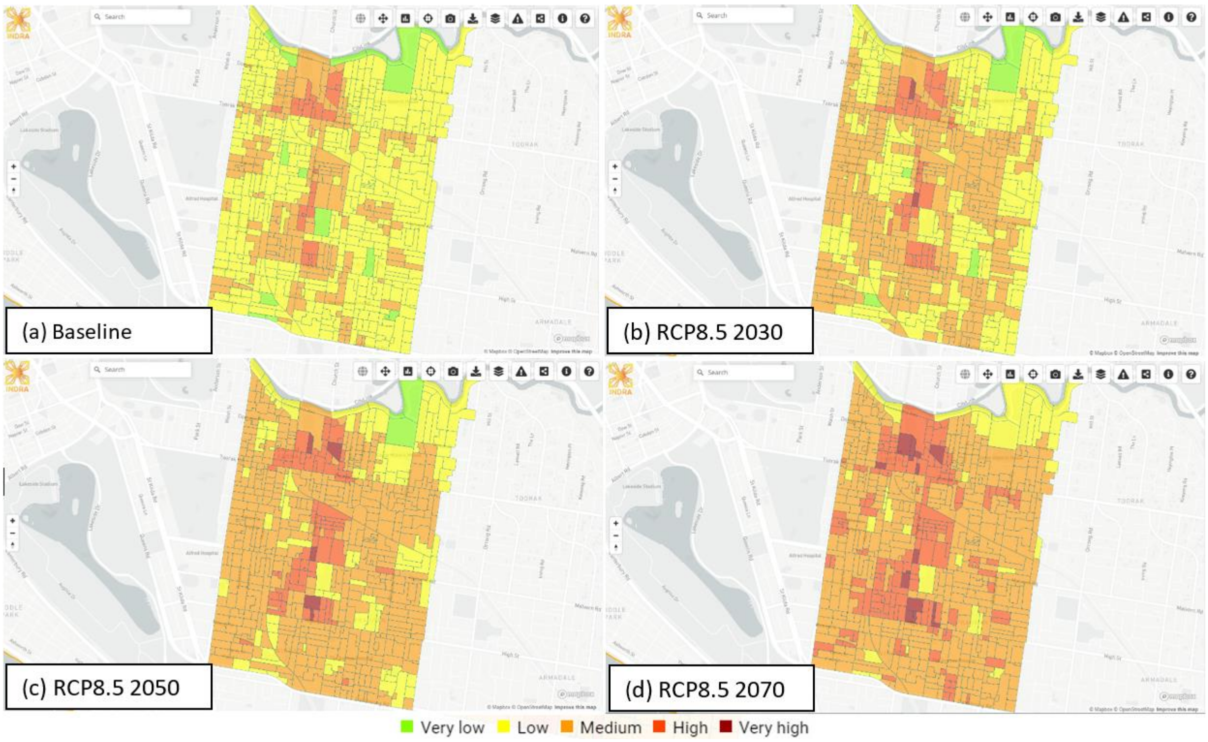


Figure 3. Socioeconomic Vulnerability Index for Mesh Blocks in the Chapel Street Precinct in the City of Stonnington under present and future climate scenarios (a) Baseline (b) RCP8.5 2030 (c) RCP8.5 2050 and (d) RCP8.5 2070. Vulnerability for each Mesh Block is given a value between 0-1, the risk levels based on the score can be interpreted as 0-0.2: very low, 0.2-0.4: low, 0.4-0.6: medium, 0.6-0.8: high and 0.8-1.0: very high

The bar plot in Figure 4 shows the variation of the SVI of all 630 Mesh Blocks in the study region across all 7 climate scenarios. The Baseline scenario shows that over 60% of the Mesh Blocks are in the Low vulnerability category (SVI value between 0.2-0.4) as represented by the yellow bars. Approximately 30% of the Mesh Blocks fall under the medium vulnerability category (SVI score of 0.4-0.6) whereas less than 25 Mesh Blocks fall under each category of Very Low (0-0.2) and High (0.6-0.8) for the baseline case. Looking at the SVI for 2030, under both RCP cases, majority of the Mesh Blocks move into the medium vulnerability category from the low vulnerability category. RCP8.5 in 2030 shows that more Mesh Blocks are in higher vulnerability than for the RCP4.5 2030 case. Moving further into the 2050's, the number of Mesh Blocks in the Very Low vulnerability category tends to go to 0, whereas a few Mesh Blocks in the Very High vulnerability category (0.8-1.0) start to appear. Comparing RCP4.5 and RCP8.5 for the 2050's, the 2050's under a RCP8.5 future demonstrates a scenario with a higher overall vulnerability. The difference between RCP8.5 2050 and RCP4.5 2070 is not significant, each vulnerability category has a similar number of Mesh Block counts. However, a significant difference in vulnerability can be observed between RCP4.5 2070 and RCP8.5 2070. Over double the number of Mesh Blocks fall in to the High and Very High vulnerability levels in the RCP8.5 2070 case compared to the RCP4.5 2070 case.

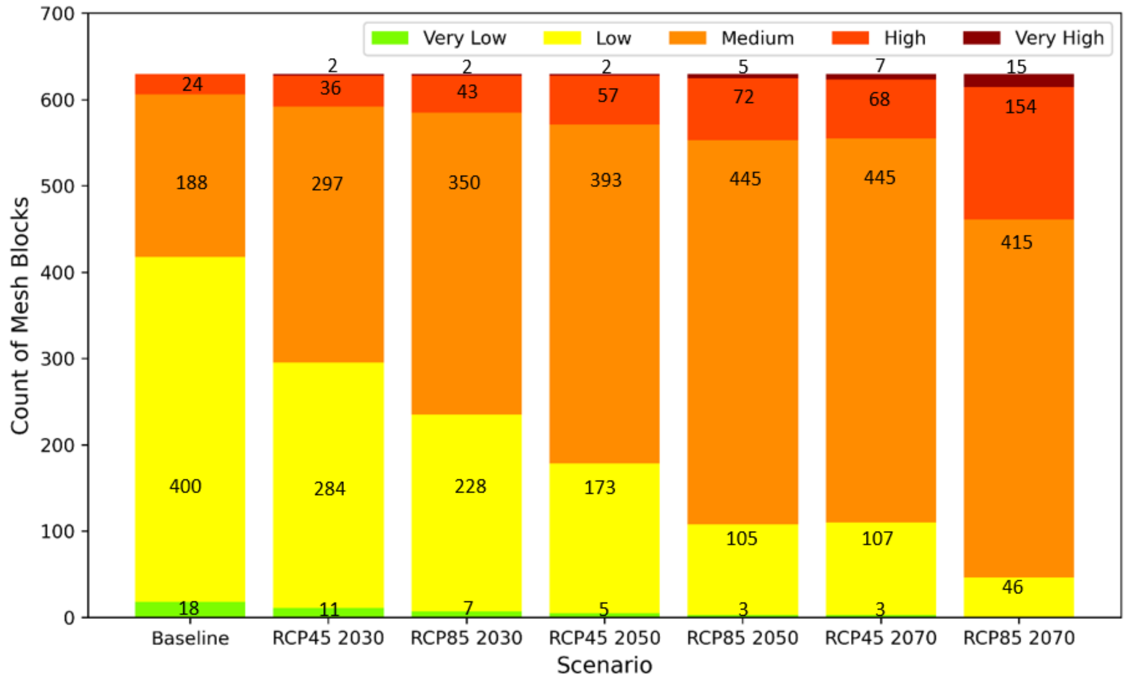


Figure 4. Socioeconomic Vulnerability Index - counts of Mesh Blocks for all modelled climate scenarios. 5 risk levels based on the vulnerability score between 0-1 are considered; 0-0.2: very low, 0.2-0.4: low, 0.4-0.6: medium, 0.6-0.8: high and 0.8-1.0: very high

CONCLUSION

The SVI developed highlights Mesh Blocks in the Chapel Street Precinct which are prone to vulnerability due to the combined effects of climate hazards including heat, floods and water availability also considering the future vulnerability due to climate change and changes in demographics in the socioeconomic context. The relative index for Mesh Blocks provides a basis for the City of Stonnington to start identifying vulnerable areas in the region. Furthermore, the insights from the SVI maps can be used by decision makers for targeted adaptive measures, and to better equip the most vulnerable communities in dealing with the implications of climate change. The weighted indicator-based approach which has been used in other similar studies provides an opportunity to incorporate several factors which may or may not have an inherent scientific relationship with each other but are still perceived to contribute to the overall vulnerability. The consideration of existing climate hazards such as UHI and flood maps at a fine spatial scale together with future climate projections is a first pass attempt to identify the increasing severity of climate hazards with future climate change. The projection of demographics into the future is useful in understanding that in a growing population, the increase in number of vulnerable communities may exacerbate the impacts of climate change. Furthermore, the consideration of current adaptive capacity as “Baseline Adaptive Capacity” will direct decision makers to think in a way that they can plan future development whilst contributing to the overall adaptive capacity in the form of green infrastructure and Water Sensitive Urban Design (WSUD) elements. The adaptive capacity contributor of the SVI can be readjusted to further investigate the best course of action to reduce vulnerability going into the future. From the SVI results obtained, it was clear that the region will become more vulnerable further into the future compared with the Baseline vulnerability, the RCP8.5 future emissions pathway indicated a higher overall vulnerability compared with the RCP4.5 future emissions pathway.

INDRA Stonnington, a tool being built alongside the vulnerability indices will help decision makers analyse the changes in socioeconomic vulnerability and the climate and demographic components in further detail by selecting the required indicators separately to better identify the underlying causes to increasing climate vulnerability. The web-based platform will be deployed such that interested parties will have easy access from any web browser with an internet connection.

In terms of the future development of the project, the city is also interested in understanding the climate vulnerability for physical infrastructure assets in the public and private realms. Infrastructure assets such as buildings, roads and drainage networks undergo accelerated deterioration under the harsh impacts of climate hazards such as extreme heat and floods which reduces the effective lifespan of these assets thereby increasing costs associated with maintenance and replacement. This excess “climate cost” is not currently well understood in a scientific and mathematical context and therefore not considered accurately in design and maintenance standards. Therefore, it is in the city's best interest to identify vulnerable locations so that climate adaptations can be targeted to those assets. The Infrastructure Vulnerability Indices for both private realm and public realm assets are currently being developed considering a suite of infrastructure related indices and further research is being done to develop projections of infrastructure vulnerability into the future which will all be incorporated into the INDRA Stonnington platform. Moreover, the current SVI will be improved further based on inputs from city stakeholders including decision makers and subject specialists and future adaptive capacity improvement scenarios will be included to better inform city decision making. The goal of this project is to develop a scalable framework that can be applied across the country to identify higher vulnerability areas within local government jurisdictions, the present version of the SVI presented in this paper can easily be applied to other LGAs.

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Deployment of Autonomous Vehicles to Support Emergency Response During Crisis

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ABSTRACT

Emergency response services face massive pressure during global crises, such as COVID-19. The food supply logistics sector is one of the pressures that impacted the emergency response services, due to crisis restrictions. A regulatory framework to deploy autonomous vehicles, in any nominated country, has been presented to boost the food supply logistics as an emergency response to critical situations to serve isolated areas. This framework resulted in three steps to deploy AVs in the nominated country, which are evaluating their legislation, modifying their existing regulations accordingly, and ensuring the full deployment of the innovative technology. This is done by minimising person-to-person contact during the transportation and distribution phase. In conclusion, fully autonomous vehicles can help lift the pressure from the emergency response teams in the food supply transportation and distribution phase to meet the basic living requirements for human needs during global crises.

Keywords

Autonomous vehicles, emergency, food, COVID-19.

INTRODUCTION

The Coronavirus, or Covid-19, is considered a crisis of public health. It results in significant life loss and human suffering globally, which examines our ability to respond to emergencies (Majdúchová, 2021). The pandemic also created a massive social, economic, and financial shock in the twenty-first century after the 2008 Global Financial Crisis (Gurría, 2020). COVID-19 has become a dangerous epidemic, with millions of cases detected globally. Over 100 nations implemented either a full or partial lockdown to combat the COVID-19 outbreak, impacting billions of humans, and industries (Reinstadler et al., 2021).

The World Health Organisation (WHO) declared the virus to be a pandemic disease in March 2020, indicating that most countries in the world will experience the crisis of the uncontrolled deadly virus outbreak (Singh & Singh, 2020). At the same time, the virus was first conducted in late 2019 in Wuhan, China. Since then, the breakout of the virus has spread quickly around the world. Therefore, social distance and isolation policies have been implemented or advocated globally to restrict disease spread, reduce the pressure on the healthcare sector, and decrease total death (Bargain & Aminjonov, 2020). However, these policies have created a massive disruption to many other sectors, including food supply chain logistics (Barman et al., 2021).

All aspects of the food supply chain have experienced disruptions because of the crisis outbreak, including transportation and logistics, food processing, agricultural productivity, and final demand (Chari et al., 2022). Different products have faced interruptions at different stages of the supply chain, and not all professions and products have been affected in the same way (OECD, 2020). Due to transportation and mobility restrictions, food supplies from rural regions no longer reach consumer centres in urban and peri-urban areas. In addition, food delivery to consumption centres was restricted due to lockdowns and anxiety of exposure to the virus (Nchanji et al., 2021).

Farmers also have been restricted from producing, harvesting, and selling their products locally and globally, due to border closures, trade and transport restrictions, and confinement measures (ILO & IFAD, 2020). Besides, millions of self-employed and waged agricultural workers who are accountable for feeding the world frequently experience high levels of working poverty, hunger, and bad health as it is the main source of their income in such a critical situation. As a result, this will increase the pressure on the food supply emergency services to respond to the food shortages globally.

For instance, the food distribution trucks in France have declined by 60 per cent due to virus limitations, which used to be 30 per cent before the virus outbreak (Aday & Aday, 2020). In addition, the European nations increased their demand for fresh bread and vegetables by 76 per cent and 52 per cent, respectively, in the week after the COVID-19 pandemic was announced (Barman et al., 2021). This results in an obvious problem that faces the food supply chain transportation and distribution worldwide. This problem needs to be addressed perfectly to solve the food supply chain emergency response issues during a crisis. Therefore, this study aims to improve the food supply emergency response by deploying Autonomous Vehicle (AV) technology to enhance the transportation and distribution processes during critical situations.

LITERATURE REVIEW

The transition to automation is happening quickly. In Australia, the Royal Automobile Club (RAC) examined the first autonomous bus in Western Australia, and the Australian Driverless Vehicle Initiative has published a timeframe that predicts accelerated prototype trialing and policy reforms for the remainder of this decade to pave the way for subsequent public acceptance and adoption of Avs, in 2016 (Pettigrew et al., 2018). The Queen stated in her 2016 State Opening of Parliament speech that the United Kingdom will be “at the forefront of technology for new forms of transport, including autonomous and electric vehicles” (Cabinet Office, 2016). The Institute of Electrical and Electronics Engineers (IEEE) predicted that 75 per cent of vehicles will be completely automated by 2040 (Read, 2012). The jobs of commercial truck drivers are predicted to be impacted by 50 to 70 per cent by self-driving vehicles in Europe and the United States, by 2030 (Baratta, 2021).

Driverless cars, known as AVs, can travel to various places with a high response rate to traffic signals and avoid obstacles on the road without requiring driver engagement (Xing et al., 2021). The engagement of AVs has many advantages for social, economic, and the environment. It is expected to improve road capacity and traffic flow by 100 per cent and 20 per cent, respectively, to save fuel, time, and money. Also, a 60 per cent reduction in CO2 is expected (Goldin, 2018). According to a study at the University of Illinois at Urbana-Champaign, as low as 5 per cent of engagement of self-driving cars might solve the traffic jams caused by stop-and-go behavior. This, in turn, will not only save individuals time, but will also cut the amount of time their automobiles are on the road, and lowering emissions (Stern et al., 2018).

The advantages of AVs are generally recognised, but questions remain regarding the deployment of their range, risks, and unforeseen effects (Taeihagh & Lim, 2019). Therefore, this section will tickle the safety, liability, and cybersecurity implementation of AVs from different governmental approaches to be deployed in any nominated country. Each implication also will be assisted against the five AV-related governing strategy types to maximise end-user benefits and minimise AV risks, as will be explained in Table 1 below. It is worth mentioning that the AV has different levels to assist the driver. At the same time, the highest level exempts the human driver, as will be explained in the next paragraph.

Table 1: AV-related governing strategy types (Li et al., 2018; Li et al., 2021)

Respondents	Position Year of experience
ADAPTATION-ORIENTED	The goal of this technique is to increase the system's or organisation's capacity for adaptation. It places a strong focus on accepting uncertainty and enhancing how well it responds to disruptions. It incorporates elements of " co-decision, shared accountability, and forward-looking planning "(Li et al., 2018). It is like the resilience and adaptive resilience methodologies put out by Nair and Howlett, and Walker et al. (2016; 2012)
TOLERATION-ORIENTED STRATEGY	The strategy's goal is to tolerate risk. In other mines, the person who makes the choices does part of the operational tasks to inspire the company to perform effectively in a steady transition atmosphere. It also relates to the understanding of various researchers' resilience, which refers to a business or sector that is resilient to a wide range of new threats and changes (Nair & Howlett, 2016).

CONTROL-ORIENTED STRATEGY	This technique relies on previous risk assessments since it anticipates that academic knowledge will lessen uncertainties, and it's crucial to comply with government policies. It seeks to mitigate known sub-optimal risks, and it is desired to achieve a favourable risk assessment by consistent risk estimation (Krieger, 2013).
PREVENTION-ORIENTED STRATEGY	The decision-makers defensive strategy of reducing risk using innovative technology (Li et al., 2018). For highly anticipated situations, a prevention-oriented approach is a good option. However, because of its slower response time, it makes policy insensible.
NO RESPONSE	There is nothing the decision-maker can do to determine the dangers. It may happen because the individual making these selections is not aware of what innovation technology might lead to (Walker et al., 2010).

AV Levels

Advanced AVs can sense the surrounding environment by relying more on technology to take over human driving duties and actions (Ma et al., 2020). The vehicle can also navigate from point to point with a high response rate to traffic signals and avoid road hazards without any human-driver interactions (Litman, 2017). Consequently, the Society of Automotive Engineers (SAE) has published the SAE international standards J3016 designed to define the six levels of Avs, from the lowest level (non-computerised vehicles) and progressing to the highest level (Fully computerised vehicles) (© SAE International from SAE J3016™, 2021), as explained in Figure 1 below.

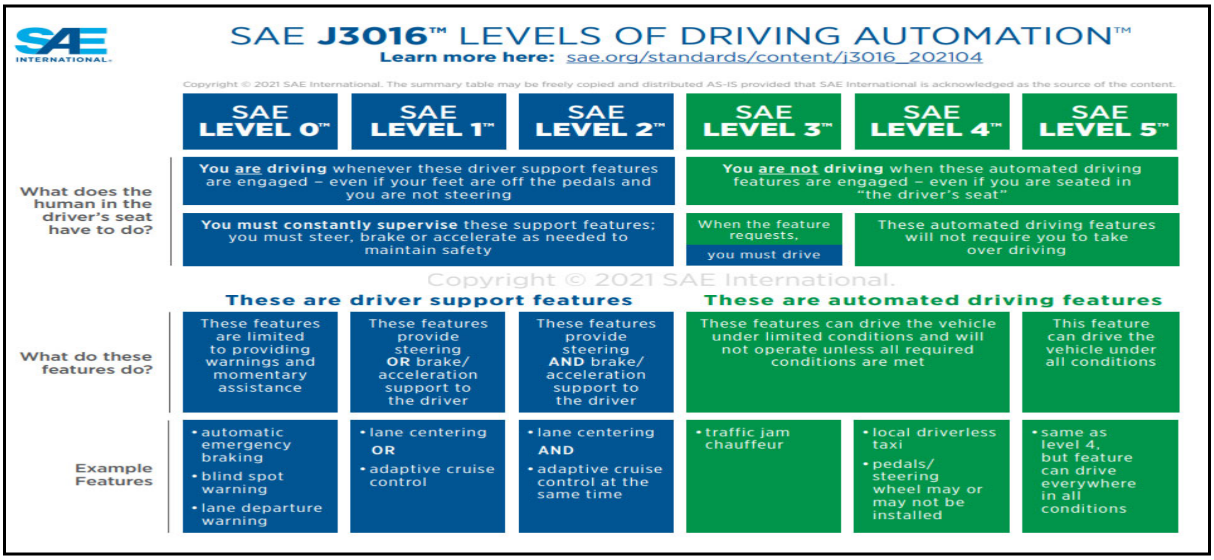

Figure 1: Autonomous Vehicles levels (© SAE International from SAE J3016™, 2021)

Safety Implications

In the modern day, vehicles are a necessary component of land transportation since they greatly enhance the comfort and activity of human existence. However, extensive studies revealed that human error globally accounts for more than 90 per cent of vehicle collisions. (Chen et al., 2019; Shetty et al., 2021). By integrating AV technology into the transportation system, automobile accidents caused by human decision-making can be reduced or even avoided, potentially saving more lives on the road. As a result, several nations have begun to implement innovative Av deployment techniques while also paying close attention to overall vehicle safety.

The United States has adopted the controlled-oriented strategy to control the AV-associated risks that follow the standards of SAE and International Standards Organisations (ISO) (NHTSA, 2016). The United Kingdom has adopted the same techniques, depending on the established transport regulations with feedback from private and public sectors, encouraging and attracting businesses and investors by enabling actual public road trials for Avs (Department for Transport, 2019). Similar to the United States, Australia has selected the same strategy to embrace AV safety testing within the country's current transportation rules, working with the Transport Infrastructure Council to set up a safety assurance system to examine all AV stages on open streets (NTC, 2017a). Australian National Transport Commission aims to adopt an oriented strategy through feedback collection from stakeholder groups concentrating on this technology and exploring opportunities to mitigate risks, rather than focusing on ignored, suppressed, or controlled risk strategies (NTC, 2017b).

Additionally, the Chinese government has adopted a similar technique for deploying AVs under government transportation norms and regulations (KPMG International, 2018; West, 2016). Furthermore, the European government requires obtaining authorisation and adhering to start the controlled strategy to test AV technology (Nicola et al., 2018). Furthermore, the Singaporean government has adopted a controlled-oriented strategy (Government of Singapore, 2017). However, the government of Japanese considered the prevention-oriented strategy as they emphasised a displayed label on the vehicle, consent from the police department, and a person to operate the vehicle with an appropriate license (Kyodo, 2017). However, no response has been shown by the South Korean government to the safety implication (West, 2016). Finally, the New Zealand government has authorised Autonomous vehicle experiments on public roads without any limitations, whereas the transport regulations remain in place since the Land Transport Act of 1998, which require upgrades (Ministry of Transport, 2020a).

Liability Implications

The AV collisions have created great doubt and confusion about liability implications (Fagnant & Kockelman, 2015). Because fully automated vehicle driving involves no human instruction while needed for lower levels, which creates more liability uncertainty over who is accountable for the accident, such as the software designer, component maker, manufacturer, or car owner (Collingwood, 2017). Therefore, Event Data Recorder (EDR) has been strongly proposed to distinguish the specific malfunction that triggered the accident from real human driving (Martinesco et al., 2019). The EDR will record the vehicle journey and all tasks performed in Automated Driving Systems (ADSs) to allocate liability concerns to the responsibility part which will accept complete responsibility for it. Because AV liability issues remain complex; various governments have adopted different approaches to managing these risks.

The Accident Compensation Corporation (ACC), known as No-Fault Compensation Scheme (NFCS), has been deployed by some countries to handle any road collision losses for any victim involved in an accident without referring to or suing the main suspect (Schellekens, 2018). Therefore, the victim should seek compensation and rehabilitation under this scheme. The collision scheme is already established in many regions such as Sweden, Quebec, New Zealand, and Israel (Van Uytsel, 2019). Moreover, the Act prohibits anybody from suing a manufacturer for personal injuries or death caused by a defective product (MBIE, 2022). As a result of this scheme, the vehicle manufacturer and parts will be protected against any claims regarding personal injury, which will encourage the deployment of AVs. However, the manufacturer will be liable for any physical damage under the product liability.

Product liability Act focuses on the low quality of services or items businesses provide to their customers. Customers can also obtain a refund, repair, or exchange if they acquire a faulty product or experience unsatisfactory service (Consumer NZ, n.d.). The MBIE (2019) mentioned that the main purpose of the Consumer Guarantees Act is imposing liability under the manufacturer's responsibility due to the significant control and influence over their product quality. However, the distributor or supplier will account for responsibility if the product is manufactured overseas. Therefore, the Act will hold the manufacturers fully liable for their product quality while exempting them from personal injuries under the no-fault compensation scheme.

Many countries have followed different liability strategy approaches for deploying Avs. For instance, most United States have taken their initial step toward a controlled-oriented approach after their ignorance of liability implications (NHTSA, 2016). In contrast, the United Kingdom has taken a toleration-oriented approach to clarify insurance and liability risks for AV deployment (Centre for Connected & Autonomous Vehicles, 2017). Besides, the UK transportation agency intends to install EDR in AVs to clarify the liability issues and distinguish human blames from manufacturing defects when the AV manages the journey (Centre for Connected & Autonomous Vehicles, 2017, p. 15; TRL, 2019). Similarly, Germany has updated their transportation legislation to tackle AV liability concerns with an initial step toward a control approach (White & Case LLP, 2017). Also, Germany implemented EDR in all AVs using the same approach as the UK (Wacket et al., 2017).

Japan, Singapore, and Australia have also made their initial moves towards a controlled-oriented approach to limit liability issues related to AV (NTC, 2017b; Taeihagh & Lim, 2019). However, no response has been shown from South Korea and China (Alawadhi et al., 2020), along with Europe (Patti, 2019). New Zealand showed great concern about assigning liability issues to AV, where a review of the liability legislation is required if the vehicles are utilised for personal purposes (Cunningham et al., 2018).

Cybersecurity Implications

Cyber risk is the dangerous threats of monetary, corruption, financial, debt, or disruption to companies as they are concerned about hacking their sensitive information system (Sheehan et al., 2019). Therefore, the cybersecurity system works as a defined line for any electronic device to secure the end-user data from cyberattacks. Every technology that relies on the internet to transfer information is at risk, as it could lead to serious life threats by hackers.

In order to evaluate the vehicle route via sharing data about the transportation system, such as Vehicle to Infrastructure (V2I) or Vehicle to Vehicle (V2V), the car must be connected to the internet. Additionally, losing communication due to a cyberattack or Denial of Service (DoS) network failure might pose serious risks to the safety of passengers as well as the surroundings, especially for critical applications that require a lower latency for their network (Weimerskirch & Dominic, 2018). Hackers may hack and control the vehicle through wireless connections like Bluetooth, keyless systems, or other connections since the AV is connected to the surroundings through the internet (Lee, 2017).

According to Shankland (2019), the 5G is a novel answer to AV cyber threats. It represents the effectiveness of AVs in terms of liability because the vehicle relies on a robust data interchange during any trip to act quickly to prevent any danger or accident by recognising the effective approach to overcome any upcoming circumstance. Furthermore, by integrating a 5G network in AV, the vehicle will be remotely operated by an authorised control centre to respond quickly to any emergency circumstance (Mutzenich et al., 2021).

Many governments, including the United States, Singapore, China, and the EU, have used a controlled-oriented approach to determine the associated AV cyber risk (Chen et al., 2020). As a result, they have adopted a voluntary guide to demonstrate the hazards linked with AV cybersecurity and to protect users' confidential information. The United Kingdom has taken a step toward an adaptive-oriented strategy to manage AV cybersecurity risks, as mentioned by HM Government (2017). Whereas Germany, Japan, and Australia showed no response to this implication (ERTRAC, 2015), along with South Korea (KLRI, 2018). In December 2021, the New Zealand Privacy Act was revised to emphasise the confidentiality of end-user data and privacy to cover the advanced AV cybersecurity risks (Ministry of Transport, 2020b).

METHODOLOGY

The study's main objectives are to understand and define the implementation of Autonomous Vehicle (AV) technology in any nominated country. However, the world implementation level for AV is still in the early stages due to the limited information on young technology. To meet this objective, a semi-structured interview experimental research was carried out with experienced AV practitioners. The interview includes 9 semi-structured questions intended to allow participants to freely discuss their opinions based on their area of expertise throughout the interview meeting, which lasted around 60 to 90 minutes. The interview questionnaires were prepared based on the current literature review and thematically analysed by the previous section to maximise the technology benefits and minimise its risks.

Based on the AV information, the NZ Transport Agency (NZTA) which is heavily involved in the AV trial phase in New Zealand, and the New Zealand Ministry of Transport, 5 official firms were selected for this study based on their area of experience. Invitation emails were issued to the 9 organisations to participate in this research, but only 5 responded and consented to cooperate. During the interview, they provide their consent to the interview session. To maintain confidentiality protocols, all interviewees' identities were suppressed, and each interviewee was allocated a code. Participants for this study's interview came from the middle and upper managerial levels. Table 2 below illustrates the information of the participants.

Table 2: Interviews information

Respondents	Position	Year of experience
participant 1	Senior Policy Advisor	19
participant 2	Senior Transportation Manager	16
participant 3	Manager Targeted Investment	7
participant 4	Academic Professor	18
participant 5	Electrical Engineer	8

The questionnaires that occurred in qualitative research to ensure the validity of the information are about the number of samples. According to Sandelowski (1995), defining a sufficient sample size is subjective; certain studies require a sample size of 5, while others require more than 5 based on their study philosophy. Creswell and Creswell (2017) also suggested 5 to 25 respondents for a qualitative study, which highlights the researcher's efforts to understand the various positions of humans as social players and to comprehend their reality depending on their experiences. Moreover, AV technology is still new, and few countries have adopted this technology making it challenging to obtain more data related to this study.

According to Patton (1990), interpreting data in a qualitative method is a big concern for researchers. This is because qualitative data is mostly made up of words, which might have various interpretations and contribute to incorrect interpretations. Therefore, NVivo software 1.3 was used to conduct a thematic analysis and develop a pattern matching the literature for better understanding.

The interviewees were from the Ministry of Transport, Accident Compensation Corporation, NZ Transport Agency, IT experts, universities, and electric car manufacturers. The research's main objective is to boost food supply chain logistics and transportation during a crisis as an emergency response to serve isolated areas. Due to time and financial limitations, the interview data was conducted only in New Zealand.

DATA ANALYSES

This section aims to analyse the data that have been collected during the interviews to support the AV implementation process. Also, the data will be analysed on NVivo software to present thematic patterns on the adoption of AVs to mitigate food supply chain shortages during a crisis. The following sections present respondents' perceptions of safety, liability, and cybersecurity implications.

Safety Implications

- Awareness level: All participants in this research agreed that global awareness is low. Participants 1 and 4 emphasise the low level of awareness about this technology. Participants 2, 3, and 5 support advertising to better understand AV levels and functions. As a result, there is an urgent need to raise awareness through commercials, public events, and a data-driven strategy.
- AV risk approach: To manage the associated risks of deploying AVs, 60 per cent of the interviewees supported an adoption strategy for liability and safety implications. A controlled-approach strategy showed 80 per cent agreement to manage cybersecurity risks associated with AV deployments.

Liability Implications

- ACC/NFCS; It is recognised as unique and the most significant key driver for deploying AVs globally to support the AV liability issue. Approximately 80 per cent of interviewees strongly agreed that the programme is highly appealing to vehicle companies looking to test and trial their technology on public roads and under current transportation regulations. However, participants 1 and 4 noted that the programme is not a significant motivator for investments and investors worldwide. Also, they will not sacrifice the locals' lives to test any technology. All interviewees also highlighted that the system would enhance AV liability by lowering the insurance required to operate the vehicle.
- Event Data Recorder: the EDR plays an essential role in supporting the AV liability implication to determine the fault that led to the collision. All participants emphasis the need for vehicle manufacturers to learn and improve the technology. Participant 2 noted the important role of algorithm process and image in the AV, which will be less effective in the future when technology improves. Finally, participants 3 and 5 strongly support the EDR only if it complies with the Privacy Act of the nominated country and does not exploit the government's ability to investigate vehicle owners. All the interviewees strongly agreed on this device and illustrated its benefits and how it could improve AV liabilities to be deployed worldwide.
- Local legislation: All participants in this research agreed and supported the same method of amending current legislation and adapting certain international regulations to allow AV deployment in the nominated country. They had a smellier point of view about the mixed approach strategy to review and understand the international strategy due to the lack of information about AV as a new technology with many associated risks. Importantly, consolidate some international regulations to standardise the most critical component for the AV by manufacturers, to make the deployment of AVs easier in any country. After that, reform some of the country's legislation and adopt some international legislation to suit the

nature of the adaptive country. However, the first participant suggested checking if existing legislation covers the new technology. If not, reform the local legislations to match the international ones.

Cybersecurity Implications

- Sharing personal data: disclosing personal information expressed similar worries by all participants for various reasons. For example, they all were highly concerned about hacking and data loss, about collecting their data to enter the market by new and young companies, and the time gaps in changing rules despite the broad adoption of new technologies. Additionally, participants 3, 4, and 5 emphasised the significance of updating the Privacy Act of the deploying country by focusing more on personal data protection. The Act may inspire the young generation to give their personal information and believe in the system.
- Traffic Control Room: The participant has expressed strong support regarding the traffic control room. Nonetheless, they were concerned about providing this power to the government to regulate and manage cybersecurity threats, which raises privacy issues. The second participant proposed installing an emergency stop button that the traffic controller could control without providing the government with complete authority during critical situations. Also, the fourth participant advised that an agreement between the AVs manufacturer and the government should be signed as a third party. This will force the government to seek control approval from manufacturers to boost transparency without using this information in any other activity by the government (participants 1 to 5).

Figure 2 is a word cloud built using NVivo software 1.3 to illustrate the top 100 most often stated terms by participants during the interviews. The aim is to analysis and conduct a thematic analysis and develop a pattern matching the literature. The created word cloud showed the vehicles, and autonomous words were most often repeated because the interviewees addressed the benefits of the technology and how it can help the transportation sectors during the crucial situation. Also, it has been highlighted by the software that the data, urgent, new, and legislation were often mentioned by the participants, where they explain and emphasise the urgent need to reform regulation for the adoption of self-driving vehicles. The risk word also appears as the participants discussed the best approach for AVs concerning AV-related governing strategy types to minimise risks and maximise benefits.

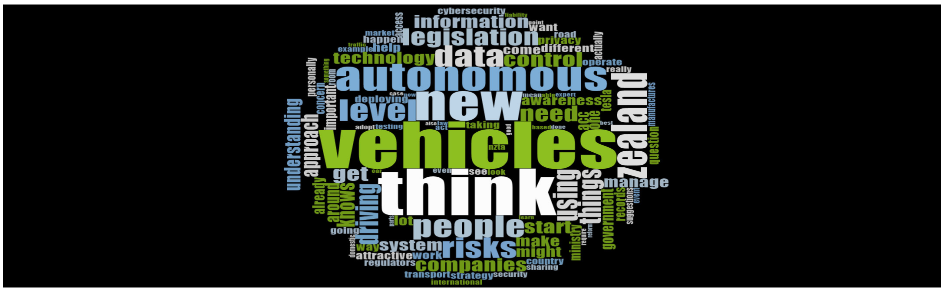

Figure 2: Top 100 Word Cloud Frequency Query

DISCUSSION

This section explains the process and steps of deploying AVs in any chosen country. The developed framework, Figure 3, has been established after a critical analysis of the literature review and the data analysis of the interviews. Therefore, the framework demonstrates the most effective strategy to deploy AVs globally. The following discussion for deploying the new technology in the selected country from different perspectives to increase its benefits and minimise the associated risks. Also, it will aid the food supply chain emergency response to overcome any crisis consequences.

1. Safety perspectives: As the initial stage in the deployment, an adaption-oriented strategy is required. This technique depends on decision-making and risk without understanding all the hazards connected with the new technology as the technology is still new and contains limited information. The aim is to speed up the deployment process instead of every county delaying the deployment until the establishment of the international guideline, which might not suit all countries due to different circumstances, existing legislation, and the environment. Also, AV levels of explanations and awareness are urgently required among people.
2. Liability perspective: an adoption-oriented strategy would be ideal by making EDR mandatory to shorten the learning curve to resolve liability problems. Furthermore, establishing or updating the ACC/ NFCS program in the nominated country due to its benefits in solving AV liability issues. The

program will support the deployment phase by lowering insurance costs and encouraging manufacturers to test and evaluate this enormous technology in real life.

3. Cybersecurity perspective: the controlled-oriented strategy is highly suggested due to the massive worries about cyber-attack risks. Also, the hackers could take over the vehicle control, which will make the rider and surroundings life-threatening. Besides, the cyber-attack can be managed by a trusted source like the traffic control room. However, involving a third party like the vehicle manufacturer to authorise the controller is highly recommended to minimise the government's influence and maximise transparency.

REGULATORY FRAMEWORK

Along with the previous literature, discussions, and analysis of expert perceptions, it is highly recommended for each country to consider the following steps to partially change, upgrade, or reform their existing legislation to fit the new technology in their regulations to enhance food supply during emergencies.

A. First step: due to the lack of information on AV, each country is encouraged to review the international approach to sense and evaluate their position regarding their existing legislation.

B. Second step: modify the existing regulations to merge some of the international legislations. It is highly recommended to consolidate some international approaches and techniques to minimise the mistakes and efforts required for each stage to be developed individually by every country.

C. Final step: A complete revision of the legislation to ensure the innovative technology has been deployed and fully covered under the nominated country rules or it might require final amendments.

The following framework has been drawn upon the summary of the discussions in the previous sections. Therefore, it is strongly advised that the Transportation Agency in the nominated country follow the procedures outlined below.

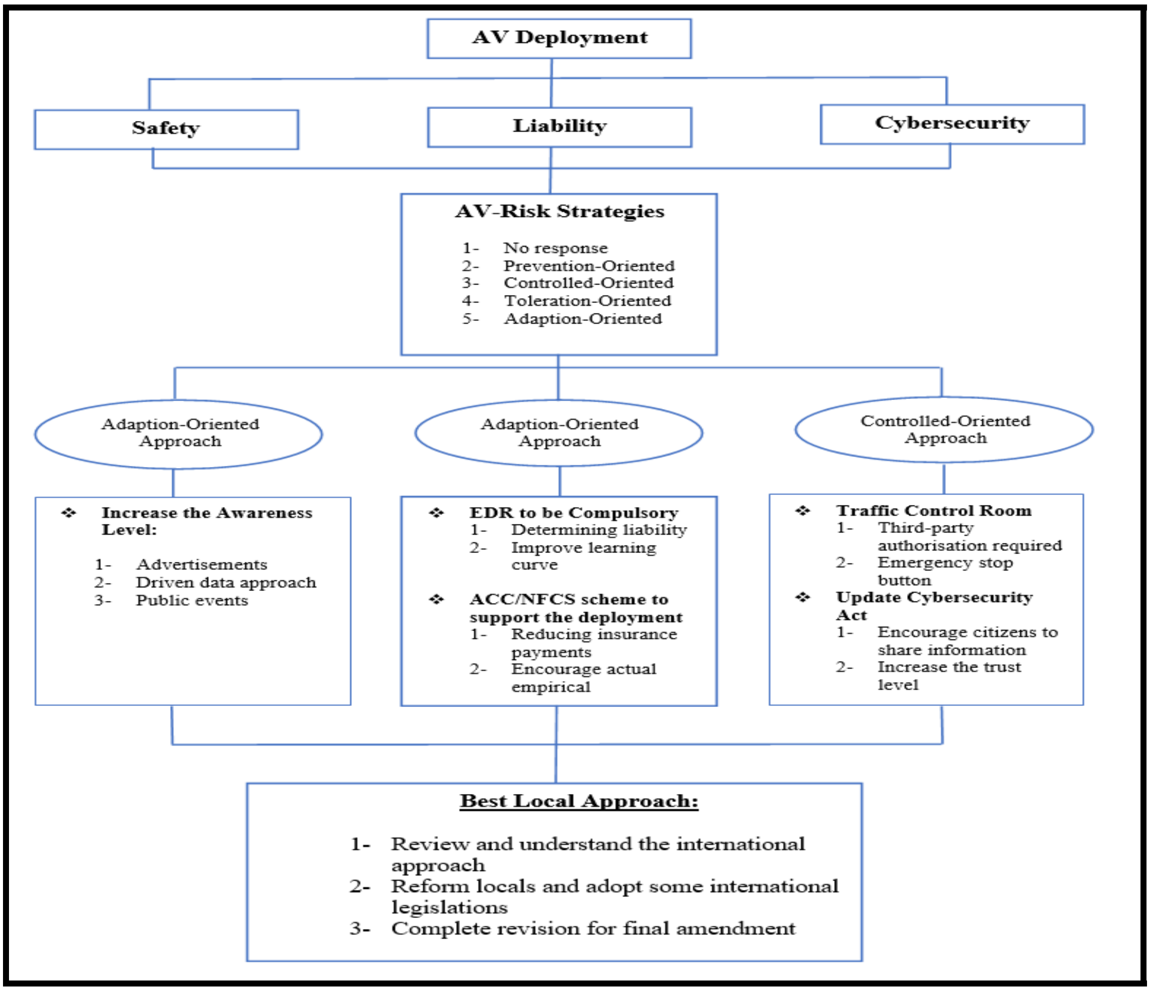

Figure 3: Regulatory Framework to Deploy AVs globally.

CONCLUSION

Crisis struck the world without notice like COVID-19, which led to massive disruption and restrictions in most sectors, including essential industries, such as the food supply chain. Due to the Coronavirus crisis restrictions, a 60 per cent reduction faced the food distribution tracks in France (Aday & Aday, 2020). As a result, during the crisis, the emergency response team faced massive pressure along the way to meet the basic living requirements for their citizens under world restrictions and countries' lockdowns.

Therefore, this research presents a comprehensive framework to deploy fully autonomous vehicles to boost the food supply chain during crises and serve isolated areas while minimising person-to-person contact. It also aims to improve the emergency response system worldwide and prepare for future unexpected situations.

Following the procedures outlined in the proposed framework is highly recommended to reflect the enormous support and collaboration to the emergency response system and aid the food supply chain transportation and distribution during crises like COVID-19. Besides, minimising personal contact to manage the outbreak of the deadly virus. Due to the study limitation, more interviews are needed that samples from different regions and an empirical trial of the framework to confirm its benefits and advantages.

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Enhancing Triage Training for Mass Casualty Incidents with Virtual Reality and Artificial Intelligence

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ABSTRACT

Mass casualty incidents (MCIs) occur with natural or man-made disasters. Training emergency staff for combating MCIs is essential, but the cost can be high as such incidents rarely occur, and a physical simulation is resource-intensive. Triage is a critical task in dealing with MCIs. In this paper, we propose to use Virtual Reality (VR) and Artificial Intelligence (AI) technologies to build a low-cost, high-efficient system for MCI triage training. Our system captures more comprehensive training data and utilizes state-of-the-art AI evaluation methods.

Keywords

Mass casualty incidents, triage training, virtual reality, artificial intelligence.

INTRODUCTION

Mass casualty incidents (MCIs) occur with natural or man-made disasters. Training emergency staff for combating MCIs is essential, but the cost can be high as such incidents rarely occur and physical simulation as a training tool is resource-intensive. In this paper, we present the design and methods of data analysis for a Virtual Reality (VR) training system that uses Artificial intelligence (AI) to evaluate the success of Mass Casualty Incident (MCI) triage of patients using a simulated environment.

Triage assesses the degrees of urgency to wounds or illnesses to allow clinicians to determine the treatment order for many patients or casualties. Given the limited time and resources during MCIs, the first responders must perform the triage swiftly and accurately. Traditional training methods for MCI triage skills include large-scale exercises (M. J. Reilly, 2011) and paper-based simulations (Fromm, 2018). Large-scale activities have the advantage of being realistic as they involve multiple teams in large open spaces, such as emergency staff, fire bridges and police. The paper-based simulations are easier to conduct but less realistic.

To overcome the disadvantages of the above methods, many researchers have proposed using Virtual Reality (VR) technology to provide an immersive training environment for triage skill training. The decreasing cost of VR devices has recently allowed more research on VR. Andreatta et al. (2010) compared the performance of VR and standardized patient (SP) drills on Simple Triage and Rapid Treatment (START) disaster triage algorithm. The performance was measured using a pretest and posttest triage rating/correctness. The result showed that VR could provide a feasible alternative for training emergency personnel in MCI triage. This is a significant early work in this area. However, the scale is small and the hardware is limited. Mills et al. (2020) present more recent research using VR kit and compared the performance of VR and live simulations in terms of immersion, clinical decision-making, satisfaction and cost. They concluded that VR can provide nearly identical simulation efficacy with much less cost than live simulations. However, this study is also small and further research is required to validate this finding. Lowe et al. (2020) studied the feasibility of VR training for MCIs using HTC VR platformat a larger scale. It measured the accuracy of triage and intervention and the experience rating for 207 participants. The work confirmed the feasibility of VR and the very positive experience by the subjects. Berndt et al. (2018) use a human-centred design process for building a VR training simulation for MCIs. The assessment was conducted on the presence and triage correctness. They concluded that VR training was useful, allowed a moderate level of presence and could be further improved. Bilek et al. (2021) presented a similar VR training application for an MCI on a highway.

Mossel et al. (2020) presented the VROnSite platform, which can support the immersive training experience for first responder squad leaders. The research evaluated two virtual disaster environments with two different navigation means using quantitative and qualitative measures. Koutitas et al. (2019) presented a VR-based training software to help emergency personnel get familiar with the bus-sized ambulance AmBus. The key tasks trained were on the locations of items on the bus, measured by time and accuracy. VR was shown to be more effective than the traditional training method. Caballero & Niguidula (2018) presented a case-driven approach to building VR training for emergency preparedness. Bjørn et al. (2021) provided technical guidance in creating a collaborative work environment in VR.

These studies have shown that VR can provide a viable solution for emergency staff training. However, these studies use some forms of tests, questionnaires, or interviews for evaluation, which are somewhat limited. We propose to improve the evaluation by collecting more comprehensive data on the training and processing them with state-of-the-art AI algorithms. More specifically, we will utilize multiple VR device sensors to collect the VR controllers' timestamps and coordinates. This allows us to detect and quantify the events and completion of the tasks during the training. We will also process the videos captured by cameras using AI-based body and action recognition algorithms to better understand the behaviour patterns. Moreover, the audio data will be processed using AI-based speech recognition algorithms. We will measure the semantic similarity of the participants' descriptions with a pre-defined description of the scenario information, which provides another way to evaluate performance. The following provides a more detailed description of our system design and the individual components, evaluating these as future research.

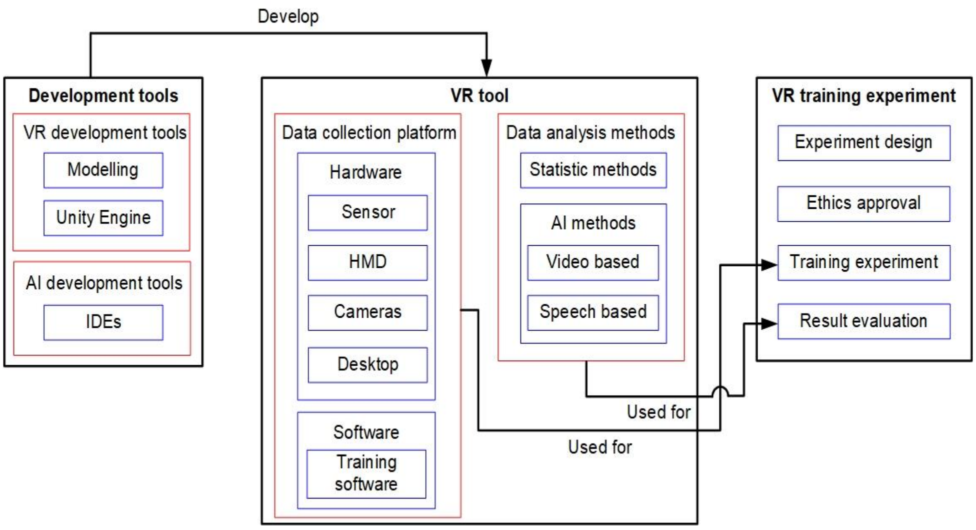

Figure 1: Research Framework

SYSTEM DESIGN

Our research framework has three major components (see figure 1). The central one is the VR tool that have built. It consists of a data collection platform and a set of data analysis methods. The left is the VR and AI development tools for developing our VR tool; the right is the component of the VR training experiment for evaluation. In particular, the data will be collected from the training experiments using the data collection platform and the results will be evaluated using the data analysis methods.

Main Component: Development Tools

We have two types of development tools. One is for VR, and the other is for AI. The VR development tools consist of the Modelling tools and the Unity Engine. We use the modelling tools to build the objects and assemble those objects in the Unity Engine to create a VR scenario. AI development tools include various development environments, and we implemented AI algorithms based on those environments. In the following, we will present details of those development tools.

Modelling tools

As VR modelling contains a complete process and involves various tools, we demonstrate our modelling process in Figure 2.

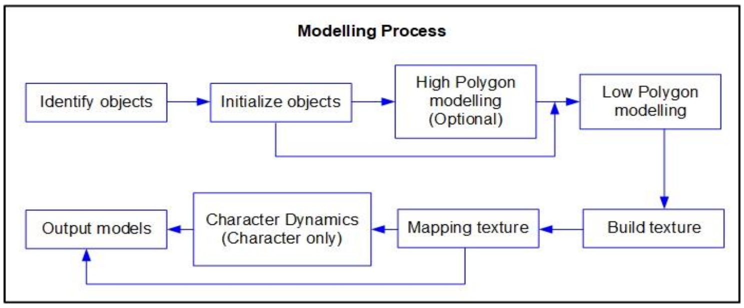

Figure 2: Modelling process

The first step in modelling is identifying objects such as cars, buildings, and humanoid characters. The objects are classified as either static or dynamic objects. We set up a target model for each object and find the reference appearance via different sources. Then, we start to initialize the target model. *Blender* and *Google Sketchup* are two draft modelling tools involved in this step. Some static objects (e.g. cars, street lights) are built by using those tools. Besides the static objects, dynamic objects such as humanoid characters will have a further processing step called Polygon optimization. This project deals with two types of humanoid characters in modelling. One type is normal characters that use default joint mapping, and the other type is patient characters that contain special joint connections or meshes for simulating patient conditions (e.g. Trauma, bone break). For normal humanoid character modelling, we directly build the low polygon model. For the special humanoid character modelling, we firstly build the high polygon model, carving the particular part (e.g. scars) on the high polygon model. And then, we convert the high polygon model to a low polygon model. In the polygon modelling steps, *Adobe Fusion* (for low polygon modelling), *Zbrush* (for high polygon modelling) and *Autodesk Maya* (for high/low polygon modelling) are used.

When building the polygon models, we also create textures for those models. Similar to special humanoid character modelling, we customize the texture for the virtual patient. Adobe Photoshop is used in this step. Finally, we use Maya and Unity to integrate the texture with the polygon models. All humanoid characters must add dynamics or so-called 'bones' or 'joints' to present animation in the scenario. Each character contains 20 joints group to simulate body action. For instance, the 'Shoulder' joint group includes two joints, connecting with the 'Upper Arm' and 'Chest' joint groups to simulate movement and rotating angle of the human shoulder. We use Maya and Unity Engine to build such dynamics for the humanoid characters. In the end, we output those models as *.FBX files and import them into the Unity Engine.

Unity Engine

We used the Unity Engine to develop the VR tool. Unity Engine is a game engine that consists of different essential development components (e.g. Physics, materials, animation bakin). Developers can use Unity Engine to initiate prototypes and conduct further development efficiently. Figure 3 shows the development process using Unity Engine. The first step is to build the environment. Then, we combine objects from the Unity asset market and custom-made sources to construct a small city-style environment. After that, we added several static objects, such as a car, stone, and fire flame, to present an MCI scenario. Currently, there is no interaction between the trainee and those static objects.

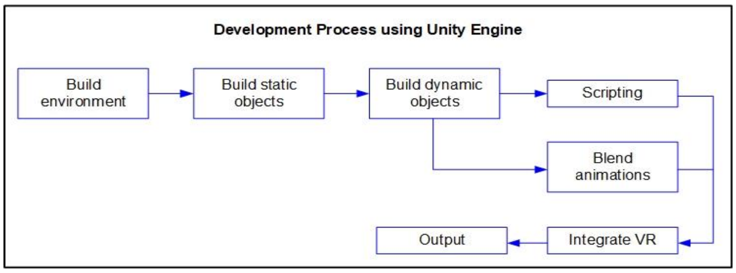

Figure 3: Development process of Unity Engine

The third step is building dynamic objects such as humanoid characters. The properties such as position, interaction method, and behaviour logic of those dynamic objects must be addressed carefully. We use two significant sub-steps, Scripting and Blend animations, to control the performance of the involved objects. We use Microsoft Visual Studio in the scripting step and focus on the dynamic object's interaction event and behaviour logic. An example is given below to indicate how the script works. In the prototype, we have built several scripts to control the vital features of the virtual patient. Those scripts can generate an arbitrary number of virtual patients with their vital features, and different vital features will also affect the visual expression of virtual patients. After reviewing the Australasian Triage Scale (ATS), we extract a triage feature schema. Figure 4 gives an abbreviated version of the triage feature schema. We notice that some features in the triage schema could be quantified. For instance, according to the ATS guidelines, a heart rate of 80 beats per minute is a vital threshold for determining if the patient belongs to ATS-1 or ATS-2. If needed, we can generate data for each quantifiable feature.

Major Features	Component	Features
	Respiratory	Respiratory Rate (RR)
		Respiratory Status (e.g. Extreme respiratory distress)
	Blood Pressure	Blood pressure (BP)
	Glasgow Coma Score	Glasgow Coma Score (GCS)
	Seizure	Seizure
	Circulation	Skin Color
		Heart Rate (HR)
		Blood loss
		Blood Glucose
	Pain	Chest
		Other pains
Other Feature	Other features include psychological features, and trauma, etc.	

Figure 4: Triage feature schema

AI development tools

The AI development tools for developing Machine Learning (ML) algorithms include video and speech-based algorithms. We use Pycharm as the primary IDE and Ubuntu OS to build and test the AI algorithms. Most ML algorithms and models use Python as a major development language. Python has several advantages that make it popular in academia and industry. Those advantages include 1) being Supported by a large number of third-party add-on toolkits and libraries; 2) Highly readable programming style; 3) High portability and extensibility making it quickly adaptable to the different environments; 4) Free to use. Therefore, Python was the primary programming language to develop the AI methods, with Pycharm as the primary IDE because it makes Python development more efficient. Besides the Pycharm, we also use Microsoft Visual Studio to compile and test some C++ ML projects. Furthermore, the Linux core-based operation system, such as Ubuntu OS, has a higher capacity than Windows, which can also increase development efficiency.

Main Component: VR tool

The VR tool consists of a data collection platform and a set of data analysis methods.

Data collection platform

The data collection platform has both hardware and software. The hardware consists of four sub-components: 1) Motion sensor; 2) Head-mounted device (HMD), 3) camera, and 4) desktop computer.

1) Motion sensor

   As the VR devices will communicate with the software and exchange sensor data such as device coordinates during run-time, we developed several scripts to record sensor data in a specific circumstance (e.g. start doing the task). After building sequences for the sensor data, we can reconstruct and evaluate the user's behaviour in the training session.

2) HMD

   With the rapid development of VR devices in the last ten years, commercial-level HMD can now provide an immersive experience for customers with small transmitting latency. However, most HMDs focus on 'display and experience VR scenario' rather than 'interaction with objects in VR scenario', which means they do not have any interaction functionality. In this project, we plan to use Oculus Rift VR HMD as the HMD and the Oculus motion sensor and controller kit to achieve interaction requirements.

3) Camera

   We use several cameras to collect video and audio data from the trainees. Those cameras will be hosted at different positions on the training ground. One wide-angle camera will be set in front of the trainees at a height of 2000mm. In addition, two side cameras will be placed on the left and right sides of the user, with chest-level height (1600mm). Additional voice recording devices will be prepared in case of that the digital camera may not be able to collect clean sound while training.

4) Desktop

   We use a desktop computer to host the training software and collect the experimental data. The desktop configuration includes an i7 8-core CPU, Nvidia GTX 1070 graphic card, 32G RAM, and 500G SSD.

In terms of software requirements, we have the following three critical aspects:

1) MCI skill training functionalities

   Based on our literature review, we built VR MCI scenarios (e.g. a car crash scenario). There are some virtual patients with various conditions in the scenario, and the trainee needs to interact with those patients by performing tasks such as measurement of vital signs using the information gathered to assign triage categories for each patient. During the training session, the training software collects the quantified data (e.g. timeframes between events and sensor coordinator information) and, in the future, combine it with other unstructured data (e.g. video data and audio data) for evaluation.

2) Modularity

   The proposed training software should be able to extend its functionalities in the future at a low cost, and the modularity of the functionalities could make it feasible. We have done the following to achieve modularity: a) reviewing the add-on tools to make sure they can embed the training software and work independently; b) encapsulating some fundamental functions (e.g. data input class) and make sure they are independent of the business logic functions; c) optimizing the software architecture to follow the high cohesion and low coupling principle. The goal is to minimize the impact of adding or changing functionalities in the future.

3) Supporting multiple MCI triage scenarios

   One main advantage of VR tools is the ability to change to a different scenario at a relatively low cost. In our implementation, we have provided two scenarios (see the details below).

In this VR tool, we have built two MCI scenarios: one is a car crash scenario, and the other is an earthquake scenario. In these scenarios, the trainee will be asked to complete several tasks, which include: a) measuring the vital signs of each patient; b) triaging patients; and c) reporting the patients' vital signs and categories. The details of the two scenarios are given below:

1) Car crash scenario:

Figure 5 shows the car crash scenario of the training software. There are ten patients (three Immediate, four urgent and three delayed) and a few bystanders in the scenario.

Figure 5: Car crash scenario

We designed a category indicator for each patient, see Figure 6 (Left). Those indicators are located above each patient and use a different colour to indicate the true category of a patient. The colours refer to the triage standard: Black – deceased, Red - Immediate, Orange - Urgent, and Green - Normal. The indicators can be set to either visible or invisible. To train the MCI triage skill, we also designed two measurement tools to measure the patient's vital signs and a triage tool to assign the different patient categories. Figure 6 (Right) shows the triage toolkit. The trainee can use controllers to set different triage categories on the wristband for the virtual patient, and colours also represent those categories. The training software will compare the triage category assigned on the wristband with the actual triage category based on the ATS guidelines (reference here) and then output the correctness of each decision.

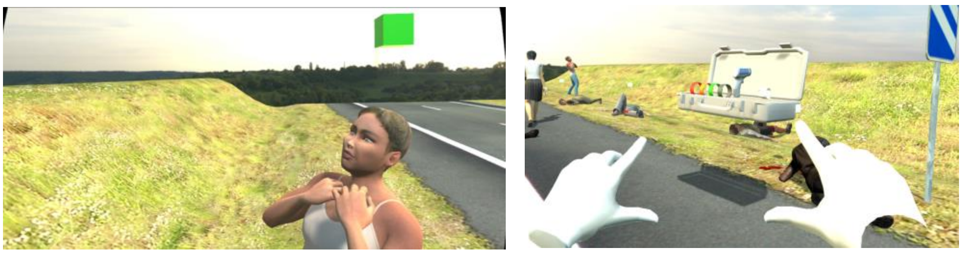

Figure 6 (Left): Triage Indicator, (Right): Triage toolkit

2) Earthquake scenario:

The second scenario is an earthquake scenario with seven patients. We add an extra task that the trainees must ensure their safety. A few patients are in a dangerous situation (e.g. under collapsing construction), and the trainees must check the environment. The earthquake scenario includes two immediate, three urgent and three delays and reused several components from the car crash scenario, which reduces development time. Figure 7 shows the screenshot of the earthquake scenario.

Figure 7: Earthquake scenario

The training software will collect sensor and performance data related to triage decisions during training sessions. Table 1 shows the triage data items and descriptions.

Table 1. Triage data items

Data Item name (Type)	Description
Patient ID (string)	Virtual patient's index
Assigned category (int)	The triage category assigned by the trainee
True category (int)	Category which pre-defined
Result (bool)	Comparison results of Assigned category
Start time(string)	The start time of the current training scenario
Triggering time (string)	The time of triggering the current recording event
Timespan (string)	Subtraction of the current time and start time

Data related to vital sign measurement is also collected, for example, when the trainee attempts to measure the patient's vital signs. In data evaluation, we compare the trainee's report with the pre-defined vital signs to determine the accuracy of triage decisions. Table 2 shows the vital sign data item descriptions.

Table 2. Vital Sign data items

Data Item name (Type)	Description
Patient ID (string)	Virtual patient's index
Var (1…n)	variables of a vital sign depend on different measurement types
Start time(string)	The start time of the current training scenario
Triggering time (string)	The time of triggering the current recording event
Timespan (string)	Subtraction of the current time and start time
Measurement type (string)	Indicates which type of measurement is conducted
Moving distance (unit)	Trainee's moving distance in the virtual world

Data analysis methods

We use quantitative analysis as our main research method for data analysis. We use traditional and AI-based methods to evaluate the training efficiency. To evaluate those methods, we collect four types of data from the experiment: personal *information, sensor data, video data and speech data*.

The personal information includes the participant's character features, such as age, gender, and previous VR experience. It aims to use this information to determine the influence of the trainees' background on their performance in the VR environment (for example, time to task or decision and movement in the scenario).

The sensor data includes quantified performance information such as timestamps and coordinates of the VR controllers. In each VR session, the participants will perform essential tasks; one is measuring the vital signs and the other is assigning triage categories. We developed a triggering module to trigger the sensor data recording when a task is performed. The module sets a triggering range for each virtual patient. When the participant accesses the controller's triggering range, the module starts collecting sensor data from the controller. The sensor data can provide the availability to derive time and distance for individual tasks (e.g., vital sign measuring) performed on specific patients. Thus, we can assess the accuracy of the triage in a precise way. By analyzing the raw data collected from the sensors, not only can the data items in Tables 1 and 2 be acquired, but also information regarding the timespan can be calculated. Timestamp-based information can indicate 1) when the participant grabs/picks up a measurement tool (e.g., thermometer), 2) when the participant uses this measurement tool to measure a vital sign, and 3) when the participant releases a measurement tool. Also, individual performance regarding the triage decision-making can be derived, which includes 1) duration of holding a measurement tool, 2) orders of measuring different virtual patients and 3) time spent between vital sign measurement and making triage category decision. In addition, we can measure the distance of the joysticks for each task (this helps to understand the cost of movements) in the virtual and physical worlds.

The video data from the cameras will be fed into an AI algorithm for body action recognition. Our system will recognize the human body skelton, and based on the movement pattern of joints, different actions will be labelled as actions such as 'stand', 'turn around', and 'squat'. This allows us to 1) precisely capture the action patterns of the participants and 2) understand the behaviour patterns for evaluation. We plan to use Spatial-Temporal Graph Convolution Networks (ST-GCN) (Yan, 2018) as the AI algorithm. Once the video data is collected, the body action pattern can be extracted by ST-GCN. ST-GCN is designed on a state-of-the-art body recognition algorithm named Openpose. Openpose recognizes the human body by identifying the coordinates of important joints and provides a visualization of the skeleton. After which, different action labels such as 'stand', 'turn around', and 'squat' are added to the proceeded video based on the movement pattern of joints.

The audio data will be used for speech recognition and evaluation. We plan to observe how the participants would report the scenarios and how they would make the decision. We propose to use Pytorch-Kaldi (Ravanelli, 2019) and Bert for the speech-based method. We have established the Kaldi toolkit and successfully proceeded with some examples. During the evaluation, we expect to use Kaldi to recognize the participant's speech and translate it to plain-text format as participant description. After receiving the participant description from Kaldi, we plan to use Bert (Devlin, 2018) to read its semantics and compare it with a pre-defined description of the scenario information. We expect to observe the training efficiency by evaluating the comparison result.

Main Component: VR Training Experiment

We will conduct experiments to evaluate the efficiency of the VR tool. The experiments will involve participants with some basic prior knowledge of triage. The expected participants would be paramedic students or professionals. For each participant, a training session with a length of 15–30 minutes will be conducted. In the session, the participant will finish both scenarios described above.

CONCLUSION

In this paper, we present the system design of our VR tool to train and assess the emergency staff for MCI triage skills. Compared with traditional training methods, VR technology allows for building multiple scenarios with many virtual patients at a lower cost and in less time. Another clear advantage of VR technology is bringing the participant an immersive experience. Compared with other VR training systems, the benefit of our system will be a more comprehensive collection of training data and the utilization of state-of-the-art AI evaluation methods.

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Citizen Science for supporting Disaster Management Institutions in Sri Lanka

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ABSTRACT

During 2016, 2017 and 2018, the country witnessed extreme rains which triggered flooding in several urban areas. The number of affected people by the 2018 floods was around 150,000 which shows a significant decrease compared to the events in 2016 and 2017. Several institutions provided their support via funding, relief, and rehabilitation mechanisms during these consecutive disasters. However, there are provisions which can further improve the performance of Disaster Management activities. Given this context, this study is carried out to investigate the application of citizen science concepts in several phases of Disaster Management in Sri Lanka. A scoping review supported by three case studies of floods was considered during the analysis. Limited participation of grass root level communities in decision-making and disaster planning, and issues related to data management are some of the main challenges identified in this study. Participatory mapping, Co-Design Projects, hackathons, and crowdfunding are some of the observed citizen science concepts which can be used to address the challenges and strengthen the Disaster Management activities in Sri Lanka. Further studies including interviews and questionnaire surveys were recommended to justify the findings.

Keywords

Citizen Science, Disaster Management, Crowdsourcing

INTRODUCTION

Citizen science is the participation of the general population in various stages of the scientific research process, such as data collection, classification, transcription, or analysis (Njue et al., 2019). Furthermore, it can be considered as a process where public communities engage in research design with professional scientists. Volunteer based monitoring (Deutsch & Ruiz-Córdova, 2015), crowdsourcing (Kankanamge et al., 2019), citizen observatories (Liu et al., 2014), participatory sensing (Guo et al., 2014), volunteered geographic monitoring are some of the many forms of public participation in science. Applying citizen science can take several forms, including top-down or bottom-up execution, implicit or explicit data provision, gathering of objective or subjective measurements, and the use of uni- or bi-directional communication paradigms between citizens and data processors. All these concepts share a broad perspective on the public's engagement in the co-generation of scientific knowledge and creates opportunities for collaborative learning (Wehn & Evers, 2015). History of citizen science dates to early 19th century as per the documentary evidence where volunteers in US were involved in rainfall measurements (Pfeffer & Wagenet, 2012). Due to the technological development in the past decades the growth of citizen science was exceptional due to the availability of smartphones equipped with web-based mapping tools and global positioning systems. The need for citizen involvement in environmental monitoring and decision-making has been further bolstered by the limited capacity and scope of monitoring because of reduced organization budgets in recent decades, increasing public awareness, the democratization of science, and concern about human induced impacts on biodiversity. According to the degree of influence and engagement in the scientific process, the common types of citizen involvement can be divided into five models as shown in Table 1 (Bonney et al., 2009).

Table 1. Five models of citizen involvement

	Description
Contract Projects	Communities hire experts to carry out a particular scientific investigation and report on the findings.
Contributory Initiatives	Typically created by scientists and mostly rely on data provided by the general population
Collaborative Projects	These are created especially by scientists, public provides data but also aids in project design refinement, data analysis, and/or dissemination.
Co-created projects	Jointly created by scientists and the public, in which at least some of the public participants actively participate in most or all stages of the research process.
Collegial contributions	These are made when people do independent research with varied levels of expectation of recognition by experts or institutionalized science

METHODS

Looking at these five models it is evident that they can be used effectively in Disaster management activities in Sri Lanka. Communities from both the urban and rural areas were affected by floods caused by severe rains in the past few years. To conduct the analysis for this research, three flood events which occurred in 2016, 2017 & 2018 were selected as case studies which caused a significant impact on both the livelihood and infrastructure in most of the administrative districts in the country. Following the methodological framework developed by Arksey H et.al, a five-stage, scoping review was carried out to find literature related to the study. The main research question was: *how to apply the citizen science concepts to support Disaster Management Institutions in Sri Lanka*. The relevant studies included several research papers, post-disaster needs assessments, guidelines, and incident reports. The documents were mainly extracted from electronic online databases and existing networks and organizations. The types of documents referred to are presented in Table 2 below.

Table 2. Types of documents studied during the analysis

	Description
Indexed Publications	ScienceDirect, Scopus, Web of Science, Wiley Online Library, and various other academic databases were searched to identify the white papers related to citizen science and the disasters which occurred in the country
Local Acts & Public Policies	These refers to the Acts by the Parliament and the other related policies published by the GoSL which have reference to Disaster Management (DM). National Disaster Management Act is one such example
Assessment reports	After each disaster, several agencies in Sri Lankan DM publish rapid and integrated post disaster needs assessments and situation reports. In this study the reports related to 2016,2017 & 2018 rains were referred. Furthermore, data collection surveys were also referred
National Guidelines & Maps	These are technical documents published by leading institutions in Sri Lankan DM which gives design guidelines and directions for various aspects in community resilience
International Reports & Indexes	Documents published by several international agencies like European Union, Red Cross, US- IOTWMS, ADPC etc were referred to get further information

The inclusion criteria were related to the types of citizen science projects and the year of flood events. Abstracts were not considered in the study as only full articles and reports were referred. Selected documents included references for citizen science projects around the globe and most of the reports related to the said floods were from Sri Lankan DM institutions. The documents were analyzed thoroughly to identify related practices and issues in DM sector of Sri Lanka. Findings were listed under the key aspects in Disaster Management namely; Development of Maps & Guidelines, Awareness campaigns, Policy Formulation, Multi-Agency Collaboration, Post Disaster Recovery, Mitigation measures and Community Relocation. The observations were mainly focused on the institutional engagements in the past and during these disaster events. On the other hand, global literature related to working citizen science projects and concepts were analyzed to identify how they can be of assistance for the proper functioning of the said themes. After the analysis, key areas where the citizen science concepts can be included were identified and summarized. Since this is a working topic, further investigations are planned to identify the applicability of various citizen science concepts in Sri Lanka which include surveys and interviews with stakeholders from the grass root level to the top professionals. Then after these inputs, a pilot citizen science model will be designed and implemented in a selected vulnerable area, and it will be monitored to do further modifications.

RECENT DISASTER EVENTS IN SRI LANKA

The Gulf of Mannar and the Palk Strait divide the island of Sri Lanka from the Indian subcontinent, which is situated across the Indian Ocean. The country has a total land area of 65,610 km^2, which is likewise not very large. The island still contains a range of natural zones, including mountains, lowlands, tropical forests, and unique coastal belts. Most of the nation is made up of lower plains with an elevation range of 30 to 200 meters. The Indian Ocean Tsunami which occurred in 2004 is the most severe example of the frequent natural disasters that Sri Lanka experienced. Furthermore, tropical cyclones can occasionally cause storms, flooding, and landslides. Due to the timing and the number of monsoon rains affected by climate change, droughts are becoming more frequent recently (CFE-DM, 2021). Furthermore, Sri Lanka's overall disaster risk in the 2021 INFORM Global Risk Index was 3.6/10, placing the country in the medium risk category.

During 2016, 2017 and 2018 the country witnessed extreme rains which triggered flooding in several urban areas. The number of affected people by the 2018 floods was around 150,000 which shows a significant decrease compared to the events in 2016 and 2017 (Relief Web, 2019). 2017 flood event which damaged both the infrastructure and communities of the densely populated districts in Sri Lanka raised the number of affected families up to 630,000 (UNDP, 2017). In 2016, Kelani River, Kaluganga, Mahaweli River, Deduru Oya, Yan Oya, Maha Oya and Attanagalu Oya, observed increasing water levels, which caused widespread flooding. In 2017, Kalu, Nilwala and Gin rivers and their tributaries caused floods while the water levels reached 6m high and remained for a week. Kalu Ganga, Maha-Oya, Attanagalu-oya reached their flood levels during the monsoon rains that occurred in May 2018. Looking at these incidents it is evident that the Western and Southern Provinces are severely affected. Figure 1 shows the cumulative number of affected people and deaths in the administrative districts of the country due to the consecutive floods from 2016 till 2018.

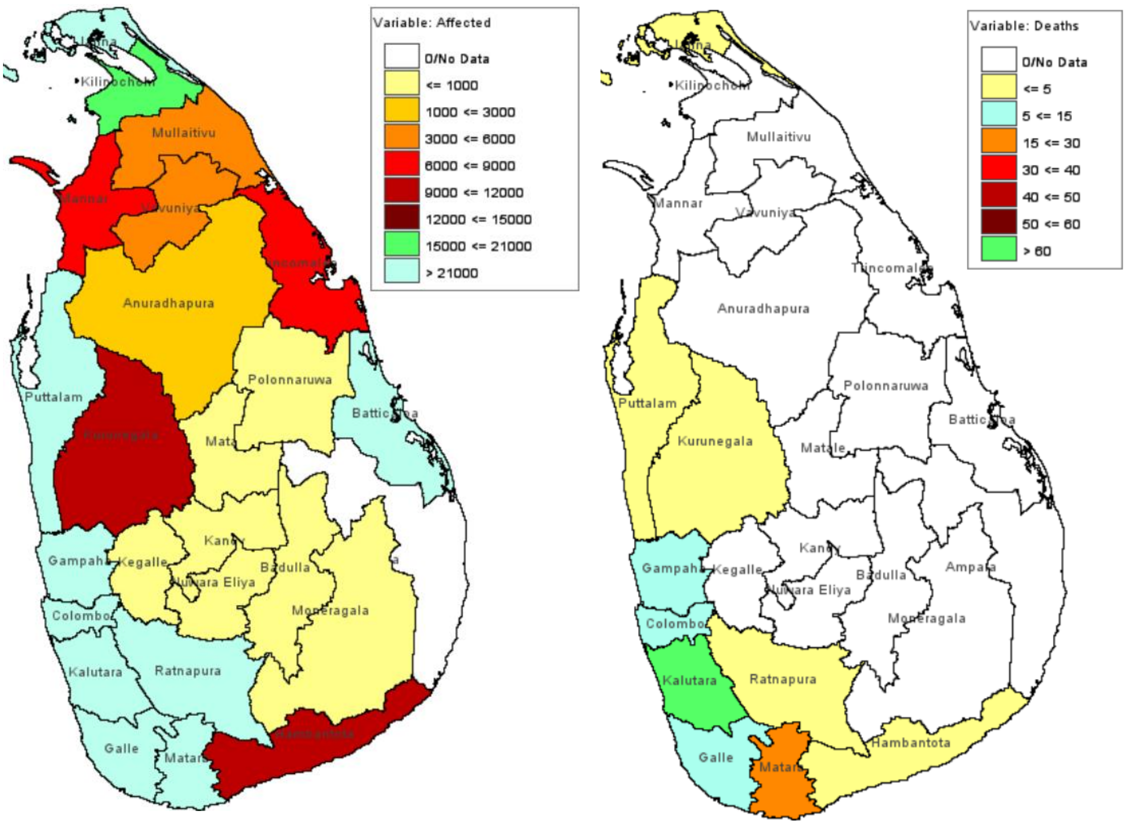

Figure 1. Affected people (left) and Number of Deaths (right) due to 2016, 2017 & 2018 floods
(Source: http://www.desinventar.lk)

INSTITUTIONS IN SRI LANKAN DISASTER MANAGEMENT

Given this context, Sri Lanka is in the process of establishing a fully functioning multi-hazard disaster management infrastructure with the inclusion of both governmental, non-governmental and foreign institutions. The government institutions play the leading roles in every phase of the DM cycle. National Council for Disaster Management (NCDM) is spearheading the government authorities followed by the Ministry of Disaster Management (MDM) which was absorbed into the Ministry of Defense recently. The MDM, both in its day-to-day operations and during emergencies, must coordinate within its own Ministry, with line institutions in other ministries, and with the armed forces. As shown in Figure 2, during emergencies, the MDM is a centre of public attention, which performs a coordinating role in assisting other agencies, government, non-government, and private to contribute to the response, relief, and rehabilitation. Disaster Management Centre (DMC), National Disaster Relief Services Centre (NDRSC), Department of Meteorology (DoM) and National Building Research Organization (NBRO) are the leading technical organizations which function under the MDM for the implementation of government policies to achieve the global and national targets in Disaster Risk Reduction (DRR) for Sri Lanka. (CFE-DM, 2021).

Figure 2. The organizational structure of the current Sri Lankan Disaster Management

DMC carries out several tasks including the formulation National Disaster Management Plan (NDMP) and National Emergency Operations Plan (NEOP), hazard mapping and risk assessment, development of preparedness plans, early warning, and dissemination activities. NDRSC is responsible for the support of disaster-affected people. It has dispatched Disaster Relief Coordination Officers to all the District Secretariats and Disaster Relief Officers to all the DS Divisional Secretariats. NDRSC could access the field disaster information immediately during a disaster with the information collection and recording system established. DoM is responsible for meteorological observation which became an affiliated semi-governmental agency of MDM in February 2006 (JICA, 2017). DoM issues the early warnings on heavy rainfall and cyclone and oversees issuing the tsunami warnings based on international meteorological information. The forecasting and Decision Support unit operates its 24/7 operation room while the Katunayaka airport office functions as the backup of the Colombo main office in case of the breakdown of the Colombo office. DoM also has 37 automatic weather systems which are deployed at regional Meteorological Stations and collaborative stations. DoM offers weather forecasts which include expected rainfall, temperature, and relative humidity. Furthermore, NBRO is the responsible agency for landslide countermeasures. NBRO installed automatic rain gauges and alarm systems in landslide-prone areas while forecasting based on rainfall, geological factors and other data helped vulnerable communities to evacuate in an event if the centrally issued early warnings fails. It also implements early warning, hazard mapping and structural and non-structural measures on landslides. Looking at flood management, Irrigation Department is responsible for the operation of rivers and reservoirs. It implements flood control via structural and non-structural measures.

While the government organizations play the leading role in DM, several Non-Governmental Agencies, and international organizations such as Red Cross, Sarvodaya, Asian Disaster Preparedness Centre (ADPC), United Nations & World Bank aid to build community resilience as well as aid in relief activities (CFE-DM, 2021). Furthermore, Higher Education Institutes (HEIs) also play a major role in DM. Their contributions to education and awareness, expertise, advocacy, research, and innovation are highly appreciated by the other organizations who are involved in DM. The tri forces and mass media are also actively involved in DM activities as well.

Each of these institutions is actively involved in every phase of a disaster event at their maximum capacities overtaking the difficulties they face. The next section of the paper describes their involvement in the said flood events, and they are summarized under the four themes of DM.

INSTITUTIONAL ENGAGEMENT IN CONSECUTIVE FLOOD EVENTS FROM 2016 TO 2018

Development of Maps & Guidelines

Preparing for a disaster while building community resilience is important and it is not a task to be done by the government alone. Multi-stakeholder participation is essential in achieving the intended outcomes. Preparation of Hazard and Vulnerability maps plays a major role in preparing for a disaster. In Sri Lanka, the National Hazard profiles (DMC, 2015b) were prepared in collaboration with several stakeholders including the expertise of HEIs. When looking at the limitations mentioned in the studies it is evident that most of the map's accuracy and coverage were an issue. Apart from preparing maps, there are several guidelines prepared by government agencies to transfer disaster knowledge to the communities. Hazard resilient construction manual(NBRO, 2015) is one such guideline which gives several tips to the communities on how to build resilient houses which could withstand floods.

Formulation of Policies and plans

In addition to the flood inundation maps and guidelines prepared by several stakeholders, the policies, plans and programmes related to Disaster Management play a pivotal role in the preparedness of the communities. At present, Sri Lanka is in the phase of aligning itself with global standards. National Emergency Operations Plan is a document which assigns clear responsibilities to the organizations and individuals on how to perform during a disaster (Disaster Management Centre, 2015c). Furthermore, the National Guidelines for School Disaster Safety (Ministry of Education, 2008) is another key document prepared by the MDM and DMC with the collaboration of the Sri Lankan-German Development Cooperation which provides guidelines to establish a school disaster safety plan. Evaluation guide of the coastal community resilience prepared from a collaborative project between local institutions including DMC, DoM and USAID give a detailed evaluative platform for the decision makers to assess the community resilience of the coastal belt of Sri Lanka (US IOTWS, 2007). The community resilience framework prepared by DMC also provides guidelines to assess the capacity and preparedness of local communities(Disaster Management Centre, 2015a). Even though these documents exist there seems to be a gap in using them effectively for the benefit of the communities in high-risk areas. Most of these guidelines are not fully implemented and understood at the grass root level. Due to this, even the most educated people in the communities seem to lack knowledge of disaster preparedness.

Multi-Agency Collaboration

Institutional fragmentation in the Sri Lankan DM sector has led to poor coordination of data management which hinders the effective preparedness of the country for disasters. Sharing of data between agencies is important to prepare effective community plans. Most government technical institutions lack the tendency to exchange data and technology which is necessary for the beneficial outcomes of the communities. Due to this scenario, the Colombo municipality area has several overlaps in functions and responsibilities when managing the drainage and canal system which was affected by 2016 floods (DMC, 2012). Furthermore, university-industry partnerships which enhance the involvement of HEIs with the industry can help in capacity building in both the technical institutions and academia in the field of Disaster Management.

During the 2017 & 2018 flood events, Dialog held a national campaign to receive customer donations for relief services. UN agencies and other national and international NGOs always come to aid during a disaster by providing funds for food security, provision of water and sanitation facilities and emergency livelihood support. During the 2017 floods as per the request of GoSL many foreign countries aided via the Ministry of Foreign affairs while countries like Bangladesh and Ireland provided direct financial support (UNDP, 2017). Several popular local and international agencies were involved in major recovery activities like cleaning wells, providing dry rations, supplying bedding and kitchen sets, distributing water bottles, non-food items and educational materials and facilitating.

Chinese International Search and Rescue Team (CISAR), dispatched by the Red Cross Society of China (RCSC), set up relief camps in a suburb of Colombo during the 2016 floods. They gave quick training to 40 Sri Lankan soldiers and 10 reserves on the same day. The Chinese government provided emergency humanitarian aid which included camps, and folding beds to the flood-affected people. Also, Indian Navy officers sent relief items for the victims as well. In addition, relief donations were collected via social media. The public who was not affected by floods sent their donations to the flood victims via social media campaigns and mass media. The relief activities are well coordinated by NDRSC while using online methods to inform the public about which rations are necessary. In addition, some of the taxi services offer free rides during emergencies so that the affected people can evacuate quickly.

During the disasters relief operations are done with national and international assistance. Considering the recent floods, immediate rescue operations were undertaken with the aid of tri forces. Furthermore, the Government of Sri Lanka (GoSL) allocated around LKR 1 billion for immediate relief services which included the cleaning of interrupting roads and infrastructure (Relief Web, 2019). In addition, MDM opened a bank account to receive donations from private organizations and individuals which had a balance of around LKR 17 million at the end of July 2017. Other governmental organizations have also come forward to give donations, even though their main objective is not to cater for disaster crisis management activities. Some of such agencies are Sri Lanka Tourism Bureau, Divisional and District secretariats, Ministry of Science, Technology and Research, Ministry of Mahaweli Development and Environment, Presidential Secretariat, Government affiliated trade organizations and Ceylon Fisheries Corporation. These organizations have given their helping hand by providing dry rations, and essential items as well as by providing facilities and equipment such as boats, generators, and tents. Also, Sri Lanka tri-forces has been actively involved in many activities in man powering, from cleaning activities to facilitating the affected with transport arrangements while ensuring the security of the area

Awareness Campaigns

All these multi-stakeholder partnerships and guidelines would become a waste without proper community awareness. At present most of the awareness programmes are led by DMC and MDM, which sometimes are funded by Non-Governmental Organizations (NGOs) as well. Red Cross and Sarvodaya are two leading NGOs that conduct awareness programmes in Sri Lanka. These programmes include mock drills, participatory hazard mapping, first aid training, boat handling, camp management and identification of safe evacuation routes as well. The two-week disaster preparedness programme initiated by DMC during the mid of May focusing on eleven districts provided great assistance via transmitting knowledge to the local communities on how to respond to a flood event (Relief Web, 2019). This programme helped in reducing the number of affected people due to the 2018 rains drastically. In addition, when the 2018 monsoon rains occurred people started packing the most valuable things to them so that they can evacuate safely while carrying their belongings. This showed that people were aware of how to respond to an emergency.

Early Warning and Evacuation

It's crucial to comprehend how to get over the information hurdles that government and military organizations experience throughout a regular disaster response mission. The Joint Task Force leaders and staff will benefit from knowing the Humanitarian Assistance and Disaster Response (HADR) resources that are available while planning missions. Since no single responding body, NGO, international government organization (IGO), helping country government, or host government can be the source of all necessary information, information sharing is essential. During the flood incidents in 2017 and 2018 responses from the external parties have made a huge impact in reducing the number of affected people. Accurate Early Warnings (EW) are necessary for vulnerable communities to evacuate safely. The threshold level for issuing a flood warning is identified as the time at which the water level reaches the flood level in rivers or reservoirs which will be declared by the assigned technical agencies.

Both DoM and ID play the leading roles in issuing early warnings related to floods. Several stakeholders are involved in this early warning coordination process from the national level up to the grass root level. While DMC and other technical agencies work at the national level District Disaster Management Coordination Units (DDMCUs) operate at the district level while conveying information to the divisional level stakeholders. At the grass root level, NGOs and several other agencies provide their assistance to disseminate the early warning messages. The Emergency Operations Centre (EOC) of DMC acts as the centre for emergency services (Wijesinghe et al., 2011). There are standard operating procedures prepared for all the responsible agencies which guide them on how to act during an emergency. In addition, the Disaster Early Warning Network (DEWN) which was produced from a collaborative project between the University of Moratuwa and DMC provides a sustainable

GSM platform between DMC and Mobile network providers to send EW messages quickly to the key stakeholders via SMS(Wijesinghe et al., 2011). The DMC Call Centre is assigned with an emergency telephone number (117) which can be accessed free of charge for disaster-related assistance. EOC will provide appropriate advice and will link up additional resources, as required. The community-based early warning system initiated by the Red Cross also assists the local villages to support DMC to develop an effective early warning mechanism which eventually increases the knowledge of a respective community (Sri Lanka Red Cross, 2018).

Furthermore, the media plays a prominent role in the dissemination of early warnings in Sri Lanka, covering the entire island easily through television and FM radios with more than 50 channels. In addition, DMC directly coordinates with tri forces and police to pass the early warning notices to vulnerable communities. Military and Police posts which are located around the entire country to support this process. Even though Sri Lanka has proper coordination mechanisms as mentioned above, during the recent floods it was observed that there was no clear difference between the "Warning" issued by the central agencies and the "Evacuation Order" by the local administration. According to the Post Disaster Needs Assessments (PDNAs) done for the floods early warning systems should be enhanced by revitalizing DDMCUs with the participation of all ministries. Furthermore, when looking at the history, the inaccuracy of the early warnings can be observed which creates a tendency for the people to not trust the evacuation notices. Most people do not have any experience with evacuation drills which sometimes create chaos during evacuation. In Sri Lanka, most evacuation shelters are religious places since there are situated in hilly areas. Most people do not have a clear idea about the fastest route to those shelters. At the grassroots level Grama Niladhari (GN) plays an important role in disseminating early warning messages and establishing evacuation shelters and local EOCs. However, there were several deaths during these floods which could have been prevented if they have trusted the authorities and evacuated (UNDP, 2016). People should be made aware that their life comes first, and their belongings should be given minor recognition during a disaster.

Post Disaster Recovery

After a disaster occurs well-coordinated recovery activities will ensure the return of the local economy to a sense of normalcy. When comparing the 2016 and 2017, flood recovery needs in both the social and infrastructure sector were risen by a considerable margin (UNDP, 2016). GoSL is always leading the recovery, reconstruction and rehabilitation processes following the Build Back Better approach in the Sendai framework. In addition, the health facilities are looked after mainly by the Ministry of Health (MoH) supported by DMC. During these floods health personnel quickly mobilized for emergency patient services for the victims while establishing mobile health camps and undertaking preventive measures to contain the spread of diseases Disease surveillance is strengthened in the affected districts while the generated reports were transferred to MoH for monitoring and action. Cleaning of wells in the affected houses will ensure the supply of clean water to the communities. The Sri Lanka Red Cross engaged in these activities with the aid of the Sri Lankan and US armies. National Housing Development Authority (NHDA) is taking care of the reconstruction of the houses for the affected communities. During the initial recovery phase, damaged sluice gates and irrigation canals were repaired to enable the recultivation of crops. Ministry of Agriculture (MoA) is leading the role of executing the recovery plans for crops which were supported by MDM, Ministry of Mahaweli & Environment and Ministry of Irrigation. The monitoring team ensures that collected data is shared with the respective parties such as UN agencies like FAO and WFP. The education facilities were assisted by the Ministry of Education (MoE) while collaborating with UNICEF and other NGOs. Army troops also came forward to sew uniforms for flood-affected Students in Kolonnawa, which included a total of 7000 students in 10 schools during the 2016 floods (Sri Lanka Army, 2016).

When looking at the compensation amounts allocated for floods, GoSL had decided to give LKR 10,000 to each flood victim in Colombo and Gampaha areas in 2016 and the amounts paid for compensating deaths is about LKR 100,000 (UNDP, 2016). In addition, the Cash-for Work project done collaboratively with Oxfam provided satisfactory revenue to around 80 flood-affected people during 2016. Furthermore, people who worked 6-day jobs received relief supplies in addition to a cash payment. Flood-affected women were happy to receive kitchen utensils which replenished a part of what they had lost. Sri Lanka Navy personnel also assisted in helping the clean-up process. Furthermore, more provisions were given to the families who were estimated to have damages worth less than LKR 10,000, also the small and medium enterprises were compensated as well, in a similar method in which the damaged houses were compensated.

Mitigation Measures

After each flood incident, several mitigation measures were undertaken in several districts following the global agendas including the Sendai Framework and Goal 11 of Sustainable Development Goals backed by the Build Back Better approach. In the PDNAs prepared by DMC the importance of mainstreaming DRR in the construction industry has been highlighted to build disaster-resilient houses. Under the Metro Colombo Urban Development

Project, several measures were undertaken to convert Colombo into risk free city of floods. Implementation of two micro-drainage projects, improvement of primary canals and increasing the drainage capacity of the gravity system by 100 cubic meters are some of the objectives of the project. Under this project Beddagana wetland was turned into a park which will aid in flood control and temperature moderation for Colombo(Denipitiya & Udalamaththa, 2020). Flood risk modelling and identification near the Kalu ganga basins are carried out by the funding assistance of Japan International Cooperation Agency (UNDP, 2017).

Community Relocation

Despite the actions taken by the governmental authorities, community engagement plays a vital role in the success of the mitigatory actions. However, it was evident that at several places, people are reluctant to change their place of livings from the near riverbanks to another place. It should be noted that these groups of people are illegal residents in the riverbanks. Although the relevant divisional secretariat proposed a compensation scheme of LKR 5000.00 per family per month for six months to facilitate families with rent, until they get a permanent place to live, in a safer place, that scheme was rejected, reasoning that the compensation is not adequate, and claiming that they won't be able to continue their livelihoods as before. At the same time, there were complaints against some individuals of the affected community, for being unconscious about the hazard situations and for not taking the precautionary actions against floods. Therefore, it is highlighted that the awareness of the people should be enhanced in some cases, and forcible actions should be taken where necessary as well, by the authorities.

HOW CAN CITIZEN SCIENCE ASSIST?

After the analysis of the engagement by the institutions in these events, it was identified that the efficiency of most of the key activities can enhance by utilizing citizen science concepts. In this section, the suggested improvements based on the documentary study are expressed in Table 3. In addition, references of the successful citizen science projects outside Sri Lanka were given, so that decision-makers can get input when they are developing local citizen science models and projects.

Table 3. Citizen Science Concepts to improve the current practices

Current Practice/ Issue	Suggested Improvements
Preparation of Hazard, Vulnerability and Risk Maps are done mostly by the technical institutions individually (Development of Maps & Guidelines)	A community-based participatory mapping can be initiated to reduce the cost of travelling in distant areas. People who are willing to engage can be equipped with modern technologies and trained to update the data online to a common platform. OpenStreetMap is one such platform which can be used effectively (Brovelli et al., 2020).
Development of guidelines and plans are done with the limited participation of grass root level communities (Formulation of Policies & Plans)	Since these are designed to serve the vulnerable communities, their input is essential. A cross disciplinary approach is needed and can implement a Co- Design project where a government institution can take the lead while the community groups can share their personal experience. However, precautions should be taken to avoid hindering of sustainability outcomes of the projects due to Citizen involvement. (Wamsler et al., 2020)
Data Management is mostly within a particular institution and multi-agency collaboration is minimum (Multi-Agency Collaboration)	Institutions like DoM can educate citizens and encourage them to establish voluntary rain gauges and use the GPS locations of their mobile devices to do local area modelling, where the citizens can also provide data to other institutions when needed. CoCoRaHS(Reges et al., 2016) and mPING (Elmore et al., 2014) are two such working models which can be used as a guidance develop a new model for Sri Lanka
Awareness campaigns are led by government organizations and NGOs and most of them are organized in a central location (Awareness campaigns)	If the decentralized awareness campaigns are not feasible, with the help of a crowdsourcing platform; relevant institutions can collect citizen reports on disaster incidents which will make them aware about the incident as well. SkyTruth is one such platform originated in US where anyone with an internet connection can monitor the dates and location of the trackable commercial fishing(Washington et al., 2016). Furthermore, creating online citizen science games like Foldit (Curtis, 2015) can easily make school children aware of disasters and risks.
Implementation of Community based Early Warning (EW) Systems	A bottom-up approach like this is essential rather than relying heavily on technology. However proper measures should be taken to reduce the

(Early Warning and Evacuation)	institutional vulnerability. In addition, existing systems can be enhanced by introducing latest mobile technology and communication systems. Like in Nepal physically interpretable time series models will assist the responsible agencies to increase the lead times in EW(Smith et al., 2017).
Information sharing among institutions is minimum and sometimes the same information is communicated twice (Early Warning and Evacuation)	Authorities can enlist volunteers locally, where they can register in a nationally managed database to collect real time data and conduct damage assessments within the allocated region. These data can be shared in a web-based platform which has access to all the institutions. OpenStreetMap (OSM) could be an ideal solution in this case where countries like Bangladesh are using for Disaster Response (Latif et al., 2011). Furthermore, social listening models can be implemented to track the comments and feedback of the public who are using social media (Anderson et al., 2017).
Accuracy of the early warnings are questionable and most of the dissemination methods are analog. (Early Warning and Evacuation)	Utilization of multiple voluntary groups in a particular area can increase the accuracy and by using social media platforms the EW can be easily disseminated. However, in the rural sites' community projects can be initiated to enhance the communication networks
Trust of communities on evacuation notices is very less (Early Warning and Evacuation)	Building Trust on evacuation notices is a timely process. In Sri Lanka due to the prediction inaccuracies, public react merely to these. To improve the accuracy, a hackathon can be introduced to in developing solutions. Codevid-19 (Vermicelli et al., 2021) is one such model introduced during Covid 19 pandemic to support crisis response where local developers can get inputs to their models.
Relief operations are done by multiple parties and some communities experience repetition of services (Post Disaster Recovery)	During the relief operations inter agency coordination is a must. Furthermore, respective parties need to know priority areas for response. In this case a network of volunteers like PRN can be organized to analyze satellite imagery available in DMC to perform damage assessments (Simmons et al., 2022). In addition, sentiment analysis (Behl et al., 2021) can be performed on social media like Facebook and Twitter which are commonly used in Sri Lanka to assess the efficiency.
Most of the recovery funds are given by the GoSL or foreign parties as donations (Post Disaster Recovery)	Crowdfunding (Bouncken et al., 2015) projects can be implemented in Grama Niladhari (GN) divisions which are identified as high-risk areas to reduce the burden to the authorities if a disaster occurs.
Damage Assessments are not accurate due to the lack of data (Post Disaster Recovery)	Participatory Research Studies can be conducted with the affected groups to collect accurate data of their needs. During a flood event due to the overflows most of the water bodies get contaminated and due to the workload of the respective institutions sometimes they miss some data. Citizens in the affected areas can partner with relevant organizations to assist environmental sampling in this case. GRACE is one such project which used community-based participatory research for the chlorine gas disaster in Graniteville, South Carolina. (Svendsen et al., 2010).
Post Disaster Rectification activities are done mostly without consulting affected communities (Post Disaster Recovery)	Community generated data can make a huge impact to the decisions of the officials. Considering the high population density in some areas volunteer-based data collection is needed to assist the relevant organizations.
Precautionary actions and risk modelling are not interconnected. (Mitigation Measures)	Can introduce low-cost sensors and data collection mechanisms which can be easily managed by local communities to increase the spatial network coverage. Then these can be utilized to increase the accuracy of risk modelling (Pandeya et al., 2021).
Due to the forced relocation most of the families are not able to continue their livelihood as before (Community Relocation)	Authorities can establish small scale community aid projects among relocated families during earlier disasters to capture their experiences which can be utilized in future. RAP in North Carolina can be taken as a pilot project in this case (Farquhar & Dobson, 2008).

CONCLUSIONS AND RECOMMENDATIONS

After the analysis, it was revealed that Sri Lanka being a lower middle-income country, has been coordinating with several local and international organizations during the disasters. While the government institutions like MDM, DMC, DoM and ID are leading the DM activities related to floods Sri Lanka Red Cross and Sarvodaya are the leading local NGOs. Apart from that United Nations, and World Bank plays a major role when providing funding for Disaster Related activities which increases capacity building and community resilience. JICA and ADPC are some of the other foreign institutions which provide support. In addition, tri forces, mass media and social media play a pivotal role during the response stage of the DM cycle by disseminating early warnings to the public.

Even though Sri Lankan communities get assistance from several external bodies, it is evident that there are some gaps and provisions for improvement in the processes and activities they engage with. Citizen science concepts can be used to enhance and improve the efficiency of these activities. Participatory mapping, Co-Design projects, hackathons and crowdfunding are some of the observed mechanisms to incorporate the knowledge of the communities in Disaster Management of Sri Lanka. However, since this is a working paper further research and investigations are required to finetune the recommendations. The ideal scenario would be to develop a citizen science model in a selected area capturing all phases of a disaster and observing it's functioning to improve it further.

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New Zealand COVID Tracer App: understanding usage and user sentiments

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ABSTRACT

The NZ COVID Tracer app is a part of Aotearoa New Zealand (NZ) Government's strategy to manage the COVID-19 pandemic. This paper investigates people's usage and sentiment on the app from its release in May 2020 to the end of 2021. Descriptive analysis of app data and sentiment analysis on user review data were used. The results show that before March 2021, the overall sentiment on the app was negative but gradually improved over time. The passive Bluetooth-tracing feature is utilised more consistently than the manual features. However, the increased proportion of positive sentiments is seen to increase with active app use. Results highlight the consistency of the Bluetooth-tracing feature but do not discredit the importance of manual interaction, as active use can improve the perception of the app. Insights from this study will be helpful as apps adapt to the changing context of the ongoing COVID-19 pandemic.

Keywords

Mobile apps, COVID-19 response, sentiment analysis, user reviews, app store data

INTRODUCTION

The NZ COVID Tracer app is a part of the Aotearoa New Zealand (NZ) Government's strategy to manage the COVID-19 pandemic in the country. The app's design and use have evolved through the different stages of the pandemic. This paper presents an investigation of the NZ COVID Tracer app performance from its release in May 2020 to the end of 2021.[1]

The NZ population of 5 Million has responded well to the app initiative, with approximately 3,500,000 total app registrations as of 31 Dec 2021 (Ministry of Health – Manatū Hauora, n.d.). Despite the high app registrations, the public's actual use of the app's functions may not show equivalence in numbers. The highest record on the number of active devices (where the user uses the device to perform manual features such as scanning or diary entries) in a day was only 1,450,129 as of 31 Dec 2021 (Ministry of Health – Manatū Hauora, n.d.). Usage patterns can also fluctuate depending on circumstances. This paper aims to uncover the performance of the NZ COVID Tracer app from its release in May 2020 to the end of 2021 and to provide an understanding of the public's perceptions of the app through user reviews. The paper seeks to answer the question: How did the public use and perceive the app during the period from May 2020 to the end of 2021?

[1] This paper covers this period of the pandemic before the Omicron variant spread in NZ.

BACKGROUND

NZ COVID Tracer app was launched in May 2020 by NZ's Ministry of Health to enable faster contact tracing for COVID-19 community cases. The app lets a person keep a digital diary of places visited by scanning official QR codes located on-premises or manually entering the details. The apps, starting 10 Dec 2020, had enabled a Bluetooth feature where the app conducts virtual handshaking of other nearby app-Bluetooth-enabled mobile devices. The Ministry of Health would then use the data from the virtual diary and Bluetooth handshakes for contact tracing should the user contract COVID-19 or would have been in contact with a person with COVID-19. The NZ COVID Tracer app developed its features through time, also in the changing context of the COVID-19 pandemic. Table 1 shows a summary of developments of the NZ COVID Tracer app.

Table 1. Summary of events relating to the NZ COVID Tracer app.

Date	Event
20 May 2020	Official launch of the NZ COVID Tracer app.
30 Jul 2020	The app was updated with an added feature that allowed users to add manual entries to their digital diary (on top of the QR code scanning feature).
19 Aug 2020	The Government made it compulsory for businesses to display the official app-compatible QR codes for premise entry doors and reception areas.
3 Sep 2020	The Government made it compulsory for all public transport providers, including buses, trains, ferries, ride-share vehicles, and operators, to provide QR codes for passengers.
23 Nov 2020	The app was updated to no longer require users to sign-up for an account or set up a password to use the app. All existing users no longer need to sign in periodically.
10 Dec 2020	A Bluetooth feature was added to the app.
22 Aug 2021	The Government announced that record-keeping, including scanning with the COVID Tracer app or manual signing, will now be mandatory for most events and businesses at all alert levels in response to the detection of the Delta variant
** These events are selected from the timeline and resources from the NZ Ministry of Health website.*	

Two studies have examined the public use and user experience of the NZ COVID Tracer app (Gasteiger et al., 2021; Tretiakov & Hunter, 2021). But these studies were conducted at the pandemic's earlier stages (between July and November 2020) and before the app had Bluetooth capabilities (implemented in December 2020). The studies by Gasteiger et al. (2021) and Tretiakov & Hunter (2021) provide good starting insights into using the app. The survey by Gasteiger et al. (2021), which ran between July to September 2020, found that only 31% of the respondents reported using the app frequently, while 24% used it sometimes, 21% had installed the app but not used it, and 24% had not installed the app. Barriers to installation and use include app-specific concerns such as technical, privacy, and security issues and behavioural and social barriers such as users' forgetfulness and lack of support from businesses on using QR codes (Gasteiger et al., 2021). App usage also relies on the environmental context (Tretiakov & Hunter, 2021); users notice a decline in app use during lower 'Alert Levels.'[2] Results from Tretiakov & Hunter's (2021) study show the need to utilise the concept of civic responsibility as it will likely appeal to users during high-threat conditions and will encourage the use of the app (Tretiakov & Hunter, 2021).

However, these studies have gaps. Tretiakov & Hunter's (2021) study only interviewed 34 users. The experience of the 34 may not represent the experiences of the entire NZ COVID Tracer app user base. Gasteiger et al.'s (2021) study had more participants (n = 343); however, the app aspect of the study was only part of a broader COVID-19 Health and Stress survey. The NZ COVID Tracer app was only appended in the broader survey with (1) a close-ended question on the frequency of use and (2) an open-ended question on their decision to use/not use the app. Gasteiger et al. (2021, p. 9) noted the limitation of their study: 'text-based responses may have limited the depth of data provided.'

METHOD

Given these gaps from previous literature, this study tries to investigate the NZ COVID Tracer app's performance and to gain deeper perspectives from the broader user base by analysing large data sets. It is important to mention that analysing large volumes of user reviews makes it possible to draw inferences on app usability and user experiences than gathered through structured surveys (Gasteiger et al., 2021; Tretiakov & Hunter, 2021).

[2] From March 2020 to December 2021, NZ operated on a four-tier alert level system (New Zealand Government, n.d.). Level 4 is the highest level where COVID-19 is not contained, and measures include strict lockdown. The lower the levels, the lower risk of transmission of COVID-19 hence more relaxed restrictions as levels go down.

Data sources

This study aims to enhance the current understanding of app use by investigating two larger data sources with broader coverages. The data sources for this study involve (1) the NZ Ministry of Health of daily statistics on usage and (2) the user reviews from the Google and iOS app stores on the NZ COVID Tracer app.

Ministry data

The NZ Ministry of Health provides statistical information about app usage. This is published on the Ministry of Health website[3], and a spreadsheet in CSV format is updated daily. The spreadsheet contains data from 19 May 2020 with the variables detailed in Table 2.

Table 2. Data variables from the Ministry of Health on the NZ COVID Tracer app.

Variable	Description	Data available from
App registrations	The number of registrations on the specified date range	19 May 2020
Poster scans	The total number of scans on QR codes made by the app users within 24 hours	19 May 2020
Daily entries	The total number of manual entries inputted by all app users within 24 hours	7 Jul 2020
Active device count	The number of devices that have either scanned QR codes or added a manual diary entry within 24 hours	24 Jun 2020
Bluetooth tracing numbers	The number of unique devices that have Bluetooth enabled and participating in Bluetooth contact tracing.	12 Dec 2020

User reviews from Google Play Store and Apple App Store

This study also analyses feedback gained through NZ COVID Tracer app user reviews. App stores, such as Google Play and Apple Store, provide means for their users to provide feedback through ratings and reviews (McIlroy et al., 2015). Analysing a large number of user reviews makes it possible to draw inferences on user experience that may not be replicated through solicited means (e.g., interviews and structured surveys) (Gebauer et al., 2008; Hedegaard & Simonsen, 2013). Users provide feedback in app stores without a predefined structure, and they can give reviews in an open-ended format where they can give as much praise or complaints about the app (Palomba et al., 2015; Tan et al., 2020a). Furthermore, these user reviews are not just summaries but are self-reports that contain insights into the user experiences (Hedegaard & Simonsen, 2013). Several studies have analysed app store data to get findings that have led to improvements in many aspects, including requirements engineering, planning, software design, and security and testing (Martin et al., 2016). For example, a study by Tan et al. (2020a) on user reviews from app stores has provided insights into users' perceptions of what makes disaster apps usable.

Data variables available from the app stores include (1) date of the review, (2) rating – score of 1 to 5, and (3) content of the user review. Raw data scraped for this study for the NZ COVID Tracer app included 3,552 reviews from Google Play and 554 reviews from Apple Store. A sample of the app user reviews is shown in Table 3.

Data analysis

The contribution of the paper is twofold. Firstly, a descriptive analysis of the NZ Ministry of Health data using numerical and graphical methods is carried out to understand the usage and the changes in activities of the COVID Tracer app. Secondly, sentiment analysis on the app user reviews from Google Play Store and Apple Store is performed to study the user perception of the app from its public release to the end of 2021.

Descriptive analysis of the Ministry of Health data

Numerical and graphical methods were used for the Ministry of Health data. The initial analysis looked first into Cumulative app registrations – the sum of the daily app registrations from19 May 2020 to 31 Dec 2021. This number is essential as it shows the total app registration representing the maximum possible number of mobile phone units that have the app installed. This number is the base for understanding the usage of the app, assuming that each registration represents a member of the population in NZ to be a user of the NZ COVID Tracer app.

[3] https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-data-and-statistics/covid-19-nz-covid-tracer-app-data

Note that the actual number of app users may be lower than the cumulative app registrations, as the data does not account for the possibility of double counting. For example, a single person may have multiple phones, or a person can acquire a new phone and install the app while retiring an old unit, or users can uninstall and reinstall. The limitation of the data is that it does not differentiate these situations but only accounts for every app registration

Table 3. Sample reviews and ratings.

Date	Rating	Content of the review
04 Dec 2021	1	*Will not work forget it and delete*
06 Dec 2021	2	*Super slow and when you try and do manual entry it can never find the location.*
15 Dec 2021	4	*Works most of the time. My Covid Record keeps falling off. Not so easy to use when out if you have to log in to the app each time.*
18 Dec 2021	3	*Scanning works well. Ability to show vaccination status needs to be easier - rather than opening a new window/going to Google pay why can't it just be a tab on the bottom of the tracer home screen?*
19 Dec 2021	2	*Unreliable app. Doesn't always work and often needs lot of positioning attemps to get it to scan code.*
19 Dec 2021	4	*It works fine, but can take ages to load, which can be VERY annoying*
23 Dec 2021	3	*A decent app. It has a long load time which is why I'm taking 2 stars off but still very good. It would encourage people to scan if it came to fit bit so you can just turn on the app and scan but sadly this collaboration hasn't happened yet*
25 Dec 2021	5	*This is so good so we stay safe*
27 Dec 2021	1	*Disgusting app disappears on screen no fix offered have to find it in my emails stupid system. And to think that is supposed to be something we have paid the government to produce for us, and can't even get a simple app to work properly.*
29 Dec 2021	5	*Helps keeps everyone safe*

The data variables were then subjected to descriptive numerical analysis where the average, maximum and minimum observations and standard deviation were calculated. Additional indicators were computed to provide further insight into app usage. Indicators include determining the average daily scans and manual entries per active user. Proportions on how many active and Bluetooth-enabled devices were compared to the maximum number of app registration were also computed. See Table 4 for more details on these indicators. Graphical methods were also used to plot the data variables over time to see changes in activity regarding the NZ COVID Tracer app. Substantial observable variations in the trend line were investigated and compared to significant events.

Table 4. Indicators to understand app usage.

Indicators	Formula	Description
Daily scans per active device	$= \frac{\sum_1^n scan/active\ device}{n_{days\ of\ observation}}$	An active app user averages this number of poster scans in a day
Daily manual entries per active device	$= \frac{\sum_1^n manual\ entry/active\ device}{n_{days\ of\ observation}}$	An active app user averages this number of manual entries in a day
Average active use ratio	$= \frac{\sum_1^n \frac{active\ device}{cummulative\ app\ registrations}}{n_{days\ of\ observation}}$	The average proportion of active apps (i.e., apps where users actively use QR scanning or diary entries)
Average Bluetooth ratio	$= \frac{\sum_1^n \frac{Bluetooth\ enabled\ apps}{cummulative\ app\ registrations}}{n_{days\ of\ observation}}$	The average proportion of apps that have Bluetooth enabled

Sentiment analysis on user reviews

Sentiment analysis is one of the major topics of Natural Language Processing which is useful for detecting people's opinions, sentiments, behaviours, emotions, appraisals, or attitudes towards products or services, issues, events, or topics (Liu & Zhang, 2012). This study identified the users' sentiments towards the NZ COVID Tracer app using the user review data from the app stores.

It should be noted that the sentiments toward the app will change over time due to various reasons. For example, a new update to the app can cause an increase in the positive perception of the app (sometimes it might cause a negative perception too). Therefore, it is informative to track the sentiments towards the app over time. The sentiment analysis focused on investigating users' perception of the app through time from its release to the end of 2021. Once the sentiments over time are identified, significant fluctuation can be further analysed to identify events or scenarios that may have caused those.

For the sentiment analysis, the app user review data from May 2020 to the end of 2021 were collected from Google Play Store and Apple Store. Each user review includes (1) the date of the review, (2) the content of the review in text format, and (3) the user rating on a scale of 1 to 5. User rating is a good indicator of the user perception of the app. However, it is limited to just a number and may not reflect the true sentiment of the user (Maks & Vossen, 2013). Therefore, the sentiment analysis was performed on the user review content in text format. When a user writes a review on the app, it reflects their sentiment towards it. However, manually reading all the reviews and identifying the sentiment is highly cumbersome and may lead to very subjective results. Two people might read the same review and come to two different conclusions about the sentiment. To avoid subjective interpretation, we used the four most frequently used machine learning (ML) classifiers and one deep learning (DL) classifier to classify each review's sentiment.

Machine learning and deep learning classifiers

The goal of sentiment analysis, through ML and DL approaches, is to deal with labelled data and help to create models using supervised learning algorithms, namely, decision tree (DT) (Zharmagambetov et al., 2015), random forest (RF) (Breiman, 2001), K-nearest neighbours (KNN) (Mitchell, 1997), multinomial logistic regression (MLR) (Hastie et al., 2009), and bidirectional long short-term memory (LSTM) (Ketkar & Santana, 2017). These are briefly explained below.

- DT is a tree-structured classifier, where internal nodes represent the features of a dataset, branches represent the decision rules, and each leaf node represents the outcome. The DT algorithm aims to create a model that predicts the value of a target variable by learning simple decision rules inferred from the data features.
- RF utilizes ensemble learning, a technique that combines many classifiers to solve complex problems. An RF algorithm consists of many decision trees. The 'forest' generated by the RT algorithm is trained through bagging or bootstrap aggregating.
- KNN solves the classification problem by assigning the object to a class by a plurality vote from its k (a positive integer) neighbours. The algorithm captures the idea of similarity amongst the object with respect to its neighbours in terms of distance, proximity, or closeness.
- MLR is a linear algorithm, and the underlying technique is similar to linear regression. The term 'logistic' is taken from the logit function that is used in classification. The idea is to develop a model that best describes the relationship between the outcome and a set of independent variables.
- LSTM is an updated version of Recurrent Neural Network which handles log sequence dependencies well. The LSTM network is fed by input data from the current time instance and output of hidden layers from the previous time instance. These two data pass through various activation functions and valves in the network before reaching the output.

Labelled training data

A challenge in the sentiment analysis through ML and DL techniques is that they require labelled training data - data consisting of reviews and the corresponding sentiments, which are not available in the NZ COVID Tracer app user reviews data. Moreover, DL requires large amounts of data to learn parameters (Pan et al., 2020). Therefore, three data sets are labelled with sentiments: (1) Google Play Store apps user reviews from Kaggle, (2) Nykaa app reviews from Kaggle., and (3) Google Play Store and Apple Store user reviews of MySejahtera COVID tracer app in Malaysia have been collected to train the models. All data sets consist of user reviews of different apps in text format together with the sentiment labels as positive, negative, and neutral. Table 5 shows the distribution of all reviews after merging the three data sets. There are 32,189 experimental data including 17,135 labelled as positive sentiments, 10,007 as negative sentiments, and 5,047 labelled as neutral sentiments accounting for 53.23%, 31.09%, and 15.68%, respectively.

Table 5. The distribution of positive, negative, and neutral reviews of the merged data set.

	Positive reviews	Negative reviews	Neutral reviews
Count	17,135	10,007	5,047
Proportion	53.23%	31.09%	15.68%

Data pre-processing included removing punctuations, changing the review content into lower case, tokenisation, filtering stop words, and lemmatisation. After pre-processing, the review data were transferred into a feature vector representation using TF-IDF (Term Frequency-Inverse Document Frequency) vectoriser (Tripathy et al., 2016). Next, the data set was divided into two sets, 80% of the data as a training set and 20% as a testing set. The training set was used to train the models, and cross-validation was used to optimise the hyperparameters of each model class. Once an optimal model from each model class was obtained, the testing data was used to identify the performance of each model. The last two steps of the sentiment analysis are (1) to use the optimal model to predict the sentiment of the user reviews of the NZ COVID Tracer app and (2) to validate the results. The user rating of each review on a scale of 1 to 5 was used in the model validation. The platform used was Python in the Google Colab cloud service, and the sentiment analysis code is available on GitHub[4]. The results of the sentiment analysis are given in the Results section below.

FINDINGS/RESULTS

Descriptive analysis results

From the app launch in 2020 until 31 Dec 2021, there were 3,531,037 cumulative app registrations – the maximum number of possible apps installed. The number indicates that there is high app uptake in NZ (approximately 75% of a population of 5 Million); if it is assumed that each app registration translates to one person having the app.

Table 6 provides a descriptive numerical summary of the Ministry of Health Data. On any given day, there are 1,086,339 scans and 37,648 manual entries from all the app users. However, on average, there are only 554,360 users that actively use their apps for either scanning or manual entries per day. On average, 1,559,428 devices in a day have enabled Bluetooth contact tracing. These results indicate that the passive feature of the app (Bluetooth contact tracing) is utilised more than the user-active features of the app (i.e., scanning and diary entries).

Table 6. Descriptive numerical summary of Ministry of Health data variables.

	Average	Max	Min	Standard Dev.
App registrations per day	6,184	233,200	302	17,850
Scans per day (from all users)	1,086,339	3,962,782	1,407	895,366
Manual entries per day (from all users)	37,648	255,338	5	31,562
User active devices per day	554,360	1,450,129	4,800	373,932
Bluetooth-enabled devices per day	1,559,428	2,401,547	351,430	562,272

On average, there are 6,184 registrations per day during the study period. But the registrations are not constant throughout this period, as seen by the standard deviation of 17,850 registrations, maximum observation of 233,200 registrations in a day and minimum observation of 302 registrations a day. Prominent peaks appear when plotting the app registrations over time (See Figure 1).

An uptick in registrations was observed during the app release, with 143,405 registrations on 20 May 2020. Registrations rapidly declined to a stable 2,000 registrations a day. Then a significant increase is observed in August. Similar patterns of rapid increase-decrease-stabilisation are seen throughout the study period. Upon investigation, sudden increases occur with significant events in NZ regarding COVID-related events. Summarised events below are gathered from the NZ Government's Unite Against COVID-19 website (n.d.-a) and RNZ (2021):

- **11 Aug 2020** - Four new cases of COVID-19 are recorded in the community; the first time for a community case since NZ moved to Alert Level 1,
- **24 Jan 2021** - NZ records the first COVID-19 community case since November 2020
- **14 Feb 2021** - Three new cases of COVID-19 are recorded in the community. Auckland moved to Alert Level 3 at 11:59 pm. The rest of NZ moved to Alert Level 2.
- **28 Feb 2021** - Auckland again goes into lockdown, moved back to Alert Level 3 due to further community cases. The rest of NZ moved to Alert Level 2.
- **17 Aug 2021** - All of NZ moved to Alert Level 4 at 11:59 pm, due to detection of Delta in the community.

[4] https://github.com/theeps/New-Zealand-Covid-Tracer-App-Usage-and-Sentiments

- **23 Jun 2021** - A traveller from Sydney to Wellington tested positive for COVID-19 upon their return to Australia. Wellington moves to Alert Level 2. The rest of NZ remained on Alert Level 1.

These results show that uptake for app registration relates to significant events. Similarly, high deviations are observed with the other data variables (see Table 6 for a summary). These results indicate fluctuations in the app's usage throughout the study period.

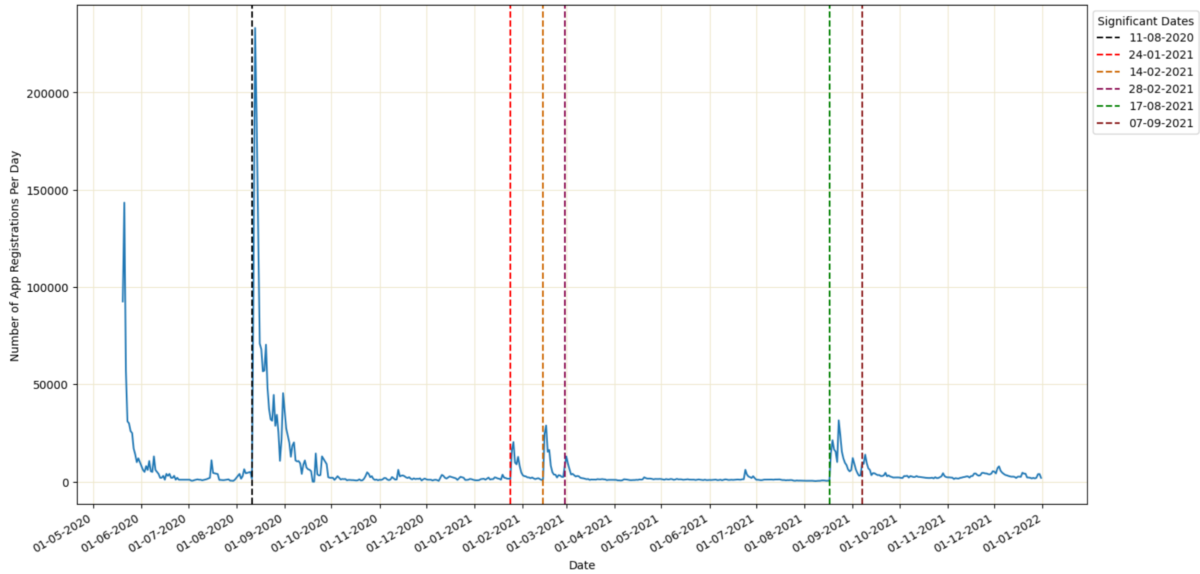

Figure 1. App registrations per day through the study period; vertical lines indicate dates associated with trend changes.

Figure 2 plots the number of scans recorded per day. It shows that scanning significantly increased after 11 Aug 2021, when the first community case was detected in NZ since it practically eliminated COVID-19 with zero community cases and went into Alert Level 1. Average scans before 11 Aug were approximately 26,000 scans a day. While average scans from 11 Aug to the end of 2020 were at 1 million scans a day, showing that people were scanning more often. Fluctuations in scans are seen throughout the period, but the scans in a day normalised to hundreds of thousands a day, not returning to pre-August 2020 levels. Another significant shift in scanning was observed on 7 Sep 2021, when NZ (except in the Auckland region) moved away from lockdowns down to Alert Level 2. As the population moved out of strict lockdown, more people were moving around and scanning. The average number of scans from 7 Sep to the end of 2021 was 2.6 Million scans per day. A significant drop can be seen on 25 Dec 2021, as most people stay home and most establishments close operations on Christmas day.

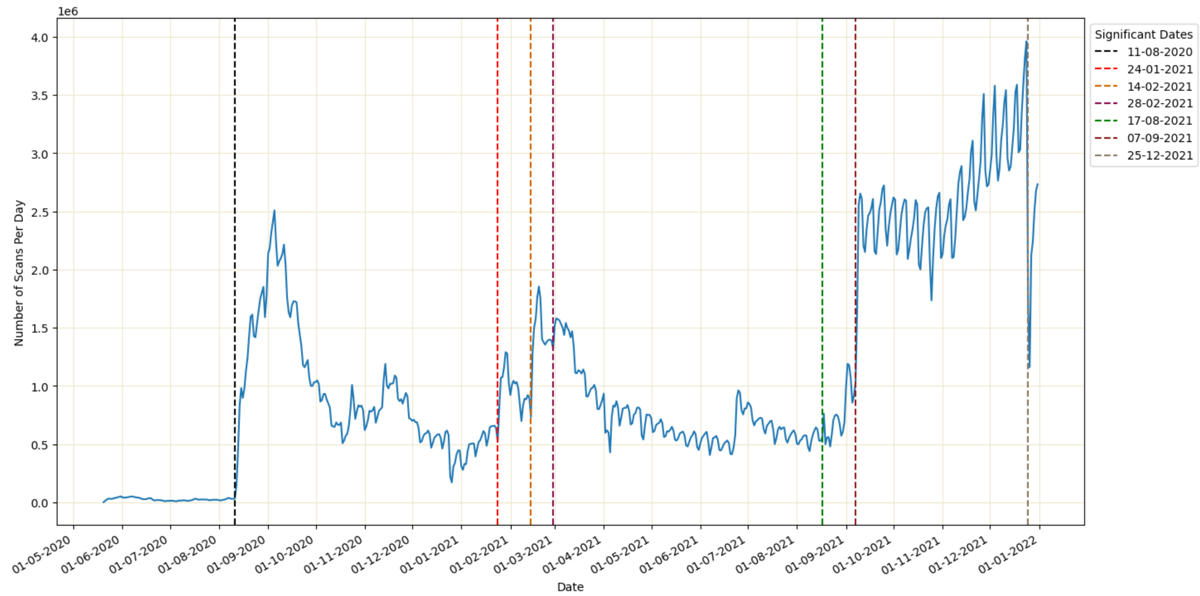

Figure 2. The number of scans per day through the study period; vertical lines indicate significant dates.

The computed indicators in Table 7 provide insight into app usage. An active device only scans 1.97 times a day. Users use the manual diary feature even less frequently, averaging only 0.09 entries per day per device. Of the possible total of approximately 3.5 million registered apps, only 20% actively engage with their devices. In comparison, 35% had their Bluetooth enabled during the study period.

Table 7. Indicators of app usage.

Indicator	Results
Daily scans per active device	1.97
Daily manual entries per active device	0.09
Average active use ratio	0.20
Average Bluetooth ratio	0.35

These utility ratios, however, may have changed over time. To investigate further, the cumulative app registrations, the number of user active devices, and the number of Bluetooth-enabled devices are plotted through time in Figure 3. The blue line represents the possible maximum in terms of the use of the app. The figure shows gaps between the maximum potential (blue line), the Bluetooth-enabled devices (green line), and the active devices (orange line). Although there are around 3.5 million devices with the NZ COVID Tracer app by the end of 2021, many devices are still not being used for scanning or diary entries. Also, a large number of devices did not have Bluetooth enabled.

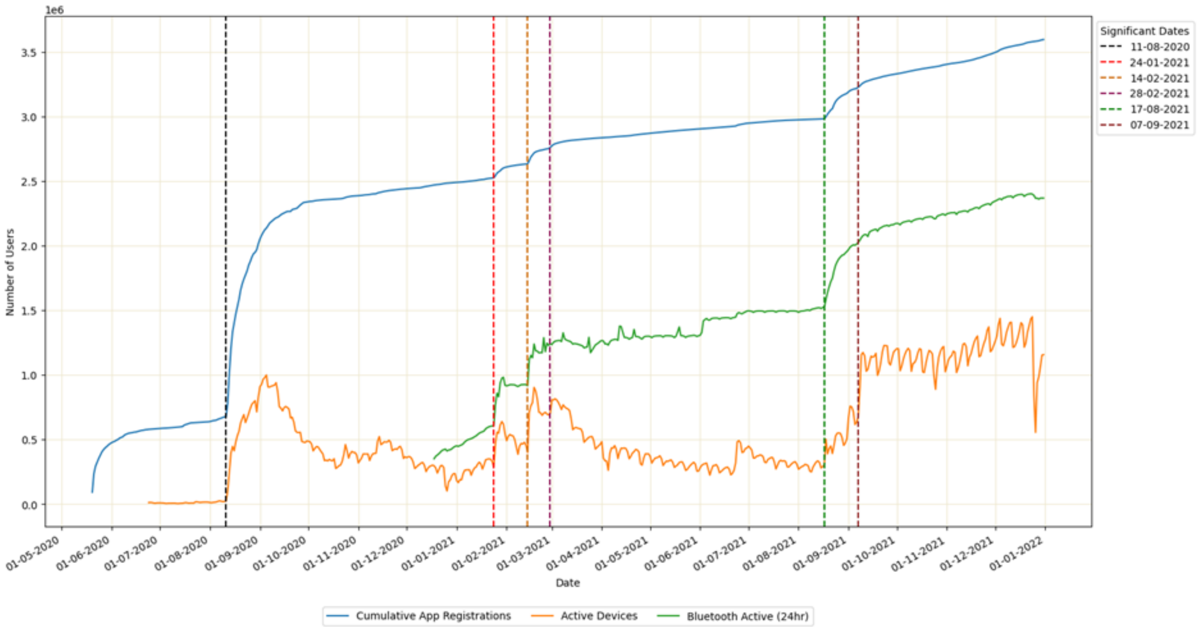

Figure 3. App utility through time. The blue line indicates the cumulative app registration through time. The orange line shows the active devices (i.e., scan or diary entry) per day. The green line portrays the Bluetooth-enabled devices per day through the study period; vertical lines indicate significant dates.

The 'active use ratio' (the active devices to cumulative registrations) and Bluetooth ratio (the number of Bluetooth-enabled devices over cumulative registrations) are plotted through time in Figure 4. The maximum value of the active ratio was attained at 0.474 on 4 Sep 2020 – the day after the Government made it compulsory for all public transport providers, including buses, trains, ferries, ride-share vehicles, and operators, to provide QR codes for passengers. After that peak, the active use ratio fluctuated but generally increased over time, especially over the later stages of 2021. The Bluetooth ratio did not fluctuate much in comparison and increased consistently over time. The Bluetooth feature seems to have a more consistent increase in use compared to the manual features of the app.

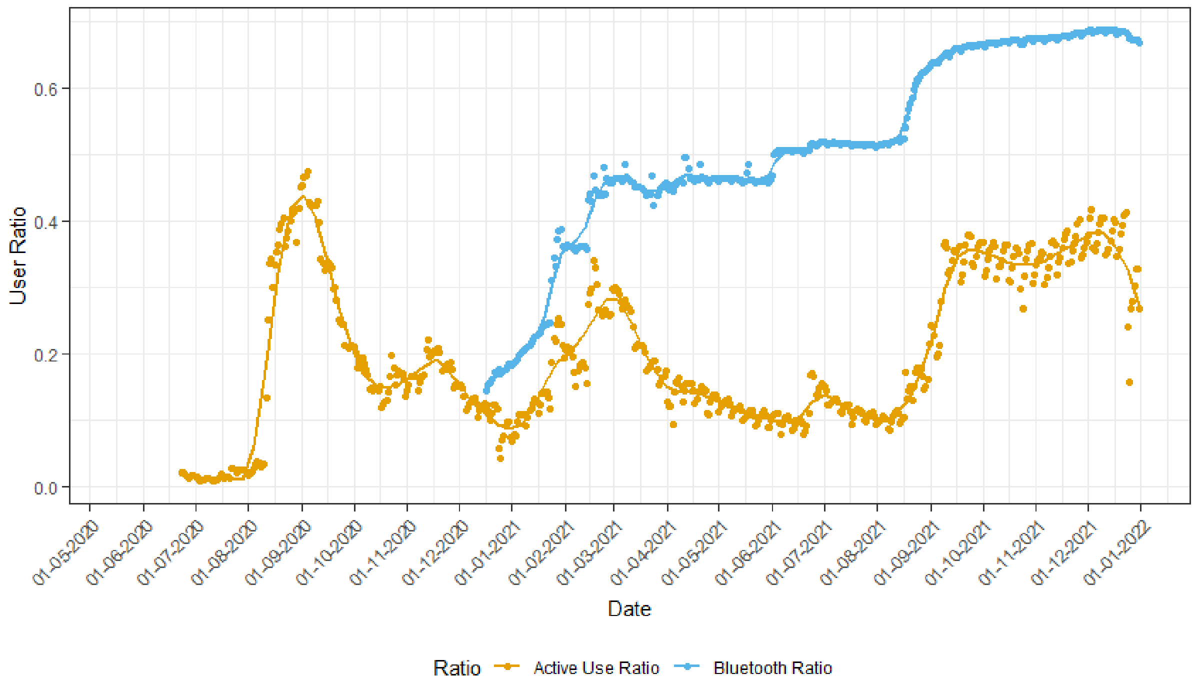

Figure 4. Active use ratio and Bluetooth ratio through time.

Sentiment analysis results

The study compares five classification models: RF, DT, KNN, MLR, and LSTM. Table 8 shows the classification results of each model, and Table 9 shows each classifier's accuracy. All these results represent how well each model performs on the testing data set.

Table 8. Classification results of RF, DT, KNN, MLR, and LSTM on performance metrics Precision (P), Recall (R), and F-measure.

	Positive			Negative			Neutral		
Model	**P**	**R**	**F**	**P**	**R**	**F**	**P**	**R**	**F**
RF	0.94	0.94	0.94	0.91	0.95	0.93	0.91	0.81	0.85
DT	0.93	0.93	0.93	0.91	0.92	0.91	0.83	0.81	0.82
KNN	0.82	0.90	0.86	0.86	0.60	0.70	0.62	0.78	0.69
MLR	0.92	0.95	0.94	0.92	0.94	0.93	0.91	0.77	0.83
LSTM	0.94	0.96	0.95	0.94	0.94	0.94	0.89	0.84	0.86

Table 9. Accuracy values obtained by each classifier.

Model	Results
RF	0.93
DT	0.91
KNN	0.79
MLR	0.92
LSTM	0.93

It can be readily seen that both RF and LSTM models performed equally well on the merged data set that consists of sentiment labels: positive, negative, and neutral in terms of accuracy (93%). From the performance metrics: Precision, Recall, and F-measure (P-R-F index), it can be seen that LSTM is more accurate in positive classification (P = 0.94, R = 0.96, F = 0.95) compared to RF (P = R = F = 0.94). Moreover, LSTM is more accurate in negative and neutral classification than RF in terms of F-measure. However, both models are almost equally accurate. Among the five classifiers, KNN has the least accuracy (79%) and the lowest P-R-F index in all three classifications. Hence, KNN does not perform well on the data set compared to the other four models. From the comparison of DT and MLR, MLR performed fairly well with an accuracy of 92% and F-measures of 0.94, 0.93, and 0.83 in positive, negative, and neutral classification, respectively. Overall, it can be concluded that both RF and LSTM models performed the best in accuracy and performance metrics. Thus, both models were used to predict the sentiments of the user reviews of the NZ COVID Tracer app.

Even though user ratings and the review's sentiment do not necessarily match (Maks & Vossen, 2013), they can be used to verify the results of the best models (RF and LSTM). Generally, a review rating of 4 or 5 indicates positive sentiment, a rating of 1 or 2 indicates negative sentiment, and a rating of 3 indicates neutral sentiment. Using this criterion, the sentiments predicted by both RF and LSTM were compared with those assigned by the user rating. This comparison validated the two models and computed the similarity between the two sentiments, where RF gave a similarity of 69.47%, and LSTM gave a similarity of 68.84%. The RF model was selected for further analysis of the sentiments, as it gives the highest similarity between the two sentiments.

Graphical methods were used to observe patterns and trends of the sentiments. Figures 5 and 6 show the changes in the proportions of three sentiments over time. These plots help to identify significant fluctuations of the sentiments (Figure 5) and can provide insight into how the perception of the app has changed during the study period (Figure 6).

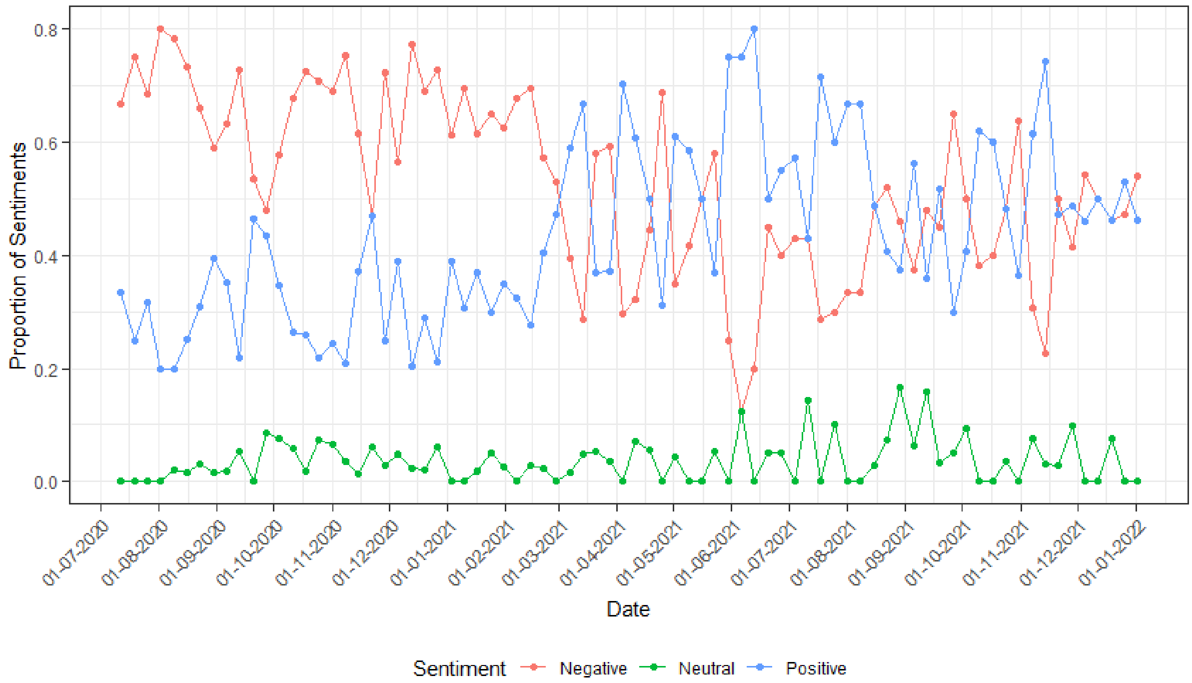

Figure 5. Weekly proportion of each sentiment.

Figure 5 plots the proportion of sentiments over a week through the study period. Proportion is calculated as the number of reviews for a sentiment category for a week divided by that week's total number of reviews. Before the first week of March 2021, the proportion of negative sentiments consistently outnumbered the proportion of positive sentiments. The week of 1 Mar 2021 shows a cross point between positive and negative sentiments; from that point, positive sentiments sometimes outweigh the negative sentiments. Fewer reviews on the week may have caused the fluctuation. However, upon investigating the history of COVID-19 events in NZ, the month of February 2021 saw numerous alert level changes in the country. On 28 Feb 2021, Auckland went into lockdown and moved back to Alert Level 3, while the rest of NZ moved to Alert Level 2. The change in sentiment may also coincide with the changing COVID-19 situation in NZ. This date was also noted in the increased app registrations, scanning, and Bluetooth use (see Figures 1, 2, and 3). In this case, the swing toward an increased proportion of positive sentiment coincides with the increased utility of the app. Future studies should investigate this relationship further to validate.

Another notable observation in Figure 5 is the increased gap between positive and negative sentiments from 25 May 2021 to June 2021. It should be noted that the Ministry of Health released the updated Version 5.0.0 of the app in May 2021. Communications on the Version 5.0.0 revealed that the update was made to make the app more useful and user-friendly; improvements included updates on the dashboard, digital diary, and Bluetooth tracing

(Ministry of Health - Manatū Hauora, 2021). The higher proportion of positive sentiments during this period may reflect how users generally supported the May 2021 app update.

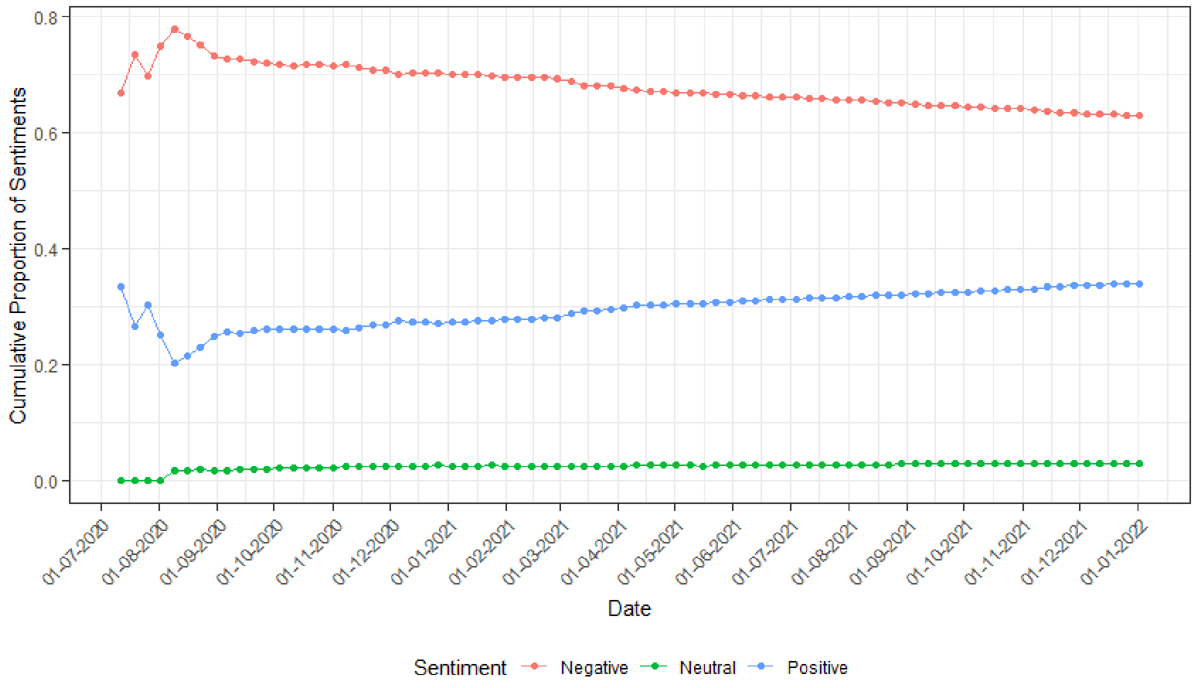

Figure 6. Cumulative proportion of each sentiment over time.

Figure 6 plots the cumulative proportion of each sentiment over time; this was conducted to investigate trends in the sentiments. Cumulative proportion is calculated as the total number of reviews for a sentiment category up to a specific date divided by the total number of reviews up to that date. Figure 6 indicates an upward trend of positive sentiments and a downward trend of negative sentiments, whereas neutral sentiments do not indicate any downward or upward trend. This implies that although the general sentiment of the user reviews is overall negative, user perception is improving over time.

DISCUSSION

The results from analysing the Ministry of Health data support the findings from Tretiakov & Hunter (2021) that app usage is affected by environmental context and the findings from Gastagier et al. (2021) that users only sometimes use the app. This study, however, provides further details on the NZ COVID Tracer app usage.

The result confirms that environmental context affects usage. However, lower alert levels do not necessarily result in a decline in usage. This study has shown that after the alert level was downgraded on 7 Sep 2021, the number of scans increased to an average of more than 2 million daily. This may be because lower alert levels mean more movement allowed for the population (from Alert Level 3 lockdown to return to business in Alert Level 2) hence an increase in the number of interactions between people and QR posters in establishments. Also, alert levels were lowered with active COVID-19 transmission still in the community. Hence there could have been an assumption of higher threat conditions which can encourage app use (Tretiakov & Hunter, 2021). This observation supports the need to utilise the concept of civic responsibility to encourage the app usage (Tretiakov & Hunter, 2021).

Manual use of the app is highly dependent on the environmental context. The active use ratio is not as high as the Bluetooth ratio, but this does not mean the manual features should be abandoned. There is good momentum in the usage of manual features as the active ratio trend is increasing through time despite fluctuations. Users should still be encouraged to interact with the app to establish trust despite limited interaction (Tan et al., 2020b). Even if apps are not regularly used, the users need to be able to interact and feel that the app is active and up-to-date or else it may result in users uninstalling the app completely (Tan et al., 2020b).

Results from this study highlight the importance of the Bluetooth feature of the app. The Bluetooth function is a passive feature that is, by default, enabled and will work in the background. Users can, however, choose to disable the Bluetooth feature. Despite being introduced later than the manual features of the app, there is a higher proportion of the registered apps that has Bluetooth enabled than active devices (i.e., users using the scan or diary feature). By the end of 2021, more than 2 million units have Bluetooth enabled, and their devices conduct virtual handshaking without the users' conscious knowledge. For contact tracing, it seems Bluetooth tracing should be utilised more, and more users should be encouraged to enable the Bluetooth feature. Bluetooth data and its utilisation for contact tracing should be investigated further.

Sentiment analysis of user reviews shows that many user reviews are either negative or positive sentiments rather than neutral sentiments. This is consistent with findings from other app store analyses, where satisfaction extremes are well represented (Hedegaard & Simonsen, 2013; Tan et al., 2020a). Because of the nature of user reviews, users tend to leave comments when they are highly satisfied or dissatisfied. The overall sentiment of the NZ COVID Tracer app is negative. However, the analysis conducted in this study looked at sentiment not just as an overarching whole but rather as the sentiments were plotted through time to observe any significant changes or trends. Extreme comments (e.g., positive or negative) may tend to dominate user reviews; hence, these are possibly ignored in understanding app performance. However, despite having a more significant proportion of negative sentiments for the NZ COVID Tracer app, plotting the sentiments' movements provided insight into specific periods of interest. It can be seen that negative sentiments are decreasing while positive sentiment is increasing, indicating sentiment is improving over time.

The findings suggest ways to help improve contact tracing by enhancing utilisation. Firstly, Bluetooth utilisation shows better consistency throughout the study period and does not depend on external events to prompt usage. Automated approaches such as Bluetooth should be prioritised, and efforts should be made to communicate and encourage people to turn the Bluetooth function on. Secondly, interaction with the app is also crucial, as observed through the sentiments over time. Improving people's positive perception of the app requires users also to be active (e.g. using QR code scanning and manual tracing). Although manual use is not as effective for contact tracing as the Bluetooth feature, as it is used less consistently, it still has its purpose as it gives users some agency over the app and may contribute to positive perceptions.

A limitation of this study is that only visual observations were analysed. Future studies can use inferential statistical methods to test for the significance of various data variables to gain further insight. Other ML and DL methods on textual data can also be used to investigate reasons for negative and positive sentiments. Future studies on machine learning can help further investigate user reviews. An area to explore is to find ways to extract usability insights for app improvements. Another limitation is that the study of this app only applies to the COVID-19 pandemic context. Further research is needed to investigate whether the utility of contact tracing apps can be used for other cases (e.g. flu or measles).

CONCLUSION

At the beginning of the paper, a research question was raised: how did the public use and perceive the app during the period from May 2020 to the end of 2021? The NZ public has high app uptake, but app utility can still improve. The number of active users (i.e., scanning and diary entry) fluctuates and is inconsistent, which may not be ideal for contact tracing. In contrast, there is a higher proportion of Bluetooth-enabled devices, and Bluetooth utility is consistently increasing over time. The consistency of the Bluetooth feature is promising as it may be more beneficial for contact tracing purposes. The sentiment analysis of the user reviews shows a higher proportion of negative sentiments on the app but, through time, showed improvement. Fluctuations favouring increased proportions of positive sentiments coincide with increased app utility in Feb-Mar 2021 and the app update in May 2021. This may imply that encouraging active use and improving usefulness will make users more satisfied with the app.

Insights from this study will be helpful as the changes in the COVID-19 pandemic continues. As of 2022, the NZ COVID Tracer app's use for the pandemic response has changed. With COVID-19 widespread in the community, the responsibility for contact tracing has moved to the people testing positive to inform their close contacts. The Government has since also dropped the mandatory scanning and displaying of QR code posters; however, the Bluetooth feature of the app is still being utilised, as alerts may still be sent out to your phone when pinged by the Bluetooth feature. Results from this study affirm the Bluetooth feature's utility but also highlight the need to understand user sentiments and how it coincides with people's active use of the app. Findings from this study show the importance of users still being encouraged to interact with the app. Even if the NZ COVID Tracer app is no longer used the same way as in 2020 and 2021, the users need to be encouraged to interact and have positive sentiments about the app. The danger is that with inactivity, users will uninstall the app entirely, which may be problematic when the NZ COVID Tracer app needs to be used for future contact tracing in response to the pandemic.

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iĀWHINA: Towards Designing an Offline Disaster Mobile Application

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ABSTRACT

The aim of this paper is to present the design stages of a built-for-purpose disaster response mobile application called iĀwhina. The authors propose to design iĀwhina as an interactive user-friendly offline mobile application that provides flawless user experience to support and aid in emergency response situations. The prototype works in both online and offline modes, using ad hoc network technology. The design process followed during the development of the user interface is based on a set of usability criteria that are presented in this paper. A systematic literature review on the usability criteria for disaster mobile applications and discussions with industry experts helped to finalize the user interface elements that will enhance the usability of the application. The relevant features that will be included in the application were drawn from literature. A discussion on how the design process plays a critical role in designing disaster mobile applications is also presented.

Keywords

UI design, User experience, Disaster mobile applications

INTRODUCTION

A disaster is defined as an extraordinary event that causes significant disruption and impact that exceeds the capacity of the available resources and the organisations to deal with (Alexander, 2002). Earthquakes, volcanic eruptions, tsunamis, pandemics, floods, and other such events are classified as disasters. The COVID19 pandemic and the 2021 volcanic eruption in Tonga are recent examples of disasters. For centuries, these events have occurred all over the world causing devastating consequences (Quarantelli et al., 2007). When a disaster strikes, people's normal lives are disrupted, and there is a desperate need for assistance, rescue, and relief for the victims of the disaster. Disasters can cause incalculable human, structural, and economic losses if not managed properly.

In recent years, there has been a surge of interest in the development of mobile applications aimed at providing aid during and after major natural disasters (Wang et al., 2018). These applications depend on Information and Communication Technology (ICT) which plays a key role in the management of any type of disasters. It facilitates efficient communication to help connect people, share information, and maintain communication between and among victims and rescuers (Andersen & Spitzberg, 2020; Pipek et al., 2014). These technologies continue to contribute significantly to disaster management through built-for-purpose disaster management mobile applications. Such disaster management apps have been developed for crowdsourcing, collaboration (among and between rescuers and victims), alerting and information, notification and collating information from various sources (Tan et al., 2017).

Despite significant increase in the number of disaster management apps, the research on their usability and user experience, and the public evaluation of their usefulness is limited. According to Tan et al. (2020) there is limited research on the user experience of such disaster mobile applications. Most of the related research focuses on the functionality of the applications. Only few researchers have examined disaster management apps from the perspective of the citizens who are the intended users (Ahmad et al., 2018). Furthermore, most of the current mobile app usability studies focus on services that are employed in non-disaster situations like mobile banking and health management (Azad-Khaneghah et al., 2021; Tan et al., 2019).

The primary objective of the research is to develop a user-friendly offline mobile phone application called (iĀwhina). 'Āwhina' means 'to assist, help, support, or benefit' in the Māori language. The 'i' in the name was introduced to connote the information and communication technology embedded in the application. iĀwhina is a collaborative built-for-purpose disaster response mobile application that will be used by the community immediately after disasters. It will be designed to enable community members to collaborate and respond in emergency situations when the communication infrastructure is either cut-off or unreliable and the availability of support services is unpredictable. The achievement of offline communication is done with a wireless ad hoc communication network. Due to the nature and the purpose of the application, the usability attributes for this application may vary from those proposed in the literature.

In this paper the design stage of the mobile application iĀwhina presented. The paper describes the process through which the researchers identified and defined the user interface elements for the application that will enhance its usability. This paper is structured as follows: It begins with a brief overview of the studies from where the user interface design elements and design principles were identified and defined. Then the methodology followed in application development and the App design is discussed. The paper ends with a discussion, conclusion, and directions for future work.

DISASTER MOBILE APPLICATIONS AND USABILITY

A well-designed disaster mobile application has the potential to improve response and recovery in a disaster situation. However, if the technologies were not adequately employed, it poses significant risks to the users of the application as it compromises the safety of the users (Büscher et al., 2016). It is important to ensure that users can effectively interact with the application even during stressful emergency situations (Sarshar et al., 2015).

Usability ensures that the mobile application assists the users in achieving their goals by making the application do what it is intended to do (Mcnamara & Kirakowski, 2006). With disaster mobile applications, usability results from designing user interface elements that allow users to receive and share critical information for efficient decision making (Sarshar et al., 2015). Usability attributes vary with different applications as the applications are developed with unique features for varying contexts. Also, usability criteria evolve continually with the rapidly changing needs of the end users and accelerated technological developments. Hence, new dimensions of usability are being continually introduced in literature (Alturki & Gay, 2019). More recently, with the increase in the number of mobile applications that serve multiple purposes, there has been significant research interests in identifying and evaluating the usability dimensions of such mobile applications.

Due to the nature and scope of various disaster management mobile apps, there is limited consensus among them on the dimensions of usability. For most of the applications, the usability guidelines were drawn from the International Organization for Standardization's (ISO) seven general principles, Nielsen's ten usability heuristics, or Shneiderman's eight golden rules. Alturki and Gay (2019) conducted a systematic literature review on usability attributes of mobile applications. They identified and summarized usability attributes from 18 published and peer-reviewed journal articles. Satisfaction, effectiveness, efficiency, learnability, simplicity, usefulness, errors, understandability, and attractiveness were frequently mentioned in these articles, together with attributes such as memorability and cognitive load. These were general guidelines for any mobile application that were developed for use.

Tan et al. (2020) proposed usability guidelines for disaster mobile apps from the end user's perspective to improve the usability of such applications. Their elaborate scoping review identified three overarching themes from literature: present information effectively; develop a non-complex interface and build trust. They also revised the wording in these themes to reflect insights on the frequency of use. The revised themes were making critical information salient, considering cognitive load when designing the interface and building trust, and anticipating the level of interaction.

From the above discussion it is evident that there is limited consensus among the researchers on the specific usability attributes that must be included in disaster management mobile applications. Also, there are limited studies that evaluate usability from the user's perspective. It is obvious that the usability dimensions vary with the scope and the purpose for which the mobile apps are developed for. Hence it is posited that the usability attributes that will enhance the user interface in iĀwhina may vary than those identified from literature. This paper elaborates on the process the researchers adopted to identify the most promising usability attributes for iĀwhina.

THE DESIGN PROCESS

The development of iĀwhina went through three stages. The first stage was to analyse relevant existing literature to identify and clarify the main features of mobile applications. In the second stage, an initial concept was developed and evaluated in an informal usability study. The feedback from the second stage was used to develop a protype that will go through a formal usability study in the third stage. The first two stages are presented in this paper. The process used to develop the iĀwhina app is illustrated in **¡Error! No se encuentra el origen de la referencia.**.

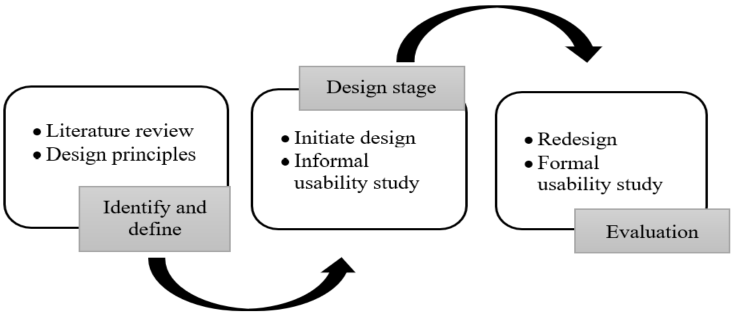

Figure 1. A graphical representation of the application development stages.

Stage one: Identify and Define

In stage one, in-depth literature review was conducted to enable a broad assessment of the studies that discussed built-for-disaster-purpose mobile applications. Even though it is contended in literature that research on new disaster technologies focus more on capabilities and functionalities than on interface issues such as usability (Tan et al., 2020; Tan et al., 2017), it is considerably harder to decide what features should be offered in the application when it is known that the victim would use the application only in emergency situations. The features identified from literature review are tabulated below (Table 1).

Table 1: Summary of Features for Disaster Mobile Applications

Feature	Explanation	Example studies
Receive disaster-related information	The user receives information from the authorities. Information may include notifications about the situation or information for raising awareness.	(Anta et al., 2021; Arslan et al., 2021a; Frigerio et al., 2018)
Share location	The application enables sharing the location of the victim. The purpose of sharing could be to rescue or collect information.	(Tan et al., 2019; Tundjungsari & Sabiq, 2017; Widagdo et al., 2021)
Broadcast information to others	The user can broadcast information to people around. The broadcasted information could be a request for help or offering help or a service.	(Fabito et al., 2016; Sciullo et al., 2018; Tundjungsari & Sabiq, 2017)
Rescue support	The application can assist rescue operations with algorithms or smart phone capabilities.	(Berawi et al., 2021; Han & Han, 2018; Ludwig et al., 2014)
Send SOS	The application contains a button that is specifically included to send requests for help.	(Gupta & Katarya, 2020; Mody et al., 2020)
Geo-fence	The application creates a local network around the victim to create a small community.	(Gupta & Katarya, 2020; Mody et al., 2020)
Communicate offline	The application offers the ability to communicate even when there is no cellular network.	(Balaji et al., 2017; Gunaratna et al., 2015; Tundjungsari & Sabiq, 2017)
Show safe routes	The application considers data collected during the disaster to show safe routes for users to follow.	(Hyoungseong et al., 2015; Tundjungsari & Sabiq, 2017)

Voice-call	Users can make voice calls using the application when the cellular network is down.	(Gunaratna et al., 2015)
Show disaster/safe zones	The application shows safe and dangerous zones for the user.	(Adeel et al., 2019; Arslan et al., 2021b; Auferbauer et al., 2015; Erdelj et al., 2017)

Few other features such as chatting, sharing location, reporting to authorities, supporting rescue operations, Real-time updating of disaster information were also identified (Arslan et al., 2021a, 2021b; Oganiza et al., 2019; Sukhwani & Shaw, 2020; Tundjungsari & Sabiq, 2017)

More recently, disaster mobile applications use offline communication technologies that use ad hoc networks to communicate between devices, even when the communication infrastructure is unreliable/completely cut off. Regarding offline communication, the review indicated that Wi-Fi technology is the most established and commonly used technology that enabled offline communication in disaster applications. Wi-Fi is a group of wireless network protocols built on the IEEE 802.11 family of standards. These protocols are frequently used for Internet access and local area networking of devices, allowing nearby digital devices to communicate via radio waves. These are the most widely used computer networks in the world. They are used in home and small office networks to connect desktop and laptop computers, tablet computers, smartphones, smart TVs, printers, and smart speakers through a wireless router to connect them to the Internet. This network technology also provides wireless access points in public locations like coffee shops, hotels, libraries, and airports to provide the public Internet access for mobile devices.

Stage two: Design Stage

Two primary questions guided the design stage: What are the suitable user interface design elements that can be used to develop a mobile application that will connect the community in a catastrophic disaster situation? And how to enable ordinary citizens in the community to provide and receive support/help from each other immediately after the disaster? The support/help offered will be sharing or offering food, medicines, psychological support, and the like.

Based on the overarching themes on usability guidelines that emerged from the literature review, an informal usability inquiry through a focused group discussion with 4 participants (three men and one woman aged 28, 30,40 and 43 years) was conducted to gather information on the target users' preferences of the usability attributes that could be included in the application. All participants were invited to the session in person to discuss the features and the design attributes. This provided an understanding of the design elements to include in the initial design of the application. The initial finding was that there are functional concerns due to the lack of functional clarity on what to do and the participants were unsure of how to request or accept support. They also requested a conversation function between the victims and the rescuers and emphasized on user-friendliness as an important criterion.

The concept behind the application was also informally discussed with two industry experts. They work in a well-known design agency in Wellington, New Zealand, as user experience designers and have a combined experience of more than 20 years between them. In the meeting, the main pages to be included in the App and ways to improve user experience was discussed. The experts emphasized on the simplicity of design, user trust in the application and flexibility of design as key attributes.

The information obtained through these processes guided the researchers to propose the initial user flows, including the main tasks and the user events. Each element was evaluated and ranked to reduce the risk of overflowing the screen.

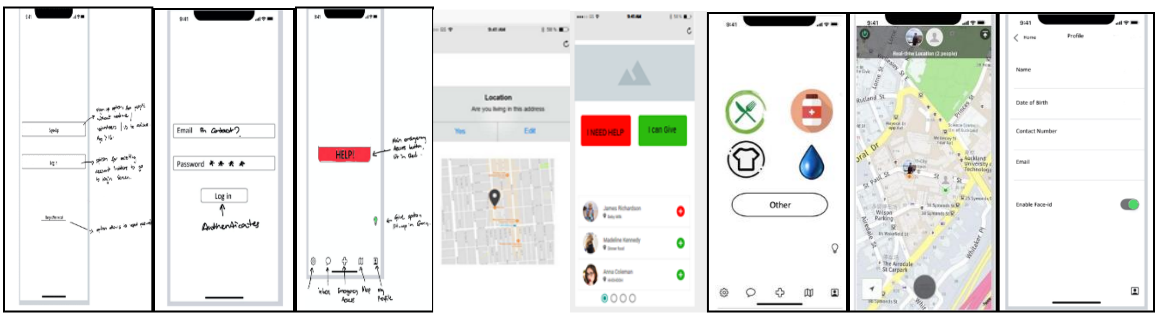

Figure 2: the initial design created for the medium-fidelity prototype.

The wireframes were then created using lean UX design. First prototype was designed using Figma, and the first version of the wireframe is shown in figure 2. Another version of the wireframe was reconstructed after using stamp and Emotes feature by Figma as shown in figure 3. This allowed the participants to evaluate the design and the user flow using 8 inspect elements. Visual feedback worked well for both real-time and asynchronous collaboration, allowing to vote among several concepts and receive feedback from both the researchers and the designers.

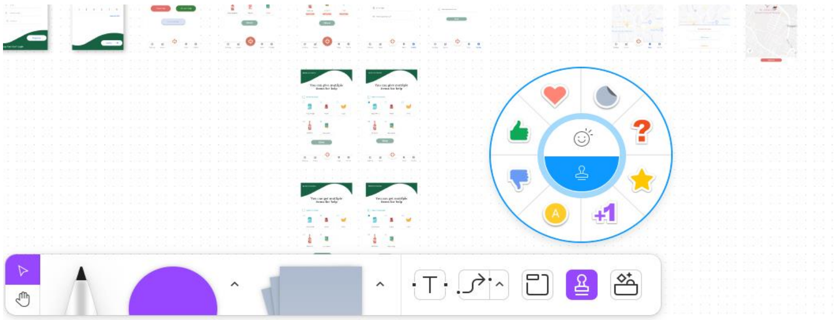

Figure 3: Stamp and Emotes Figma Features.

The third version has 8 main pages. In Page 1, the Splash Screen, Registration, and Login Screen are first seen by users who download the App and log in for the first time. The application allows the user to sign up or log in or to reset passwords if they already have an account. The log-in screen will not appear for users who have already signed in. In page 2, the Main Screen provides the user functionalities. The main feature in this page is seeking or providing help, along with settings, inbox, emergency access, map, and profile tabs. In page 3, Location Detection Screen will appear for first-time users to verify the user location, which is critical in this application. In page 4, the Help Screen 1. Clicking on the help button takes the user to give or request for help. In pages 5 and 6, Help Screen 2, clicking on the help button takes the user to a screen with graphical illustrations where they can easily identify their needs, which in turn sends a request to a helper. In page 7, the Map Screen is displayed to a ‘helper’ to provide the location of the emergency service required. It is also displayed to the person seeking help so they could view where their helper is located. In page 8, the Profile Screen contains details of the users such as name, DOB, phone number and email address. These details can be updated by the user as required.

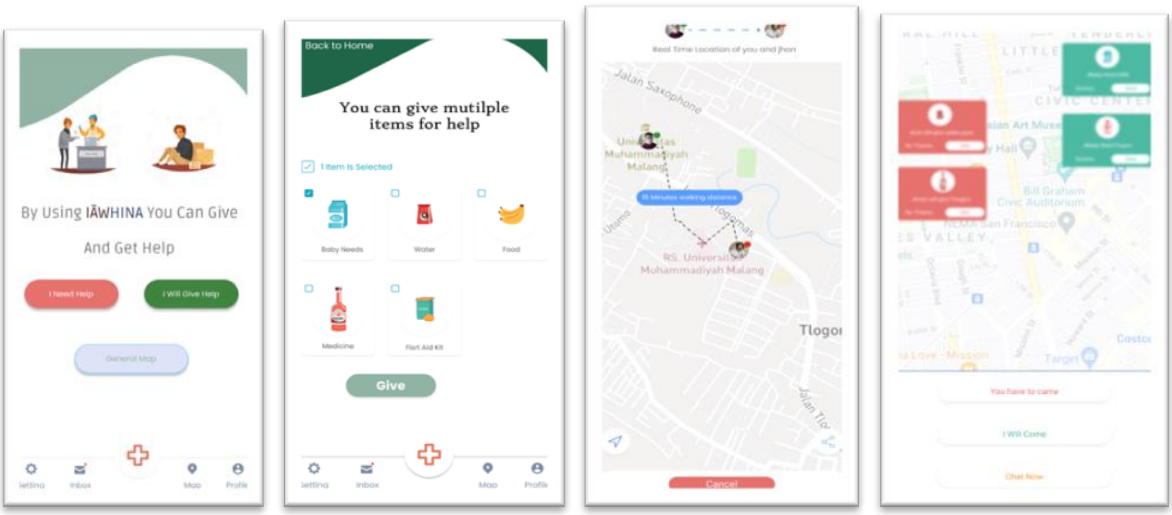

Figure 4: Example of iĀWHINA final draft pages.

Stage 3: Evaluation

This stage is in progress. A formal usability study with a sample of new users will be conducted to fine-tune the design elements to enhance the usability of the application. The goal is to conduct semi-structured interviews with 18 individual users. Ethics approval has been obtained to conduct the study.

CONCLUSIONS AND FUTURE WORKS

With the development of the App, we hope to equip the community with an offline tool that can facilitate communication among members in a neighborhood, enabling them to support each other until the arrival of emergency support services and/or the restoration of the communication infrastructure. Hence, this application helps in the response phase of the disaster management cycle.

Like most of the other studies related to built-for-disaster-purpose applications, the importance of functionality for an application is recognized in this study. This study also highlighted the need to align functionality with an uncompromising focus on usability. Enhanced usability of disaster management mobile applications certainly leads to saving lives and reducing costs. Therefore, designing such an application should be user-centered and should provide a satisfactory user experience.

Among the many usability principles reviewed, it was concluded that reducing cognitive load, increasing learnability, user friendliness and enabling effective information delivery were the most prominent usability principles for mobile applications in the context of disasters. Through iĀwhina users have the fastest way to get or provide help/support. This makes sense in a disaster situation where users panic and are desperate to survive. Therefore, a minimalist user interface is recommended for such applications. In terms of features, reverting to the most basic communication features is essential. A simple feature such as enabling an SOS call makes a big difference. However, the most significant feature that must be in the application is the ability to work in an offline mode. Users wanted a reliable application with less fancy features. The Wi-Fi protocol is a promising technology that could be used to provide offline communication when communication networks are unreliable/interrupted.

Future work concerns implementing the recommendations that were obtained from this study. Further usability tests will be conducted, and the App fine-tuned before it is published in Android and/or iOS operating systems. The published application will serve as a valuable research tool to understand how to build effective communication systems during disasters. Finally, in relation to the application itself, further work is needed on accessibility features of the application. The application could be extended to include an efficient user interface for adults with physical and mental limitations.

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A Peer-to-Peer Communication Method for Distributed Earthquake Early Warning Networks: Preliminary Findings

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ABSTRACT

This work-in-progress paper presents preliminary findings of ongoing research into alternative peer-to-peer (P2P) communication methods for earthquake early warning (EEW) systems. It expands upon previous work (Prasanna et al., 2022) that explores a network architecture for a decentralised EEW system. This paper explores using Quick UDP Internet Connections (QUIC) over a hole-punched UDP tunnel as a potential alternative to a Software-Defined Wide Area Network (SD-WAN) for peer-to-peer networking in an experimental EEW network architecture. The performance of QUIC is tested and compared to TCP over ZeroTier, an SD-WAN chosen as a P2P communication method in the previous work, over a realistic network topology. The results show that QUIC can outperform TCP over ZeroTier. Future work is needed to produce a method suitable for actual use in an EEW system. This paper contributes to the EEW literature by introducing a new method of communication tailored for EEW.

Keywords

Earthquake Early Warning, QUIC, Peer-to-peer, Decentralised

BACKGROUND

Earthquake early warning (EEW) systems are designed to rapidly disseminate warnings of impending earthquakes to allow people and infrastructure to take protective measures (Strauss & Allen, 2016). Traditional centralised EEW systems typically consist of a network of sensors that detect the first signs of an earthquake, called the primary wave, and a series of computer algorithms that use the sensor data to estimate the location, magnitude, and arrival time of the main shock wave (Yih-Min, Kanamori, Allen, & Hauksson, 2007). The warnings are then disseminated to the public through various channels, such as sirens, smartphones, and radio broadcasts.

The effectiveness of EEW systems depends on the timely delivery of warnings to the people and infrastructure that are at risk (Grasso, Beck, & Manfredi, 2007). EEW systems must have a robust and reliable communication network to achieve this. The traditional communication paradigm for EEW systems is a client-server architecture, in which sensors send data to a central server, and the server then disseminates warnings to the public (Böse et al., 2014; Brooks et al., 2021). However, this paradigm can create significant bottlenecks and limitations (Prasanna et al., 2022).

This paper presents preliminary findings of research into an alternative peer-to-peer (P2P) communication method for earthquake early warning (EEW) systems. P2P communication has several advantages over traditional communication paradigms, such as being more resilient to infrastructure damage because there is no single point of failure and better performance because the connection is more direct without a server in the middle (Fleming et al., 2009). However, P2P communication also has challenges, such as the need for a reliable discovery mechanism and some networks preventing connections from being established (Ford, Srisuresh, & Kegel, 2005). This paper expands upon previous work exploring an experimental Earthquake Early Warning network architecture (Prasanna et al., 2022) that uses a distributed peer-to-peer sensor network for EEW.

In the previous work (Prasanna et al., 2022), a decentralised EEW network architecture consisting of Internet of Things (IoT) seismometers hosted by the public was proposed as an alternative to the traditional centralised EEW networks. It is designed to be resilient during disasters due to its decentralised nature and be highly scalable while maintaining high-performance capabilities. In this architecture, an extensive network of sensors communicates using a Software Defined Wide Area Network (SD-WAN), ZeroTier. It uses a two-station trigger concept to decrease false positives and increase accuracy. Each sensor connects to others within a 30km radius. When a sensor detects sufficient ground motion, it will notify the connected sensors, and if the other sensor also detects sufficient ground motion, an alert will be issued.

Using the ZeroTier P2P-VPN raised some concerns. ZeroTier is a commercial solution, and, as such, it has associated fees. It also, by default, allows network members unfiltered communication with each other, which can lead to security concerns, although this can be mitigated using flow rules (ZeroTier). Because individual members of the general public host sensors, it is not impossible for someone to attempt to gain control of individual sensors and launch attacks across the network. Further, complications could arise during deployment when organisations are hesitant to allow another VPN into their internal networks. Therefore, as one of the ongoing research activities on a community-engaged low-cost EEW network, this work-in-progress paper investigates an open-access and free-to-use method for peer-to-peer communications as a potential alternative to a Software Defined Wide Area Network (SD-WAN).

METHOD

Peer-to-peer communication without needing to pass through a centralised server is ideal for the resiliency and performance advantages mentioned in the background. Hole punching is an established simple and effective method for establishing peer-to-peer communication between computers on the internet. Peers connect to a public server, exchange their public IP addresses and ports, and connect peer-to-peer with this information. Previous research found that 82% of networks support UDP hole punching, while 64% support TCP (Ford et al., 2005). In order to maximise direct peer-to-peer communication, the explored method uses UDP hole punching. There is, however, a risk of losing packets that come with UDP and a lack of encryption and security.

Missed alerts due to lost packets mean the EEW will not protect some people, so retransmission of lost packets is essential. Sending out false alarms can impact the credibility of the issuing organisation and reduce the effectiveness of future alarms, so it is essential to lower the risk of false alarms (Grasso et al., 2007; Simmons & Sutter, 2009). Therefore, the possibility of malicious actors impersonating sensors and sending out false notifications of ground motion should be minimised by authenticating them. In this particular scenario, only the sensor sending the notification needs to be authenticated, so security can be improved by using existing client-server technologies such as HTTP, where the server authenticates using Public Key Infrastructure (PKI).

Looking into HTTP leads us to Quick UDP Internet Connections (QUIC), a new transport protocol designed by Google, which is the base for HTTP/3. QUIC uses UDP as its underlying transport layer and provides many benefits over TCP, such as reduced latency, improved security, and better congestion control (Roskind, 2012). Features of interest for this scenario are the use of UDP, the ability to reliably transmit data in order, and the built-in Public Key Infrastructure (PKI) based encryption, providing authentication. Combining UDP hole punching with QUIC achieves a free, encrypted, low latency, and reliable peer-to-peer connection.

IMPLEMENTATION

Performance/latency is a significant consideration when comparing the different networking solutions, as it directly affects the detection time and human safety (Prasanna et al., 2022). In order to compare the latency of this solution to the chosen solution in the previous work (Prasanna et al., 2022), we recreate a test used in the previous work. This test involves using a small group of Raspberry Shake ground motion sensors connected to the internet and running the solutions to be compared in parallel and measuring the latency. For this test, a proof-of-concept implementation of the explored solution was put together in Node.js using the WebTransport library and compared with TCP over ZeroTier. Over 6 hours, pings were sent out every 10 seconds, and the round-trip time was recorded. The sensors used in the original test could not be accessed, so to maintain consistency and have a fair comparison, a new group of sensors was selected in positions as close as possible to those used in the Wellington region in the previous test. A total of 5 sensors were part of the test and are shown in Figure 1.

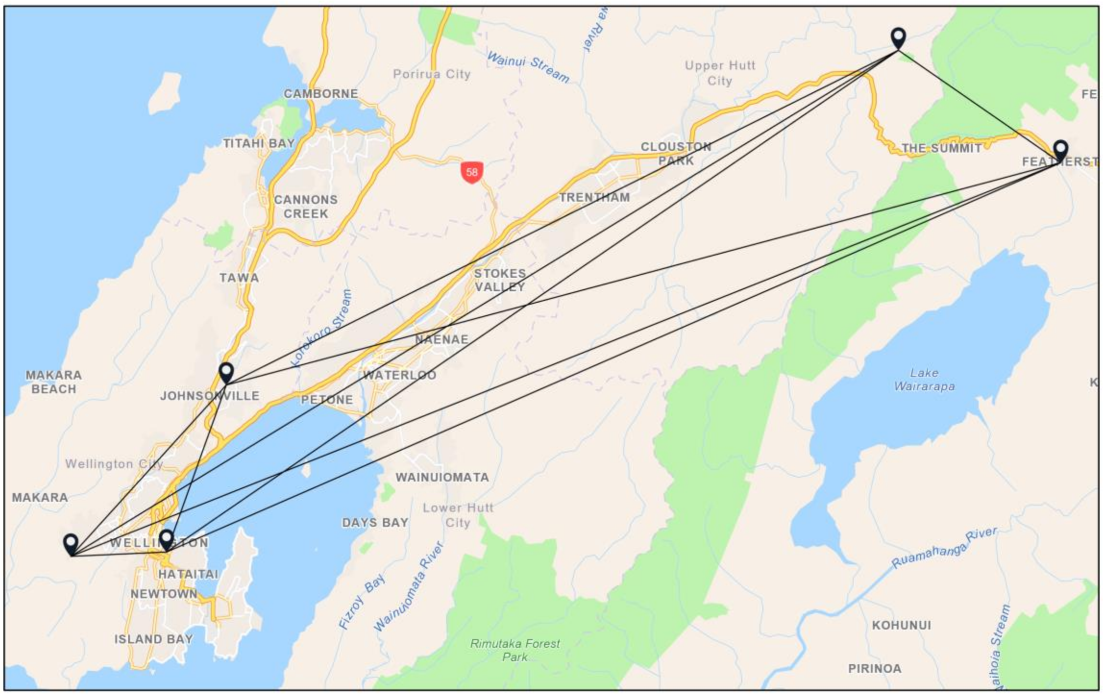

Figure 1. Sensors used in the test

Because only latency is being tested, the test can be simplified. Instead of testing with simulated ground motion data like in the previous work, it is sufficient to simply run a ping server. This simplification significantly reduced the complexity of the codebase and simplified the testing procedures.

Implementation findings

For future proofing and ease of use, the implementation is split into two modular components: the router and the application. The router is responsible for the peer-to-peer communication and forwards packets to the application. The application handles encryption, authentication and business logic and can be implemented similarly to a regular QUIC application using any QUIC library. This means that programs such as the EEW software can implement the application using its native languages' existing APIs and libraries, significantly decreasing the work needed to integrate this method into existing projects.

The Router

To initiate peer-to-peer communication, a practice known as signalling is used to allow peers to find each other. This involves a server with a public IP address and two peers. This process includes NAT traversal, so peers behind a NAT will be able to communicate.

First, both peers send a UDP packet to a public server, and then the server replies with the address of the other peer. Once each peer has the address of the other, they each send a packet to the other. When both peers receive replies from the other peer, the connection is considered successful, and the application can start sending data. The public server is similar to a Session Traversal Utilities for NAT (STUN) server (Rosenberg, Mahy, Matthews, & Wing, 2008).

For each incoming address, a new local UDP client with a unique address is created and used to forward only packets from the incoming address, so each peer still appears to have a unique address, and the application can treat it as a regular client. Because the router emulates a regular UDP client, the router should be compatible with most UDP-based protocols.

The Application

The application interfaces with the router and performs business logic such as authentication and earthquake alerts. For this proof of concept, it is a simple echo server for testing performance.

This application uses Public Key Infrastructure (PKI) to authenticate sensors. A Certificate Authority is set up to issue certificates to each sensor and is installed on every sensor so they can verify other sensors' certificates. Sensors use these certificates to authenticate with a TLS handshake when a QUIC connection is initiated. In an EEW system, the sensor which is the source of alerts is the server and presents the certificate. This way, each alert can be verified to be from the claimed sensor. Mutual TLS (mTLS) can also be enabled, but it was deemed unnecessary because of the public nature of earthquake alerts and how it does not have any runtime performance impact, so test results without mTLS are still applicable to it.

On an incoming connection, the application initiates a bidirectional stream and immediately returns received data. The application creates connections to other sensors, sends the message "ping" every 10 seconds, and times how long it takes for the reply to arrive back.

When the application wants to create a tunnel, it sends a message to the router containing the peer ID, and the router will communicate with the public server to find the peer, hole punch to get a peer-to-peer communication, and then open a local port that the application can communicate with as though it were the peer application.

RESULTS

Raw ping times were collected from the sensors in the test and loaded into Microsoft Excel. For each connection between two sensors and for each connection type, the median and 90th percentile round trip time was calculated. The median time shows average performance, but the 90th percentile is also important because even a few slower messages can slow down detection time. The difference between the median and 90th percentile is shown to help in comparison.

Each connection yielded ~2,000 ping measurements over six hours. For all ten connection pairs possible in a group of five sensors, this results in ~20,000 pings for each connection type and ~40,000 pings in total. The results are shown in Table 1.

Table 1. Comparison of Round Trip Time (milliseconds)

Peers	ZeroTier Median	ZeroTier 90th Percentile	QUIC Median	QUIC 90th Percentile	Median Delta	90th Percentile Delta
1 - 2	52	113	48	59	-4	-54
1 - 3	26	79	30	32	4	-47
1 - 4	22	85	25	28	3	-57
1 - 5	10	66	13	17	3	-49
2 - 3	69	130	63	76	-6	-54
2 - 4	68	150	59	74	-9	-76
2 - 5	51	118	54	64	3	-54
3 - 4	26	79	29	32	3	-47
3 - 5	27	80	31	34	4	-46
4 - 5	17	74	20	26	3	-48
Average	**36.8**	**97.4**	**37.2**	**44.2**	**0.4**	**-53.2**

The results show that the median time across all sensors is similar; the average median time for QUIC is 0.4 milliseconds higher than ZeroTier. However, the average 90th percentile time is significantly lower for QUIC compared to ZeroTier: 44.2 and 97.4, respectively. QUIC has almost half the 90th percentile latency, indicating that QUIC latency is more consistently lower. Therefore, it can be said that QUIC outperforms TCP over ZeroTier.

LIMITATIONS AND FUTURE WORK

The findings found that using QUIC over hole-punched UDP appears to be a viable method for peer-to-peer communication in an EEW context. More work still needs to be done to get an implementation capable of actual use in an EEW. A significant limitation in the explored method is that there are no fallback mechanisms if a sensor cannot establish connectivity in environments that do not allow UDP Hole Punching, like a symmetric NAT. Future work aims to resolve this by implementing a relay running on a publicly exposed server, similar to a TURN server (Rosenberg et al., 2008), which sensors that cannot communicate peer to peer may use as a proxy.

A limitation in the test conducted is that the throughput of QUIC over hole-punched UDP is not tested. This was done because, in the architecture proposed in (Prasanna et al., 2022), communication between peers consists solely of single packet notifications of ground motion, so very little bandwidth is required. If bandwidth were to be tested, the results should be consistent with other comparisons between QUIC and TCP and show that QUIC supports a higher throughput (Soni & Rajput, 2021).

Additional improvements can also be made. In the explored method, clients still rely on a centralised server for initiating connections, which could be a problem as this is a single point of failure. A possible solution is using Universal Plug and Play Internet Gateway Device (UPnP IGD) to allow sensors already part of the peer-to-peer network to act as the public servers, as described in the implementation section. This is possible because it allows the sensor to request a public port to be forwarded to it by the router, essentially removing the complications in P2P communication introduced by a NAT (Boucadair, Penno, & Wing, 2013). This decentralises the connection initiation process and makes the system much more resilient in disasters, as sensors attempting to reconnect after a telecommunications fault only need to reach one other sensor to join the network. This also solves the issue of maintaining low latency when UDP Hole Punching is impossible, as the relay server can be one of these sensors acting as a public server, which would be much closer than a cloud server. Future works also include adding compatibility with LoRa, a radio communication technique to allow running the network independent from the internet.

CONCLUSION

This paper introduced a new method of peer-to-peer communication designed with a decentralised EEW system in mind: QUIC over Hole Punched UDP. The latency of a proof-of-concept implementation of this is compared with a peer-to-peer method chosen in previous work (Prasanna et al., 2022), TCP over ZeroTier, and the results show that QUIC over Hole Punched UDP outperforms TCP over ZeroTier.

Both approaches are similar, using UDP hole-punching as the underlying technology, but QUIC over Hole Punched UDP has several advantages, mainly that it is free and open access and has lower latency than ZeroTier. Though more work is still needed until it is suitable for actual use, QUIC over Hole Punched UDP has the potential to be a better method for peer-to-peer communication in an EEW system than TCP over ZeroTier.

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Understanding and Improving Collaboration in Emergency Simulations with a Local Chain of Survival

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ABSTRACT

Out-of-hospital cardiac arrest (OHCA) and choking are two emergencies where the rapid action of a bystander can increase the victim's chances of survival. Few bystanders act because they are not aware of their role as the first link in the chain of survival. Working on collaboration among a local chain of survival and using applications to improve communication and provide tutorials of actions to perform can be used to overcome this issue. We investigate these elements in the context of the Geneva Chain of Survival using simulations. The results show that an optimal collaboration means a lead's handover between the intervening parties. Collaboration can be degraded by problems of communication, panic[1], and confusion. Applications constitute a valuable addition to enhance the dispatcher's awareness and to help guide the CPR while not extending the intervention time. Finally, the debriefing that follows enables the acquisition of competencies through experiential learning that relies on emotions.

Keywords

Chain of survival, collaboration, bystander, dispatcher, app

INTRODUCTION

Early action is essential for the survival of a victim in an emergency, notably in the case of cardiac arrest or foreign body airway obstruction. Every year in Europe, at least 343,496 people suffer cardiac arrest outside the hospital (Empana et al., 2022). Among these victims, only about 10% survive (Gräsner et al., 2020). Public health authorities and associations have been trying to improve this rate for several years by promoting measures to be carried out, as training citizens in first aid, prevention and deployment of semi-automatic defibrillators. From 2015 onwards, guidelines have introduced digital applications as a resource to call first responders to perform first aids gestures before the arrival of the rescue team (Wyckoff et al., 2021; Perkins et al., 2015). Recommendations also insist on the importance of integrating bystanders on the rescue team (Mentzelopoulos et al., 2021). The issue is to further implicate bystanders into a local system of rescue and improve the collaboration between the different interveners. Our research is carried out in a multi-partner context (academic, private and public) financed by a French foundation that aims to promote prevention amongst citizens. In this research, the goal was to work with local community actors within a geographical area. Our focus was on the community of Geneva involving the dispatch center, Geneva Save a Life first responders and paramedics as well as citizens living in the city.

[1] The term panic is used to refer to the inability of the bystander to take appropriate action because they perceive 1) an immediate threat to themselves or others, 2) the belief that they cannot get out of the situation, and most importantly, 3) the feeling of helplessness in dealing with the situation, especially in situations where others are not perceived as being able to help (Gantt & Gantt, 2012). This panic translates into a strong sense of anxiety.

STATE OF THE ART

The chain of survival

The Chain of Survival model was created by Nolan (Nolan et al., 2006) in order to explain the required steps to achieve greater rate of survival of cardiac arrest victims. This model has been taken up in the form of recommendations (Figure 1) by the European Resuscitation Council (Perkins et al., 2015).

The model identifies four steps in the treatment of an OHCA victim, early recognition and call for help, early cardiac massage, early defibrillation and post-resuscitation care. The first three steps may be performed by the witness (called a bystander) and the fourth by the paramedic team. Many more parties are involved; the dispatcher in the emergency control center, potential other bystanders and eventually first responders. All these interveners have to collaborate (Deakin, 2018). According to Linderoth et al (2015), the links in the chain should be thought as teams and bystander and dispatcher would be "the first resuscitation team". However, even before calling the dispatcher, several elements could already change the bystanders’ intention to act or not.

Figure 1: Chain of survival (European Council Guidelines for Resuscitation, 2015)

Components affecting the bystander behavior

Less than a third of all bystanders start cardiac resuscitation on their own (Takei et al., 2014). Two elements can explained this phenomenon (Dobbie et al., 2018; Malta Hansen et al., 2017):

- Their level of knowledge, of the gestures to be performed (23% of the bystanders who have not been trained are confident to perform CPR against 72% of those trained) and of their awareness that their intervention is vital and cannot harm the victim.
- The number of bystanders on the scene; a bystander alone will be more likely to act than when surrounded by others, due to the “bystander effect” and the dilution of responsibility (Fischer et al., 2011) or due to the difficulty of managing other panicked bystanders (Malta Hansen et al., 2017).

Challenges in bystander / dispatcher interaction

The second link in the chain concerns early resuscitation. The dispatcher is considered the central actor for initiating this action (Harjanto et al., 2016). According to the research on emergency management, the assessment is often seen as challenging due to the difficulties in obtaining complete and adequate information from the bystander (Van den Homberg et al., 2018; Bharosa et al., 2010). The bystander has to become the eyes of the dispatcher and provide relevant information. However he/she is not always near the victim, nor is he/she fully aware of the urgency of the victim's situation (Linderoth et al., 2015) neither is he/she familiar with the pertinent information to share (Bird et al., 2020; Reuter et al., 2016; McLennan et al., 2016). Additionally, communication and language barriers (up to 30% of difficulties according to Case et al. (2018)) can cause delays.

When cardiac arrest is recognized, the dispatcher may attempt to perform cardiopulmonary resuscitation. While in one survey 82% of bystanders stated they were willing to perform CPR if guided by a dispatcher (Dobbie et al., 2018), in reality the rate of Bystander-CPR deliveries is at least halved (Valeriano et al., 2021). Two factors were identified by Case et al. (2018). The first one is the lack of CPR knowledge resulting in a lack of skills (81% of responders) and a lack of "perceived benefits" (28%) i.e. in their opinion the victim has already died and their action would be useless. The second factor, referred to as "personal factors", concerns the physical capacity to perform the massage (physical inability of the bystander (45%) or positioning of the victim (31%)) and the emotional capacity (20% mentions the possibility of panic).

Collaboration between others interveners

Although studies have shown that citizens are often perceived as a nuisance by health care professionals (Bird et al., 2020; Scanlon et al., 2014), a study in Denmark showed that 67.9% of emergency physicians perceived the assistance of citizen responders as useful and that 84.9% were satisfied with the cardiac massage performed (Jellestad et al., 2021). The study also showed that paramedics often asked citizens to continue massaging when they arrived, showing that they trust them. This trust probably results from the success of the interventions of first responders, citizens trained in first aid, who are alerted in case of vital emergencies including cardiac arrest via applications such as Save a Life (Switzerland), GoodSam Alerter (UK) or Staying Alive (France)(Valeriano et al., 2021). Their early intervention on OHCAs has increased the survival rate of victims to 35% (Derkenne et al., 2020). Therefore, technological solutions can improve the management of an emergency by adding a link to the chain of survival. We will look now at technological solutions available to assist the initial bystander-dispatcher link.

The technological resources to help collaboration between bystanders and dispatchers

Two types of technologies are currently being developed, applications designed to give awareness to the dispatcher by giving him access to a visual feedback via the bystander smartphone and applications dedicated to the bystander allowing him to follow demonstration of first's aids gestures send by the dispatcher. Video feedback is becoming more and more widespread and has shown benefits especially for the evaluation of the patient's condition (Linderoth et al., 2019, 2015). According to a study on GoodSam (Linderoth et al., 2021), it is perceived as useful by 88.6% of dispatchers and has been reliable, with 82.2% of attempts working. This study specifies that video should only be used under certain conditions; at least two bystanders and a condition difficult to assess (e.g. pediatric). One criticism of this video app is that it takes longer than usual[2] to deal with the situation, even with a cooperating bystander. Another option is the transmission of a demonstration video of emergency procedures that need to be accomplished by the bystander. Several studies have shown that it increase the rate of bystander CPR (Lee et al., 2020) and improve its quality (Lin et al., 2018; Stipulante et al., 2016; Bobrow et al., 2011).The two can be combined since visual feedback is also useful in guiding cardiac massage (Linderoth et al., 2021).

Experiential learning to construct improve memory retention

A second way to improve the rate of CPR bystander in a community is to train them in a situation that enhances acquisition and skills retention (Yu et al., 2020). Research has demonstrated that the regular way to learn in BLS leads to an oblivion of the skills after 6 months. Therefore, even when the course is mandatory, as in Switzerland to obtain a driver's license, the benefits are short-lived. Kolb (2014) suggests that it may be worth considering experiential learning as a means to improve retention. Experiential learning is described as learning by being actively engaged in the process, playing a role and experiencing events both cognitively and emotionally. The more intensive the emotion is, the more it can have an effect on the retention. In order to create a realistic testing ground that can elicit these emotions, simulation can be implemented (Gerhold et al., 2020; Mentler et al., 2017). To reinforce the realism of the simulations, it is even more interesting to have access to real professionals (Meischke et al., 2017) and to gradually integrate them into the real-time handling of the "victim" by a bystander (seeking help from other bystander, calling the emergency department, using the defibrillator, and being reached by the paramedics). The aim is to provide the most similar experience of the real activity (Linderoth et al., 2015). Finally, allowing time for discussion and shared reflection as a training team has shown positive effects on skill learning (Cheng et al., 2018; Rumsfeld et al., 2016).

Few literature reports experimentation integrating the complete survival chain in the same experience while several authors underline the importance of collaboration between each link of this chain. Therefore, the purpose of this paper is to understand the obstacles and facilitators of the collaboration within a local survival chain as well as to document how the Living-Lab process could increase this collaboration.

METHODS

The aim of this research is to study the collaboration within a local survival chain, with its specific characteristics and stakeholders, to investigate the impact of digital applications on patient care in this setting as well as to determine the relevance of a collective method allowing experiential learning.

[2] The median time to recognize a cardiac arrest is 1 to 3 minutes and 3 to 5 minutes to perform CPR from the time the dispatcher answer the call (Syväoja, 2019)

Research question

RQ1: Which components influence collaboration in the chain of survival during the handling of a victim of a vital emergency?

Research suggests that collaborative work can be affected at several levels depending on the various links (Bystander/dispatcher; firsts responders/paramédics). Our intention is to examine these different "teams" and the effect on overall collaboration and patient outcome.

RQ2: How does the use of one or more applications affect the treatment of victims?

We seek to analyze 3 points; the reliability of the applications and the duration of the interventions, the effect of a single application (feedback video / demonstration video) and of combined applications to deepens the understanding on when it is beneficial to use these apps and when it is not suitable.

RQ3: Is experiential learning supported by the simulation / debriefing approach?

Initially, we will examine whether the simulations trigger intense emotions among the participants and if sharing them with the stakeholders provides a deeper immersive feeling. Next, we will investigate the effectiveness of debriefing as a means of learning.

Field of experimentation; HUG 144 Health Emergencies center

The 144 Health Emergencies Center is a unit of the Geneva University Hospitals (HUG). The unit responded to 126,000 emergency calls in 2020. In Switzerland, the 144 number is only dedicated to medical emergencies and the dispatchers are either nurses or paramedics who completed a 6-month training as dispatchers. In each center, there is also one or more physicians. The Geneva 144 center currently employs 47 people: 26 dispatchers, 6 supervisors, 3 managers, 4 doctors and 8 support staff. Since three years, the center also collaborates with the Save a Life First Aid application, which reaches a community of 1'500 citizens divided into three groups of volunteers (health professionals, first aiders, citizens with BLS) alerted in case of a life-threatening emergency.

Population

The HUG published an announcement on social networks advertising the "144 days" to recruit a general population. It mentioned that any person wishing to participate in simulations of cardiac arrest and choking of an infant followed by a training in first aid could register on one of the 32 slots proposed on the HUG website over 2 days. There were 34 participants: 18 for the ACR and 16 for the OHCA, 27 women (79%) and 7 men. The majority of the participants were between 20 and 39 years old (21% of 25-29 years old, 20% for 30-35, 18% for 20-24 and 12% for 35-39). Participant are coded as followed in the verbatim: B1A = B: Bystander, 1: simulation 1, A: first bystander to take action. The other participants were 8 dispatchers[3] from 144 center, 4 paramedics[4] and 14 first responder[5].

Material; SARA and Urgentime apps

The applications we propose for these simulations are Urgentime (videos feedback) and SARA application (demonstration video). Urgentime is an app that allows the dispatcher to see through the caller's camera via an sms link connecting the smartphone and the dispatcher computer. SARA includes a smartphone / web app and a back office for the dispatch center. Through a sms link, the dispatcher can send the bystander one of eight demonstration gesture videos implemented in the app. In this experimentation, we tested CPR (adult, infant) and Mofenson maneuver.

Protocol

The experimentation protocol is divided into 3 phases; a first simulation phase (10 minutes), then a common debriefing phase (30 minutes) followed by an artistic restaging phase (1 hour). In this article we focus on the first 2 phases.

Simulation

[3] Coded D1, D2, …
[4] Coded P1A, P1B, …
[5] Coded FR1, FR2, …

We performed 16 simulations on 2 scenarios, an adult cardiac arrest (8) and an infant choking (8). The scenario for cardiac arrest was:

"You are in the waiting room for a job interview with someone who is starting to feel ill and collapses. You can call for help and call 144."

The dispatcher use Urgentime for the assessment and diagnoses the cardiac arrest. The scenario for the chocking infant was:

"You are keeping your neighbor's baby. He starts to choke and turns blue. You can call for help and call 144."

The dispatcher use Urgentime for the assessment and finds out that the infant is chocking. He sends the video of the demonstration of the Mofenson maneuver[6]. The participants are invited to practice the maneuver until the situation deteriorates into cardiac arrest.

In both scenario, participants starts to perform CPR on the dummy until the arrival of the ambulance with SARA video. Save-a-Life first responders join the participant(s) around the 6 minutes mark with a defibrillator (AED)

Debriefing

Debriefing in form of collective elicitation interviews follow the simulations with all participants per simulation (about 30 minutes). Elicitation interviews (Vermersch, 1994) are a technique aiming to focus on feelings during a particular event. The interviewer aims on deepening the lived-experience and sensations while avoiding questions that lead to a rationalization of discourse (Vermersch, 1994; Cahour et al., 2016). This technique can be used with a single person or a group (Balas-Chanel, 2014).

Data collection and analysis

The simulations and interviews were audio/video recorded then fully transcribed and analyzed with Atlas according to our research questions. We also extracted timing for each simulation (time of recognition of ACR and time to start CPR).

We made a thematic analysis of the verbatim. The data was first separated into three main axes: collaboration between stakeholders (positive or negative emotions, feedback on the simulation, discussions, and clarifications during the debriefing), impacts of the applications and effects of the method. First, we compared the 16 simulations with their debriefings in order to identify the postures and elements that could affect the experience of collaboration. We matched the actions observed in the simulation with the effects described during the debriefing. Subsequently, we compared which actions had which effects and categorized them on the basis of the feedback from the debriefing to extract the positive actions for the collaboration and the problematic actions. Then we analyzed the data to gain a deeper understanding of connections between each local stakeholder duo. The second step was to apprehend the impacts of applications by measuring their reliability and reviewed the benefits and difficulties encountered. Lastly, we categorized each verbatim regarding the method to evaluate benefit (experiential learning, confrontation with emotions, involvement) and biases.

RESULTS

Features and behaviors that affect collaboration within the local survival chain

Our first question concerned the understanding of the elements and characteristics of stakeholders that facilitate or hinder collaboration within a local chain of survival. The table 1 provides an overview of the different indicators, features, and effects on collaboration between each pair of partners.

Characteristics of an optimal collaboration

Collaboration is optimal when there is either one particularly competent bystander (S8) or several bystanders with one taking the lead (S1/2/5/11/15). The presence of other bystanders was experienced as reassuring for most participants. When a bystander takes the lead, it helps organize the handling of the situation and even start cardiac massage before the call with the dispatcher (S1/15). Optimal collaboration between the dispatcher and the bystander means that the dispatcher has quick access to important information (address, patient status) thanks to the designation of a dedicated bystander to speak on the phone (D8 to B8 :" *I found you very calm in particular in the information, the address, it was very clear.* ") and that he has the assurance that his instructions are

[6] The Mofensen method is a technique used in the case of an infant (under 2 years old) choking. It requires positioning the infant on his or her stomach on the thigh and delivering 1 to 5 taps on the child's back between the shoulder blades.

understood and carried out (D11: «So *on my side I had information that was clear with people confirming the actions*."). For the bystander, the impression of a good collaboration comes from the feeling of being guided (S4/6/9/13), reassured (S9/12) or encouraged (S1/15). During CPR, the dispatcher being positioned more in the background to give encouragement and the bystander giving information on what he is doing (counting aloud) reflects good collaboration.

Table 1: Features, behaviors and indicators of collaboration between members of the chain of survival

Link		Indicators of collaboration +	Features +	Actions	Indicators of collaboration -	Features -	Compensatory actions
Bystander / bystander		Sense of psychological support (S1/11) Trust in others (S15)	Lead bystander	Coordination (S1/2/5/11/15) Gives instructions to the other and organizes the takeover	Feeling of wasting time explaining to the other person (S2/4/8) Stress of having to organize (S13) Panic of one of the bystanders (S3)	Panicked bystander	/
Bystander / dispatcher	B	Feeling of being guided (S4/6/9/13) Feeling of being encouraged (S1/15) Sense of reassurance (S9/12) Confidence in the service (S8)	Calm dispatcher	Receptive listening/makes actions and feedback	Fear: Not hearing (S15) Not being understood (S3) Jargon (S5) Confusion with defibrillator (S10/15)	Overwhelmed bystander	Attaches to a part (video/defibrillator/dispatcher)
	D	Bystander gives the information (address communicated quickly (S1/8) Bystander confirms actions taken (S2/8/11/10) Ability to understand the dispatcher's needs (S3)	Cooperative calm bystander	Positions himself in support and spreads encouragement	Uncertainty about the implementation of gestures (S9) Uncertainty about the situation (S9/S13/S14) Uncertainty of number of people (S2)	Bystander un/badly responding	Repeat Ask the bystander to count to make sure they are doing things Gives very strict guidance
Bystander / First Responder	B	Soothing (S12) Feeling of being guided (S2/8) for the massage and for the defibrillator	Leading and cooperative First responder	Active and receptive listening	/	/	/
	FR	Listening and Proactive Bystander (S4/14)	Receptive bystander	Use the bystander as a relay for AED or massage	Difficulty to get information (S2) Difficulty in managing defibrillator and bystander (S3)	Bystander un/badly responding	Dispatcher does the transmission (S2)
Bystander / Paramedics	B	Feeling of being guided for the massage (S7) Relief (S2/3/7/11/13)	Attendance of paramedics	Actively participates	/	/	/
	P	Bystander gives information (S1/7/11) Bystander gives a proper massage (S7) Bystander stays and helps to organize the care (S7/11/13)	Bystander available/near/willing	Relay with bystanders S4/5/6/7/9/10/11/12/13/14	Bystanders step aside (S2/9/12/15)	Passive and withdrawn Bystander	Ask the bystanders to stay (S2,9,12,15) To start the massage again (S2/4/5/7/9/10/12/13/15) Relay with first (2/8/15/16) Relay with paramedics (1/3)
First responder / dispatcher	FR	/	/	/	Trouble managing defibrillator and talking to dispatcher (S9)	/	Focus on the defibrillator
	D	First who guides bystander (S2/7/8/10/12/15) Trust in someone trained (S2) First who informs about the situation (S2/8/10/15)	First reporting leading	Hands off and cuts off communication Encourage	Unaware that the first responder is there (S6/11/13) Uncertainty about the treatment (S9/14) Doubt about the ability of the first (S3/5/9)		Takes over control (S2/5/9/14) Keeps talking until he hears something satisfying (S9/14)
First responder / paramedics	FR	Feeling of not being alone (S16)	/	/	First goes away (S6,9)	/	/
	P	First structured and lead (S6) First source of information (S2)	/	Use the first to relay	/	/	/

The first responder then joins the bystander(s). When the first responder takes the lead and integrates the bystander into the process by giving instructions (S2/8/12), the pbystander feels calmed ("B12A: *Honestly it was soothing. It was much easier to wait for rescue at that point*."). The first responder expects the bystander to be active and receptive to his directives (S4/14). Fluid collaboration is achieved when the first responder uses the bystander as a relay either to apply the AED patches or to massage. The link with the dispatcher is still present, either through the bystander or through the first responder, which is valued by the dispatcher (S2/8/10/15). He then delegates and shifts his responsibility to the first responder as D2 expressed "*it is likely that he will take over, we may very well cut off communication* ". The dispatcher express that the trust in the first responder comes from the certainty that he is trained (S2) and from their awareness that he guides the bystander (S2/7/8/10/12/15).

The final step is the integration of paramedics into the situation. Bystanders expressed feeling great relief (S2/3/7/11/13) just from the arrival of the paramedics. It is also a release for the first responder (S16) who appreciates not being alone anymore. For the paramedics, good collaboration emerge when the bystander is in an active position:

- By doing an "adequate" massage (S7) as described by P7A about B7A: "If *I find the person adequate, I'm not going to stop them. It's the first time I've had trust the person doing this*".
- By giving information (S1/7/11)
- By staying available (S7/11/13)

These elements are essential for a good collaboration. This leads them to use the bystanders as a relay for the massage (S4/5/6/7/9/10/11/12/13/14). They also appreciate a first who leads and gives information (S2/6).

Difficulties in collaboration and compensatory actions

The results show that in some situations (S2/3/4/13) the collaboration between several bystanders might be problematic. Some of the bystanders reported feeling stressed because of the time they had to spend explaining the situation or organizing the assistance. During one simulation (S3), bystander B3A also had to deal with the panic of bystander B3B, which put her under pressure, as expressed later "w*hen you said "the man is dying" for 2-3 minutes, I didn't listen at all. I wasn't listening to anything because otherwise I would have completely panicked."* (B3A).The main issue here seems to be dealing with a very stressful situation with unfamiliar people who may become an extra burden, as the bystander already feels unable to handle the injured person. In many cases, the situation was solved by calling 144, who distributed the roles.

When it comes to the collaboration between the bystander and the dispatcher, two main issues can arise:

- Difficulties in communicating; the bystander does not hear (S10/15/16) or does not understand (S5/9). When bystanders were confused because of an overload of information, they focused on a single element (the dispatcher "*I could always listen to the voice of the dispatche*r" (B15B), AED instructions "*The defibrillator has a much louder sound so it goes over 144"* (B10A) or video instructions "*I couldn't prioritize. So afterwards, I followed the video*" (B3A)) to complete the task.
- A poor awareness of the dispatcher; if the bystander doesn't or hardly answers, there is no certitude for the dispatcher over what is happening; the surroundings, the number of people (S6), the execution or not of the gestures…Dispatchers reported that in these cases they used techniques to ensure that the bystanders are doing something, such as repeating instructions or asking to count (D6 ""*I was making you count, trying to pick up clues over the phone* ").

The arrival of the first responder may also affect collaboration. They sometimes struggles to obtain information from the bystander or have difficulties managing the defibrillator with another person (witness (S3) or dispatcher (S9)). Once again, awareness problems may persist or arise on the dispatcher' side: sometimes he is unaware that the first responder has arrived (S6, 11, 13) or if the cardiac massage is continuing. In some situation, the dispatcher has expressed a doubt about the abilities of the first (S3, 5, 9), in these cases they take over ("D9: "*In my head, she didn't really need me but I felt like she did so I went back to 1 and 2 and 3 and 4*") and continue talking until they hear something "*satisfactory*". Concerning the last link, there is an important break in the collaboration because most bystanders move away when the paramedics arrive (S2/9/12/15) or stop massaging (S4/5/7/9/10/13), so the paramedic often have to call back the bystanders and ask them to remain involved. It is also worth noting that there are two situations where the first responders also moved away (S6, 9). That is two situations where the previous collaboration was difficult with either the bystander or the dispatcher.

Identify the effects of video to define usage criteria

Reliability of applications and temporal impacts

During the 16 simulations, Urgentime (video feedback) was used on each simulation and was not successful 3 times, which gives it 81% of success while SARA (CPR demonstration video) was used 11 times and was successful 4 times, which corresponds to 36% of success. Regarding the time of recognition of the cardiac arrest, it was recognized the fastest in the Urgentime modality doubled with SARA (1'40) and the slowest for the Urgentime modality alone on the OHCA situation (3'20). Times for starting cardiac massage was the fastest with Urgentime / SARA modality for OHCA (2'47) followed by choking baby without application (3'20) then Urgentime and SARA - for OHCA (3'39) and finally Urgentime alone for OHCA (3'53). Interestingly, in terms of time between recognition of the arrest and CPR, the double use of Urgentime and SARA allows to obtain the best starting times with 12 seconds for OHCA and 58 seconds for child arrest against 1’03 for OHCA and 1’26 for child arrest with Urgentime alone. These findings indicate that the use of two coupled applications allows the shortening of time between the recognition of the cardiac arrest and the CPR. The technical problems does not always affect the starting time of the procedures (in particular for the OHCA). However, waiting for the link or the video can generate frustration or even panic on the part of the bystander ("B3B: *the time before the video starts, I think that we have lost a lot of time*" / "B12A: "*the video, I can't wait for it to download.*”).

Urgentime: the beneficial addition of a visual channel for the dispatcher

This system was strongly appreciated by participating dispatchers because they "*regain their sight*" (D5) and stop working with "*the imaginary and the figurative but directly with the concrete*" (D8). The visuals allow the dispatchers to "*get the ambiance*" (D3), "*see if it's panic, if it's organized*" (D11) and to "*confront the anxiety on the spot*" (D2), enabling them to reassure the anxious bystanders. Secondly, the visual is a real help in terms of diagnosis, especially in pediatrics. In the chocking situation, the dispatchers used the camera to assess the baby's breathing "*it's a child described as blue and then I see him and it helps me confirm the diagnosis.*" (D6). Being able to see also gives them the opportunity to guide cardiac massage more effectively:

- By correcting the position ("*we could say you're too high, you're too low*" D7, «I *was able to tell you to come closer*» D13) and the rhythm in real time if necessary ("*I told you to massage more gently. It seemed to me that you were going very fast"* D15).
- By stepping aside and avoiding an overload of information: “*if it goes more or less well, you can give more or less instruction and let things happen*" (D8).

Finally, visualization enables the dispatcher to be more directly involved "*we are even more with the people*" (D1) since he can directly see the different interveners arriving on the scene. He does not need to ask for information from the caller as mentioned by D11 «I *was able to acknowledge certain steps of the procedure* ". By relieving him of the need to confirm verbally, the video increases the reliability of his representation of the situation while confirming (or not) his confidence in the on-the-spot bystanders. Indeed, when video is not available, the dispatcher has to go "*pick up clues by phone*" (D6). Moreover, the fact of filming also allows the second bystander to be more involved, as he/she does not perform the massage.

SARA: a visual aid for bystander

SARA allows reassuring the bystanders in the gestures of a resuscitation, "*from the moment I had the video, I felt able to do it*» (B1B). The videos of cardiac resuscitation for children and adults helped by mimicry to obtain the right position ("*it is especially the video that helps, naturally I had put my arms outstretched*") and the right rhythm "*with the video it was a little easier to count the frequency too*" B3B). The participants appreciated the addition of a visual channel "*It's much easier to tune in to images than to verbal information*" B3A. It also has been an advantage for foreigners.

Limiting elements

For Urgentime, several elements proved to be blocking in the process. The application required clicking on different messages displayed and was a source of stress as evoked by B6B: “*It wasn't easy, it's stressful and I don't know where to press*.” It can also lead to an error as for B14A "*So what I did was press photo instead of video*" and B9: "*I actually write a response*". There is also a network flow problems, shared with SARA. A bad connection invariably leads to lags in the video, degradations in its quality, and thus confusion between the dispatcher and the bystander. For SARA, a bad network implies that it is difficult to send the demonstration video or that the dispatcher sends the video, thinks that it is received by the bystander and stops guiding the massage as in simulation 5 "*From the moment I clicked on send the video and it started to play at my place I thought it was playing at your place and in fact not at all*" (D5).

Is simulation and debriefing a way to achieve more long-term learning?

The emotions and the feeling of immersion

The emotion massively evoked by the participants is a certain stress (10 out of 18 for OHCA, 7 out of 16 for chocking) which appears from the beginning of the simulation (B11A: *“the moment we realize that the person is in difficulty”*), continues until the end of the simulation and sometimes even after (B3A during the debriefing "*my emotions are still running high*"). This stress originates from several components:

- A sense of responsibility; they felt it was their role to take action, especially in the child case «*it makes you feel almost more responsible than if it was your own child*." (B14A)
- A feeling of being emotionally overwhelmed "*I felt like I needed help I felt like I couldn't handle it."* (B3A)
- The time spent before the call (B16A "*seeing the seconds tick by and seeing that the child remains unconscious* ") or waiting during the call (B6A "*the longer we wait, the more stressed we are* ")

Moreover, we notice that there is a personification of the dummy, the participants evoke "*the person*" "*a little one*" "*the baby*", they have completely integrated the dummy as real. The child's situation can also lead the participant to project themselves into their own situation (B12A: "*I have a baby about that age. When I saw the mannequin it was difficult*"). We thus note a pronounced involvement in the situation (B2A: "*I really felt a stress as if the person was real*"). This emotional involvement can also have an impact on the future engagement of bystanders as the dispatcher noted "*living it and feeling part of it with us on the phone, with the paramedics, or the first responders, I think that it is a better way to understand and feel it"* (D1) and D2 "It *reinforces the feeling of belonging of the first responders and bystanders to this chain of rescue. We feel that we are all part of the same core. And in terms of federation, I believe it is essential*."

Learning benefits of shared lived situation

Simulation is a way to get experience before being confronted to the real situation. This is a benefit recognized by the bystanders (B2A: *the fact that I have tried it now prepares me in case it happens* ", B8 "*it was really a stressful moment but we never learn as well as in that way* ", B9"it's *a simulation, but if you can already manage this situation it's easier afterwards in real life.*") The first responders (FR10: «to *engage in such exercises is very interesting. To push yourself to act instead of waiting for the day it happens.* ") but also by the dispatchers themselves. Indeed, for young or trainee dispatchers, it gives an opportunity to be confronted for the first time to the handling of a cardiac arrest regulation and as D1 underlines "*It is better that she is stressed and that she loses her means on a simulation rather than on the day she will lose her means and that puts the patient in danger*". For the senior dispatchers, it is a question of "breaking *out of the routine*» (D2) and learning new practices while having the right to make mistakes "because *being wrong about a real vital distress is a real problem, there are real consequences, potentially serious for the patient. Even if we are wrong, we won't make that mistake again*" (D2).

The emotion caused by the situation can remain after the situation is over, so it is essential to have a space to welcome and discuss these emotions in order to give the participants the opportunity to appease themselves. Therefore, a debriefing session is mandatory and can be an opportunity for further development through discussion with the stakeholders of the specific situation. The bystanders learn by having a direct feedback on their actions and deepen their knowledge on emergency procedures and on the local chain of survival. It is also at this time that some participants became aware of their roles in the chain of rescue and the importance of performing the gestures, as in the example below.

B15C: How bad can it be if we stop massaging?
D15: Every time you stop, the person's heart stops. You are the person's heart.
B15C: Oh my God
Finally, the debriefing also enabled the dispatchers to get feedback on their practices from the bystanders "*something they never have access to*" (D5) and notably to realize that some instructions were misunderstood ("every *word we use is very important and can be interpreted differently "D2*) and that some individuals were afraid to even call 144. Therefore, these drills should lead to adjustments in their procedures.

DISCUSSION

The Geneva chain of survival

The chain of survival (Nolan et al., 2006) in Geneva is composed of bystanders, Save-a-life first responders, dispatchers and paramedics. We saw that when the collaboration is effective, the lead is passed from the first bystander to the dispatcher to the first responder and then to the paramedics. If collaboration is not optimal, the dispatcher remains the lead throughout the intervention until the paramedics arrive. The more confident the dispatcher is that the care is going well, the more he/she will take a back seat and move to a position of encouragement or cut off communication. The more he/she feels that the situation is unstable, the more he/she will continue to guide very strictly. In line with literature (Takei et al., 2014), our results showed that few bystanders started resuscitation alone (2 out of 16). However we did not witness a "bystander effect" (Fischer et al., 2011), all participants performed cardiac massage even though their emergency training was old (in

Switzerland, the BLS is mandatory to pass the license) and therefore can be considered as bystanders with little CPR knowledge (Case et al., 2018). The biggest problems between the dispatcher and the bystander were related to communication and to the management of several people and tools at the same time. When the dispatcher is in difficulty related to awareness (Van den Homberg et al., 2018; Bharosa et al., 2010), he/she puts in place compensatory techniques such as making people count, he/she repeats several times or he/she talks until he/she gets a satisfactory feedback. The first respondent is seen as a real relay and support, he has the confidence of the dispatcher and the bystander perceives him as a health professional so the expectation of the paramedics becomes less urgent. Finally, contrary to what we can read in the literature (Bird et al., 2020; Reuter et al., 2016), the paramedics in this situation were rather fond of the presence of the bystanders whom they consider as a resource in terms of information and relay for the massage. The biggest difficulty mentioned was the fact that most bystanders move away when they arrive.

The applications effects on the handling of a victim

The first point we sought to evaluate was the reliability of the applications. 81% of the attempts with Urgentime were successful, similarly to the study with GoodSam (Linderoth et al., 2021), but only 36% with SARA. In terms of treatment, the recognition time for cardiac arrest and for starting CPR are in the average of what is described in the literature (between 1 and 3 minutes to recognize the arrest and between 3 and 5 to start CPR)(Syväoja, 2019). However, the implementation time of the applications generates a certain stress for the bystanders (whether the application works or not). Next, we wanted to evaluate the effects of the applications themselves. We saw that Urgentime added an essential channel for the dispatcher. By restoring his sight, it increases his awareness of the situation, the course of the intervention, the environment and the gestures while allowing to unload the auditory channel which is strongly solicited elsewhere (by the presence of several persons, the SARA video and the defibrillator). It also allows guidance and back off as the dispatcher witnesses that a situation is being handled. When SARA application was successful, there was a reassuring effect on the bystanders who felt guided and supported to perform CPR. The findings show that it does indeed allow for more adequate massage performance as other research has indicated (Lin et al., 2018; Stipulante et al., 2016; Bobrow et al., 2011). It is also an element on which they can fix their attention when they feel lost. In addition, the demonstration video helps to overcome communication difficulties (Case et al., 2018) by demonstrating the gestures to be performed without resorting to oral guidance. Recommendations suggested using visual feedback only when there are two bystanders (Linderoth et al., 2021). While we have seen a situation where a single bystander was able to manage both applications, it would still seem advisable to use SARA when there are two bystanders. According to the dispatchers, it is also more interesting to use Urgentime in pediatric cases to assess the child's condition. Finally, Urgentime can do the guidance of the resuscitation and if it goes on correctly (good angle of view, adequate massage), there is no interest to send SARA, which would lead to an interruption.

The experiential learning effect of these simulations

The literature suggests that experiential learning is triggered by emotions (Kolb, 2014) and by incorporating all the stakeholders into the learning situation (Meischke et al., 2017). The first step was to investigate whether the simulations provoked any emotions in the participants. The main emotion identified was stress leading to a strong projection of the participants who perceived the dummy as a real person. Undergoing these emotionally charged simulations with first responders and paramedics had a federating and unifying effect. It also allowed the bystanders to train in conditions close to real life and the dispatchers to test new applications in a secure environment to be able to assess the potential difficulties. Lastly, the debriefing, considered as an opportunity for acquisition of knowledge (Cheng et al., 2018), is also a safety valve, providing a space to unload the emotions experienced by the participants. It also indeed allows more acquisition of skills since the participants can have feedback on their actions and medical, technical or procedural clarifications on what happened.

CONCLUSION

This Living-Lab has shown its value as a training tool for both the bystanders and the dispatchers. It has allowed the emergence of a certain feeling of unity throughout this survival chain. However, we only worked with volunteers dispatchers and it leads to a bias in the acceptability of the process and of the tested applications. It would therefore be worth pursuing this work with other dispatchers (in other dispatcher center or in this same center) with a more "general population" on the operator side. Further work to analyze the photographic restaging process would also be valuable.

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Adaptation: A Proposal to Replace Recovery in the Phases of Emergency Management

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ABSTRACT

Mitigation, preparedness, response, and recovery are the four phases of emergency management that have arguably been unchanged since their inception nearly 43 years ago. This paper proposes to replace recovery with adaptation as the post incident phase of emergency management. Recovery focuses on a return to normal while adaptation better encompasses acknowledgement, healing, strengthening, and improving quality of life for a more resilient outcome. This paper reviews seminal work within emergency management and work pertaining to other types of adaptation to better comprehend adaptation as applied to emergency management.

Keywords

Adaptation, recovery, change, disaster, emergency management, transformation, resilience.

INTRODUCTION

Since the dawn of time, violent and relentless natural forces have been altering and shifting the course of events on Earth. Changes in weather have altered the landscape, drying swamps into deserts, creating grand canyons with flood waters, creating islands and land masses, and reshaping the continents. Time and time again, Mother Nature has shown her awesome power in her ability to change the world in which we live. Often, that power is demonstrated in what we claim to be disasters. After a disaster, emergency managers are called upon to bring communities back to normalcy. This has been the doctrine of emergency management for nearly a half-century, and it has served the emergency management community well, but it is time for change. It is time to adapt. The current doctrine has become dogma and inhibits progressive change. In an era where we are grappling with a global pandemic, climate change, and increasing frequency and intensity of natural hazards, it is time to reevaluate what was once considered fundamental in search of advanced concepts that promote healing, strengthening, and survival. Adaptation is a process that fulfills the goals of recovery while applying a different mindset. It is a mindset that focuses on acceptance, change, healing, and improvement. Adaptation will enable emergency managers to take advantage of the opportunities created by disasters and ensure survival and prosperity.

This article is organized first with this introduction followed by a review of literature. The literature review will examine adaptation as in the context of emergency management and irrespective of its relevancy to emergency management. The literature review will explore the origin, meaning and intent of recovery as a phase in emergency management. The literature review will be followed by a discussion that compares and contrasts adaptation versus recovery as a phase of emergency management. A recommendation will then be provided in the conclusion.

REVIEW OF THE LITERATURE

There is little to be found about adaptation in the context of emergency management and what happens after a disaster occurs. There is even less addressing the idea of replacing recovery as an emergency management phase. Since this is an innovative proposal, literature was reviewed about adaptation as a conceptual idea. Documents were examined to identify what adaptation is and why it should replace recovery as a phase of emergency management.

A study investigating resilience as it relates to emergency management concluded that emergency management should be more proactive (Tveiten et al., 2012). This research shows that emergency management can be proactive by predicting risks early and that emergency management should be adapted to new and future work practices (Tveiten et al., 2012). This study may be limited in applicability to this paper because the study focused on emergency management within the petroleum industry.

In the United Kingdom, the electric power companies have incorporated adaptation into their resiliency strategy (Espinoza et al., 2016). The electrical grid managers develop systems to withstand the initial shock and rapidly recover from natural disaster impacts (Espinoza et al., 2016). The companies then apply adaptation measures to bolster the survivability of the electrical system in anticipation of future events (Espinoza et al., 2016). These system operators are following a framework by Panateli and Manacarella that offers five key resilience components to gauge resiliency, specifically: robustness/resistance, resourceful-ness, redundancy, response and recovery, and adaptability (2015).

The North Atlantic Treaty Organization (NATO) and its member nations have embraced the concept of adaptation into its resilience and crisis management cycle (NATO, 2022). This cycle includes the phases of preparation, absorption, and recovery and adaptation (NATO, 2018) (Shea, 2016). NATO expects each member country to be adaptable as part of NATO's preparedness and resiliency doctrine (NATO, 2022).

In the 1980's, doctors realized that the AIDS virus was highly mutable and determined that a vaccine was not going to be achieved quickly so they began to focus on mitigating the symptoms of AIDS rather than attempting to prevent or cure it (Flynn, 2007). In other words, they developed a strategy for adapting to the epidemic. This is one example of how adaptation enables emergency managers to achieve a quicker and preferable end state than an un-adapted course of action in which recovery is the focus rather than adaptation. Before other literature is reviewed, it will be beneficial to examine various definitions of adaptation.

According to *Dictionary.com* (2021), Adaptation includes the following relevant definitions:

Adjustment; any alteration in the structure or function of an organism or any of its parts that results from natural selection and by which the organism becomes better fitted to survive and multiply in its environment; a form or structure modified to fit a changed environment; the ability of a species to survive in a particular ecological niche, especially because of alterations of form or behavior brought about through natural selection; a slow, usually unconscious modification of individual and social activity in adjustment to cultural surroundings. According to its scientific definition, adaptation is a change in structure, function, or behavior by which a species or individual improves its chance of survival in a specific environment. Adaptations develop as the result of natural selection operating on random genetic variations that are capable of being passed from one generation to the next. Variations that prove advantageous will tend to spread throughout the population. In a cultural context, the website defines adaptation as changes made by living systems in response to their environment.

Adaptation usually refers to a process, action, or systemic result within a particular community or cohort that occurs for the system to better cope with an altered state, stressor, hazard, risk, or opportunity (Smit and Wandel, 2006). There are numerous adaptation definitions, and many are linked to climate adaptation. Regardless of the context, the definitions are similar. The themes demonstrated by all the definitions is that adaptation requires change in response to an unfavorable condition to create a more favorable condition and increase the chances of survival. This will be the theme this paper seeks to propose as a replacement for the concept of recovery which is defined by the same source as the regaining of or possibility of regaining something lost or taken away or restoration to any former and better state or condition.

Further literature indicates emergency managers should be community change agents and seize the opportunity for change when there is the biggest desire for it, which is immediately following a disaster (Drabek, 2013). Adaptation requires learning and the ability to identify problems including threats and opportunities quickly and efficiently with a significant degree of decisiveness (Ackoff, 1974). Adaptation also requires the capability to plan and to implement those plans (Ackoff, 1974). Additionally, Ackoff confirms Drabek's theory by stating that reacting to actual or potential threats and opportunities adaptation is accelerated and reflecting on consequences enables quicker learning (Ackoff, 1974).

Cronin and Genovese discussed adaptation in their book *Leadership Matters*. They pointed out that Darwin is often miscredited with the phrase survival of the fittest and that Darwin's true theory is survival of the most adaptable (Cronin & Genovese, 2015). To further the point, they provided an example of a strong tree that can snap in strong winds but that an adaptable and flexible tree will bend in the wind and will survive (Cronin & Genovese, 2015).

James Lee Witt also encouraged a modified version of recovery in his book where he stated, "The recovery after most natural disasters involves rebuilding. It's a chance to lay new foundations and support beams that can weather the next disaster better. It's a chance to decide if there's a way to get out of the way of that disaster altogether. It's a chance for you to revise your crisis preparations, fine-tuning or rethinking your values, your on-hand resources, your early-warning flags, your reporting systems, your team's setup and their skills, your support network, your lightning rods and the sparks they create, and everything else I've touched on in this book." He recognized that the disaster creates new opportunity to improve the environment (Witt, 2002). Adaptation can mean rebuilding stronger, but adaptation is more complex and could also mean not rebuilding or not rebuilding the same thing. Adaptation can include being strong, being able to absorb, rebuilding, or even being able to live without that which you once depended on (Friedman, 2016). Adaptation is a grouping of concepts that may be implemented individually or all together (Friedman, 2016). Adaptation requires evolution and natural selection and constant feedback loops (Friedman, 2016). A unique aspect of adaptation is rapid, constant, and endless learning (Friedman, 2016). Feedback loops are used to identify environmental changes from which to select favorable traits and characteristics and then utilize those traits in the next evolution (Friedman, 2016). Learning is key to the adaptation process (Friedman, 2016). Learning is achieved through experimentation where the experiments often fail more than they exceed (Friedman, 2016). The successful experiments are a result of a specialized niche of learned behavior that allow flourishing and regeneration (Friedman, 2016). This change in learned behavior based on experimentation is the essence of the adaptation process (Friedman, 2016).

Friedman's perspective that learning drives adaptation is also shared by Hammond (2004) who stated, "All organizations seek to survive and prosper. They do so by enhancing their freedom of independent action or establishing symbiotic relationships through timely adaptation to a constantly changing environment. Those who adapt will survive; those who do not, die. Those who do survive do so by being good at doing observe, orient, decide, and act loops." He further states that adaptation requires variety and rapidity (Hammond, 2004). The use of variety, experimentation, and learning is also supported by Harford who claims trial and error is an effective tool for solving problems because it uses an evolutionary algorithm that searches for solutions to problems that keep changing (2011).

Adaptation is about changing according to the environment, but it isn't simply change or adjustment; it is change in response to what is learned about the change in the environment (Simon, 1996). The environment is in a constant state of change. Adaptation identifies the change, learns from it, and matches the change (Simon, 1996) This is further highlighted by Haas & Drabek's seminal work where they indicated that organizations utilize adaptive processes to respond to changes in the environment (1974). If change is to occur, it must happen immediately (Drabek & Hoetmer, 1991). Support for dramatic action will wane as each day goes by (Drabek & Hoetmer, 1991). Therefore, preparations for development must be made before a disaster occurs (Drabek & Hoetmer, 1991). An emergency manager who is well-prepared can use a crisis to change the public agenda (Drabek & Hoetmer, 1991). A disaster is not just a misfortune; it is also an opportunity (Drabek & Hoetmer, 1991).

DISCUSSION

The term recovery may have outlived its purpose within emergency management. Recovery implies a return. In emergency management it implies trauma has occurred and the goal is to get back to the way things were before the traumatic incident. In so doing, it deters survivors, communities, or emergency managers from taking advantage of the opportunities and possibilities that are created by the traumatic incident. The mere notion of trying to return to a previous status instills an implicit bias that diverts the psyche away from acceptance of the incident and envisioning an improved future.

Drabek and Hoetmer documented recovery concerns for local governments in their seminal work regarding emergency management and local government. They indicated that stakeholders want to return to normal business quickly after a disaster. Simultaneously, the public may favor making significant changes to prevent future incidents from occurring (1991).

Heifetz, Grashow, and Linsky summarized the problem of recovery versus adaptation in a bureaucratic environment since the problem-solving defaults of an organization reveal information about how it functions as a system and how adaptable it is (2009). Defaults are perspectives on events that encourage people to act in ways that are familiar to them and have produced desirable outcomes in the past (Heifetz et al., 2009). Organizations rely on defaults because they are comfortable with them and because they have previously worked well for revealing reality and resolving issues (Heifetz et al., 2009). When individuals inside an organization discover that a particular answer to a specific event worked effectively, they are inclined to repeat that response whenever they encounter a problem of a similar nature (Heifetz et al., 2009). However, the more often a default is used, the more difficult it is for an organization to modify when new circumstances call for a different course of action (Heifetz et al., 2009).

Recovery suggests bringing those things that were damaged back to their original state. If buildings are the focus of recovery and are returned to their original state, a recovery-based approach limits the ability to improve their construction and subjects them to the same fate if another similar traumatic incident occurs. Recovery, or in this case, rebuilding, should only be reserved for items of historic or environmental significance that intentionally need to be preserved.

The concept of recovery limits progress and advanced learning because it asks us to look back instead of envisioning a preferable future. It also encourages a denial of the incident instead of acceptance. Recovery implies getting back to the way things were instead of looking forward and adjusting to the way things could be. Rubin, Saperstein, and Barbee conclude in their seminal work that even communities that experience numerous disasters do not focus on an improved end state during the recovery and mitigation phases (Rubin et al., 1985). The pattern and rate of recovery and reconstruction after a disaster are influenced by a number of conflicting forces (Drabek & Hoetmer, 1991). Most of the time, people rush to rebuild their houses and businesses (Drabek & Hoetmer, 1991). Additional pressure to rebuild as soon as feasible is frequently brought on by development and real estate interests, with little to no consideration given to mitigation (Drabek & Hoetmer, 1991). Key local players will need to be reminded repeatedly of the necessity of disaster preparedness by public officials and civic leaders (Drabek & Hoetmer, 1991). This may be best achieved by focusing on adaptation rather than recovery.

The earliest citation of recovery in emergency management appears to be found in a Governor's guide to emergency management in 1979 by the National Governor's Association. This is how it defines recovery: "Recovery activities continue until all systems return to normal or better. They include two sets of activities: Short-term recovery activities return vital life-support systems to minimum operating standards (for example, cleanup, temporary housing). Long-term recovery activities may continue for a number of years after a disaster. Their purpose is to return life to normal, or improved levels (for example, redevelopment loans, legal assistance, and community planning)." (National Governor's Association, 1979)

This definition, and obviously the phase itself has largely been unchanged since that time. The concept is approaching a half-century of unchanged doctrine in emergency management and focuses on returning to normal, albeit making a concession for improvement. However, it continues to focus on what once was. In fact, the word "return" is used twice in the definition, as is the word "normal." These two words may perhaps be the reason why the concept falls short for today's needs in a post incident environment and why adaptation should be considered.

The human race is programmed to adapt, evolve, and survive (Lotto, 2017). Since the beginning of time, our species has been adapting, as have all other species (Lotto, 2017). Our brain seeks ways to help us survive, some simplistic and others creative (Lotto, 2017). It encourages experimentation which leads to learning. Learning leads to adaptation which then results in evolution (Lotto, 2017). The adaptation and evolution process leads to survival therefore survival requires innovation (Lotto, 2017).

Change is a natural part of human evolution. Samuel Henry Prince identified how change results from disaster in his ground-breaking work *Catastrophe and Social Change* while studying the sociological effects of the Halifax Disaster, resulting from a large explosion on a ship in the Halifax harbor in 1917. He stated change occurs even more so after disaster because disaster prepares the groundwork for social change by disturbing social factors and creating a desire for change among the population (Prince, 1920). However, strengthening, healing, and improvement is not an assured result of change (Prince, 1920). Flourishing after a disaster results from wise efforts and sacrifice (Prince, 1920).

After a disaster, things change. It may be a micro, meso, or macro level change, but change does occur. At a micro level, change may occur within a single individual who was deeply moved, affected, or victimized by the incident. Another micro level change could be a single home that was burned down. A meso level change could be illustrated by a single affected community or significant destruction of infrastructure within a general area. Change can also manifest itself at the macro level. Disasters like 9/11 or Hurricane Katrina are great examples of disasters that resulted in significant changes, perhaps even impacting the entire world.

Disasters generate short, medium, and long-term recovery efforts (Drabek & Hoetmer, 1991). Likewise, adaptability depends on short term learning, development beyond the short term, and evolution in the long term (Lotto, 2017). This can also be applied to the discipline of emergency management where emergency managers need to learn, develop, and change doctrine to evolve as a discipline.

Adaptation defined simplistically is changing with the changes. An adaptation process requires a projection forward and possibly making anticipatory changes. Adaptation does not return to normal because it does not view normal as a legitimate concept. Adaptation has no memory from which to establish normalcy, it only has what is in the present and future. Adaptation does not cling to what once was, it only supports improvement, strengthening, and healing.

An important aspect of healing is accepting what has happened. The world is in a constant state of change and disasters will happen. When disasters happen, lives are lost, people are physically and emotionally traumatized, buildings and infrastructure are destroyed and damaged, and lives are changed. The change is forever. The effects of a disaster cannot be erased. Therefore, to heal appropriately, the goal should not be to go back to the way things were, but rather to acknowledge the change in the environment and to embrace and leverage the opportunities that the change creates. The goal should be to adapt.

Adaptation requires the person, community, or process to accept that an incident has occurred, and that change has resulted from the incident. From this point of view, adjustment to the environmental change can be made. This adjustment should be an improved, stronger, and beneficial end state, allowing learning from mistakes and encouraging trial and error. The traumatic incident should be analyzed to determine what caused the disaster, what was needed to survive the disaster, and what would have been a preferred situation before the disaster occurred. From this point, there can be additional analysis evaluating future hazards and vulnerability and decisions can be made about what an adapted environment needs to look like and how to achieve it.

A traumatized person that experiences a disaster survives and flourishes if, after they experience disaster, they are willing to adapt. If they are willing to accept the reality of the experienced trauma, learn from it, and adjust to the new reality, they will fare well. Those who long to return to a pre-disaster state may survive but will likely not flourish.

A community that experiences disaster must be willing to adapt. Adaptation will allow a community to identify what has changed and adjust to the change enabling its members to take advantage of new opportunities to thrive which may be found in the economy, technology, social structures, or within the government.

An emergency management program can prosper by leading its citizens, community, and governmental organizations through an adaptation process that puts its stakeholders on the path it needs to be versus where it has been. The emergency management program may adjust processes so the system can better cope with future hazards, risks, vulnerabilities, altered states, stressors, or opportunities. Any emergency management program that leads its benefactors to modify their environment and/or behavior such that it is better fitted to survive in the future is a stronger program than one that asks it to simply recover.

Disasters will continue to occur, and people will continue to be affected by them. Our ability as humans to adjust to our environment and create opportunity out of change enables us to become stronger. Our ability to adapt permits us to evolve into a stronger species that can thrive and flourish. By failing to adapt, we put ourselves at risk. In her book *The Unthinkable*, Amanda Ripley cautioned of such failure indicating that we are at risk of devolving rather than evolving (Ripley, 2008). She concluded that we can either adapt and improve at surviving or we can devolve and become worse at surviving (Ripley, 2008).

CASE STUDY: COVID-19

Beginning in early 2020, the United States initiated its response to the COVID-19 global pandemic. As a novel coronavirus began its worldwide spread which would ultimately be blamed for the deaths of millions of people and the ruining of the global economy. The concept of recovery was never an option for emergency managers. To recover, COVID-19 would need to be eradicated and life would need to return to a 2019 status.

People, communities, jurisdictions, and organizations adapted in many ways. The short-term adaptation process included the wearing of face coverings, implementing social distancing protocols, and installing plexiglass barriers. Adaptation resulted in building virtual capabilities, working from home, increasing delivery services, and outdoor dining. In the long term, adaptation involved vaccinations and developing herd immunity. The U.S. will never go back to a scenario that eradicates COVID-19 and will never return to life in 2019. Life will continue to move forward, and the U.S. will embrace the changes made and will be stronger from adapting and thereby evolving.

Returning to 2019 is not what happened. Adaptation was the only realistic option. Across the globe, adaptation occurred. Adaptation occurred to keep the economy moving. Adaptation occurred so educations at school were minimally interrupted. Adaptation caused the creation of new businesses taking advantage of new demands within communities. Adaptation gave businesses new operating models which have been retained or modified and continued despite the elimination of COVID precautions. Businesses continue to embrace more personal delivery options, web-based meetings, and remote working.

CASE STUDY: GREENSBURG, KANSAS TORNADO

On May 4, 2007, the Town of Greensburg, Kansas was 95% destroyed and the other 5% was severely damaged by an EF5 tornado. The tornado killed 10 of Greensburg's estimated 1,594 residents. The concept of recovery would have every building returned to its original state. This was not an option for the residents nor its governing body. They chose to adapt. The city council passed a resolution stating that all city buildings would be built to Leadership in Energy and Environmental Design (LEED) standards, making it the first town in the nation to do so. Several homes and buildings that replaced destroyed ones included hazard mitigation improvements. These buildings can now withstand 195 mile per hour winds. Greensburg adapted and emerged from the rubble as a "green" town, with the help of Greensburg GreenTown, a non-profit organization created to help the residents learn about and implement the green living initiative. As a part of their adaptation efforts, this City is now and completely powered by a 12.5-megawatt wind farm. In so doing, Greensburg has demonstrated the adaptation mindset discussed in this paper by utilizing the very hazard that destroyed their town and channeled it into a energy solution. Greensburg today stands as a model often described as the greenest in America.

COMPARISON

These two incidents are quite different from a hazard perspective. One is a pandemic where a biological illness caused global consequences to people's lives, livelihood, and quality of life. The pandemic was a long-term event where some may still is arguably still ongoing. Adaptation had to occur during and will still occur once the pandemic is declared over. As a result of the pandemic, public health agencies implemented draconian mitigation measures in an attempt stop the spread of the disease. These measures had severe consequences on businesses that failed to adapt to the new measures. Those businesses that were able to transform and provide new or modified services in alignment with the measures had far less impact to their business. Governments that also adapted to support their businesses by issuing special permits to offer outdoor dining, special parking for pick-up retail, and offering other variances to local ordinances.

Greensburg, by comparison, was a local incident weather-based incident whose damage to a small geographic area, compared to the pandemic, did its damage in just a few minutes. Adaptation couldn't occur during the tornado. The changes made after the destruction were a product of planned and deliberate steps by the community and its leaders. The changes took years to implement. Several in the community did not embrace the changes on an individual level and in an attempt to return to normalcy simply rebuilt private property to the same standard their destroyed property had before. Just like in the COVID-19 incident, those that adapted, and the community, are more prepared and protected for future tornados and energy is now more sustainable. In many respects, the adaptable are flourishing after the disaster.

FUTURE WORK

The topic of adaptation as it pertains to the phases of emergency management raises interesting opportunities for future research. Specific adaptation strategies can be identified for specific hazards. Adaptation for floods are likely to be different than adaptation for tornados. Researchers can also attempt to identify how to synthesize hazard specific adaptations and fuse them together to provide even more protection and opportunity for flourishment. Research should also be focused on both physical adaptation of property and the community and behavioral adaptations of people. Sociological research might also inquire as to why some people are quick to adapt to a new situation and others resist. This could lead to actions emergency managers can take to promote adaptation and increase resiliency within a community.

With this paper serving as a proposal for adaptation to replace the recovery phase of emergency management, it begs to question what other emergency management phases and emergency management doctrine has become dogma. Emergency management as a discipline may need to itself adapt to the threats and hazards that are present now that weren't present, or as frequent, or as severe four decades ago. Future research might focus on how planning can incorporate adaptation concepts into emergency operations plans, comprehensive emergency management plans, strategic plans, and even in incident action planning during an incident. Other research may include how to teach adaptability in emergency management training courses or in emergency management higher education curriculum. Emergency managers will also need to know how successful adaptation efforts are, therefore research may be conducted to determine mechanisms to measure community adaptation measures and efforts.

CONCLUSION

When disasters occur, change also occurs. It could be social change, environmental change, economic change, or even personal change. As emergency managers we should be seeking to evolve our communities, jurisdictions, and organizations to thrive and flourish in the face of change. Evolving requires adaptation. The current practice of recovery falls short of an evolutionary concept. A recovery concept has a focus of returning to normalcy and going back to life before a disaster. Recovery is not an evolutionary process; it is a static process. An adaptation process is dynamic and allows emergency managers to focus on acceptance, healing, and adjustment to current and future conditions. Adaptation enables communities, jurisdictions, and organizations to seize the opportunities created by disaster instead of succumbing to the destructive impacts of it. Adaptation is evolutionary and enables the building of long-term resilience. Adaptation should replace recovery in the four phases of emergency management.

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Algorithms for Detecting P-Waves and Earthquake Magnitude Estimation: Initial Literature Review Findings

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ABSTRACT

Earthquake Early Warning System (EEWS) plays a major role during an earthquake in alerting the public and authorities to take appropriate safety measures during an earthquake. Generally, EEWSs use three types of algorithms to generate alerts during an earthquake; namely: source-based, ground motion or wavefield-based and on-site-based approaches. However, source-based algorithms are commonly used in most of EEWSs worldwide. A source-based EEWS uses a particular time frame of the P-wave of an earthquake to estimate the source parameters such as magnitude and the location of that earthquake with the support of P-wave detection and earthquake magnitude and location estimation algorithms. As the initial step of a research project which aims to explore the best use of P-waves to generate earthquake alerts, this Work in Progress paper (WiPe) presents the initial partial findings from an ongoing literature review on exploring the algorithms used for P-wave detection and earthquake magnitude estimation.

Keywords

Earthquake Early Warning, P-waves, Magnitude Estimation, EEW algorithms

INTRODUCTION

Earthquake Early Warning (EEW) algorithms adopted by the various systems globally can be categorised into three main types: source-based, ground motion or wavefield-based and on-site-based algorithms (R. M. Allen & Melgar, 2019). Each of these has its strengths and weaknesses. To overcome the weaknesses and utilise the strengths of these different types of systems, researchers have explored developing hybrid systems – systems that use more than one type of algorithm for generating EEW (Kodera, 2018; Peng et al., 2020).

An ongoing work In New Zealand, a research project led by the Crisis Response and Integrated Simulation Science Laboratory (CRISiSLab) of the Joint Centre for Disaster Research (JCDR), Massey University, is currently studying innovative approaches to Earthquake Early Warning System[1] (EEWS) including using low-cost sensors and decentralised approaches. They have implemented a unique EEW network architecture using the PLUM (Propagation of Local Undamped Motion) based algorithm at the sensor nodes to detect earthquakes (Prasanna et al., 2022). However, the PLUM algorithm has limitations, as the algorithm is mostly limited to a 30-kilometre radius which only can give a 10-second warning time (Prasanna et al., 2022). Having a 10-second warning time can be beneficial to the areas near the epicentre but providing 10 seconds of warning time for the areas far from the epicentre is not sufficient since a longer warning window can be provided to those areas at the moment of detecting an earthquake.

To overcome this key limitation with EEW algorithms, a novel hybrid EEWS has been proposed for low-cost MEMS-based sensors which use the PLUM approach to generate a warning to the areas near the epicentre and a more traditional source-based method to generate warnings to the areas far from the epicentre with increased warning time through exploring the feasibility of implementing a P-wave detector to detect the P-waves[2] and predict the earthquake's magnitude at the sensor node itself. This could benefit the EEWS to disseminate the alerts to the end-users with the earthquake's magnitude and help the EEWS dynamically change the alerting region according to the predicted magnitude to reduce the number of false alerts. However, when exploring literature related to P-wave-based detection and warning, it is evident that detecting P-waves in real-time and estimating the magnitude of an earthquake using the characteristics of the P-waves create significant challenges which lead to inaccuracies. Therefore, it is important to analyse the P-wave-based approaches carefully to overcome these challenges to gain the end-user trust toward EEW.

Even though there are several algorithms for detecting P-waves and estimating the earthquake's magnitude using the P-waves, there is no literature discussing the different algorithms used for EEWS in terms of their processing time, reliability and accuracy. As a first step toward reviewing the pros and cons of each EEW algorithm, the P-wave detection algorithms and earthquake magnitude prediction algorithms should be clearly understood. Therefore, towards generating such a comprehensive understanding of the use of P-waves for EEWS, this Work in Progress paper (WiPe) reviews present and past literature on P-wave detection algorithms and their applications for earthquake detection. Identifying the different approaches carried out toward generating EEW will be helpful for researchers in the future to develop more appropriate and robust algorithms for their EEWS.

The paper is structured as follows. The paper starts by providing a background on earthquake early warning, Then the paper presents the methodology for conducting the proposed literature review. This will be followed by the initial findings of the literature review. Finally, the paper concludes with the next steps of the research.

BACKGROUND

Throughout history, disasters have created devastating consequences to people and infrastructures (Coppola, 2007). Earthquake is one that poses a serious threat to areas near major active faults on land or offshore subduction zones (Adhikari et al., 2018). Compared to other hazards such as cyclones and tsunamis, earthquakes cannot be predicted hours in advance where they can only be detected in the event of an earthquake: earthquake detection and warnings happen within seconds. This makes building an EEWS challenging due to the short period between the detection of an earthquake event and its forthcoming destructive impact (Fischer et al., 2012). Two facts enable the operation of EEWSs (i) the information travelling over communication networks moves faster than seismic

[1] A system of accelerometers, seismometers, communication, computers, and alarms that are devised for notifying regions of a substantial earthquake while it is in progress.

[2] Primary waves are a type of body waves that are generated at first during the earthquake and travel faster compared to any other seismic waves.

waves - P-waves (primary or pressure waves) and S-waves[3] (secondary or shear waves), and (ii) the most damage during an earthquake occur with S-waves which arrive later than P-waves (Fischer et al., 2012). To generate alerts, EEWSs use a network of sensors distributed in a geographical area to detect earthquakes and transmit alerts in real-time. Generally, the early warning window can be a few seconds to tens of seconds depending on the specific geometry of the earthquake and the stations used in EEWS (Y. M. Wu & Zhao, 2006).

During the last three decades, many high-end EEWSs have evolved and operated in several countries or regions worldwide including Japan, Taiwan, Mexico, South Korea, China and USA (Y. Wang et al., 2020). Even though these systems have improved significantly, become more robust, and have shown better results in detecting earthquakes, exorbitant costs associated with building modern-day high-end EEWS can make it impractical and less affordable not only for developing countries but even for developed countries (Prasanna et al., 2022). For example, the ShakeAlert EEWS in the USA is currently implemented only in three states namely California, Oregon, and Washington and the implementation costs approximately 100 million USD (Brooks et al., 2021). The high financial costs associated with current EEWSs and the latest technical advances in sensor technology have steered researchers to investigate low-cost EEWSs to detect earthquakes (Lin et al., 2012). There have been several research conducted in developing EEWSs using low-cost Micro-electromechanical systems (MEMS) based sensors. Examples of systems that use low-cost MEMS-based sensors include those in Taiwan (Lin et al., 2012), California (Clayton et al., 2015), China (Peng et al., 2013), Iceland (*TurnKey Earthquake Early Warning*, 2020) and New Zealand (R. M. Allen & Stogaitis, 2022; Prasanna et al., 2022).

When it comes to EEW algorithms, source-based algorithms detect the earthquake and disseminate the alert to EEW stakeholders with detailed information about the detected earthquake. These algorithms typically use a few seconds of P-wave data (0.5–4 s) from 2 to 6 sensors close to the epicentre to detect an earthquake and characterise the location, origin time, and magnitude by employing an appropriate ground motion prediction equation (GMPE) (R. M. Allen & Melgar, 2019). Ground motion and wavefield-based algorithms became popular due to their robustness and fast processing time. They do not estimate the source parameters of an earthquake (Hoshiba, 2013; Hoshiba & Aoki, 2015; Kodera, 2018). Thus, they avoid vulnerabilities of the source-based algorithms (Hoshiba, 2021). The core idea of these algorithms is the use of the present state of ground shaking and knowledge of propagation physics in a concise time to forecast the likely evolution of ground motion intensity in the future (R. M. Allen & Melgar, 2019). On-site-based algorithms detect an earthquake using a single station using a simple ground motion threshold to generate an alarm or warning (R. M. Allen & Melgar, 2019; Bindi et al., 2015; Picozzi, Emolo, et al., 2015). However, few improved on-site-based algorithms can detect P-waves and generate an alert when the intensity of the following S-wave is predicted to be destructive (R. M. Allen & Melgar, 2019). Generally, source-based algorithms take a longer time to detect an earthquake compared to other types of algorithms due to their source parameter estimation (R. M. Allen & Melgar, 2019). Therefore, almost all the EEWSs that adopted the source-based algorithms generate only alerts to areas far from the epicentre whereas on-site algorithms were adopted for alerting the areas near to the epicentre (D.-Y. Chen et al., 2015; C. Y. Wang et al., 2022). However, adopting on-site-based algorithms for generating alerts resulted in a higher number of false alerts (R. M. Allen & Melgar, 2019). Ground motion-based algorithms became popular recently due to their robustness and fast processing time (Prasanna et al., 2022). These types of algorithms are becoming suitable for alerting regions near the epicentre. However, it can be used to alert only a defined distance. For example, for the PLUM-based ground motion approach, it is 30 km (Kodera et al., 2018).

METHOD

To explore the different algorithms used for EEW, relevant articles were collected from the databases Scopus and Web of Science using a keyword search on 17 May 2022. Articles published since 2000 were considered for the search because a scan of existing literature showed that there was not much literature related to EEW before then. To review the different algorithms used for P-wave detection and earthquake magnitude estimation, “earthquake early warning” and “p-detector” were used as the primary keyword to answer the questions. In addition to that, “earthquake warning” and “earthquake detection” were used as alternatives to “earthquake early warning”. Similarly, "p-wave", "s-wave", "p-phase", "s-phase" were used as alternatives to “p-detector”. Peer-reviewed academic publications available online in a full-text format and relevant to the research aims are only included in the search, and publications in languages other than English; grey literature, such as government or industry reports; and non-academic research are excluded from the search. The initial search produced 491 relevant articles. Duplicates from the Initial results were removed and filtered further if they had the following content.

[3] Secondary or shear waves arrive following the P-waves during the earthquake and these are more destructive compared to P-waves.

- Algorithms which are not related to generating EEW.
- Evaluating and assessing the performance of the EEW algorithms.
- Algorithms related to structural monitoring and civil engineering.
- Algorithms not related to ground motion sensors, such as Optical fibres, Distributed Acoustic Sensing, GPS sensors, Gravity strain meters, GNSS sensors, and Transoceanic smart cables.
- Algorithms are only related to earthquake location estimations, calculating site factors, and reducing power consumption.
- Articles only discuss the EEW implementation and not the detection algorithm.

After filtering the articles, 144 articles were selected for review. Figure 1 illustrates the number of papers returned at each step following the filtering process.

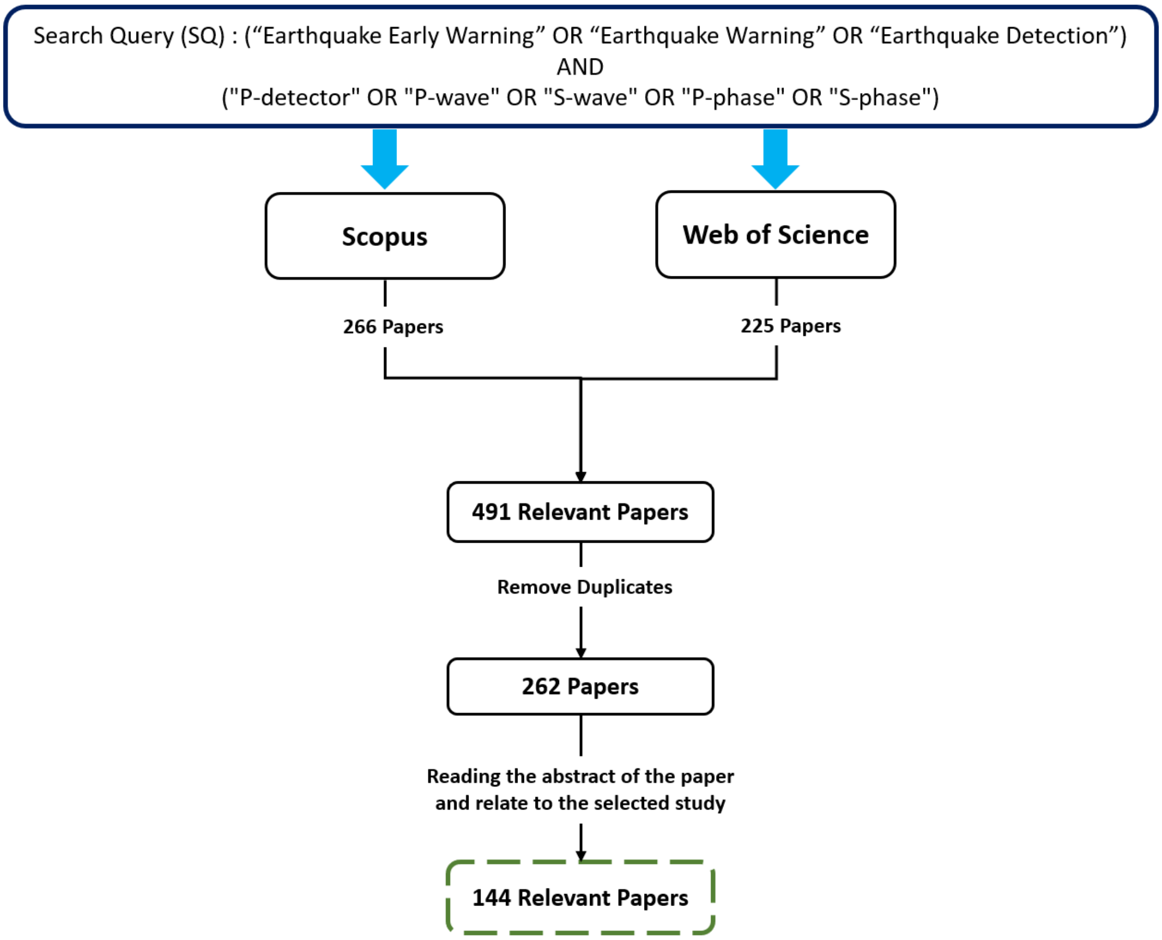

Figure 1. Flow diagram for the article filtration.

The relevant data from the selected articles are extracted by introducing a qualitative systematic review process where the research evidence is searched systematically from the primary qualitative studies and the findings are merged. Analysed information added to a Microsoft excel sheet by creating a table in an organised manner. Summary of the selected 144 articles made available upon request for the readers who are interested.

FINDINGS

Analysis of the 144 articles reveals the different P-wave detection approaches, earthquake magnitude prediction techniques implemented worldwide, and the contextual differences between using such algorithms and the technologies used. The first sub-section discusses the various P-wave detection techniques adopted by different EEWSs. This will be followed by a discussion on the earthquake magnitude estimation algorithms.

P-Wave Detection Algorithms

Firstly, the literature on P-wave detectors was explored where different algorithms are proposed for the automatic detection of real-time P-wave arrivals. From the literature, the most commonly used method for detecting the P-waves is the Short-Term Average/Long-Term Average (STA/LTA) method (Ding et al., 2017; Peng et al., 2017; Qingkai & Ming, 2012; Y.-M. Wu & Mittal, 2021). STA/LTA was introduced by Allen (R. v. Allen, 1978) for automatically detecting the P-waves in seismology. The STA/LTA is the most used algorithm in weak motion. It has two moving windows namely: the STA window and the LTA window. It calculates the sum of the absolute value of STA and LTA amplitudes. The STA/LTA ratio is then calculated, and when it exceeds a predefined threshold, the phase of the P-wave is identified. (Khalqillah et al., 2018). Even though STA/LTA algorithm has been adopted by several EEW implementations, STA/LTA algorithm is prone to result in false alerts due to the high background noise of the seismic instruments (Bose et al., 2020). This led researchers to implement different algorithms to detect P-waves with a minimal number of errors. The following table (Table 1) summarises different P-wave detection approaches attempted by researchers to detect P-waves during an earthquake.

Table 1. Summary of the approaches implemented for detecting P-waves during an earthquake.

Authors	Title of the Article	Approach in detecting P-waves
Küperkoch et al., 2010	Automated determination of P-phase arrival times at regional and local distances using higher order statistics.	Identification of the P-phase is done by applying Akaike Information Criterion to the characteristic function. The accurate P-wave arrival time is determined using a pragmatic picking algorithm on the recalculated characteristic function. Also, a Jackknife procedure and an envelope function analysis are applied to the characteristic function to reduce the false P-phase picks.
Hafez et al., 2010	Clear P-wave arrival of weak events and automatic onset determination using wavelet filter banks.	Automatic P-wave arrival detection of local events using wavelet transformation. The proposed algorithm is independent of the nature of the noise at the site and the type of seismometer used.
Qingkai & Ming, 2012	Evaluation of earthquake signal characteristics for early warning.	This approach uses a modified STA/LTA method to detect P-waves. This approach eliminates the impacts of spike-type noise and small pulse-type noise prior to the commencement of the P-wave from the usual STA/LTA approach by adding two new parameters.
Bhardwaj et al., 2013	Root sum of squares cumulative velocity: An attribute for earthquake early warning.	P-wave is detected by computing two parameters namely: Root Sum of Squares Cumulative Velocity (RSSCV) and Cumulative Absolute Velocity (CAV), and compared with predetermined threshold values.
Baillard et al., 2014	An Automatic Kurtosis-Based P - and S -Phase Picker Designed for Local Seismic Networks.	A new kurtosis-based technique for automatically selecting P-phase and S-phase arrivals and easy to implement with high picking accuracy.
Bogiatzis & Ishii, 2015	Continuous wavelet decomposition algorithms for automatic detection of compressional- and shear-wave arrival times.	This method uses the continuous wavelet transformation of the waveform where P-waves are identified by calculating the wavelet coefficients using the vertical component of the ground motion recording.

Z. Wang & Zhao, 2017	Automatic event detection and picking of P, S seismic phases for earthquake early warning and application for the 2008 Wenchuan earthquake.	This approach uses combination of high-precision algorithms to detect phases of P and S-waves. First, an amplification coefficient is introduced to the STA/LTA characteristic function for a better detection of the P and S-phases. Along with that, higher order statistics and the Akaike information criterion function have been utilised to narrow the signal and lock more accurately on the arrival time of the P and S-phases.
Kwon et al., 2018	A new P-Wave detector via moving empirical cumulative distribution function.	This method is based on the shape of the absolute-valued signal's moving empirical cumulative distribution function (MECDF) in a moving window. It uses one fewer window than the STA/LTA approach, which removes the load of window length optimisation while maintaining a comparable level of performance.
Z. Li et al., 2018	Machine Learning Seismic Wave Discrimination: Application to Earthquake Early Warning.	A machine learning based method It uses Trained Generative Adversarial Network (GAN) to detect P-waves.
Kodera, 2018	Real-Time Detection of Rupture Development: Earthquake Early Warning Using P Waves from Growing Ruptures.	This approach uses simple polarisation analysis technique to detect P and S-waves.
Dokht et al., 2019	Seismic event and phase detection using time-frequency representation and convolutional neural networks.	A machine learning based method. Using a deep convolutional network (ConvNet), a generalised model has been created to enhance the ability to distinguish between earthquake and noise recordings. P and S waves are separated from one another, and their approximate arrival times are calculated using a secondary network that employs the main seismic arrivals' wavelet transform.
Mousavi et al., 2020	Earthquake transformer—an attentive deep-learning model for simultaneous earthquake detection and phase picking.	A machine learning based method. It uses a global deep learning model for detecting earthquakes and picking the phases of P and S waves at the same time.
Walter et al., 2020	easyQuake: Putting machine learning to work for your regional seismic network or local earthquake study.	A machine learning based method. This approach uses an associator and a phase picker driven by machine learning to detect the arrival of P-waves.
Tous et al., 2020	Deep neural networks for earthquake detection and source region estimation in north-central Venezuela.	A machine learning based method. P-wave earthquake detection and source region estimate using a deep convolutional neural network called UPC-UCV (Universitat Politecnica de Catalunya-Universidad Central de Venezuela), using single-station three-channel signal windows.
Bose et al., 2020	Framework for Automated Earthquake Event Detection Based on Denoising by Adaptive Filter.	An Enhanced Variable Step-Size Least Mean Square (EVSSLMS) technique for P-wave detection. The EVSSLMS algorithm is used in the proposed event detection strategy to denoise the seismic data before the usual STA/LTA technique is used to detect the arrival of the P-wave.

Sugondo & Machbub, 2021	P-Wave detection using deep learning in time and frequency domain for imbalanced dataset.	A machine learning based method. The Synthetic Minority Oversampling Technique (SMOTE) approach to detect P-waves is proposed using deep learning with time domain and frequency domain as inputs.
Lapins et al., 2021	A Little Data Goes a Long Way: Automating Seismic Phase Arrival Picking at Nabro Volcano with Transfer Learning.	A machine learning based method. Using the data from the Nabro volcano, a technique known as transfer learning was used to create a deep learning model for automating phase arrival detection for P-waves using a limited amount of training data.
Saad & Chen, 2021	Earthquake Detection and P-Wave Arrival Time Picking Using Capsule Neural Network.	A machine learning based method It uses a capsule neural network (CapsNet) to identify and detect P-waves during an earthquake automatically.
Yanwei et al., 2021	Deep learning for P-wave arrival picking in earthquake early warning.	A machine learning based method Convolution neural network-based automatic algorithm (DPick) was created and trained to detect P-waves.
Liu, Li, et al., 2022	Discrimination between Earthquake P Waves and Microtremors via a Generative Adversarial Network.	A machine learning based method Generative adversarial network (GAN) for detecting P -waves and microtremors from the training set obtained from JAPAN.
W. Zhu et al., 2022	An End-To-End Earthquake Detection Method for Joint Phase Picking and Association Using Deep Learning.	A machine learning based method A neural network design for processing seismic waveforms from several stations that were captured using a seismic network which proves that the end-to-end method can successfully detect P- and S-wave arrivals and accomplish precise earthquake detection.
Liu, Song, et al., 2022	Seismic Event Identification Based on a Generative Adversarial Network and Support Vector Machine.	A machine learning based method A hybrid model based on a generative adversarial network (GAN) and a support vector machine (SVM) is introduced for the purpose of detecting P-waves and differentiating between earthquakes and microtremors.
D'Angelo et al., 2022	A new picking algorithm based on the variance piecewise constant models.	It uses the variance piecewise constant models of the earthquake waveform to detect P and S-wave automatically.
Khan & Kwon, 2022	P-Detector: Real-Time P-Wave Detection in a Seismic Waveform Recorded on a Low-Cost MEMS Accelerometer Using Deep Learning.	A machine learning based method It uses a deep learning model that can detect P-waves in noisy environments.
Yamada & Mori, 2022)	P-wave picking for earthquake early warning: Refinement of a Tpd method.	A refinement algorithm called Tpd method is used to determine the P-wave arrival time accurately.
Wibowo et al., 2022	Earthquake Early Warning System Using Ncheck and Hard-Shared Orthogonal Multitarget Regression on Deep Learning.	A machine learning based method. It uses an algorithm called Ncheck for picking the p-arrival on a multi-station waveform by handling the noise.

As captured in Table 1, it can be clearly seen that, the number of attempts in detecting P-wave have increased over the past years. There are several approaches in detecting P-waves based on the mathematical equations (statistics) where the skewness, kurtosis and frequency changes of moving seismic windows were analysed for detecting P-waves (Baillard et al., 2014; Kodera, 2018; Küperkoch et al., 2010; Kwon et al., 2018; Yamada & Mori, 2022). Some researchers have tried wavelet transformation to detect P-waves. Usage of wavelet transformation shows that P-wave can be detected clearly even in a weak seismic event (Bogiatzis & Ishii, 2015; Hafez et al., 2010). As discussed, STA/LTA has shown issues in detecting P-waves in noisy environment. To overcome this issue, some researchers have tried improving the method by modifying or adding new parameters to the algorithm to eliminate the effects of noise (Qingkai & Ming, 2012; Z. Wang & Zhao, 2017). However, with the increased processing power of the computers, machine learning became one of the main tools in detecting P-waves. There are a significant number of articles show that researchers are more focussing on machine learning techniques to detect P-waves where every year the number of papers published on machine learning based P-wave detection are increasing (Bose et al., 2020; Dokht et al., 2019; Khan & Kwon, 2022; Lapins et al., 2021; Z. Li et al., 2018; Liu, Li, et al., 2022; Liu, Song, et al., 2022; Mousavi et al., 2020; Saad & Chen, 2021; Sugondo & Machbub, 2021; Tous et al., 2020; Walter et al., 2020; Wibowo et al., 2022; Yanwei et al., 2021; W. Zhu et al., 2022).

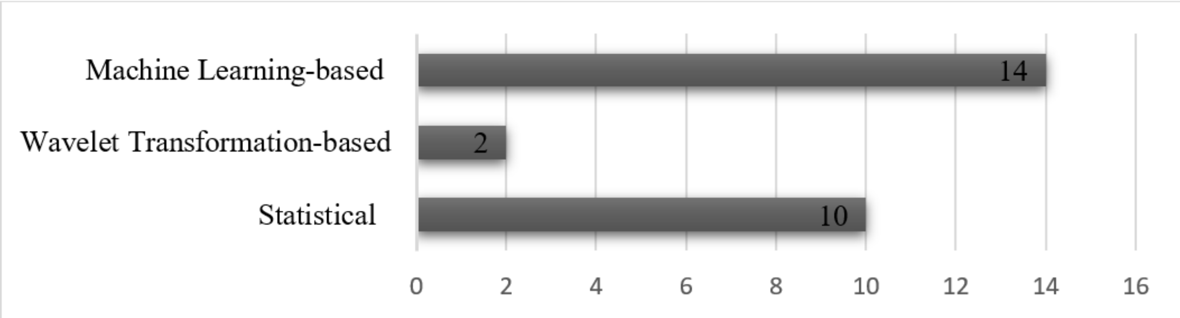

Figure 2. Number articles published in P-wave detection according to the type of approach

Analysis of different algorithms used for P-wave detection and the number of articles published in three different approaches (Figure 2) shows that the evolution of the algorithms started from statistical equations related to the skewness, kurtosis and frequency change of the seismic wave and moved towards machine learning-based techniques over the years. Having discussed the P-wave detection algorithms implemented by different researchers, the next section discusses the algorithms which can predict an earthquake's magnitude using a time window of a detected P-wave.

Algorithms for Estimating an Earthquake's Magnitude

As previously mentioned, estimating an earthquake's magnitude at the first instance of P-wave detection could assist the EEWS to provide alerts to end users with the earthquake's magnitude and it will help in dynamically changing the alerting zones according to the expected magnitude. The literature on techniques used to predict the magnitude of an earthquake has been explored. Generally, in most of the algorithms, an earthquake's magnitude is predicted by analysing a 0.5-4 second time window of the detected P-waves (R. M. Allen & Melgar, 2019). The common technique used in many EEWS implementations is to determine the earthquake's magnitude from the time parameter(Ʊ_c) and Peak displacement Amplitude (P_d) (Linear regression model) (Alcik et al., 2011; D. Y. Chen et al., 2017; Hsiao et al., 2011; Kuyuk & Allen, 2013; Nazeri et al., 2017; Park et al., 2010; Peng et al., 2013; Peng, Yang, Xue, et al., 2014; Peng, Yang, Zheng, et al., 2014; Pinsky, 2017; Romeu Petit et al., 2016; Sasani et al., 2018; Sheen et al., 2014; Tusa et al., 2017; Vallianatos et al., 2021; W. Wang et al., 2009; Y. Wang et al., 2021; Y. M. Wu et al., 2007; Y. M. Wu & Zhao, 2006; Y.-M. Wu, 2017). Several studies indicate that magnitude estimation of S-wave tends to saturate when using such a short time window of P-wave where earthquakes are significantly large and have long rupture durations (M > 6) (Hoshiba et al., 2011; Rydelek & Horiuchi, 2006). To overcome the saturation issues related to the linear regression model, different approaches were implemented by researchers to predict an earthquake's magnitude. The following table (Table 2) summarises the different earthquake magnitude prediction algorithms attempted by researchers.

Table 2. Summary of the approaches implemented for predicting an earthquake's magnitude during an earthquake

Authors	Title of the Article	Approach in Estimating Earthquake Magnitude
R. M. Allen & Kanamori, 2003	The potential for earthquake early warning in Southern California.	It uses the frequency content of the P-waves to determine earthquake's magnitude before any damaging ground motion occurs.
Odaka et al., 2003	A new method of quickly estimating epicentral distance and magnitude from a single seismic record.	It calculates the magnitude of an earthquake from the maximum amplitude measured during a specified short time window following the arrival of the P-wave using an empirical magnitude-amplitude relationship.
Simons et al., 2006	Automatic detection and rapid determination of earthquake magnitude by wavelet multiscale analysis of the primary arrival.	It uses the discrete wavelet transform-based method to analyse the waveform and calculate the final magnitude of an earthquake from the first few seconds of the P wave.
Y. M. Wu & Zhao, 2006	Magnitude estimation using the first three seconds P-wave amplitude in earthquake early warning.	Peak amplitude of displacement (Pd) in the first three seconds after the arrival of the P wave is used for the estimation of the earthquake's magnitude.
Lancieri & Zollo, 2008	A Bayesian approach to the real-time estimation of magnitude from the early P and S wave displacement peaks. Click or tap here to enter text.	It uses the early P and S wave displacement peaks along with the Bayesian probabilistic approach for the real-time estimation of earthquake's magnitude.
Qingkai & Ming, 2012	Evaluation of earthquake signal characteristics for early warning.	It uses stepwise regression analysis of 12 kinds of parameters from the first 3 seconds of the P-wave to estimate the epicentral distance and magnitude of the earthquake.
Kuyuk & Allen, 2013	A global approach to provide magnitude estimates for earthquake early warning alerts.	It determines the earthquake's magnitude using the global scaling relation between Pd (Peak amplitude of displacement) of the P-wave window and magnitude of an earthquake.
Reddy & Nair, 2013	The efficacy of support vector machines (SVM) in robust determination of earthquake early warning magnitudes in central Japan.	This method uses an improved wavelet transformation-based earthquake magnitude prediction approach to estimate an earthquake's magnitude accurately.
J. Li et al., 2013	Continuous estimates on the earthquake early warning magnitude by use of the near-field acceleration records.	It uses the statistical analysis method to determine the earthquake's magnitude by measuring the acceleration, displacement, and effective peak acceleration in each seismic record within a certain time after P wave arrival.
Hloupis & Vallianatos, 2013	Wavelet-based rapid estimation of earthquake magnitude oriented to early warning.	It uses a wavelet-based algorithm for estimating the earthquake magnitude.
Heidari et al., 2013	Magnitude-scaling relations using period parameters τc and $\tau pmax$, for tehran region, Iran.	It determines the magnitude of an earthquake by combining and using the period parameters $\tau pmax$ and τc from the vertical and horizontal components of a P wave's first three seconds.
Meier et al., 2015	The Gutenberg algorithm: Evolutionary Bayesian magnitude estimates for earthquake early warning with a filter bank.	It uses the broadband frequency information of seismic signals in a probabilistic algorithm to estimate the earthquake magnitude.

Picozzi, Colombelli, et al., 2015	A Threshold-Based Earthquake Early-Warning System for Offshore Events in Southern Iberia.	It calculates the Pd (Peak amplitude of displacement) of the P-wave window and uses log Pd vs PGV (Peak Ground Velocity) empirical relationship to predict the earthquake’s magnitude.
Hloupis & Vallianatos, 2015	Wavelet-Based Methods for Rapid Calculations of Magnitude and Epicentral Distance: An Application to Earthquake Early Warning System.	It determines an earthquake's magnitude and estimate its epicentre using wavelet transform (WT) as a processing method. Wavelet coefficients used to characterize the seismogram of the P-wave portion are used for earthquake’s magnitude and location estimation.
Yang & Motosaka, 2015	Ground motion estimation using front site wave form data based on RVM for earthquake early warning.	A machine learning-based method. It uses five input variables observed in the P-wave (earthquake PGA, PGD, pulse rise time, average period and the Vp max/Ap max ratio) in a relevant vector machine (RVM) to estimate the magnitude of an earthquake.
Atefi et al., 2017	Rapid estimation of earthquake magnitude by a new wavelet-based proxy.	It uses a wavelet-based scale regression of log (λlog) value extracted from the P-wave window for predicting earthquake’s magnitude.
Noda & Ellsworth, 2017	Determination of earthquake magnitude for early warning from the time dependence of P-wave amplitudes.	It calculates the displacement of the P-wave before the arrival of the peak amplitude and uses the built relationship between the earthquake magnitude (M) and P-wave displacement to estimate the earthquake’s magnitude.
Lizurek et al., 2017	Fast Moment Magnitude Determination from P-wave Trains for Bucharest Rapid Early Warning System (BREWS).	It uses P-wave spectral levels to determine the earthquake’s magnitude.
Cuéllar et al., 2018	An earthquake early warning algorithm based on the P-wave energy released in the ts–tp interval.	To estimate the magnitude threshold, the P-wave coda's energy on the vertical component during the tS - tP period is measured.
Z. Wang & Zhao, 2018	A new Mw estimation parameter for use in earthquake early warning systems.	It calculates the initial P-wave window’s squared displacement integral (ID2) to estimate earthquake’s magnitude.
Ochoa et al., 2018	Fast magnitude determination using a single seismological station record implementing machine learning techniques.	A machine learning-based approach. It uses only five seconds of signal from a single three component seismic station's P wave to derive the earthquake’s magnitude (Ml) using the Support Vector Machine Regression (SVMR) algorithm.
J. Zhu et al., 2021	Magnitude Estimation for Earthquake Early Warning Using a Deep Convolutional Neural Network.	A machine learning-based approach. An advanced model for magnitude prediction that employs the 3-seconds of P-wave data into a deep convolutional neural network for earthquake magnitude estimation.

Zhang et al., 2021	Real-Time Earthquake Early Warning with Deep Learning: Application to the 2016 M 6.0 Central Apennines, Italy Earthquake.	A machine learning-based approach. A deep learning technique that analyses continuous seismic waveform streams to simultaneously detect earthquakes and estimate their source properties such as earthquake's magnitude and location using fully convolutional networks.
Abdalzaher et al., 2022	A Deep Learning Model for Earthquake parameters Observation in IoT System-based Earthquake Early Warning.	A machine learning-based approach. A deep learning model based on integrating autoencoder (AE) and convolutional neural network (CNN) is presented (3S-AE-CNN) for a rapid determination of an earthquake's magnitude and location after three seconds from the beginning of the P-wave.
J. Zhu et al., 2022	Magnitude Estimation for Earthquake Early Warning with Multiple Parameter Inputs and a Support Vector Machine.	A machine learning-based approach. To estimate earthquake magnitudes, it uses a variety of parameter inputs, including the support vector machine magnitude estimation (SVM-M) model.

From the above table (Table 2) it can be clearly seen that the number of attempts in predicting the magnitude of an earthquake have increased over the years. As mentioned, almost all the algorithms analyse the characteristics of a P-wave in a particular time window to predict the magnitude of an earthquake. However, similar to the P-wave detection algorithms, the evolution of the magnitude estimation algorithms started from linear regression models where the magnitude of an earthquake estimated by forming a correlation between the parameters of the detected P-wave time window and historical earthquakes' magnitude, and moved towards machine learning-based techniques over the years. Analysis of different earthquake magnitude estimation approaches show that an earthquake's magnitude can be estimated successfully.

NEXT STEPS AND FUTURE WORK

From the above analysis, it is evident that the implementation of the P-wave based EEWS is achievable. Therefore, in order to select an appropriate P-wave detector, as a next step, experiments will be conducted to identify an appropriate lightweight and easy-to-implement detection algorithm to detect the P-waves. This is important since the low-cost MEMS-based sensors used in our CRISiSLab EEW network only possess limited processing power and memory. While selecting an appropriate P-wave detector, experiments will be designed in such a way that the P-wave detectors will be ranked according to the processing time of the algorithm. It is crucial to keep the processing time to be minimal so that the warning time can be maximised. Furthermore, the detection error will also be compared between the P-wave detectors before making the selection. In addition to that, the performance of the algorithm in a noisy environment will be analysed, because according to the literature, P-wave detectors produce inaccurate results in noisy environments. Finally, the algorithms will be tested in the sensor environment, for example, algorithms which perform well only in the sensors that are installed in the boreholes (Kodera, 2018) will not be a feasible option to implement since the sensors installed in the CRISiSLab EEW network are surface-based stations which are installed in homes belonging to members of the public. Therefore, the P-wave detector will only be selected after having considered the above-mentioned criteria.

After selecting the appropriate P-wave detection algorithm, our next phase of work will be identifying the appropriate earthquake magnitude estimator which can use the characteristics of the P-wave. For that, an in-depth comparison and analysis of the magnitude predictors will be conducted. To select the most suitable magnitude estimator, the complexity of the algorithm will be reviewed in terms of the processing time and estimation error. As mentioned, earlier, due to the limited processing power and memory of the low-cost MEMS sensors used in the CRISiSLab EEWS, the most appropriate method to estimate the earthquake's magnitude needs to be simple and easy to implement. Also, the methods will be analysed and the one with the least estimation error will get selected. In addition to that, the selected magnitude estimator will be tested with complex scenarios related to large earthquakes (M > 6) where the possible entanglement of P-wave and S-waves will occur as the earthquake size increases. Such P and S wave collisions could lead to detection errors and may result in false alerts. However, such challenges will be overcome by including aleatory and epistemic uncertainties of seismic waveforms from large-magnitude earthquakes. The selected earthquake magnitude predictor should satisfy all the above-mentioned factors.

After identifying the appropriate P-wave detector and earthquake magnitude predictor suitable to be used along with the PLUM-based approach, the plan is to compare the results with the previous work carried out on P-wave-based EEW approaches in other parts of the world. In this stage, the plan is to evaluate the results about the processing speed, estimation error and warning time by using appropriate evaluation procedures and engaging with international experts. Also, a comprehensive systematic literature review on the EEW algorithms will be submitted to a journal.

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Geospatial Impact Analytics of Hydrometeorological Hazards: A Study on Urban and Suburban Floods in Sri Lanka using Online Textual Data

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ABSTRACT

Urban and suburban communities in tropical countries like Sri Lanka typically experience hydrometeorological hazards that substantially damage property and lives. Although accurate forecasts of weather events are available, the decision-makers often fail to mitigate the actual impact of these forecasts alone. The adverse impacts experienced by the community and reported by news and online media complement this fact. The forecast-impact disparity underpins the scope for holistically linking the forecast data with actual impact. This paper presents a work-in-progress study that develops a geospatial analytics framework using online textual data for assessing the spatiotemporal impact of the hydrometeorological hazards in disaster hot spots. The preliminary findings show prospects for extending the study to impact-focused visualization and forecasting that capture the community's and decision makers' attention for better interventions. For example, these include the degree of disaster response, planning and scheduling critical infrastructure and estimating damages, compensations and insurance claims.

Keywords

Impact-based warnings, geospatial impact, textual data, urban flood.

INTRODUCTION

Hydrometeorological hazards such as floods, landslides, and mudslides caused by extreme weather events, such as hurricanes, tornadoes, and tropical monsoons, inflict significant damage on property and human lives. Sri Lanka, a tropical island nation close to the Bay of Bengal, frequently experiences the adverse consequences of hydrometeorological hazards. The Disaster Management Center of Sri Lanka reported that approximately 1.98 million Sri Lankans were affected by hydrometeorological hazards (mainly floods) from 2009 to 2018 (Basnayake et al., 2019). Moreover, Dias et al. (2018) employed a flood damage forecast model to show that a flood event in a 140 square km urban area, with average inundation depths ranging from 0.48 m to 1.28 m (and outliers up to 5.8 m), could inflict damages that range from USD 37 to 549 million. Many factors, including anthropogenic activities such as wetland reduction, land reclamation, and unsustainable development projects, can cause the impact severity of flood events to significantly differ from the predictions (Wagenaar et al., 2019). Investing in prevention, mitigation, and preparedness strategies that counter these causes can significantly mitigate the impact and severity of the hazards while reducing the inflicted economic damages by 70% (Shreve and Kelman, 2014). However, in developing countries such as Sri Lanka, the problems in regulatory structure, lack of funding, deficiencies in necessary laws and regulations, and lack of required resources and skills hinder the implementation of holistic measures for disaster resilience (Ginige et al., 2010; Jayawardena, 2015). A more pragmatic approach should enable a swift decision-making process for households, authorities, and government entities to minimize the impact severity of hydrometeorological hazards. Such an approach could use an input-output variable-based impact forecasting system, which requires lesser capital investments and resources.

Figure 1 shows a macro-level aggregation of the textual data on contemporary studies focusing on the hazards in Sri Lanka for the period 2011-2022. The bibliographic search conducted on the Scopus database (https://www.scopus.com/search) using the search term (TITLE-ABS-KEY (“hazards" AND "Sri Lanka")) yielded 494 results in this area. As shown in Figures 1a and b, the studies have focused on three fronts: disaster risk reduction (red colour code), understanding the natural disaster phenomena (blue colour), and socio-economic impact of disasters (green colour code). The studies scrutinize the approaches to modelling the impact of natural hazards using physical or computational approaches. Moreover, Figure 1c shows that the links between studies have minimal scope for the impact-based forecasting of meteorological hazard events. The application of hydrological models such as the Synthesis and Reservoir Regulation (SSARR) hydrologic model, the Hydrologic Modeling System (HEC-HMS), the North American Mesoscale Model (NAM) and the Non-linear Cascade Model has been a common trend to systematically forecast the physical damages in most countries similar to Sri Lanka (Sivakumar, 2015). For instance, this practice has been commonly employed in countries like India, Thailand, Kampodiy, Vietnam and China in forecasting the flood events induced by rivers in inter-state or inter-country regions (Sivakumar, 2015). The impact of the hydrometeorological hazards on the river basins and urban and sub-urban regions in Sri Lanka can be seen in the studies (Figure 1d). The notion has shifted towards using social media and natural hazard effects on communities in more recent studies (i.e., 2017-2018). More flooded sites were found in central urban districts, generally residential or industrial areas, roads, and other traffic-related places for hot spots affected by the disaster.

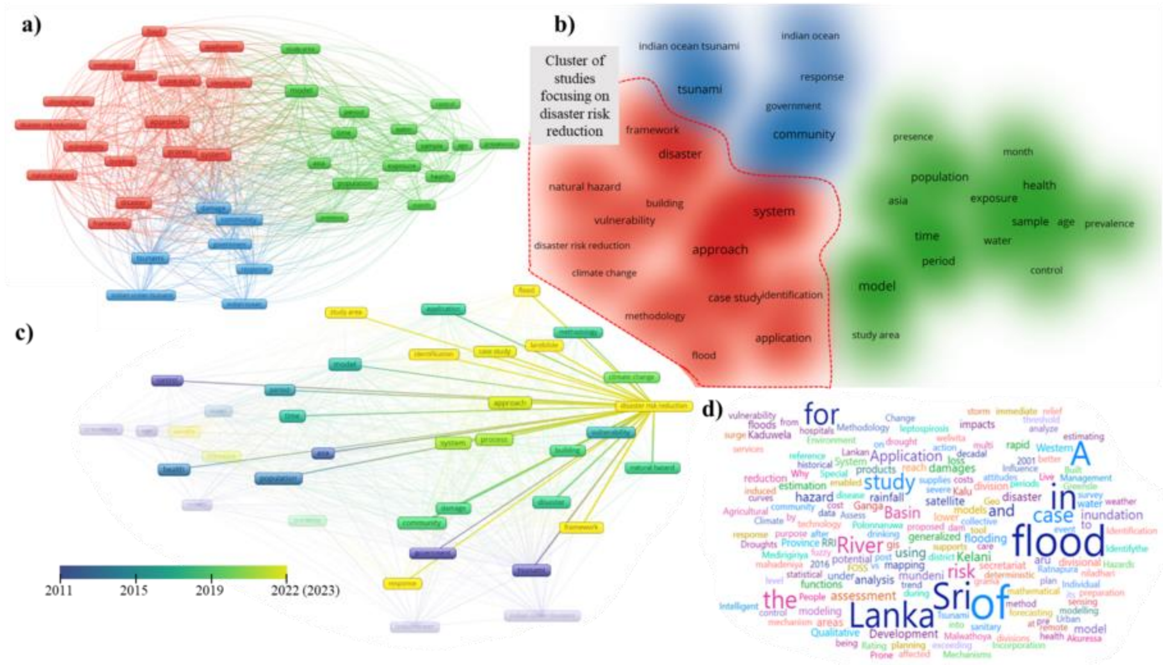

Figure 1. Textual data analysis of the studies pertinent to hazards in Sri Lanka published on Scopus indexed journals from 2011 to 2022: a) network of bibliographic cluster analysis of 494 articles [*Search term:* TITLE-ABS-KEY ("hazards" AND "Sri Lanka")]; b) high frequency words in respective study clusters (colour code: red - disaster risk reduction, blue - understanding natural disaster phenomena, green - socio-economic impact of disasters); c) key focus areas linked to disaster risk reduction with the year of publication; d) word cloud generated from the abstracts of the articles related to hydrometeorological hazards

Although the predictive capability of hydrometeorological models has significantly improved with time, the disasters continue to result in severe adverse impacts on the communities (Weyrich et al., 2018). The evidence suggests that people tend to overlook the hydrometeorological warnings since they have little understanding of the forecast with the potential damages (Weyrich et al., 2018). The recent literature advocates including information about hazards, impacts, and 'what to do' in a warning message (e.g., Singkran 2017; Potter et al. 2018; Robbins and Titley, 2018). Potter et al. (2018) indicate that impact-based warnings may be more effective than phenomenon-based warnings in influencing the recipient's perception of the hazardous event (their sense of threat, concern, and understanding of the potential impacts). Robbins and Titley (2018) show that a symbol and polygon-based summary layer give an at-a-glance view of likely high-impact weather for the week ahead, together with the gridded daily probability forecasts would make the forecast message stronger. For instance, shifting from a passive response that relies mainly on structural measures and emergency responses to a progressive response that emphasizes non-structural measures and participatory collaboration among government agencies and stakeholders (people, public, and private agencies in the affected areas) have improved the flood risk management of Thailand (Singkran, 2017). Word frequency analysis and text mining from social media have substantial applications in impact forecasting and modelling the dynamics of hurricane evacuation decisions (Jayasingh et al., 2016; Fang et al., 2019; Dou et al., 2021; Roy and Hasan, 2021). The significant advantage of these attempts is the rapid modelling capability of temporal variation of precipitation distribution and hazard intensity using real-time data. Yeo et al. (2018) showed that rapid network assessment and manual content analysis could expedite the information extraction from the megabytes of digitally available data. The recent developments in these areas have focused on rapid and accurate disaster response strategies using the fusion of multi-source multimodal data through robust deep learning techniques (Algiriyage et al., 2022). Nevertheless, ensuring the accuracy of online information and expanding the application for all phases of disaster management pose substantial challenges for future research.

This work-in-progress paper shows the potential of developing a geospatial analytics model that provides both visualizations and predicts the impacts of hydrometeorological hazards by extracting both online and offline weather impact data for Sri Lanka. Moreover, to counter the absence of online data in rural Sri Lanka due to infrastructure issues and a relatively low number of technology users, this study explores the possibility of collecting primary textual data reported from various stakeholders. The collation of data from such sources expands the sample size and the number of attributes or predictive variables to analyze. The working paper employs online impact reports to extract the textual data and mine the location information. The geospatial distribution of the hazard events is visually analyzed using the mined data employing open-source geographical information system software (i.e., QGIS). The prospective steps of the study would develop supervised learning classification models to predict the impacts using the insights taken from visual analytics. The study will produce a recommender system that can provide descriptive, predictive and scenario analytics for the decision makers to make informed decisions almost in real-time.

PROPOSED METHODOLOGY

Figure 2 shows a holistic framework of the work-in-progress methodology used in this study. It contains the following phases: data acquisition, preprocessing, development of analytics models, visualization analytics and impact predictions. Data acquisition tools extract weather impact data from online newspaper articles, social media, and other online sources. In the data preprocessing stage, insights into hydrometeorological hazards are derived using descriptive statistic measures. Here, the data summarizations provide basic information about the characteristics of the variables in the data set, such as the mean number of deaths, and injured, where the highest number of events occurred, and the relationships between the variables.

Moreover, data transformations, such as min-max and log transformations, are applied to address the skewness of scale-dependent multi-modal data. The development of the analytics model includes feeding the data to a geospatial database and visually analyzing the impacts. The impact prediction model will be developed using a machine learning model that feeds the output dashboard (developed using Microsoft Power Bi) to visualize and better reveal the impact of the hazard. As such, the optimum machine learning model calibration would be defined based on the insight derived from the preliminary analytics phases.

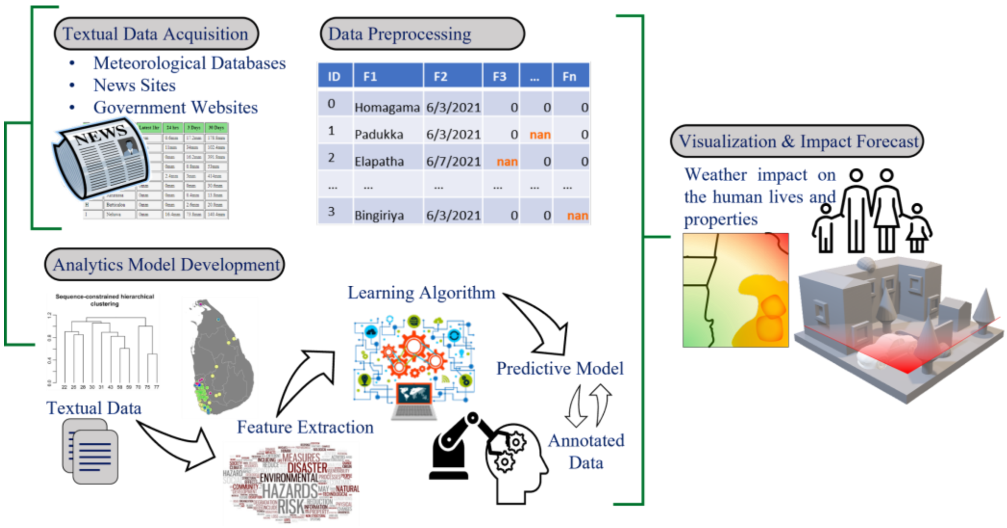

Figure 2. Proposed integrated framework for forecasting flood impact using online textual data

PRELIMINARY WORK

Textual Data Acquisition

The weather forecast data for Sri Lanka from the year 2016 to 2022 was taken from the website of the Department of Meteorology Sri Lanka (meto.gov.lk). The impact data was collected from a disaster inventory system called DesInventar (desinventar.net). The DesInventar database was created in 1994 by the Network for Social Studies in Disaster Prevention in South America (Montgomery and Pinchoff, 2017). DesInventar offers an updated version of the local disaster index within the guidelines of the disaster risk and management indicators program with the aid of the Inter-American Development Bank for the Americas (Marulanda et al., 2010; Edirisinghe and Maduranga, 2021). Also, DesInventar has found applications in Economic Analysts and Sectoral decision-makers since it can identify both the potential effects of extreme events and the persistent accumulation of small local disasters (Marulanda et al., 2010). Moreover, the reported information has been manually fact-checked using local news websites.

Data Pre-processing

Text-based data acquired using web data mining contains repeated information with incomplete information on geolocations. Typically, the dataset contains missing values since online news sources report the incidents differently. In some instances, the reported locations were ambiguous: the central city was reported instead of the administrative division. Thus, the dataset was manually checked to identify the significant discrepancies. The missing values were replaced by the highest frequency of the reported data obtained from the meteorology department of Sri Lanka (meto.gov.lk). Text analytics and matching algorithms were used to check for discrepancies in the English spellings of the local town names using a lexicon of the towns and villages. Table 1 contains the ordered principal feature classes pre-processed for the descriptive and geospatial visual analytics.

Table 1. Feature Collection

Feature	Description
Event	Floods occurred due to hydrometeorological events
Division	Administrative area or city that is affected by the incident
Date	Date of occurrence of the flood event
Deaths	Number of fatalities recorded as directly caused by the flood event
Injured	Number of injured recorded as directly caused by the flood event
Missing	Number of individuals whose whereabouts is unknown since the disaster. This also includes people who are presumed dead, although there is no physical evidence
Houses Destroyed	Number of houses levelled, buried, collapsed, or damaged to the extent that they are no longer habitable
Houses Damaged	Number of houses with minor damage, not structural nor architectural, which may continue being lived in, although they may require some repair or cleaning
Affected Individuals	Number of individuals including all gender and age who were affected by the flood event
Families Affected	Number of families affected by the flood event
Rainfall (mm)	The precipitation height (in mm) reported by the selected media

Analytics Model Development

The impact of the disaster evolved with time and space, presenting scope for establishing a data-driven approach from the forecast and the reported impact data. Figure 3 shows the repeated events and locations and indicates the property damage. The number of houses damaged has been used as a measure for this because the community equally experiences the same impact. The figure shows that the impact can fluctuate in different magnitudes since the number of families affected had changed in orders of tenfold when the impact on the property was comparatively low. In the case of high property damage, the affected families were less. This shows the uncertainty associated with the impact predictions. A potential approach to solve this issue would be employing another layer of data - a data fusion technique to include the qualitative measure of the inundation. Also, a digital elevation model with a proper dataset on the building locations would enable correlating the actual impact. However, that requires multiple parameters such as the surface characteristics of the area, slope characteristics and the vegetation characteristics of the respective area to overlay the inundation map on the locations. The data well represent the impact of the 2017-2018 extreme weather events since a relatively uniform impact was recorded throughout Sri Lanka.

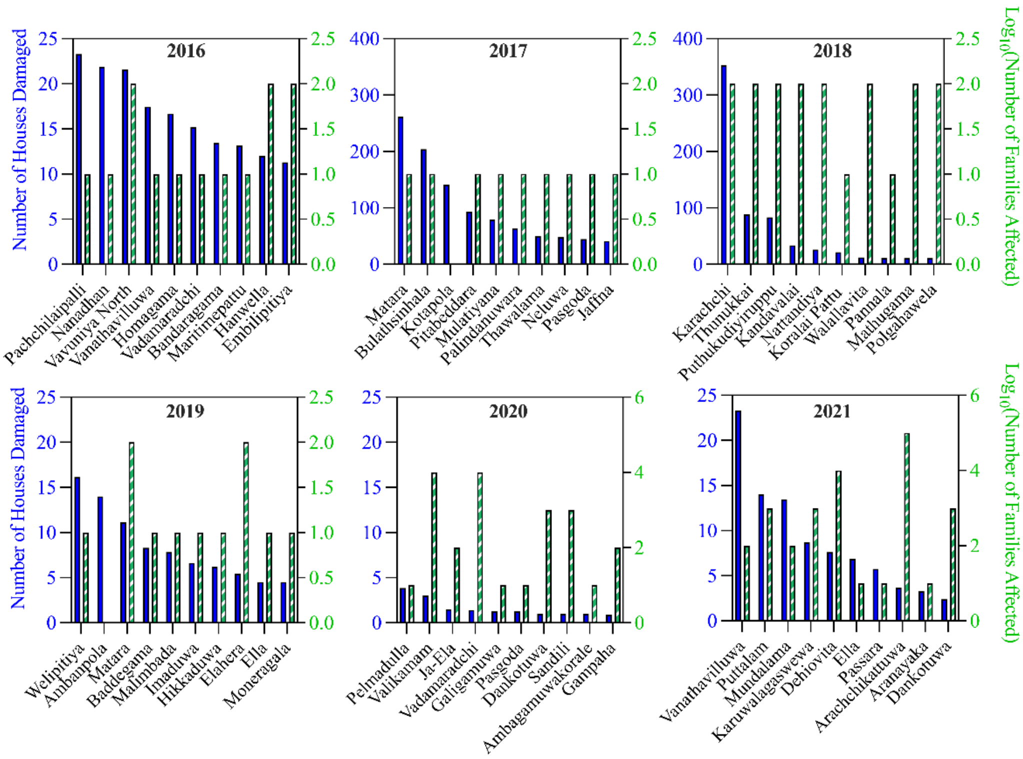

Figure 3. Top ten cities with the largest impact of the flood events from 2016 to 2021.

Figure 4 shows the overlay maps generated for spatial and temporal variation of the hazard incidents for the 2016-2018 period. A high collation of the points can be observed in southwest Sri Lanka (Figure 1a). This conforms to the prior knowledge since Sri Lanka experiences severe adverse impacts from the southwest - monsoon season (May - September). Also, the spatial segregation of the point cloud towards the northern part of Sri Lanka shows the impact of the northeast-monsoon Season (December - February), which generates rapid and extreme hurricane events due to the pressure fluctuations of the Bay of Bengal. The repeated nature of the hazard events along the Kelani valley and the Attanagalu Oya - a river in Gampaha District- (Figure 1b) demonstrates the occurrence of flash flood events near the urban and suburban regions in the western province after the southwest-monsoon season. From the visual analytics, it is clear that the disaster hotspots are geospatially distributed and concentrated near the river valleys (mainly the Kelani valley) and directionally distributed along the southwest to northeast direction.

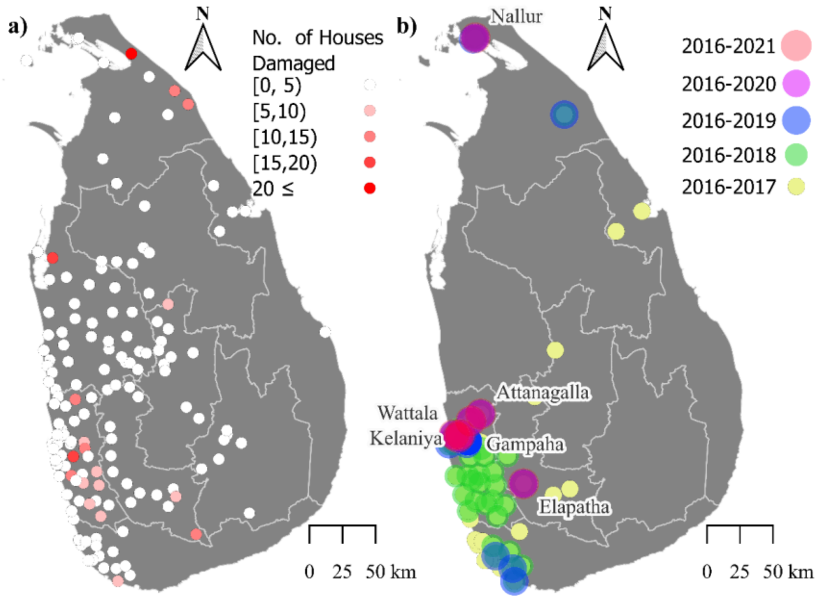

Figure 4. Geospatial distribution of the weather impacts: a) property damages in terms of the houses damaged; b) Repeated occurrences of the flood events from 2016 to 2021

CLOSING REMARKS AND FUTURE WORKS

The fusion of geospatial analytics and textual data analytics can effectively provide deeper insights into the impact of hydrometeorological hazards in urban and suburban regions of the island nation of Sri Lanka. An improved measure for the impact severity of these hazards derived from this analysis can be integrated into the decision-making process. The next stage of this study will classify the impact severity based on a five-scale rank: very low, low, moderate, high, and critical. This would help to compare the magnitude of the hydrometeorological intensity of the weather impact and the necessity of the corrective measures. Such an approach will enable the respective stakeholders and government entities to assess the expected level of intervention they should make during extreme hydrometeorological events. The preliminary results presented in this work-in-progress paper will be extended to visualize and predict the impact and severity of the events. To this end, future studies shall integrate cloud-based machine learning and deep learning approaches.

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A Climate Resilience Platform for Agriculture

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ABSTRACT

The changing climate will see an increase in the frequency, scale, and intensity of future natural disasters. While communities and governments need to work together to mitigate the impact of these emergency events, the business community will also need to adapt to ensure the ongoing sustainability of their enterprises. This is especially true of the agricultural sector which is exposed to climate variability. The Climate Services for Agriculture (CSA) tool is an online interactive digital platform bringing together a variety of climate information specifically for farmers and the agricultural sector. It will enable agricultural businesses, planners, and communities to explore various climate related datasets to better understand how the expected future climate may impact different regions and commodities. This will help people to anticipate and plan for the impacts of a variable and changing climate. We present the CSA tool, available at https://climateservicesforag.indraweb.io/, outlining how it is being developed in collaboration with key stakeholders in the Australian farming community, the climate data available and usage scenarios.

Keywords

Climate, Climate Change, Adaption, Resilience, Agriculture

INTRODUCTION

In recent years, Australia has seen an increase in frequency and intensity of natural disasters, from the drought of 2017-19, the 2019/20 bushfires to the various floods in NSW and Queensland in 2022. These events could become a new normal because of climate change. As well as the immediate impact on communities these emergency events pose, the changing climate exposes the agriculture sector to an increase of business volatility and food security if action isn’t taken to adapt.

To help with this adjustment process, in 2018 the Australian Government established the Future Drought Fund (FDF) (DAFF, 2020) managed by the Department of Agriculture, Fisheries and Forestry (DAFF) (DAFF, 2022a) to assist the agriculture sector to adapt to drought and climate variability. Initial funding supports a four-year work plan from 2020 through to 2024 to build drought resilience in regional Australia.

Drought is a common occurrence throughout the Australian continent and one which has ongoing economic, social, and environmental impacts. The FDF aims to drive adoption of new drought resilient technologies and practices, delivered through various work programs. Key to the success of the FDF is making climate variability and resilience data more accessible to the agricultural sector to help Australian farmers and farm business better understand drought and other climate risks.

The Climate Services for Agriculture (CSA) project (DAFF, 2022b) is one of nine programs under the Future Drought Fund. The aim of CSA is to help Australian farmers understand the impact to their business of climate variability and related trends. This is achieved through a combination of historical weather data, seasonal forecasts and future climate projections made available through an online tool.

The impacts from climate change and future extreme weather events can be mitigated by providing the agricultural sector with the information they need to assess possible future scenarios and to plan adaption strategies. For this to occur, it is essential to have access to authoritative, accurate, reliable and region specific climate information tailored for farmers and the wider rural sector. This is the goal of the CSA tool.

The rest of the paper is organised as follows. First background information is presented about the Climate Services for Agriculture project, including the development process used, the data that's available and the current work plan. Then we provide an overview of the online CSA web tool. Example case studies of how the CSA tool can be used to explore the future climate are then presented. The paper concludes with an outline of future work and a summary of our findings, highlighting how the CSA tool will be a valuable resource for farmers to plan for a future that will be impacted by a changing climate.

BACKGROUND

As noted above, the Australian Government's Future Drought Fund is designed to provide secure, continuous funding for drought resilience initiatives to help Australian farms and communities prepare for the impacts of drought. The first round of FDF funding in 2020 included financial support for the Climate Services for Agriculture project, a collaboration between CSIRO and the Bureau of Meteorology (BOM) to deliver a public website that describes common climate driven agriculture relevant risks for anywhere in Australia.

The partnership between CSIRO and the BOM leverages their respective expertise in agriculture, climate science and their track record of delivering operational science-based systems supporting the Australian community. The BOM is leading the customer engagement and climate data work activities while CSIRO is building the operational online system, managing state engagement activities and the governance oversight.

The CSA project has progressed through several key organisational factors:

- Pilot Regions
  While the CSA tool is a national resource providing climate information for all regions in the country, to focus the development initial regions of interest have been defined. These pilot regions (DAFF, 2022) allow the project team to establish ongoing engagement with key stakeholders and to nurture relationships with target users to ensure the developed system meets their needs.
  The first for pilot regions, decided in March 2021, were the Queensland Dry Tropics, Condamine and the Northern Tablelands, Victorian Mallee and south-east South Australia, and the Western Australian Wheatbelt. Another four pilot regions were announced in November 2021: Tropical North, Central West New South Wales, Riverina and Goulburn-Murray, and Gippsland and Northern Tasmania.

- User centred design
  The CSA tool is being developed through a co-design methodology, to ensure that outputs are fit-for-purpose and are used by the target audience across the agricultural sector.

- Climate Data
  The CSA tool uses various existing climate datasets including historical weather data (temperature and rainfall), seasonal forecasts from the BOM and future climate projections, specifically rainfall and temperature projections for 2030, 2050 and 2070 from CSIRO and the Bureau of Meteorology for medium and high emissions scenarios.

- Commodities
  A commodity is the primary agricultural product or farm output such as wheat, barley, sheep or beef. Each commodity has specific climate and production conditions such as sowing and harvesting times, ideal growing conditions, adverse temperature or rainfall thresholds for example heat stress or frost risk and so on. The CSA tool provides appropriate climate information customised to individual commodities for specific regions.

- Operational System
  The CSA tool has been developed using an agile development methodology, deployed using a Continuous Integration/Continuous Deployment process on a cloud infrastructure.

THE CSA TOOL

The CSA tool is intended to assist Australian farmers and producers to better understand the risks and opportunities facing them over the next 30-70 years. This is done by providing climate data tailored to commodities at specific regions. The data includes historical data (1961-2021), seasonal forecasts (1-3 months) as well as future climate projections (2030, 2050, 2070) for a given location.

Example CSA Interaction

The online tool has been developed under a user led co-design methodology focusing on the user journey. To provide a motivating example of its use, we present the steps taken to interact with the CSA tool for someone interested in the sugar cane commodity in the Cairns region. Several screen shots from the tool will be shown and explained, but the reader is encouraged to follow this example on the web site to explore the many features available. These examples can be repeated using a common web browser (for example Edge, Firefox or Chrome) on a laptop or desktop device. The web site also works on tablets and mobile devices, however the web page presentation will differ from that shown below.

An example interaction with the tool would be as follows:

1. Navigate a web browser to the tool home page: https://climateservicesforag.indraweb.io/.
   The user is presented with a disclaimer that must be accepted before continuing.

2. Select a region.
   This is done by entering a place name, 'Cairns' in this case, or navigating the presented map to the region of interest. This automatically takes the user to the explore page.

3. Explore your future climate.
   This page is divided into two sections 'Climate data to explore' and 'Select specific data sets', described below:

   A. Climate data to explore.
      Choose the climate data to explore. The data options available are:

      i. Key climate indicators for a commodity
         Explore how climate change impacts a chosen commodity at the region of interest. The tool prompts the user to choose from a list of commodities appropriate to the previously chosen region, in this case they are: Dairy, Sugarcane, Northern Beef, Southern Beef. An overview of the commodities available in which regions is described below.

         The user is then presented with three panels showing relevant climate information for the chosen region and commodity, with options to explore different climate change scenarios, see Figure 1. This figure shows that two future climate change scenarios can be chosen (medium or high emissions) for three future 30 year time periods (2016-2045, 2036-2065 or 2056-2085) in reference to two historical reference time periods.

         Various climate information is presented, in this example rainfall and temperature since they are relevant to sugar cane, also shown in Figure 1.

         The third panel shows the various graphs and plots of climate projection data, with examples shown in Figures 2 and 3 below. These show the historical record and future projections of the average minimum temperature at ripening for sugarcane in Cairns for the period May – July.

      ii. General climate trends
         As well as showing climate data for specific commodities, there is an option to show general climate information for the chosen region. This includes annual and seasonal rainfall, various temperate profiles (average maximum and minimums, heat and frost risk) and seasonal evapotranspiration information. As the commodity name suggests, this is general climate information that is expected to be of interest and usual for farmers throughout Australia regardless of location.

      iii. Seasonal outlook
         This presents the expected rainfall for the season ahead by selecting a time period of seasonal or monthly.

   B. Select specific data sets.

The options above have been customised to present the relevant climate data for the selected commodity. Instead of using these tailored interfaces, the user can scroll down the 'Explore your future climate' page, to select a specific commodity and the data sets they are interested in seeing.

Climate Data

Figure 1 (left) shows an example of how the user can select different climate data sets. This example is for the sugar cane commodity in Cairns, but similar options are available for all regions and commodities shown by the tool. Note there are two historical time periods that can be chosen. The first, 1961-1990 and 1991-2020 compares the recent period of 1991 – 2020 to the past period of 1961 – 1990. Similarly, the other time period available, 1962-1991 and 1992-2021 compares the recent period of 1992 – 2021 to the past period of 1962 – 1991. These comparisons allow the user to see if there have been any recorded changes in climate in the selected region over time, providing context for any projected climate changes in your region.

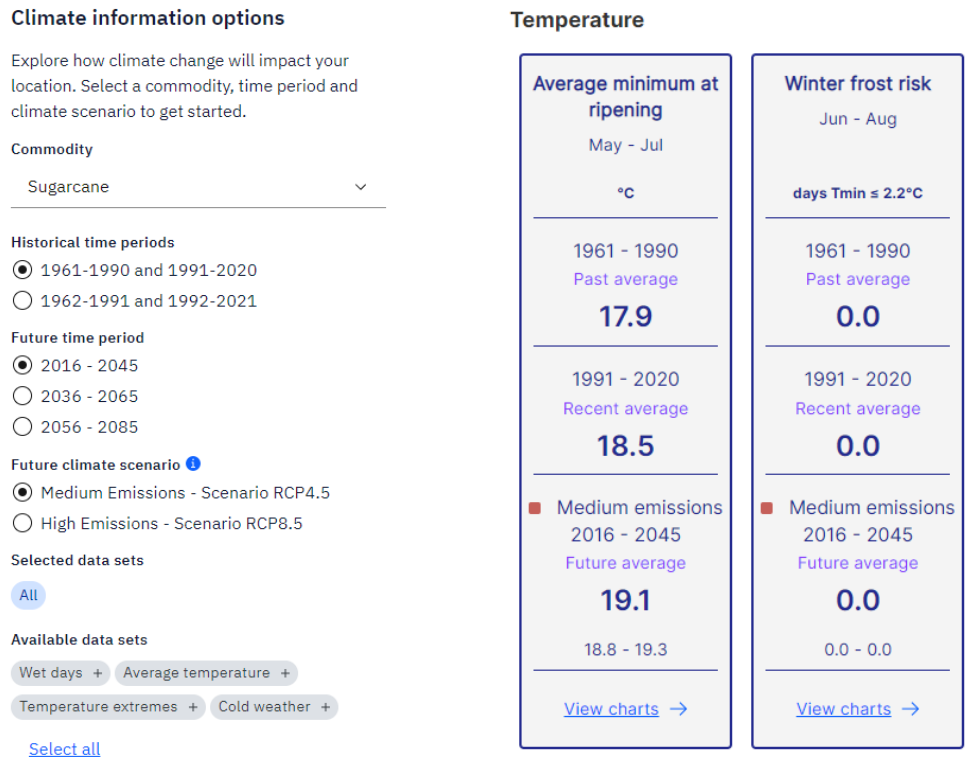

Figure 1: Climate options (left) and Temperature factors relevant to sugarcane (right).

Thirty years is an internationally recognised standard time frame used to describe the observed climate in a region. This is considered long enough to allow for a mix of expected weather conditions, for example some dry, some wet, some cold and some hot periods, allowing a reliable depiction of the climate to be presented.

In Figure 1 (left), there are three 'Future time periods' options available: 2016-2045, 2036-2065, and 2056-2085, corresponding to the different future climate projection periods.

Also, the available emissions scenarios, medium and high, represent two plausible future climate change possibilities. The scenarios used for the Coupled Model Intercomparison Project Phase 5 (CMIP5) are known as Representative Concentration Pathways (RCPs) and results for two RCPs are shown in CSA: RCP4.5 (medium emissions) and RCP8.5 (high emissions) (CSIRO and Bureau of Meteorology, 2015). The RCP numbers relate to the amount of excess energy in the climate because of additional greenhouse gases. RCP8.5 assumes emissions continue to increase through to 2100 (Hausfather, 2019). RCP4.5 assumes emissions peak around 2040, and then decline to below current emission levels by 2100.

Note that the actual future emissions will depend on global action on climate change. In order to evaluate the potential impact on your commodity, it is useful to consider both the best and worst possible future climates.

Figure 1 (right) shows the temperature factors relevant to sugarcane in Cairns and is indicative of how commodity specific climate information is presented by CSA. In this example, two important features of temperature for sugarcane are the minimum temperatures during the ripening months of May through to July and the frost risk for the period June to August. Note that sugarcane is not frost tolerant. Here we see that the trend of average ripening temperatures is increasing for a medium emission scenario while there continues to be no frost risk in this region.

The depiction of these climate factors in CSA are referred to as ‘cards’ and are clickable by the user, as indicated by the link titled ‘View charts’ at the bottom of the card in Figure 2 (right). Doing so updates the plots and graphs shown in the third panel on the right of the climate data explorer page. This was done, selecting the ‘Average minimum at ripening’ card shown in Figure 1 (right), and the results are shown in Figures 2 and 3 below.

Figure 2 shows the historical record of the average minimum temperature at ripening, comparing the historical 30 years periods of 1961-1990 and 1991-2020. Sugarcane needs a lot of water during cultivation and as noted above is not frost tolerant, preferring warmer temperatures. Figure 2 indicates that the average minimum temperatures have been increasing when comparing the period 1961-1990 to 1991-2020.

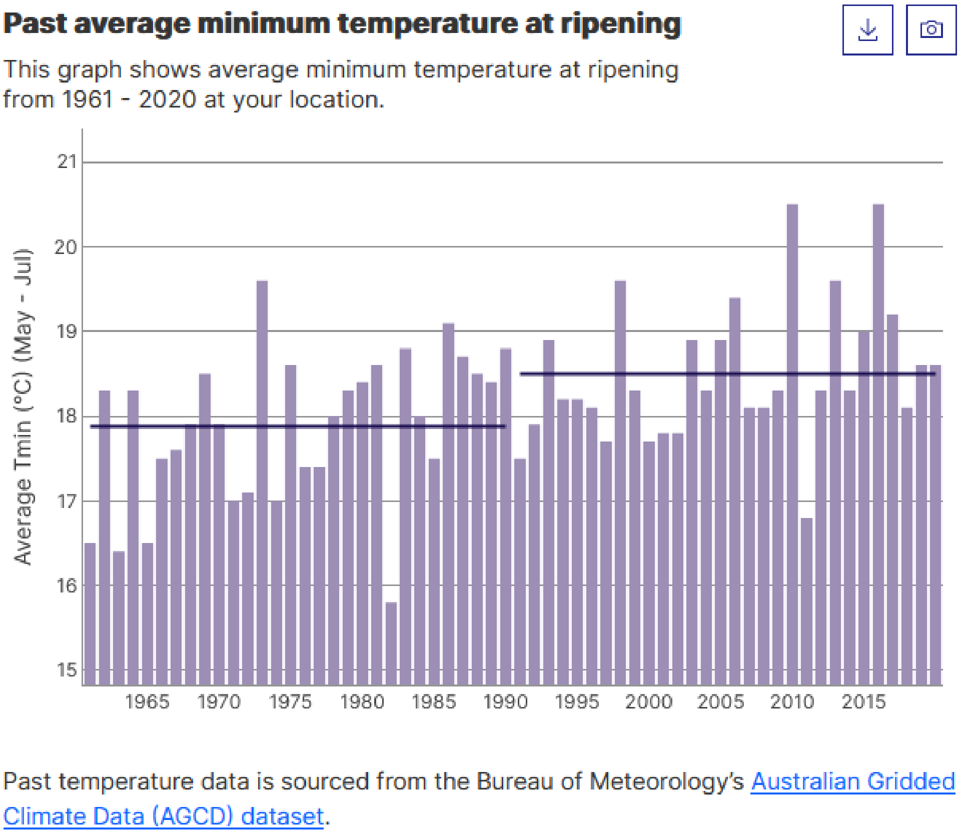

Figure 2: Past average minimum temperature at ripening for sugarcane in Cairns.

Figure 3 shows the future average minimum temperatures at ripening during the months of May through to July for the medium and high future climate scenarios for the three future projection periods. The two historical minimums are also shown for comparison purposes. Again, we see that the average minimum temperatures are rising over time, with increases being greater for the high emission scenario.

There is further climate information available when the ‘Seasonal outlook’ is selected. This information is not shown here due to space constraints however the information available is the short term rainfall expected, either for the next month or for the upcoming season.

Commodities

The current list of available commodities includes general, cotton, dairy, oranges, sorghum, sugarcane, wine grapes, northern beef, southern beef, northern sheep and southern sheep. These commodities are representative of the major agricultural sectors in Australia and combined represent 95% of Australia's farmed area; 15 of the top 20 agricultural commodities by gross value and approximately 86% of the gross value of Australia's agricultural production.

For each commodity, the main production regions were defined in consultation with respective commodity experts, using the pre-defined Australian Agricultural and Grazing Industries Survey (AAGIS) boundaries (ABARES, 2022). These regions define the various cropping and livestock predominantly found across Australia and consists of 32 regions corresponding to areas of climatic conditions suitable to support various farming production activities.

The commodity selection is a key aspect of the CSA tool: by choosing a commodity the climate information presented is customised to be relevant for that commodity. The sugarcane example in Cairns provides an example: the important factors for growing sugarcane are the number of wet days at harvest (calculated from the average rainfall from June to November), the average minimum temperatures at ripening (calculated from temperature data for the period May through to July) and the frost risk (also from the temperature data but for the period June through to August).

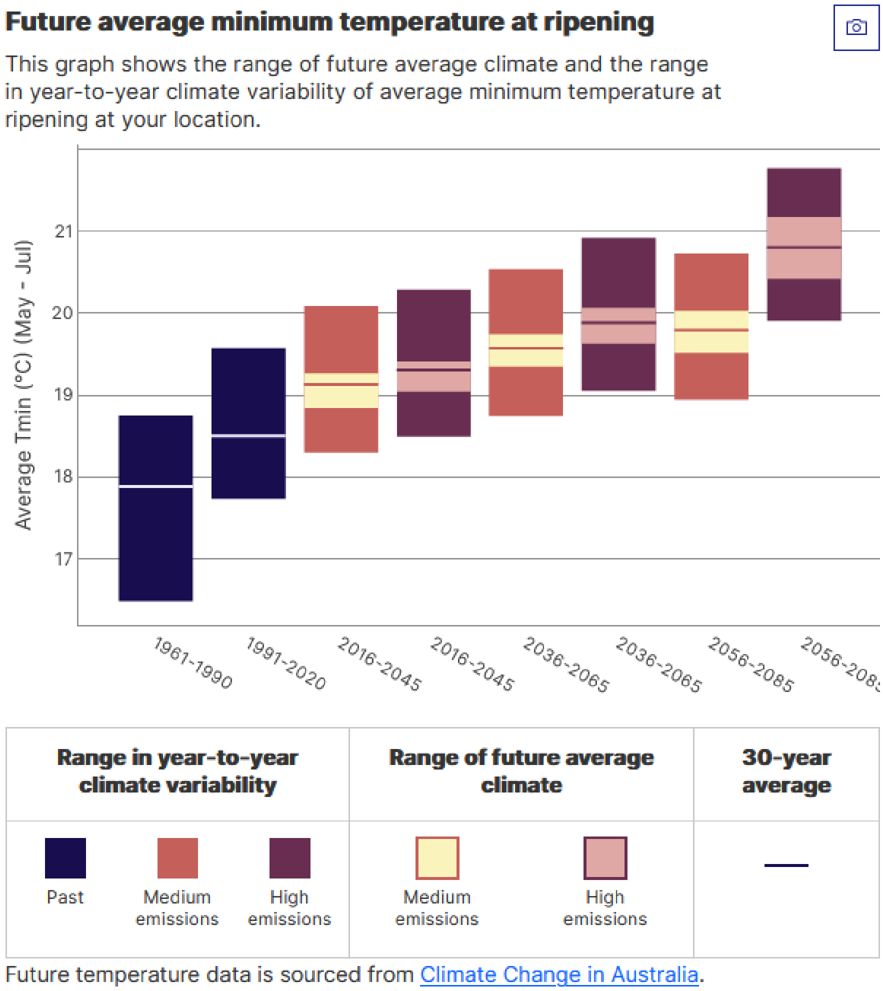

Figure 3: Future average minimum temperature at ripening for sugarcane in Cairns.

This association of the relevant agricultural climate metrics to the commodities were defined through scientific review and an expert consultation process, which included the farming community. Subject matter experts were also consulted to provide expert opinion to ensure these metrics were relevant to agricultural production of the commodities.

Note that there is the option of the general commodity. This allows the user to view common rainfall, temperature and evapotranspiration data sets for the chosen region that are not specific to any commodity, for example annual rainfall.

CASE STUDIES

The detailed example described above provides a simple introduction of how the CSA tool can be used to explore the impact of climate change for a specific commodity (sugarcane) at a specific location (Cairns). The project contributors and tool developers initially envisioned several use cases that we expected would be relevant to farmers and the wider agricultural sector. These use cases were along the lines of:

- As a farmer growing canola near Cowra, how will the growing conditions compare in 20 years to now?
- What crops would be best to cultivate for future climatic conditions in my area?
- As a bank, how does climate change impact our agricultural investment portfolio in the future?

These initial use cases were useful for early development but to ensure the long term fit for purpose of the tool, an extensive co-design methodology was undertaken by a cohort with diverse skill sets including user experience experts, agriculture sector researchers, social science specialists, customer engagement coordinators along with various representative end users, from farmers, financial providers, government agencies and others from the agricultural sector. This is an ongoing long-term engagement that has focused on an evolving co-design process that has resulted in a focus on user journeys.

As part of this process, we have captured several high-level case studies that explain the utility of the CSA tool in terms of the user goals and needs. Some of these are outlined in Table 1 below.

Table 1: Example Case Study Summaries.

Goal	Need
Provide accurate advice about long-term future climate projections for clients/farmers in a specific place/industry.	I want to be informed so that I can advise others, whether they're clients or in my community.
Assess, adapt and possibly transform agricultural enterprise by altering their farming practice, industry and/or location.	I'm looking to pivot the way my farm operates so that I can be more profitable or diversify my risk profile.
Gather a range of information that includes climate data to help take advantage of opportunities to diversify or generate additional windfall.	I have an opportunity to take advantage of favourable conditions, but I want to be sure I'm protecting myself from risk.
Gather further (or different) climate information to help them make smart business decisions about their enterprise investments.	I want information that is going to support me to change the way my business runs into the future.
Determine what impacts seasonal climate information will have on day-to-day operations so they can plan effectively.	I have lots of operational upkeep to do and I want to make sure I'm doing it at the optimal time.

FUTURE WORK

The first release of the CSA platform occurred in June 2021 and since then there have been two other releases at six monthly intervals in December 2021 and July 2022. These releases have seen changes to the user interface based on interactions with end users, the inclusion of more commodities and system performance improvements. The CSA project has secured funding to mid-2024 and over this time the release cycles are expected to occur every three months. These release cycles will continue the integration of more commodities and an ongoing engagement with the user community to ensure its fit for purpose. We also have plans to make the tool more appropriate for mobile devices such as tablets and phones.

Future extreme weather events are of particular interest to farmers and we have plans to include new indices such as the Forest Fire Danger Index (FFDI) (CSIRO, 2022) which can be used to predict the likelihood of bushfires in the area and the Standardised Precipitation Index (SPI) (McKee et al., 1993) that can be used to predict extremely wet or dry periods of 6 months or more. Other indices that we may include are: Standardised Precipitation-Evapotranspiration Index (SPEI) (Beguería et al., 2022) and Excess Heat Factor (EHF) (Nairn and Fawcett, 2015).

There are other specific areas of future research work that will be included in the platform. The climate change data is currently point based. When the user selects a location, the information presented corresponds to the data from the corresponding gridded climate datasets. A farm asset can span multiple gird cells and we are exploring new ways of aggregating and summarizing this information in meaningful and accurate ways. For large regions it is not practical to simply present all the data available, nor is it always appropriate to just give an average of all the available data. For example, when the region of interest crosses areas of different topographic and climatic conditions, presenting averages of future climate scenarios are unlikely to be representative of the variability across the region. While such outputs may be relevant for some use cases, it is important that this summary information is not used for the wrong purposes. This is aligned with the challenges of ensuring the tool is fit for purpose with end users and requires extensive user experience expertise to achieve appropriate outcomes.

Another area of research interest is to investigate climate analogues. This uses projected climate change information at a location of interest to find matching locations that have similar conditions now. For example, a farmer could be cultivating specific commodities today but be aware that due to the changing climate, their climatic conditions in the future will be similar to other regions in Australia. By identifying these other regions, the commodities being farmed there would provide a pathway for what they could choose to produce in the future. This could be a useful long term planning tool. Such tools already exist, see for example the Climate Change in Australia Climate Analogues tool (CSIRO and Bureau of Meteorology, 2020), however this task provides an opportunity to undertake further research about improved methods of determining regions of similarity based on past, current and future climatic conditions.

Lastly, we are working to make our system compatible and interoperable with other similar initiatives. Specifically, we are working closely with another FDF project, the Drought Resilience Self-Assessment Tool (DR-SAT) (DAFF, 2022c). DR-SAT currently uses some of the data available in the CSA back end and we will continue to ensure our system is compatible with theirs and provides the information they need as their tool evolves. We also have plans to integrate some of our features with the CliMate tool (CliMate, 2016). This engagement is in its infancy, but it provides an opportunity for CSA to be made available with the extensive CliMate user base who are already familiar with and understand climate datasets for the agriculture sector.

CONCLUSION

The Intergovernmental Panel on Climate Change (IPCC), the United Nations inter-governmental group responsible for advancing knowledge on climate change, recently released their sixth assessment report (IPCC, 2022a). As part of this process, the IPCC distribute regional fact sheets of key findings, with the fact sheet for Australasia noting a high confidence of:

> *Disruption and decline in agricultural production and increased stress in rural communities in south-western, southern and eastern mainland Australia due to hotter and drier conditions* (IPCC, 2022b)

This disruption from climate change can be considered an emergency event. This can be mitigated by providing appropriate climate change information to the agricultural sector customized to their needs.

The Climate Services for Agriculture tool is an example of such an online interactive digital platform bringing together a variety of climate information specifically for farmers and the agricultural sector. It will enable agricultural businesses, planners, and communities to explore various climate related datasets to better understand how the expected future climate may impact different regions and commodities. This will help people to anticipate and plan for the impacts of a variable and changing climate.

CSA is also an education tool. By engaging with farmers and the broader agricultural sector about the possible impact of climate change to their businesses in the years ahead, we are also advancing the general knowledge of key climate science concepts such as climate models, the available historical data and how it has been produced, the applicability of climate projections, the assumptions underlying different emissions scenarios, agricultural climate metrics and so on. This literacy involves communicating complex climate science concepts in a way that engages them and the wider community.

ACKNOWLEDGMENTS

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Continuity of Operations Planning in Public-Safety Answering Points during the COVID-19 Pandemic

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ABSTRACT

Continuity of Operations (COOP) planning helps ensure that municipal agencies maintain essential functions when disasters threaten critical infrastructures. COOP planning is especially important for Public-Safety Answering Points (PSAPs), which must continue to answer 911 calls and dispatch first responders during crises. However, COOP planning guidelines often focus on threats to cyber-physical infrastructures rather than outbreaks of infectious disease that threaten the human work arrangements—social infrastructures—agencies rely on to perform essential functions. This study reports preliminary findings from interviews with U.S. PSAP officials who developed plans to decentralize 911 facilities, networks, and personnel to maintain essential functions during the COVID-19 pandemic. These findings suggest revisions to COOP planning guidelines that consider requirements for redundant, diverse, and interdependent cyber-physical-social infrastructures.

Keywords

Emergency management, Business continuity planning, Critical infrastructure, Resilience.

INTRODUCTION

A Continuity of Operations (COOP) plan "details how an individual organization will ensure it can continue to perform its essential functions during a wide range of emergencies" that can include "localized acts of nature, accidents, and technological or attack-related emergencies" (FEMA, 2000, p. J-2). While federal, state, and local agencies routinely create and update all-hazards continuity plans that address threats to cyber-physical infrastructures (i.e., facilities, networks, power sources, transportation systems, etc.), outbreaks of infectious disease threaten social infrastructures: work arrangements that centralize essential personnel in shared physical spaces to perform agencies' essential functions.

This study reports preliminary findings from interviews with 15 911 officials representing 10 Public-Safety Answering Points (PSAPs) from across the U.S. whose existing COOP plans left them unprepared for the COVID-19 pandemic. Our interviews highlight gaps in general and pandemic-specific COOP guidelines published by the Federal Emergency Management Association (FEMA) (2018) and National 911 Program (2020) that focus on disruptions to cyber-physical infrastructures and require the *transfer* of essential functions to alternative facilities. In contrast, our interviews focus on disruptions to social infrastructures that require the *decentralization* of essential functions across primary and alternative facilities to reduce the risk of essential personnel contracting infectious diseases such as COVID-19. Learning from the ad hoc planning of PSAPs attempting to decentralize 911 facilities, networks, and personnel during the pandemic, our preliminary findings offer implications for all-hazards COOP planning by PSAPs and other municipal agencies.

Below we briefly review research on continuity planning and general and pandemic-specific COOP guidelines available to PSAPs. Next, we introduce our interview method and findings to describe the COOP plans created by PSAP officials during the pandemic. Lastly, we discuss limitations of existing cyber, physical, and social infrastructures identified across these interviews, and suggest guidelines for assessing the redundant, diverse, and interdependent infrastructures PSAPs will likely require for future public-health crises.

BACKGROUND

Studies of continuity planning address processes of organizational resilience: "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions" (Hollnagel, 2011, p. 275). The extensive literature on organizational resilience is expanding with studies that assess the resilience of critical infrastructures during the COVID-19 pandemic (Galbusera et al., 2021). These include public-safety communications that PSAPs manage by answering 911 callers' requests for assistance and dispatching appropriate first responders, including public health workers.

However, few studies address COOP planning by PSAPs (Oliver et al., 2012), or assess the utility of all-hazards continuity planning guidelines provided to 911 officials during outbreaks of infectious disease such as COVID-19. These resources include guidelines by FEMA (2018; 2020) and National Emergency Number Association (NENA) (2018), which organize COOP planning around four phases:

1. **Readiness and preparedness***:* warnings initiate planning and mitigation activities that prepare for potential disruptions to essential functions (i.e., continuity events).

1. **Activation**: continuity events activate continuity operations which may involve relocating and/or transferring essential functions to alternate locations or agencies per mutual aid agreements.

2. **Continuity operations**: essential functions are resumed at an alternate location or transferred to another agency; long-term continuity operations may require the acquisition of additional resources.

3. **Reconstitution**: normal operations resume once conditions stabilize; essential functions return to the primary facility, remain at the alternative facility, or resume at a new primary location.

These guidelines tend to focus on disruptions to cyber-physical infrastructures (e.g., damage to facilities, electrical outages, loss of connectivity, network intrusions, etc.) that require the *transfer* of essential functions to alternative facilities, networks, or nearby agencies in the case of devolution (i.e., transferring essential functions to other agencies) or the activation of mutual aid agreements.

In contrast, outbreaks of infectious disease disrupt social infrastructures: "the arrangements of organizations and actors that must be brought into alignment in order for work to be accomplished" (Lee et al., 2006, p. 484). Disruptions to social infrastructure occurred when essential personnel could not report to work after contracting or contacting someone with COVID-19, or when organizations implemented mitigation measures such as social distancing and remote work during the pandemic. Significantly, pandemic-specific guidelines published by FEMA, NENA, and other authorities acknowledge the vulnerability of essential functions when centralized among collocated people in a primary or alternative facility but overlook the interdependent cyber-physical-social infrastructures required to *decentralize* operations across multiple facilities to ensure that agencies can maintain essential functions during outbreaks of infectious disease.

These gaps appear in FEMA's (2018) *Continuity Planning for Pandemics and Widespread Infectious Diseases,* which recognizes that "Essential functions… will continue to be people dependent" but does not specify the interdependent infrastructures required to facilitate "human interactions [which] may be remote or virtual, resulting in the employment of appropriate teleworking and other approved social distancing protocols" (p. 5). Similarly, COVID-19-specific guidelines published by the Association of Public-Safety Communications Officials (APCO), NENA, and European Emergency Number Association (EENA) (CC:IPS, 2020; National 911 Program, 2020; EENA, 2020), advise 911 and 112 officials to "consider dividing personnel between the backup and primary facility," but do not outline the cyber-physical-social infrastructure requirements that officials must consider when planning to decentralize facilities, networks, and essential personnel.

METHODS

We interviewed 15 officials representing 10 U.S. PSAPs to learn how they maintained COOP during the early stages of the COVID-19 pandemic (Table 1). Semi-structured interviews were conducted via web conference software in the summer of 2020. We recruited 911 officials from our existing contacts and referrals from a public-safety consulting firm (Grace, 2021). Each interview lasted between 1-1.5 hours, was audio/video recorded after obtaining participants' consent, and then transcribed. Inductive analysis was performed by iteratively identifying and refining themes observed across the interview data. These were then compared with the COOP framework outlined by FEMA (2020) and NENA (2018) to organize the presentation of findings and draw implications for discussion.

Table 1. Interview participants' PSAP location, position, and jurisdiction characteristics

Participant	Location	Position	Jurisdiction Size/Type
1	Texas	Supervisor, 911 operations	Large, suburban counties
2	Oklahoma	Director, 911 communications	Small; rural county
3	Illinois	Director, 911 communications	Large; Suburban County
4	Texas	Supervisor, 911 operations	Small; rural County
5	Virginia	911 systems manager	Large; urban county
6	Virginia	Deputy Administrator, Systems	Large; urban county
7	Virginia	Deputy Administrator, Operations	Large; urban county
8	New York	Director, Emergency management	Medium; suburban county
9	Pennsylvania	Director, Emergency management	Medium, suburban county
10	Pennsylvania	Director, Emergency communications	Medium, suburban county
11	South Carolina	Director, Consolidated 911 center	Large; urban county
12	South Carolina	Deputy director, Consolidated 911 center	Large; urban county
13	Oklahoma	Supervisor, 911 operations	Large; urban county
14	Oklahoma	911 training analyst	Large; urban county
15	Oklahoma	Director, Communications center	Small; rural county

FINDINGS

Beginning in February 2020, PSAP officials discovered that existing COOP plans focused on threats to cyber-physical infrastructures did not prepare them for social infrastructure disruptions caused by the outbreak of the COVID-19 pandemic. In response, officials developed pandemic-specific COOP plans to maintain essential functions by *i*) transferring essential functions to backup call centers, *ii*) distributing essential functions across multiple call centers, and *iii*) allowing staff to work from home.

Transferring Essential Functions to Backup Call Centers

PSAPs planned to transfer 911 operations to backup call centers in the event of COVID-19 exposes among personnel within primary facilities. Initially, PSAPs sought to adapt existing continuity plans which included provisions for transferring operations to PSAPs in nearby jurisdictions linked through mutual aid agreements:

> Prior to covid our backup center was [nearby agency] police dispatch… We have been working with [adjacent] counties. However, as we moved into covid we looked at that and saw that each one of them had drawbacks when trying to use them as a backup center because they are dealing with the same problem: what would happen if someone got exposed in the 911 center? What would we do? There was not a whole lot of back up abilities there. (P7)

> We had a COOP plan on the shelf … which involved sending our telecommunicators to two other centers and, in the heat of the moment, we were like, "Do we really want to send potentially contaminated people to one of our partner centers and potentially contaminate them?" (P3)

Transferring operations to neighboring PSAPs did not address the "same problem" created by the pandemic: the risk of losing essential functions if the disease were to spread among essential personnel collocated in the call center or those of neighboring PSAPs. Consequently, rather than transfer operations and/or personnel to a call center in another jurisdiction, officials planned to decentralize their own facilities and not rely on facilities provided through mutual aid agreements included in existing continuity plans.

PSAP continuity planning therefore involved standing up backup call centers where essential functions could be transferred as long as primary call centers remained unavailable. Adapting existing continuity plans, backup 911 centers were set up at alternative facilities:

> In our options plan we looked at where we could dispatch from. We have a primary dispatch center where we work in our building now and we have a backup dispatch center that is fully functional. So, one of the plans was to leave one area as a clean area. In case we have an outbreak at the primary center, we can move people and operate from the second facility. (P8)

PSAPs also created clean backup centers at the primary facility that could support continuity operations during the pandemic:

> For covid we decided to leverage our technology and set up a temporary backup center here [at the primary facility]... We rented a job trailer like they use at construction sites, ran network cables out there, got a backup generator to power the site, and moved three complete workstations with CAD, radio, and phone from our main center out there. We also brought in our mobile command vehicle, stationed it beside it, and hooked up an intercom system between the two. (P7)

These backup facilities were intended as short-term solutions: "if someone got sick and we could come in and clean the existing center while continuing operations in the backup" (P7). Small PSAPs in rural areas acted similarly within the resources they have available: "this office is a dark station so… if someone were to get sick on shift, I need to leave for the other person to come in and dispatch while we disinfect that room" (P2).

Distributing Essential Functions across Multiple Call Centers

After preparing to transfer essential functions to backup centers, officials planned to distribute essential functions across multiple call centers to perform concurrent 911 call taking and dispatch operations. This required splitting and separating the shifts of essential personnel across existing and new workspaces established at primary and alternative facilities during the pandemic. As officials explained:

> Another option was for workers with underlying conditions to find a separate work site. So instead of having them on the floor exposed to multiple people, we set up another 911 center in our primary building, but in a different location, so we could separate them out so that they would not be affected. (P8)

Rather than transferring centralized operations to alternative facilities as described in FEMA guidelines, pandemic COOP plans attempted to decentralize essential functions across multiple workspaces and facilities.

However, these attempts revealed limitations of existing cyber-physical infrastructures. PSAP's primary facilities often lacked sufficient space to accommodate multiple dispatch centers and featured open-office designs that could not be remodeled to restrict interaction and possible exposures among personnel. Smaller PSAPs with less resources most often encountered these constraints:

> I would like to have more options for dispatchers as far as places to be more remote… but I feel like we've been very fortunate that our city manager and our chief have really been supportive and getting things that have helped them to do their jobs and to be confident to come to work each day…hand sanitizer, toilet paper, Clorox wipes, things like that. (P2)

The disparity between large and small PSAPs was a theme across the interviews: the former had the administrative autonomy and resources to create and staff decentralized facilities while the latter, in this example, had to settle for additional cleaning supplies.

Technology, particularly network access points, also introduced challenges for officials planning to decentralize 911 operations:

> We looked at different options. We have a backup center and we looked at splitting staff. Logistically, however, that was not possible because our 911 trunks are not geo-diverse, they are separate, so a separate set of trunks come into the primary center and a separate set of trunks go into the backup center and they cannot be live at the same time. So, basically, if we split our staff only one center could take 911 calls. (P6)

Instead, the PSAP transferred administrative staff to the backup center to lower the risk of exposure for essential personnel—911 dispatchers— who would continue to work in the primary facility. Another PSAP, located in a large metropolitan area, made use of its substantial technical and personnel resources when planning to isolate shifts and concurrently staff both its primary and backup center: "we have talked about splitting our shifts so… first and third shift report to the backup facility which means the first shift would go home and later the third shift would arrive so there would be no overlap" (P9). Overall, officials' attempts to decentralize 911 operations revealed limitations of existing cyber-physical-social infrastructures that only PSAPs with redundant and diverse resources were able to overcome.

Allowing Staff to Work from Home

Lastly, PSAPs explored and implemented remote work arrangements to further decentralize 911 operations. Most of these efforts involved administrative and IT staff working from home and away from 911 dispatchers who remained collocated in primary and backup call centers:

> We had been experimenting with "bunny slipper" project before covid… When it came time all of our admin and support staff worked from home. I [director of the 911 center] am in the office alone. We found we have the capability to do that. (P8)

> Out of all 43, maybe 5-6 of those PSAPs, as far as the communications manager, worked from home. But the rest, their manager and supervisors were in there working with them like nothing had changed. It depended on the administration's decisions whether administrative staff work from home or if key individuals could still work in the building. (P1)

Only one PSAP created remote workstations by connecting mobile 911 dispatch systems, i.e., VESTA CommandPost, with FirstNet hotspots and then adding on additional capabilities:

> Due to COVID-19, we purchased twelve [remote call taking systems]. Soon we will have the ability not just to take calls but dispatch [to first responders]… For what we accomplished there was zero playbook… We are the early builders who are leading the trend in the county.

For most PSAPs, however, multiple barriers precluded the ability to create at-home dispatch solutions. These barriers included the inflexible, often legacy, technologies in many PSAPs:

> We would have loved to let people work from home. But we didn't have a) the number of computers on the CAD system, or the number of licenses for CAD or the mapping solution that sits behind CAD to be able to deploy that elsewhere. We've built our system on a model of shared workstations so our vendors (P3)

> We are technologically unable to do that and still function. Basically, the computer networks, IT and connectivity, the CAD, the radio, the admin computers they use on a regular basis—all are separate domains. It would be impossible to have the dispatchers function remotely from home because of the separate networks they work on. There would be no way to give them that capability… (P7)

Other barriers include the lack of reliable internet connectivity:

> The internet is not reliable enough at home for emergency communication. Some agencies turned to the FirstNet. Terrible coverage in that area. Without that we are not able to send people home. They should not lose a 911 caller…We are spread out and many people live outside our county. Geographic diversity will make it difficult. Some have home telephone company (P8)

Lastly, PSAP officials in some rural areas perform multiple roles, e.g., jailer, that require collocated work. For these PSAPs, essential functions involve more than 911 call taking and dispatch: "I think it would be an amazing option. I just don't know that we would be able to close the center here because we do so many other things as well" (P2). While many officials we interviewed investigated options for remote work, few were able to implement these arrangements due to a lack of available networks, potable technologies required for at-home dispatch work, and limited access to network-based services.

DISCUSSION

Our interviews with 911 officials reveal limitations of existing cyber-physical-social infrastructures that constrained PSAP COOP planning during the COVID-19 pandemic. Officials identified the following limitations:

- ***Limited space*:** PSAPs lacked extra or reconfigurable workspaces to socially distance personnel or create new call centers at their primary facilities. Some PSAPs whose continuity plans involved call routing and mutual aid agreements with neighboring PSAPs also lacked alternative facilities that could serve as backup or additional call centers.
- ***Limited access:*** PSAPs lacked redundant and geo-diverse networks which restricted the number and location of call centers that could be set up to decentralize 911 operations. PSAPs also lacked additional software licenses to cloud-based platforms, e.g., CAD, that prevented the creation of new workstations at primary and alternative facilities. Officials also faced challenges acquiring and transporting hardware to alternative locations.
- ***Limited collaboration:*** PSAPs lacked flexible, hybrid work environments that could support collaboration among personnel working across primary, alternative, and at-home workspaces. For redundancy, PSAPs require that each call center is capable of operating independently. However, PSAPs also require distributed collaboration across personnel collocated in call centers and personnel working remotely, including administrators, IT staff, and at-home dispatchers.

PSAPs also confronted challenges related to external conditions created by the COVID-19 pandemic:

- ***Uncertainty****:* Like most organizations, PSAPs were forced to respond to scientific uncertainties related to the transmission, symptoms, and complications of COVID-19, effective public health measures to stop the spread of the disease, and political uncertainties related the adoption and adjustment of public health mandates. Officials were forced to make ad hoc plans to address multiple contingencies and adopt incremental, temporary solutions.
- ***Limited authority:*** All PSAPs operate under local government control, however, larger, consolidated PSAPs often exercise greater control over operations, facilities, and resources than smaller PSAPs incorporated within public-safety agencies, i.e., police departments. Consequently, 911 officials who lacked independent authority to repurpose agency facilities, reassign staff, and acquire resources also lacked the authority to implement COOP plans that decentralized 911 operations.

These limitations suggest requirements for redundant and diverse infrastructures that can help PSAPs prepare for disruptions to existing social infrastructure: "one big room" where collocated essential personnel answer 911 calls and dispatch information to first responders. These limitations also suggest that planning to decentralize 911 operations requires addressing the interdependence of cyber-physical-social infrastructures in revised guidelines for all-hazards continuity planning.

Future Work: Guidelines for PSAP Continuity Planning

The implementation of continuity plans created by officials during the pandemic—transferring essential functions to backup call centers, distributing essential functions across multiple call centers, and enabling remote work among (non-)essential personnel—each require interdependent cyber-physical-social infrastructures. Our preliminary findings motivate further investigation of guidelines and diagnostic criteria for COOP planning in PSAPs and other municipal agencies (CISE, 2020). However, we begin by offering a set of deceptively simple questions that can help officials assess the redundancy, diversity, and interdependence of PSAP infrastructures (Table 2).

Table 2. Key questions for ensuring redundant and diverse PSAP infrastructures

Infrastructure	Redundancy	Diversity
Physical	Do we have backup facilities?	Can we repurpose our facilities?
Cyber	Do we have backup networks?	Can we access multiple networks at each facility?
Social	Do we have backup staff?	Can staff work together across our facilities?

Redundancy refers to the functional duplication of primary cyber-physical-social infrastructures available to the PSAP. In our interviews, officials, especially those from small PSAPs in rural jurisdictions, often reported lacking backup facilities, networks and network access points, and personnel. Answering the three questions addressing redundancy in Table 2 requires officials to take stock of agency resources under their authority, identify needs, and make plans for acquiring additional assets and personnel needed to activate continuity operations during a crisis. However, ensuring redundancy is a necessary but insufficient first step in COOP planning.

Diversity refers to the functional variation of primary and alternative cyber-physical-social infrastructures available to PSAPs. For example, diverse physical infrastructures can be repurposed to support different essential functions. However, repurposing facilities requires redundant and diverse cyber- social infrastructures. While officials from one PSAP repurposed their training room to create an additional call center, other officials could not do the same because they lacked the requisite network access points, portable equipment to create additional workstations, and enough personnel to split shifts between a primary and backup call center. For redundancy, staff at each call center needed to be able to operate independently but, whenever possible, also collaborate with personnel in other call centers or working from home. Diversity of social infrastructure thus refers to the variety of distributed work arrangements that allow staff to perform essential functions. Our interviews show these arrangements involve a mix of collocated and remote work (Olson & Olson, 2000), and require interdependent cyber-physical-social infrastructures that can support hybrid collaboration among dispatchers working together at call centers, between dispatchers working at separate call centers, and, at the same time, various personnel working from home.

CONCLUSION

Beginning in February 2020, PSAPs began planning for disruptions caused by the COVID-19 pandemic. Unique to outbreaks of infectious disease, these disruptions threatened the social infrastructure of public-safety communications: arrangements of essential personnel that allow PSAPs to answer 911 calls and dispatch information to first responders. This study reports COOP planning among U.S. PSAPs that attempted to decentralize 911 operations by *i*) transferring essential functions to backup call centers, *ii*) distributing essential functions across multiple call centers, and *iii*) enabling remote work among (non-)essential personnel. These attempts highlight limitations of existing cyber-physical-social infrastructures when called on to support decentralized 911 operations, and suggest all-hazards COOP planning requirements for redundant, diverse, and interdependent infrastructures that can make PSAPs and other municipal agencies more resilient during future crises.

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Reliability of Methods for Extracting Collaboration Networks from Crisis-related Situational Reports and Tweets

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ABSTRACT

Assessing the effectiveness of crisis response is key to improving preparedness and adapting policies. One method for response evaluation is reviewing actual response activities and interactions. Response reports are often available in the form of natural language text data. Analyzing a large number of such reports requires automated or semi automated solutions. To improve the trustworthiness of methods for this purpose, we empirically validate the reliability of three relation extraction methods that we used to construct interorganizational collaboration networks by comparing them against human-annotated ground truth (crisis-specific situational reports and tweets). For entity extraction, we find that using a combination of two off-the-shelf methods (FlairNLP and SpaCy) is optimal for situational reports data and one method (SpaCy) for tweets data. For relation extraction, we find that a heuristics-based model that we built by leveraging word co-occurrence and deep and shallow syntax as features and training it on domain-specific text data outperforms two state-of-the-art relation extraction models (Stanford OpenIE and OneIE) that were pre-trained on general domain data. We also find that situational reports, on average, contain less entities and relations than tweets, but the extracted networks are more closely related to collaboration activities mentioned in the ground truth. As it is widely known that general domain tools might need adjustment to perform accurately in specific domains, we did not expect the tested off-the-shelf tools to perform highly accurately. Our point is to rather identify what accuracy one could reasonably expect when leveraging available resources as-is for domain specific work (in this case, crisis informatics), what errors (in terms of false positives and false negatives) to expect, and how to account for that.

KEYWORDS

Collaboration networks, natural language processing, interorganizational collaboration, situational awareness

INTRODUCTION

Collaboration between organizations in large-scale crisis response events is critical as it ensures that response entities have the capacities and resources they need to meet the needs of vulnerable populations (Waugh Jr and Streib 2006; Ganji et al. 2019; Kapucu and Hu 2016). Specifically, collaboration structures during response reveal the extent to which shared situational awareness (SA) is achieved (Nofi 2000; Benson et al. 2010) and consequently how organizations collectively make decisions about response actions (Lee et al. 2012; Sarol, Dinh, and Diesner 2021; Sarol, Dinh, Rezapour, et al. 2020). Prior literature in emergency management has traditionally constructed organizational collaboration networks using surveys and interviews with emergency response personnel (Kapucu 2005; Ganji et al. 2019; Saoutal et al. 2015). While these methods can yield accurate information about actual collaborations that took place, the time and other resources needed for data collection limit the scalability of these methods (Guo and Kapucu 2015; Diesner and K. M. Carley 2005). As a result, a number of studies have leveraged unstructured text data such as police reports (Diesner and K. Carley 2010; Noori et al. 2016), news articles (Diesner, K. M. Carley, and Tambayong 2012; Sarol, Dinh, and Diesner 2021; Diesner and K. M. Carley 2004), and social media data (tweets) (Sheikh et al. 2017; Sarol, Dinh, Rezapour, et al. 2020; Sutton 2010) to extract information about organizational collaboration structures. The findings from these studies show that extracting crisis-related entities and their interactions from unstructured text data remains difficult due to a lack of crisis-specific a) training data and benchmarks (Sheikh et al. 2017; Nouali-TAboudjnent and Nouali 2011; Li et al. 2021) and b) knowledge about how to select methods and parameterization (Diesner 2012; Sarol, Dinh, and Diesner 2021; Diesner, Aleyasen, et al. 2014; Diesner 2013).

With the need for understanding collaboration structures during crisis response based on unstructured text data, this paper applies entity extraction and relation extraction to unstructured, natural language text data about hurricane events to improve our understanding of how to reliably obtain relevant network data that can than be used for network analysis, visualizations, simulations, etc (K. M. Carley, Diesner, et al. 2007). To this end, we compare the networks resulting from applying three different relation extraction techniques (two state-of-the-art methods and one newly developed heuristics-based method) to the same data sets (situational reports and tweets), and assessing the accuracy of each method by comparing the resulting networks against manually constructed ground truth network data about crisis-relevant collaboration. We recognize that while highly accurately performing off-the-shelf methods and models for entity and relation extraction exist (Honnibal and Montani 2017; Akbik et al. 2019; Angeli et al. 2015), they are not necessarily trained on crisis-specific text data. In response, we examine if and how methods and/ or models trained on crisis data (our heuristics-based model) differ from methods trained on domain-agnostic/ general domain text data. This leads to our two primary research questions:

RQ1: In what aspects is each of the three tested methods (heuristics-based, OneIE, OpenIE) accurate in detecting collaboration-related entities and relations, what errors do they make, how do the methods compare to each other?

RQ2: What do our findings imply for the practical use of these methods in the given domain?

Answers to these questions will help to design solutions that bring crises related network data extracted from texts closer to ground truth data, and accounting for remaining differences by at least being able to identify them. More specifically, this study contributes to the existing literature in crisis information systems in two ways: First, we identify and validate entities (of the type organizations, persons, geopolitical entities, national/religious/political groups, and locations) as well as relations between these entities that indicate collaboration activities that took place. Second, we further expand the knowledge about how choices for relation extraction methods and parameter settings influence networks we use for analysis, and consequently, impact our understanding of collaboration patterns that took place during response, which might be used as input to data-driven decision making and policy development or review.

RELATED WORK

Prior literature asserts that effective collaboration between organizations across governmental jurisdictions is a crucial success factor for large-scale crisis response (Comfort and Haase 2006; Kapucu 2005; Van Borkulo et al. 2005). A primary factor for effective collaboration between crisis response organizations is their shared SA about the main objectives as well as resources and actions needed to complete these objectives (Benson et al. 2010; Kurapati et al. 2013; Nofi 2000). A lack of SA may be due to several reasons, including inadequate technical infrastructure (Ganji et al. 2019), different organizational cultures and standards for response (Benssam et al. 2013), information overload (Hiltz and Plotnick 2013), and, most importantly, communication failures between organizational members in terms of not knowing what information is needed, from whom to request this information, and what agents or organization(s) have what resources (Saoutal et al. 2015; Ley et al. 2014; Bharosa et al. 2010; Weil, K. M. Carley, et al. 2006; Weil, Foster, et al. 2008).

We propose that taking a network perspective can help to solve this problem by making the observed response structures salient, visible, and analyzable, thereby allowing us to identify the entities that did collaborate during a response. Prior work has already leveraged organizational network analysis to examine patterns of collaboration among and between organizations at various levels of the government Kapucu (2009) and Kapucu and Garayev (2016). More specifically, network analysis has been used to analyze expected structures of collaboration based on federal guidelines (e.g. the Incident Command System) (Kapucu 2009) and to identify the key players (by calculating network centrality measures) to better understand who holds special roles in terms of power and influence in local-level response networks (Kapucu and Garayev 2016). While network analysis has been used to identify crisis-related content from unstructured text data (Sutton 2010; Diesner, K. M. Carley, and Tambayong 2012; Guo, Kapucu, and Huang 2021), network construction based on unstructured text data often requires labor-intensive methods such as sociometric surveys (Kapucu and Hu 2016) or content analysis to identify organizations and relations between them (Sutton 2010; Guo, Kapucu, and Huang 2021). These methods do not scale to analyzing large corpora. Other methods rely on unsupervised clustering to identify subgroups of organizations (Noori et al. 2016). These methods can return results that are not domain-relevant (Alam et al. 2020) if no training with crisis-related text data took place. Automated and semi-automated text mining methods exist, but entail limitations in terms of accuracy and/ or degree of automation (Diesner, K. M. Carley, and Tambayong 2012; Diesner 2015; K. M. Carley, Columbus, et al. 2008).

To address these limitations, we comparatively test three scalable relation extraction methods for their ability to *reliably* extract relevant relations, which we for the purpose of this project define as *collaboration*, between relevant entity types, e.g. organizations. Traditionally, text-based network construction has relied on word co-occurrences (user-defined window of words between a pair of entities) to extract relations (Danowski 1993; K. M. Carley 1997; K. M. Carley, Columbus, et al. 2008). However, this approach is susceptible to high false positive rates (i.e. retrieving incorrect relations (Diesner and K. M. Carley 2010; Diesner 2015)). To remedy this shortcoming, a number of relation extraction methods are available that leverage syntactic features such as shallow (Jiang and Diesner 2019) and deep parsing (Fundel et al. 2007; Xu et al. 2015) to classify and predict relations in semi- and un-structured texts. In addition to that, solutions such as Stanford's Open Information Extraction (Open IE) also leverage syntactic information (i.e. part-of-speech patterns and dependency trees) to extract triples, where a subject and an object are connected via a predicate (verb/verb phrase) (Angeli et al. 2015; Stanovsky et al. 2018; Gerner et al. 2002; Ogden and Richards 1925). Recent relation extraction methods have leveraged neural-network language models (Devlin et al. 2018; Dai and Le 2015) to learn more features (lexical, syntactic, and semantic) and improve overall accuracy (Wu and He 2019; Dai and Le 2015). In this context, OneIE (Lin et al. 2020) is a state-of-the-art method that was built by using a neural network-based model for supervised learning and extraction of both entities and relations at the same time. To date, OneIE outperforms existing solutions such as DyGIE++ (Wadden et al. 2019) and BERT-based event extraction models (Du and Cardie 2020).

In this paper, we apply state-of-the-art solutions to text data (situational reports and tweets) from the domain of crisis response to assess these solution's accuracy by comparing automatically extracted or predicted entities and relations to networks built from ground truth data, i.e., manual annotations of entities and relations. Specifically, we assess three models: (1) a heuristics-based model that we built by leveraging co-occurrence, shallow, and deep syntax as features, (2) Stanford's OpenIE (Qi et al. 2020; Angeli et al. 2015) prediction model that leverages part-of-speech tagging and dependency trees to construct relation triples, and (3) OneIE's joint entity and relation extraction model (Lin et al. 2020). In summary, constructing networks of entities that were mentioned in text data (Van Atteveldt 2008) to have collaborated in a disaster is relevant for reviewing disaster response and related policies ex post factum. However, this approach is also a highly specialized use case of entity and relation extraction, and most likely not the one that standard entity and relation extraction tools, such as CoreNLP and OneIE, were designed or fine tuned for. Therefore, we expect the congruence between the ground truth networks and the networks extracted by using general relation extraction tools to be lower than the tool's benchmark performances. For the same reason, we also expect the vast majority of mismatches not to be blamed on tools, but on the assumptions of the researchers conducting this work. In short, we want to find out to in what ways non-NLP-expert practitioners from an application domain can expect off-the-shelf tools to provide reliable information to them, and what errors they should expect and account for.

METHODOLOGY

Ground truth data

This study focuses on networks that encode or represent interorganizational collaboration during hurricane response as reported in text data. Specifically, we analyze four major hurricane events that made landfall within the continental United States, namely 2016 Hurricane Matthew, 2017 Hurricane Harvey, 2017 Hurricane Irma, and 2018 Hurricane Michael. We selected these events because they were federally-declared disasters based on the Stafford Act (Sobel and Leeson 2006) and thus warranted collaboration between organizations at the federal, state, local, and non-governmental level. We collected a total of 109 situational reports (SITREPs) and 28,050 Twitter posts (tweets) that were released two weeks before to two weeks after landfall of these four hurricanes. The ground truth data was constructed by (1) drawing a random sample of four SITREPs (approximately 8,000 words) and 1000 tweets (details in Figure 1), and (2) annotating entities (if any) and relations (if any) between entity pairs in our sample. Each of the three human coders marked up every sentence in the sample for entities. A sentence can contain zero, one, or many entities, and any two entities in a sentence may share a relationship or not. More specifically, based on the annotation schema we developed, an entity is defined as any named entity that is either a person (tag: PER), organization (tag: ORG), geopolitical entity (tag: GPE), national/religious/political groups (tag: NORP), or location (tag: LOC). The tag of each entity is then used as the entity type. We define a relationship as two entities being connected by a word or phrase (typically or noun or a verb) that indicates (to the trained human coders) an instance of *collaboration* between two entities, whereby two entities collaborate on a certain crisis-related task. To give an example, a sentence with two entities would be marked up for entity 1, entity 1 type, entity 2, entity 2 type, and a binary indication of a relation between entity 1 and entity 2 (relation exists or not).

For the SITREPs-based ground truth dataset, two coders engaged in a three-stage coding process (initial coding, reconciliation, and re-coding). They ultimately obtained an interrater agreement of 89.8%. For the tweets-based ground truth dataset, where we applied the same three-stage coding, three coders ultimately achieved an interrater agreement of 86.95%. Interrater agreement was assessed based on exact matches of (1) entity pairs (exact boundary matches, no partial matches counted, which is a strict condition), (2) entity types, and (3) existence of a relation (yes or no). The ground truth data was used for two purposes: First, to evaluate the two considered state-of-the-art relation extraction tools against this gold standard. Second, to computationally identify heuristics for locating relevant entities and relations, and discriminating those from irrelevant words, entities, and relations, and then using these heuristics as features for training a model for predicting or extracting entities and relations (pipeline discussed in next section).

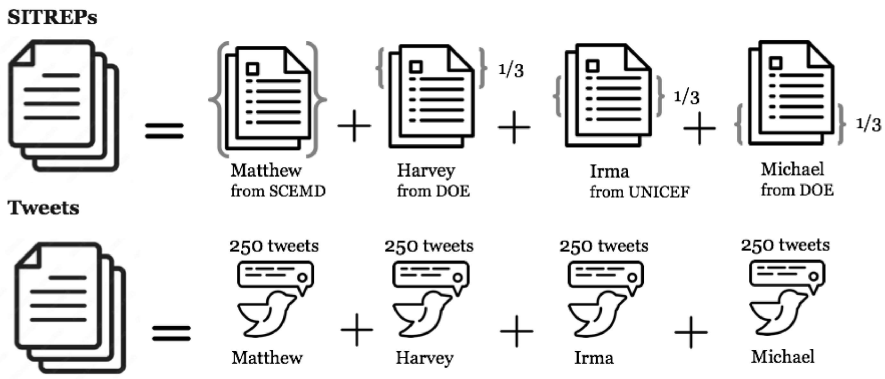

Figure 1. Ground Truth Sample

Relation extraction methods

We assess the accuracy of the three outlined relation extraction methods in terms of locating and classifying entities (n-ary classification) and relations (binary classification) that represent nodes and edges in collaboration networks during hurricane responses. In particular, we develop a heuristics-based method for entity and relation extraction and compare the performance of this method to two existing state-of-the-art relation extraction methods (OneIE (Lin et al. 2020) and Open Information Extraction (OpenIE, (Stanovsky et al. 2018)). The sections below discuss each method in detail.

Heuristics-based model

The model entails (1) named entity detection and labeling based on a combination of two off-the-shelf models (SpaCy and FlairNLP), followed by (2) relation extraction via a combination of optimal features based on entity co-occurrence as well as shallow and deep syntax parsing. By optimal we here mean resulting in the highest accuracy in our annotated ground truth data. The named entity labeling process entails finding optimal settings for applying SpaCy and FlairNLP. As shown in Figure 4, we found that the optimal setting is to choose entities that are labeled by both Flair and SpaCy (i.e. Flair + SpaCy) for the SITREPs-based ground truth, and entities labeled solely by SpaCy for the tweets-based ground truth. We speculate this result is due to differences in Flair and SpaCy's pre-trained models (even though both were trained on OntoNotes 5.0 (Weischedel et al. 2012)) that may deem one method more suitable for tagging tweets data than another. For the relation extraction task, we identified the following optimal features: (1) top three co-occurrence-based window sizes, (1) top three part-of-speech patterns from constituency trees, (3) top three dependency-based window sizes, and (4) top three dependency patterns between every two entities. For co-occurrence, window size indicates a number of words in between two entities, not including the entities themselves. For example, a co-occurrence window size of zero represents adjacent entities, with zero words in between them. For dependency, window size represents the shortest path length between two entities in the dependency parse tree. For instance, a dependency window size of zero represents two entities connected by a direct dependency path from one entity to another. The top three instances of each feature are shown in Tables 1–3. With these features, we trained a Support Vector Machine (SVM) model with a 80%-20% train-and-test split, along with 10-fold cross-validation to evaluate the performance of the heuristics-based model. We acknowledge that building a model with these "optimal" features can lead to overfitting when applied to new and unseen data, even after k-fold cross validation was applied, such that further calibration with other data from the same domain might be beneficial. The point here is mainly to compare a domain-specific solution to general domain alternatives.

Table 1. Top co-occurrence-based (left) and dependency-based (right) window sizes of relations present in SITREPs-based and tweets-based ground truth data

	# of relations with **co-occurrence-based** window size in:		# of relations with **dependency-based** window size in:	
Window size	SITREPs	Tweets	SITREPs	Tweets
0	10 (1.414%)	1 (0.124%)	62 (8.769%)	4 (0.498%)
1	**134 (18.953%)**	**127 (15.796%)**	**170 (20.045%)**	67 (8.333%)
2	**102 (15.134%)**	93 (11.567%)	70 (9.9%)	99 (12.313%)
3	**97 (13.72%)**	**126 (15.7%)**	**86 (12.164%)**	145 (18%)
4	85 (12.022%)	**113 (14.054%)**	**72 (10.183%)**	158 (19.652%)
5	71 (10.042%)	102 (12.687%)	62 (8.769%)	104 (12.935%)
6	57 (8.062%)	78 (9.701%)	47 (6.648%)	69 (8.582%)
7	55 (7.779%)	68 (8.458%)	46 (6.506%)	34 (4.229%)
8	48 (6.789%)	55 (6.841%)	32 (4.526%)	26 (3.234%)
9	43 6.082%)	41 (5.099%)	23 (3.253%)	3 (0.373%)

Table 2. Top three part-of-speech patterns between two entities in SITREPs-based and tweets-based ground truth

Constituency pattern	# of relations in **SITREPs** ground truth	Constituency pattern	# of relations in **tweets** ground truth
1-8 PROPNs	29.8%	1-3 PROPNs	34.415%
CCONJ	3.9%	VERB-ADP	12.553%
ADP	1.6%	NOUN-ADP	6.488%

Table 3. Top three dependency patterns between two entities in SITREPs-based and tweets-based ground truth

Dependency pattern	# of relations in **SITREPs** ground truth	Dependency pattern	# of relations in **tweets** ground truth
2-16 PROPNs	48.949%	VERB-ADP	22.003%
VERB-ADP-PROPN	3.704%	2-4 PROPNs	14.81%
VERB-NOUN	1.401%	NOUN-ADP	6.347%

OneIE

OneIE (Lin et al. 2020) extracts relation(s) from a sentence by encoding each word, identifying and classifying entity mentions and event triggers, and decoding to find the graph with the highest global score. The context of each input sentence (and the words within a sentence) is determined using a pre-trained BERT encoder (Devlin et al. 2018). Entity mentions and event triggers are identified using a feed-forward neural network, meaning that the connection(s) between entities do not form a loop. The outputs from that become the nodes in our resulting network. Label scores are calculated by averaging each word representation and employing another feed-forward network. Finally, a beam search-based decoder (sample multiple sequences at once then predict iteratively) was implemented to find the optimal network with the overall highest global score.

OneIE is trained based on the Automatic Content Extraction (ACE 2005) dataset. ACE 2005 contains different data genres, including newswire data, broadcast news and conversation, weblogs, discussion forums, and telephone speeches (Walker et al. 2006). As this study focuses on English text data, we leverage the ACE2005 English training dataset, which includes annotations of entity mentions, entity mention types (named entities only), relations, and events. Each entity mention is tagged with one of seven entity types (PER, ORG, GPE, LOC, vehicles (VEH), facilities (FAC), and weapons). Each relation between an entity pair can be one of six types, namely person-social (PER entity pair), physical (PER/FAC/LOC/GPE entity pair), general affiliation (PER-PER/LOC/GPE/ORG entity pair), part-whole (FAC/LOC/GPE/ORG entity pair), org-affiliation (PER/ORG/GPE entity pair), and artifact (PER/ORG/GPE-FAC entity pair). We consider all relation types in this study, and created an additional category that groups all tagged relations as "relation" edges and those without relation tags as "no relation". The training data also contains relations coded into event types (n=33) and argument roles (n=22), which we did not consider as they are beyond the scope of this study.

OpenIE

OpenIE (Stanovsky et al. 2018) is different from OneIE in that relations extracted are not limited to predefined entity types and relationship types based on training data (Etzioni et al. 2008). Instead, OpenIE leverages part-of-speech (POS) tagging and syntactic parsing to extract triples (subject, predict, object) from a sentence. OpenIE is suitable for the scope of this study as the output includes entity-relation-entity information, and is thus suitable for network construction. We leverage the Stanford CoreNLP's implementation of OpenIE (Qi et al. 2020) to extract triples from our SITREPs and tweets data, where each entity is tagged based on CoreNLP's fine-grained NER annotator, which includes 24 entity types (e.g. PER, ORG, LOC, and fine-grained categories such as CITY, RELIGION, CAUSE_OF_DEATH). The relation for each subject-predicate-object triple has no predefined label, but is rather a verb/verb phrase that lies in between two entities. An example of relation triples extracted by OpenIE is shown in Figure 2, where OpenIE outputs five triples from one input sentence.

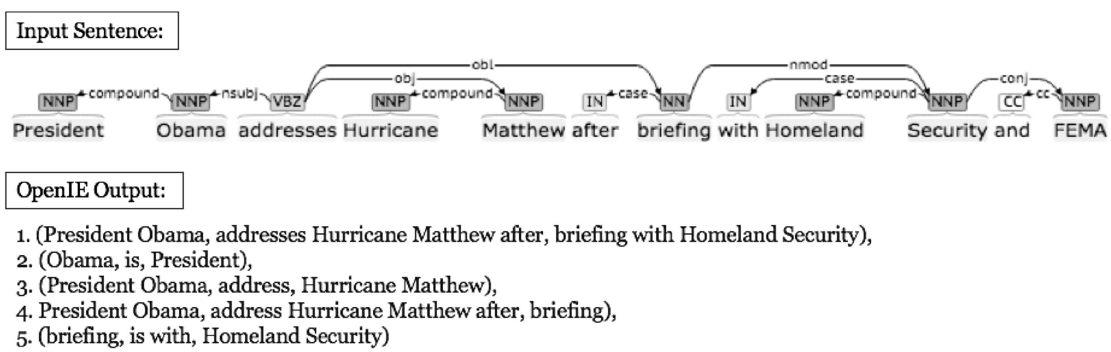

Figure 2. OpenIE output for an input sentence in Hurricane Matthew's SITREPs dataset

EVALUATION AND NETWORK ANALYSIS RESULTS

In this section, we compare the resulting networks from each entity and relation extraction methods to the ground truth. We start with evaluating the performance of each method in terms of precision, recall, and the F1 measure, where F1 was calculated based on whether an entity pair was found to have a relation that is also present in the ground truth data or not. While each of the two entities in a link must match the ground truth in boundary and type, the order of occurrence of these entities in a sentence does not matter (e.g. UN <-> EPA is the same as EPA <-> UN). Any partial entity matches are not considered a match. For the evaluation of entity extraction, we require a perfect match in entity name and entity type with the ground truth. For the evaluation of relation extraction, we require a perfect match in the linked entities (as in prior sentence) and in the binary classification of the existence of a relationship between an entity pair.

The performance results for the three entity extraction methods are shown in Table 4, and the results for the three relation extraction methods in Table 5. Among the three entity and relation extraction methods, our heuristics-based entity and relation extraction methods yield the highest performance (in terms of F1 measure). Among the other two methods, OneIE consistently outperforms OpenIE for both entity and relation extraction. Across the two ground truth datasets, all methods yield better performance on SITREPs than tweets. In particular, OpenIE-based entity and relation extraction on tweets yields an F1 measure of 0, primarily because there is no match in entity type (e.g. Haiti:*COUNTRY* (OpenIE) versus Haiti:*GPE* (ground truth). Dropping the entity type match requirement, we find that the F1 measure for OpenIE would increase to 0.912 (precision: 0.899, recall: 0.924), and relation extraction accuracy would also improve (though minimally: F1: 0.041, precision: 0.025, recall: 0.118).

Table 4. Performance of Entity Extraction methods

Model	SITREPs			Tweets		
	Precision	Recall	F1	Precision	Recall	F1
OneIE	0.163	0.269	0.203	0.100	0.156	0.122
OpenIE	0.0006	0.0006	0.0006	0	0	0
Heuristic Method (newly developed)						
Flair	0.840	0.718	0.774	0.838	0.337	0.481
SpaCy	0.772	**0.799**	0.678	0.730	**0.576**	**0.644**
Flair + SpaCy	**0.909**	0.722	**0.805**	**0.895**	0.394	0.547
Flair or SpaCy	0.777	0.570	0.658	0.751	0.444	0.558

Table 5. Performance of Relation Extraction methods

Model	SITREPs			Tweets		
	Precision	Recall	F1	Precision	Recall	F1
OneIE	0.408	0.498	0.449	0.051	0.110	0.070
OPENIE	0.033	0.135	0.053	0	0	0
Heuristic Method (newly developed)	**0.928**	**0.913**	**0.920**	**0.928**	**0.820**	**0.870**

Next, we compared the networks resulting from each method's entity and relation extraction output (shown in Figures 4-6) to the ground truth networks (shown in Figure 3) in terms of (1) network structure and (2) amount of overlaps in entities and relations. A visual examination indicates that the networks generated by the heuristics-based method resemble the ground truth networks most closely based on the overall structure of entities and relations between them, and network density. Specifically for the ground truth and heuristics-based SITREPs networks, there is a dense cluster of entities (names of counties) surrounded by smaller subgroups and triads. This shows that the heuristics-based SITREPs network accurately captures the active collaboration between county-level emergency operation centers that are recorded in the ground truth. In contrast to that, the tweets-based networks show no prominent clusters, but small subset of nodes that are central in both networks (e.g. hurricane names and state names). This finding shows that the heuristics-based tweets network fails to capture the collaboration patterns present in the ground truth network. OneIE's and Stanford OpenIE's based networks are notably different from the ground truth networks: Among the SITREPs-based networks, the one generated by OneIE is least dense, thus does not capture the dense cluster of connections between local-level entities in the ground truth data. Similarly, OneIE's tweets-based network is the least dense tweets network, however, the central nodes detected (i.e. state names such as Florida and Texas) are the same as those in the ground truth network. The networks extracted by OpenIE are distinctive from the ground truth and other empirical networks in that they are notably larger and contain more clusters.

Table 6. Network descriptives for ground truth networks (SITREPs-based and tweets-based) and networks resulting from heuristics-based, OneIE-based, and OpenIE-based entity and relation extraction methods. Preprocessing includes removing self-loops and isolates

	GT		Heuristics		OneIE		OpenIE	
Network measures	SITREPs	Tweets	SITREPs	Tweets	SITREPs	Tweets	SITREPs	Tweets
# of Nodes	300	531	183	892	166	377	1,431	2,600
# of Edges	1,304	1,306	1,019	7,001	210	418	1,737	3,371
Deg. Centralization	8.693	4.919	11.198	15.697	2.530	2.217	2.428	2.593
Density	0.029	0.009	0.062	0.018	0.015	0.006	0.002	0.001
Global Clustering	0.454	0.153	0.509	0.749	0.042	0.046	0.004	0.007
Average Path Length	3.617	3.485	3.236	2.892	5.737	4.559	8.964	5.283
Size of Largest Component	1,218	1,267	990	6,915	123	287	938	2,360

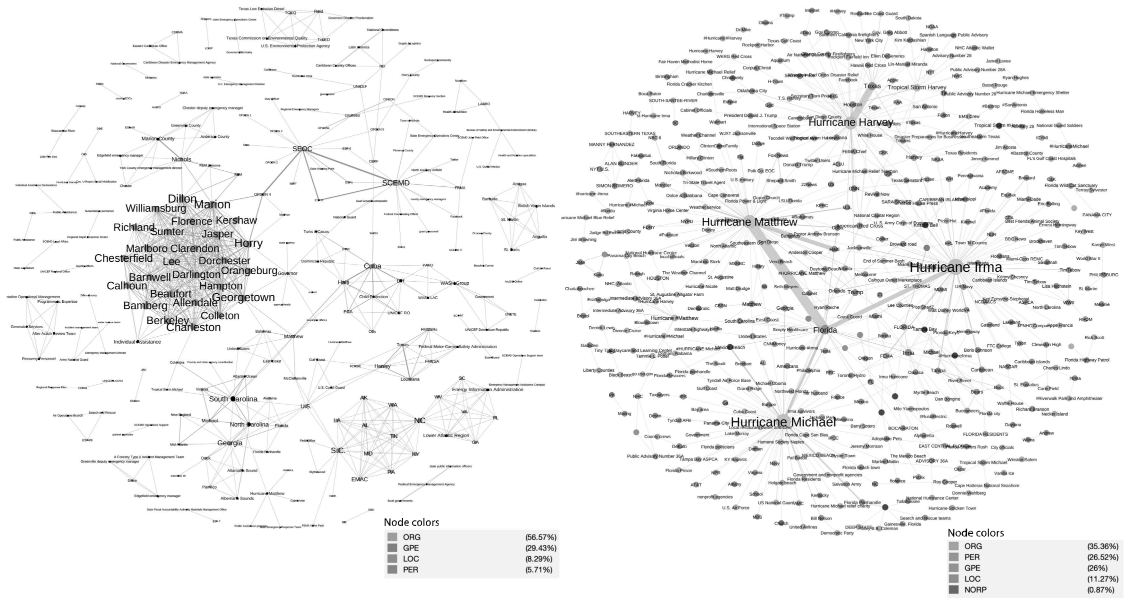

Figure 3. SITREPs-based (left) and tweets-based (right) networks generated with ground-truth data

Common network analytic metrics are shown in Table 6. Looking at the three relation extraction methods, the size of the heuristics-based networks is most similar to the ground truth, followed by OneIE-based networks, though those are slightly smaller with notably fewer edges. OpenIE-based networks are the largest, followed by heuristics-based networks and OneIE-based networks. The tweets-based networks are, on average, larger (average size=1,100 edges) than the SITREPs-based networks (average size=520 edges), which is different from the ground truth networks were SITREPs and tweets networks are similar in size (1,304 and 1,306, respectively, although tweets-based network has more nodes). Similar to the ground truth networks, networks from all three methods have low densities, indicating that the actual number of relations between entities is much lower than expected. In terms of topological characteristics, the heuristics-based and ground truth-SITREPs networks are the only networks with high global clustering and short average path lengths. This combination of features is an indicator for a small-world network (Watts and Strogatz 1998), where on average, an entity has many immediate connections and a few distant connections. The remaining networks show relatively low global clustering and high average path length, suggesting that these networks are not behaving like small-world networks.

Beyond the structural network differences, tweets-based networks resulting from the three methods contain more diversified entities than SITREPs-based networks, such as celebrity names (e.g. Vanilla Ice, Donnie Wahlberg), political parties (e.g. Republicans, Democratic Party), and mentions of sports teams (e.g. [Chicago] Bears, [Tampa Bay] Buccaneers), some of which may not be related to crisis collaboration activities. Though smaller in network size, SITREPs-based networks extracted from the three methods contain more crisis-related organizations at multiple levels of the government (e.g. Red Cross, Bay County Emergency Operations Center) and individuals (e.g. Gov Cuomo, SERT personnel) involved in response collaborations. Both SITREPs-based and tweets-based networks overall contain specific location names (e.g. Tyndall Air Force Base, Blythewood Field Office), which are helpful to identify areas of collaboration activities, and tweets-based networks contain more generic locations (e.g. Airports, Atmosphere, Cities) than SITREPs-based networks.

In this section, we report on the types of entities and relations contained in the networks extracted with the three tested methods. OpenIE finds more entity types that differ from the ground truth networks than the other two methods, despite the fact that OpenIE's NER model has fewer entity types than heuristics-based's NER model (12-class versus 18-class, respectively). The most prominent entity types detected by OpenIE in the SITREPs-based network, i.e. *numbers* (26.21%) and *date* (9.22%), may not provide as much information about collaboration activities as *organizations* (20.13%) and location (6.92%). For the tweets-based networks, OpenIE detects a substantial number of *URLs* (56.24%), followed by *organizations* (9.31%) and *persons* (7.51%). As for top relationship types detected, OpenIE's SITREPs-based network in dominated by "were in" (7.58%), "is providing" (6.44%), and 'was on" (4.29%). Only "is providing" is potentially indicative of some collaboration activity between two entities, while the other two types may be indicative of physical co-location of agents and/ or resources. In OpenIE's tweets-based network, the top relationship types are "is" (5.52%), "is in" (3.6%), and ''has" (1.99%). The top relations in

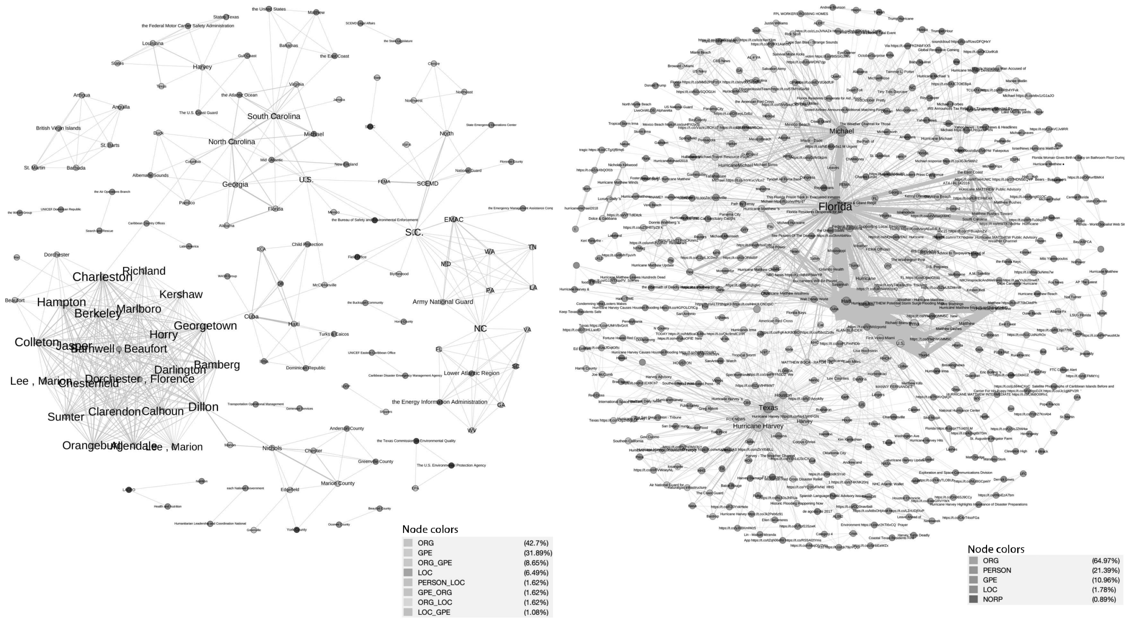

Figure 4. SITREPs-based (left) and tweets-based (right) networks generated with heuristics-based relation extraction method

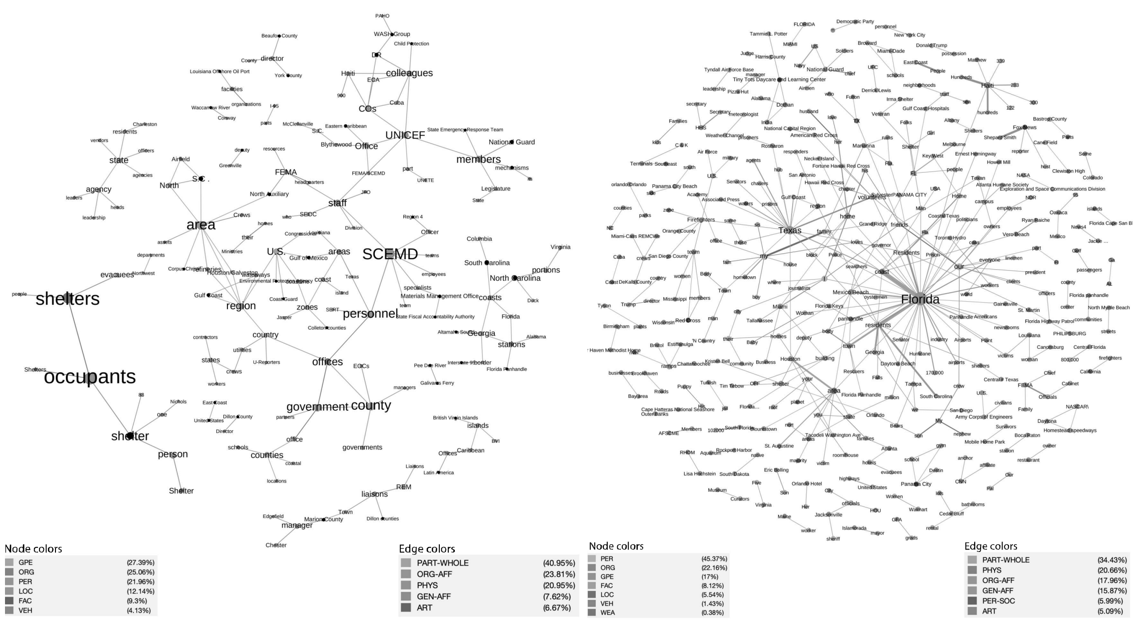

Figure 5. SITREPs-based (left) and tweets-based (right) networks generated with OneIE relation extraction method

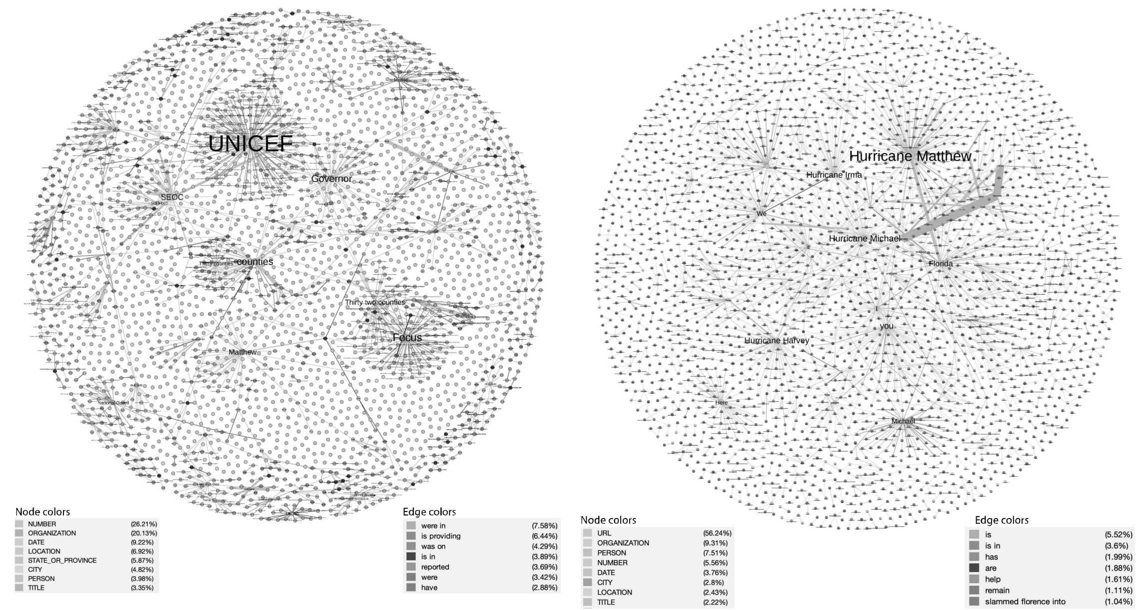

Figure 6. SITREPs-based (left) and tweets-based (right) networks generated with Stanford OpenIE relation extraction method

OpenIE's tweets-based network, however, is not representative of the entire (long-tail) distribution of relations detected. Hence, a larger number of relations detected in tweets compared to SITREPs show that the language used in tweets is more diversified than that in SITREPs.

One-IE's tweets-based network contain more types of entity and relations than the SITREPs-based network, with *persons* (45.37%), *organizations* (22.16%), and *geopolitical entities* (17%) being prominent entities. However, these entities are not exact matches with those mentioned in the ground truth tweet network, resulting in low performance (F1 for NER: 0.112). Between these entities, most relations are of the types "part-whole" (34.43%), "physical" (20.66%), and "organization-affiliation" (17.96%). These relations are also not explicitly present in the ground truth networks because the ground truth only contains a binary relation/no relation. OneIE's SITREPs-based network also has the same top three entity types (*geopolitical entities* (27.39%), *organizations* (25.06%), and *persons* (21.96%)) as the tweets-based network. The entity pairs are also frequently connected via "part-whole" (40.95%), "organization-affiliation" (23.81%), and "physical" (20.95%) relationship types.

The heuristics-based networks contain the least amount of entity types compared to the other two methods (for SITREPs, four entity types detected as opposed to six types detected in OneIE and eight types detected in OpenIE; for tweets, five entity types detected as opposed to seven types detected in OneIE and eight types detected in OpenIE), however, the relations predicted have the highest performance compared to the other methods. In the heuristics-based SITREPs network, a majority of entities are tagged as *organizations* (56.57%), followed by *geopolitical entities* (29.43%), and *locations* (8.29%). There are no entities with the *national, religious, or political groups* tag detected in this network. For the tweets-based network, entities detected are also primarily *organizations* (35.36%), *persons* (26.52%), and *geopolitical entities* (26%). *National, religious, or political groups* entities are present, but minimal (0.87%, e.g. "Democratic", "Texans").

DISCUSSION AND FUTURE WORK

Our first research question asked what collaboration-related entities and relations each of the three tested methods (heuristics-based, OneIE, OpenIE) gets right (in comparison to the ground truth), what errors each method makes, and how the tested methods compare to each other. The variability in performance results and networks generated by these methods further confirms that methodological choices about node and edge detection impact and potentially distort how we perceive the evolution of collaboration among various actors during crisis response. Specifically, the entity and relation extraction results confirm that interorganizational collaboration is closest to ground truth when using our heuristic-based model. However, our solution might overfit to domain data and needs further calibration. Furthermore, models trained with supervised learning (i.e. heuristics-based and OneIE methods) and unsupervised approaches (i.e. OpenIE) yield different results, indicating that training and testing are crucial to ensure that relation extraction is applicable to crisis-related content. Furthermore, OpenIE's low performance in terms of both entity type labeling and, consequently, relation extraction may suggest behavior early on in the syntactic parsing and part-of-speech tagging pipeline that drives accuracy away from ground truth resemblance, which in turn influences the accuracy of the extraction of triples (Gashteovski 2020). Another possible explanation might be that OpenIE's definition and operationalization of a relation differs from what we did in the ground truth, and thus logically leads to low overlaps in entities and relations extracted. OneIE, while it performs better than OpenIE for this particular application scenario, still contains high false positive and false negative rates, specifically higher number of false positives than false negatives (precision lower than recall). Given that OneIE was pre-trained with non-crisis related benchmark dataset (i.e. ACE2005 dataset[1], the results suggest that training with domain-specific data may help boost performance. The networks generated with OneIE, however, do contain entities and relations that are relevant to crisis response (shown in Figure 5), and thus a joint entity-relation extraction pipeline (where NER and RE are performed simultaneously to minimize errors cascading from one task to another) is useful for this context. It is furthermore imaginable that the employed tools do find false positives, i.e., entities and/ or relations relevant to crisis response but not contained in the ground truth, which would require further investigation to test for that.

Our second research question is about the implications of our findings for bringing the tested methods into practical application scenarios in crisis research. We have shown that the application of state-of-the-art relation extraction methods requires domain-adaptation with crisis-specific training data. Furthermore, the choices for what entity and relation extraction method or combination of methods to use, how to configure them, and what types of entity and relations to consider in the scope of a crisis response network do influence the networks generated. Last but not least, it is important to determine whether a research study's definition of a relation is aligned with the method's operationalization of a relation. For instance, our heuristics-based method focuses on the binary detection of relation, while OneIE and OpenIE extract multiple relation types which may be helpful to further explore and categorize the content of relations. We also demonstrated that a heuristics-based model trained with crisis-specific text data can leverage text features (including word co-occurrence and constituency and dependency parse trees) that more accurately reflect crisis-specific language use than general-domain models (i.e. OneIE and OpenIE). Understanding the language used in crisis text data is thus necessary to distill relevant information about the entities involved and the interactions that took place between them during response.

Our work is driven by the assumption that effective collaboration relies on adequate shared SA of the conditions and needs surrounding a crisis (U.S. Department of Homeland Security 2008; Nofi 2000; Benson et al. 2010) to inform decision-making and guide response actions. However, prior literature also finds that information exchange between organizations, which is necessary to achieve shared SA, remains difficult (Bjurling and Hansen 2010; Saoutal et al. 2015). One reason for this difficulty is the lack of formal information pipelines for connecting requesting and responding organizations to various crisis-related resources and services (Lee et al. 2012; Sarol, Dinh, Rezapour, et al. 2020). Consequently, the lack of collaboration between requesting and responding organizations may negatively influence the overall ability of members within an interorganizational network to dynamically interact with each other (Benssam et al. 2013; Kurapati et al. 2013) and to address crisis-related needs (Ganji et al. 2019). To address this shortcoming, our analysis of the collaboration dynamics based on situational reports and tweets surrounding actual hurricane response shows that organizations and persons at various levels of the government (e.g. FEMA, Florida Highway Patrol, Bay County Operations Center) did work together with non-governmental entities (e.g. UNICEF, United Methodist Committee on Relief, American Society for the Prevention of Cruelty to Animals). While doing a substantive analysis of these dynamics is outside the scope of this paper and part of our future work, the work shown in this paper enables the collection or construction of data needed for such analyses. We also showed that domain-adaptation of entity and relation extraction models is important to reliably extract crisis-related collaboration information from text data. In future work, we will also continue to examine existing structures of crisis collaboration to identify areas of improvement for crisis response policy planning. In terms of methodological improvements, we plan to expand our ground truth corpus to include more texts from different crisis events to cover the language used in crisis reporting and communication more broadly and thereby advancing the generalizability of computational, domain-specific information extraction solutions.

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[1]https://catalog.ldc.upenn.edu/LDC2006T06

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Challenges of Emergency Management Digital Transformation in Industrial Parks

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ABSTRACT

Industrial parks are economic drivers of the cities where they are located. These parks are constantly at risk of catastrophe due to the diversity of industries and the dangerous materials used in their production processes. Despite this constant threat, there is a digitization shortfall in the emergency management process in industrial parks. This research paper seeks to describe the importance of digital transformation in industrial parks, as well as, how information systems can contribute to proper emergency management. Based on the preliminary analysis of the literature, it was possible to determine how the implementation of an emergency system would facilitate the prevention of catastrophes according to the analysis of scenarios, simulation, management, and proper coordination of emergencies in real-time. However, the proper functioning of this system depends on the implementation of environmental innovation, exploration, and observation skills, without neglecting the commitment of organizations and their material, human and technological resources to achieve a significant change.

Keywords

Digital Transformation, Safety, Industrial Parks, Emergency Management, Simulation.

INTRODUCTION

Industrial parks represent extensive urban areas often neglected, which contribute to the degradation of the urban environment, including low thermal comfort levels as a result of soil sealing and low albedo surfaces (Alves et al., 2022). These places are found in vulnerable areas where significant quantities of dangerous substances are stored or processed. Therefore, all the industries that carry out their productive activity in these places are exposed to different types of risks including natural, industrial, economic, financial, or health emergencies. The survival of such organizations is conditioned to appropriate management of risk factors. It is important to understand what the differentiating factor, which allows overcoming or preventing catastrophic events is within an organization. This success factor could be given by its resilience, defined by Patriarca et al. (2018) as a property of the system that confers the ability to remain intact and functional. Enhancing this definition Carden et al. (2018) states that resilience is the ability to resist stress or recover and regain its previous form.

Industrial facilities must always have active responsiveness, which can result directly from an appropriate development of emergency plans, development of new methodologies, skills, and technologies that allow the use of common designs and resources as a strategy to respond to new and emerging threats, which would allow preventing, evaluating, and controlling their consequences. Thus, Cozzani (2017) states that Information Systems (IS) can contribute to achieving this goal by improving the improvement of processes and risk prevention. From our perspective, it is of vital importance that industrial parks have an IS capable of managing emergency plans in dispersed locations in an accessible manner, as well as notifying, controlling, and activating alerts in real-time through sensors and mobile technology, optimizing resources by enhancing the response in industrial parks. Therefore, it would be important to have industrial parks with infrastructure integrated with Industry 4.0 technology that allows users to monitor, control, and optimize the social, economic, and environmental repercussions of industrial activities (Pan et al., 2015). In this context, IS can be used in the phase of planning, preparation, detection, and responsiveness to emergencies in industrial parks through the design of emergency plans developed collaboratively. Thus, facilitating organizations with comprehensive management, planning, and responsiveness in light of emergencies.

This article is structured in the following sections. In the first section, a theoretical approach is described regarding digital transformation and technological resources that can be used by industries in the security monitoring process. In the second section, an explanation about industrial parks and the risks they are exposed to is given. Section three describes the proposal for a metadata modeling that integrates prevention, monitoring, and responsiveness to catastrophic events, and finally, the challenges of digital transformation are recognized. The paper ends with conclusions.

DIGITAL TRANSFORMATION IN INDUSTRIAL PARKS

Industry 4.0, which is known as the fourth industrial revolution, was named for the first time in Germany in 2011 as part of a new concept of economic policy based on high-tech strategies. This fourth industrial revolution, according to Roblek et al. (2016) is based on the digitization of production, automation, and correlation, for which it is necessary to have resources such as the Internet of Things (IoT), a Cyber-Physical System (CPS), Information and Communications Technology (ICT), Enterprise Architecture (EA), and Enterprise Integration (EI) (Lu, 2017). The implementation of these technologies seeks to improve processes and achieve a suitable digital transformation for the company.

Therefore, with the application of technological resources of Industry 4.0, it is possible to improve the internal processes and competitiveness of organizations. This phenomenon is usually called digital transformation, which according to Vial (2019) is a process that aims to improve an organization by causing significant changes in its properties through combinations of information, computing, communication, and connectivity technologies. Consequently, the expansion of new digital technologies makes digital transformation relevant to almost all industries. For this reason, nowadays companies are beginning to carry out digital transformation in a more systematic and strategically planned manner by creating measurable objectives and defining roles and responsibilities in the organization (Berghaus, 2016).

Thus, digital transformation has become a topic of great importance for companies since it changes relationships with customers, internal company processes, and the establishment of the value of organizations through the use of Information Technologies (Zaoui & Soussi, 2020). In the application of digital transformation, the strategy of change and the establishment of continuous practices of transparency and incorporation must be considered (Morton et al., 2020). This will allow organizations to create, capture and transfer information within companies by utilizing appropriate IS, the strategies for use, and the people who sustain the information for the use of IS (Porfirio et al., 2021).

The transformation and improvement of the different types of traditional industrial parks are inseparable from the replacement of the dominant industrial structure and the change in form and function (Bai & Lai, 2022). Therefore, to achieve a true digital transformation in industrial parks, information technologies must be incorporated through interconnected devices such as the Internet of Things (IoT), industrial applications in the cloud, and fifth-generation mobile networks (5G). To establish flexible and efficient solutions in response to security problems with the advantage that they may be of use to numerous heterogeneous devices, which companies have, generating a sustainable vision (Hatzivasilis et al., 2018).

The greatest disadvantage of the digital transformation applied to industrial parks is the lack of interoperable solutions that adjust to the integration and the utilization and management of many devices and associated services making it difficult to establish industrial environments with artificial intelligence. For this effect, the use of inter-organizational information systems, digital platforms, and the development of new IT capabilities (Delmond et al., 2016) would help generate scenarios, optimize resources, and improve the resilience of industries; but this must be strengthened through a collaborative process to create capacities. According to

(Helfat & Raubitschek, 2018) there are three types of capacities such as the capacity for innovation, environmental research, and discovery capacities, and lastly integration capacities. If companies can acquire these capacities, we could achieve collaborative resilience, which takes into account strategies, participation, and consideration of the situation (Mahajan et al., 2022).

Safety and Security in Industrial Parks

An industrial park as such emerged in North America and Europe in the 1950s as a solution to the issues of expansion and development. Thus, they can be described as "a large extension of land, subdivided and developed for the use of several companies simultaneously, (Pieser & Chang, 1998) and industrial buildings may be part of an integrated industrial park, or they may be individual buildings located in industrial districts or neighborhoods that are part of a "park-like setting". In addition, it can be considered as a community of companies that are in a common property sharing materials, energy, or infrastructures (Valenzuela-Venegas et al., 2018). Therefore, industrial activities generally seek proximity to each other to benefit from easy access to resources, logistics, and customers and can take advantage of their complementarity (Le Tallier et al., 2022).

In addition, industrial parks are located in places where different types of industrial activities are developed such as vehicular, metallurgical, chemical, food, etc., where different types of materials are used for production. Moreover, these companies store chemical materials, so these places often face threats, which can cause great damage and jeopardize the safety of the organizations that conform to them as well as the safety of the employees of such companies. In the normal functioning of these companies, their raw materials or manufactured, transported, and stored products are usually present in flammable, explosive, or toxic locations (Hao et al., 2015). This situation results in the frequent occurrence of pollution and personal injuries, and it also causes great threats to the surrounding environment.

It is important to highlight that in multi-company parks, safety, security, and environmental responsibilities are not always clear, and the risk map has changed since these places are always at imminent risk of emergencies or catastrophes of all kinds (Rui et al., 2014). Furthermore, this situation continues to be an obligation for the security management entities to prepare emergency plans, which allow facing any type of catastrophe more efficiently by taking advantage of the benefits that digital transformation provides us with. Additionally, it is important to consider the design of an integrated park, (Du et al., 2019) based on distributed storage, smart contract, non-manipulation, traceability, and other characteristics of technology (Abraham et al., 2022) in that regard, the incorporation of resources allows industries to encourage circular operations that lead to the creation of sustainable systems.

MODELING EMERGENCY SITUATIONS IN INDUSTRIAL PARKS

In this section, we propose a generic IS for serving as a reference for digital transformation processes of emergencies in industrial parks. From our perspective, is crucial to develop a metamodel for emergencies in dispersed locations. This model is the backbone of the application of advanced interaction models, the development of concept tests with advanced interfaces, and the definition of a process model of emergency response in industrial parks. Digital transformation plays a dominant role in achieving this objective through the production of an IS and understanding how the interaction of these, needs three pivotal phases such as information input, data processing, and as a result the responses or reports of the collected data. The information to be gathered should begin with the characterization of the dispersed locations within the business parks. Such will allow identifying where the security cameras and the infrared sensors that monitor temperature, humidity, and air concentration will be located, it will monitor all kinds of activities that potentially risks business parks into an emergency. The data coming from the cameras and infrared sensors should be transmitted immediately to the new SI, which will analyze any possible crisis in real- time, using the metamodel for emergency management.

The metamodel includes interfaces and document engineering, which allow the analysis of real-time crisis scenarios for emergency management in industrial parks with all the benefits that it entails in terms of simulation and flexibility. With scenarios that consider the various phases of emergency management such as the response, control, and mitigation of the damage generated by the crisis. Scenarios for response and control during emergency management, scenarios that support group decision-making for the implementation of contingency plans during emergency management, or scenarios to improve collaboration between rescue services, police, and military staff during crisis scenarios (Figure 1).

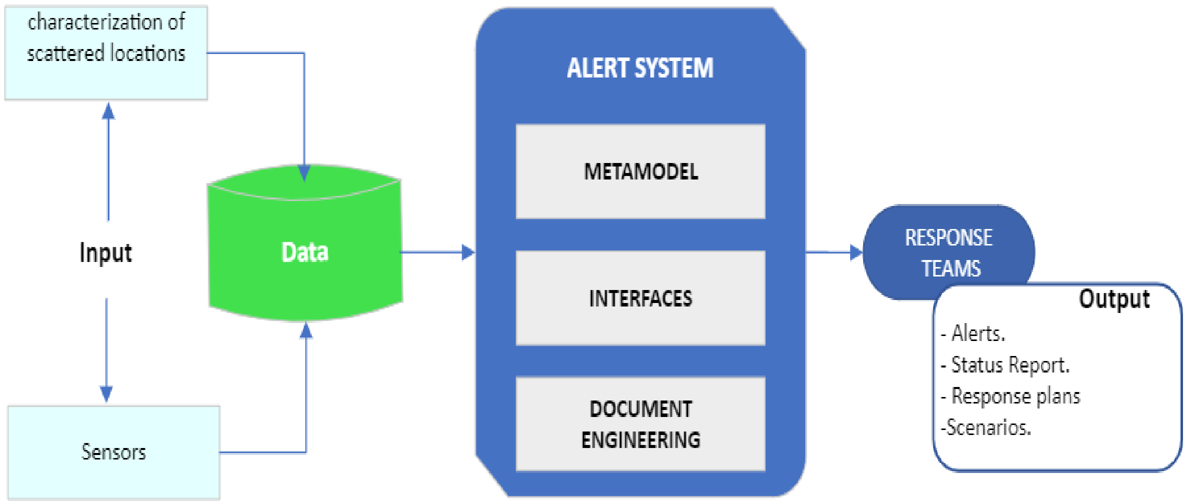

Figure 1. System Outline

Although scenarios play a very significant role in the current management and responsiveness to emergencies in both, the main international and national organizations, we identified the lack of developments capable of producing and analyzing this set of scenarios in more complex crises in real-time. This is where the intervention of IS comes into play for the efficient creation of emergency plans, which integrate these capacities, facilitating outstanding communication and interaction between the participants, promoting a better understanding and analysis of the situation from different perspectives, and improving their document management. There is currently a lack of a simulation and analysis methodology capable of integrating data of different nature to provide successful support for decision-making in real-time.

Therefore, our proposal is based on the successful use of Industry 4.0 resources; it will allow the development of multiple perspectives regarding economic, environmental, and social sustainability and provide a framework to think of a strategy for the design of sustainable industrial parks (Cochran & Rauch, 2020). The establishment of an emergency management system that allows the design of simulated scenarios for training, in such a way that emergency management capacity is produced, as well as for the evaluation of the plan itself, in such a manner that its benefits and weaknesses can be identified. Hence, three components are proposed to be considered and developed with the interaction of Information Systems. The first component considers the analysis of scenarios and emergency simulation, the second component contemplates the management of emergencies, and the third component considers real-time coordination through a system that manages the interaction of these three scenarios (Figure 2).

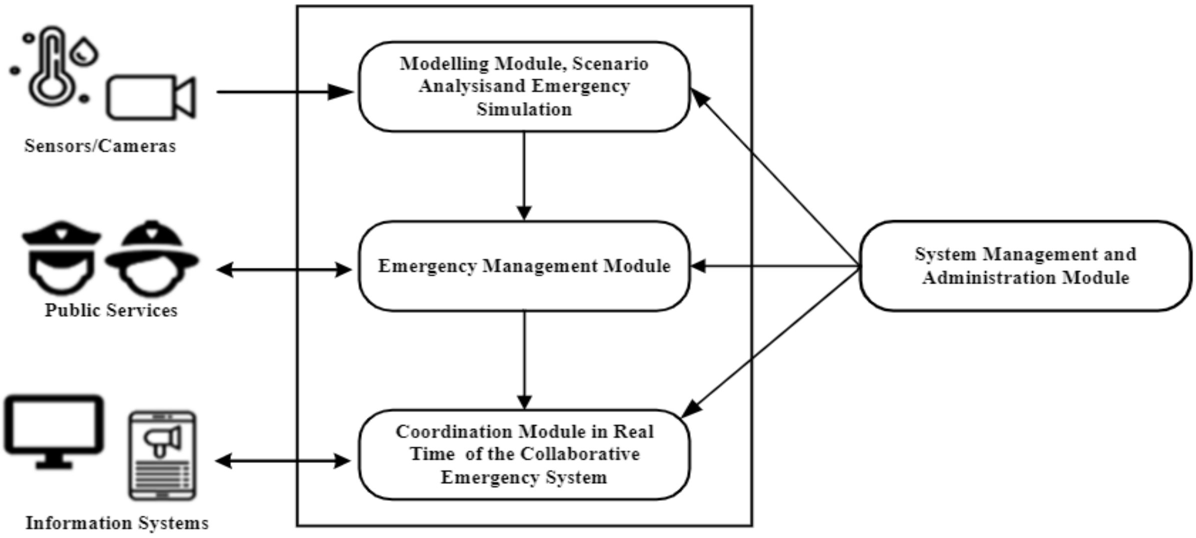

Figure 2. Modules of the Emergency Management System

The emergency management system should be able to "plan and prepare for", "seize", "recover" and "adapt" to any unfavorable event that may occur in the future (Sharifi & Yamagate, 2016). Thus, the modeling component, scenario analysis, and emergency simulation will be based on the dynamic analysis of emergency scenarios (incidents → essential services → responsiveness to the incident) based on the modeling of these scenarios by linking variables, in such a manner, that risks that may be triggered can be anticipated in different emergencies. By sensors (Ansaldi Silvia M. & Bragatto Paolo, 2022) which can be widely distributed throughout the entire establishment, in the workplace, and can be utilized by the employees. Together with Artificial Intelligence, they offer a great opportunity to make safety management at service sites much more dynamic and collaborative.

Meanwhile, the second component of emergency management must achieve intelligent management of emergencies in Industrial Parks to carry out the coordination between those involved more efficiently. This can be achieved through adequate intercommunication via the industrial internet (Boyes et al., 2018) which includes two key components: the connection of sensors and transducers of industrial machines to the local processing of the Internet and the subsequent connection with other important industrial networks that can achieve value independently.

As for the coordination module of the collaborative emergency proposal in Industrial Parks in real time, it must allow communications between the system and the actors involved, enabling very cautious coordination of the response teams. Thus, this information and emergency management system based on new technological advances can assist in the development of safety ideas between intelligent facilities and applications that are possible due to world organizations, (Saber et al., 2019) based on scientific knowledge to be successful.

CHALLENGES

Although digital transformation is a process aimed at improving the competitiveness of companies through digitization, optimization of production, automation and adaptation, human-machine interaction, and automatic data exchange and communication (Sousa & Rocha, 2019). Effective digital transformation will take place when organizations embrace the potential learning in the design and the content delivery process, informal problem solving, knowledge exchange, communities of practice, and user-generated content. The main challenges that industrial parks must overcome include.

Innovation Capacity

Considering that, the organizations, which carry out their activity, are different and use different types of raw material for the manufacture of their products, which makes them vulnerable to industrial catastrophes; it is important to design an integrated and participative system with the modeling of an information system for emergency management.

Capacity for environmental exploration and detection through the development of a technological solution that allows modeling, simulation, and intelligent management of collected data with the application of advanced interaction models, the establishment of concept tests with advanced interfaces, and the definition of a process model that guarantees collaborative participation in cases of emergency.

Integration Capacities

Furthermore, digital transformation must be carried out independently between the administrators of the transformation and its beneficiaries and with participation in the processes of socialization and training in the use of new technologies. It is important to create a competitive advantage for organizations by participating in efforts to systemize processes, and by assuming responsibility for the use and treatment of data generated by organizations.

CONCLUSIONS

Industrial parks are places of economic development and infrastructure within big cities, but they have always been exposed to constant threats, which makes them an easy target for various types of catastrophes. Currently, the implementation of Industry 4.0 is oriented towards a process of building resilience in the face of adverse events to which they may be exposed. Organizations in the security field need to have the capacities to anticipate, confront, and adapt to problems that may arise without it meaning that they are affected by these events.

Additionally, the industries must be enclosed in the design of a participative and inclusive safety plan that allows the use of digital transformation to produce an emergency management system, which in real-time allows them to have the necessary restorative measures and the ability to respond. Yes, technological resources can help prevent catastrophes, but it is important to emphasize that these technological resources are successful due to the adequate intervention of the human being, and this can be achieved through participatory processes in which its functioning is socialized.

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Supply Chain Resilience in the New Zealand FMCG Sector: A Study of the 2021 Canterbury Flooding

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ABSTRACT

Disasters can severely disrupt the flow of Fast-Moving Consumer Goods (FMCGs) in New Zealand (NZ), preventing the replenishment of essential products and causing shortages on retailers' shelves. This paper presents work-in-process research that aims to better understand how the NZ FMCG retailers build resilience into their replenishment operations to mitigate disruptions in the wake of a disaster. The two key components of supply chain resilience (redundancy and flexibility) are investigated in the context of the 2021 Canterbury flooding. A survey was used to collect data on retailers' routine replenishment operations, the impacts of the flooding, and practices mitigating disruptions. The preliminary findings suggest that redundant inventory is used to compensate for insufficient flexibility in the NZ freight system (due to not only the lack of adequate secondary roads and alternative modes of transport, but also the centralised distribution system limiting the sources of supply). This study contributes a better understanding of the FMCG distribution and replenishment operations in NZ and highlights the need for public and private investments (e.g. redundant transport infrastructure and distribution facilities). Additional research investigating the most influential investments to improve the ability of the FMCG sector to manage post-disaster freight disruptions would benefit the literature.

Keywords

Freight Disruptions; Supply Chain Resilience; Redundancy; Flexibility; Fast-Moving Consumer Goods

INTRODUCTION

The COVID-19 outbreak and other recent events have brought supply chain resilience to the forefront of business decisions and academic discussions. Supply chain resilience is defined as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations" (Ponomarov and Holcomb, 2009, p. 131). Building resilience into freight systems is critical to mitigate the impacts of major disruptive events such as disasters (Sheffi, 2019). By causing infrastructure damage and disrupting deliveries, disasters expose the fragility of supply chain systems that have been designed to achieve a high level of efficiency and cost control in normal circumstances (Sáenz and Revilla, 2014). In particular, the continuous implementation of efficiencies and cost reduction strategies in the distribution of Fast-Moving Consumer Goods (FMCGs, namely low-cost, non-durable household products quickly sold and replenished) has left retailers vulnerable to supply chain disturbances and, ultimately, to shortages of goods on store shelves (Agigi et al., 2016; Simba et al., 2017). Resilient supply chain operations are critical for FMCG retailers that cater for essential everyday needs by making large volumes of consumer goods (including food, drinks, and personal care) widely available (Bala and Kumar, 2011). Despite the FMCG sector's essential economic and societal role (Sable, 2019), academic studies investigating the resilience of FMCG distribution systems and the strategies implemented to ensure supply chain continuity and product availability scarcely focuses on post-disaster response and recovery.

To fill this gap, this paper presents work-in-process research focusing on the May/June 2021 Canterbury flooding that damaged major transport links and disrupted FMCG distribution operations in the lower South Island of New Zealand (NZ). The following research question guided the investigations: *how can the NZ FMCG retailers build resilience into their replenishment operations to mitigate disruptions in the wake of a disaster?*

To address this question, data was collected through an online survey of the FMCG retailers affected by the 2021 Canterbury flooding. The analysis of the responses collected so far indicates that participants build buffer stock to enhance resilience and ensure that goods are available on shelves. However, the lack of flexibility in the NZ freight system (few adequate secondary roads, lack of alternative modes of transport, and limited backup sources of supply) leaves them vulnerable and limits their ability to re-arrange replenishment operations in the wake of a disaster. Although this research project is still in the early stages, the preliminary results contribute a better understanding of the FMCG distribution and replenishment operations in the NZ context.

The remainder of this paper is structured as follows: the next section reviews the literature on supply chain resilience and distribution practices. The research context and the methodological approach are subsequently presented, before the findings of the research are reported, and then discussed. The limitations of this study, its contribution, and concluding comments are provided in the final section.

LITERATURE REVIEW

Supply Chain Resilience: Redundancy and Flexibility

For almost two decades, the supply chain literature has highlighted the critical role of two key components of supply chain resilience (redundancy and flexibility) and the importance of building them into supply chain systems (Christopher and Peck, 2004). Redundancies are additional resources and excess capacity kept as a buffer to manage fluctuations and mitigate disruptions. Commonly used in supply chain management, this capacity-adding strategy includes buffer inventory, backup suppliers, additional facilities, and low capacity utilisation rates (Tomlin, 2006; Knemeyer et al., 2009; Stecke and Kumar, 2009). As discussed by Sheffi (2019), redundancy provides an immediate (but short-term) solution to deal with disruptive events by quickly smoothing fluctuations in the demand and/or supply of goods. Since the building of redundancy is a strategy incurring a high level of upfront costs without providing benefits until the disruption occurs (Rice and Caniato, 2003; Kamalahmadi and Parast, 2017), it is often described as an insurance policy or a just-in-case approach (Sheffi and Rice Jr., 2005).

Flexibility is the ability to rapidly reconfigure operations in order to mitigate disruptions in the flow of goods and to ensure that they are delivered when and where they are needed (Sheffi and Rice Jr., 2005; Sreedevi and Saranga, 2017; Sheffi, 2019). Common aspects of flexibility include the ability to swiftly re-route freight movements across alternative routes/modes when a route/mode is unavailable and/or to use alternative sources of supply, including alternative suppliers or alternative distribution centres (Tang, 2006; Agigi et al., 2016). Compared to redundancy, flexibility requires some initial reconfiguration time but provides a longer-term solution (Sheffi, 2019).

Redundancy and flexibility are commonly presented as contrasting strategies in the literature. While the building of redundancy is viewed as a passive strategy incurring a high level of cost (e.g. capital investment and depreciation), flexibility is often considered a more dynamic and cost-avoidance approach (Kamalahmadi et al., 2021). However, as explained by Sheffi (2019), flexibility requires a level of redundancy built into the supply chain system. For example, building a flexible distribution network with geographical dispersion (e.g. two or three distribution centres serving retail stores in specific service areas) calls for a lower level of capacity utilisation at the distribution centres (to enable them to serve different service areas when handling disruptions).

Efficient (and Fragile) Distribution Practices

Due to the growing use of information technology enhancing supply chain visibility (DeGroote and Marx, 2013), to the prevalence of lean practices, and to the constant quest for costs savings (Womack and Jones, 1994; Holweg, 2007), freight operations have been streamlined and spare resources and capacity systematically eliminated from supply chain systems. In other words, supply chains have been designed to operate like clockwork, with a high level of efficiency and little latent capacity (Hendricks and Singhal, 2012). From the late 1980s, these highly efficient practices have been applied to downstream supply chain operations (i.e. distribution operations) in order to squeeze distribution costs and, in turn, increase profit (Zylstra, 2006; Reichhart and Holweg, 2007). More specifically, inventory has been taken out of the distribution systems by promoting just-in-time deliveries, single sourcing has been implemented to reduce purchasing prices and the costs of managing the supplier base, and distribution operations have been concentrated to achieve economies of scale and lower transaction costs (Hendricks and Singhal, 2012). Concentration has been carried out, for example, by centralising distribution and arranging replenishment from a small number of large distribution centres (Agigi et al., 2016).

Although transitionally efficient, these practices have increased the fragility of distribution systems by leaving little or no capacity to absorb and mitigate shocks, namely little or no redundancy and flexibility. This, in turn, has increased the chance of disruptions in distribution operations and the risk of delays and stock-outs (Hendricks and Singhal, 2012). These concerns are particularly apparent in FMCG distribution systems that are characterised by a high level of concentration and typically consist of large retail players with central, strategically located distribution centres that continuously replenish a vast number of stores operating under their banners. In addition, trucks are predominantly used for moving FMCGs between distribution centres and the retail stores, limiting the opportunity for flexible transport when roads are inaccessible (Kellner et al., 2013; Rodrigues and Potter, 2013; Manders et al., 2016).

RESEARCH CONTEXT AND METHODOLOGY

2021 Canterbury Flooding

NZ is prone to natural hazards such as floods, earthquakes, tsunamis, and volcanic eruptions. Due to the country's over-reliance on road transport, natural hazards and the subsequent road infrastructure damage frequently disrupt freight operations (Davies et al., 2017). This study focuses on the May/June 2021 Canterbury flooding that made major transport links inaccessible and disrupted transport in the lower South Island of NZ. From 29th to 31st May, severe rainfalls affected the Canterbury region, with the largest accumulation of rain (526 millimetres in 48 hours) recorded in Mt Somers (Environment Canterbury, 2021). The National Institute of Water and Atmospheric Research (NIWA) estimates that the probability of such an extreme weather event is once every 200 years (NIWA, 2021). As a consequence, the Canterbury region experienced widespread flooding and declared a state of emergency on 30th May (Environment Canterbury, 2021). Floodwaters caused significant infrastructure damage to bridges, railways, and state highways in the Christchurch, Ashburton, Waimakariri, Selwyn, Timaru, Hurunui, and Mackenzie districts (McDonald, 2021; Stuff, 2021). As a result of the infrastructure damage and the subsequent road closures, trucks had to travel almost 900 additional kilometres between Christchurch and Timaru, increasing the travel time from 2 hours to 13 hours (Newstalk ZB, 2021). Figure 1 shows the road closures in the aftermath of the flooding as well as the alternative route used.

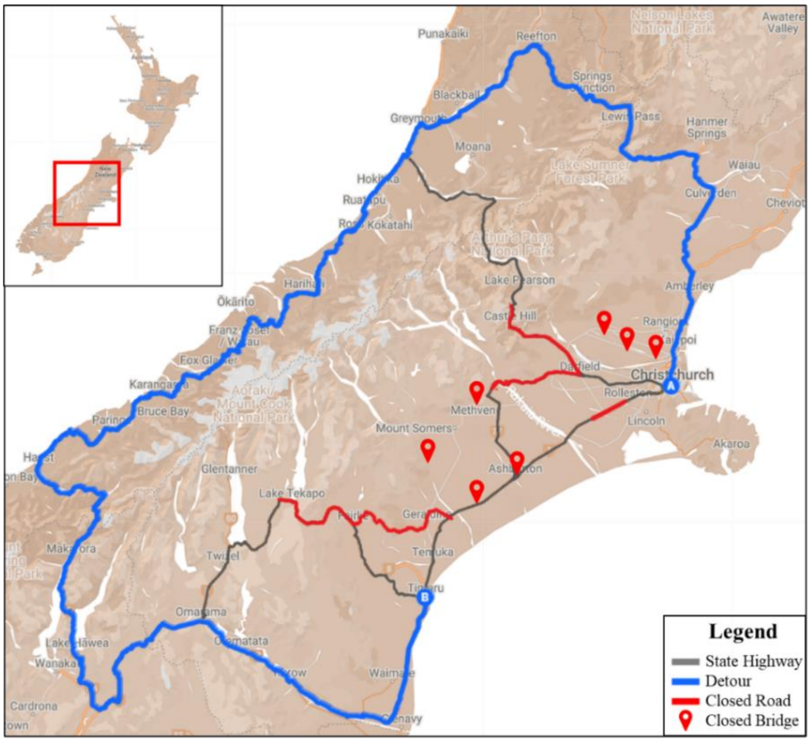

Figure 1. Transport Adjustments in the Wake of the 2021 Canterbury flooding

The 2021 Canterbury flooding was selected for this study because it severely affected the deliveries of consumer goods to the lower South Island (including Ashburton, Timaru, Oamaru, Dunedin, Mosgiel, Gore, and Invercargill) and resulted in shortages on the shelves of supermarkets and other retailers (Harding, 2021; McDonald, 2021). It was, therefore, expected to provide relevant insight into the resilience of the NZ FMCG sector. In addition, this event was sufficiently recent to reflect the current state of practice in this sector.

Data Collection and Analysis

A survey was used to collect data from the grocery retailers located in the three lower South Island regions impacted by the 2021 Canterbury flooding (Canterbury, Otago, and Southland). While Otago and Southland experienced relatively little flooding, the FMCG distribution operations within these regions were disrupted by the road closures in Canterbury (Harding, 2021; McDonald, 2021). The survey participants included supply chain professionals and store managers of grocery retail outlets in the above regions. Questions focused on their routine replenishment operations, the impacts of the Canterbury flooding, and the practices used/recommended to mitigate disruptions. The data was collected anonymously.

The survey was administered in a challenging time for the FMCG retailers since data collection started in December 2021, namely during the busy Christmas season (which was followed by the NZ Omicron outbreak in January 2022). In this context, retailers were overworked, making it difficult to achieve an adequate level of survey participation. At the time of writing, only 14 usable responses have been received, and the data collection is currently suspended. The responses were analysed by using exploratory data analysis, a statistical analysis method that conveys information through visual representation of the data. Given the limited number of responses and the fact that no definitive findings can be presented at this stage, exploratory data analysis is deemed appropriate to preliminarily address the objectives of this research, namely to perform an initial assessment of the impacts of natural hazards on FMCG distribution operations in NZ and to identify the mitigation practices used.

FINDINGS

The findings are reported in the same order as respondents answered the survey questions.

Sources of Supply

All participating retailers reported using a combination of distribution centres and direct suppliers for replenishment. However, 57% of the participants have access to only one distribution centre, limiting their alternative sources of supply and, therefore, their flexibility when roads are closed in the wake of a disaster.

Replenishment Intervals

Respondents were asked to indicate their replenishment intervals for a range of product categories. As shown in Figure 2, retailers appear to have uniform intervals across the various categories. 86% of the participants have replenishment intervals of 3 days or less in place. 50% of the respondents replenish every day, 36% every 2-3 days, 14% every 4-7 days, and no respondents have restocking intervals longer than seven days. These results indicate that retailers place regular orders with their distribution centres and direct suppliers, and that small, frequent quantities are replenished, most likely to decrease inventory levels.

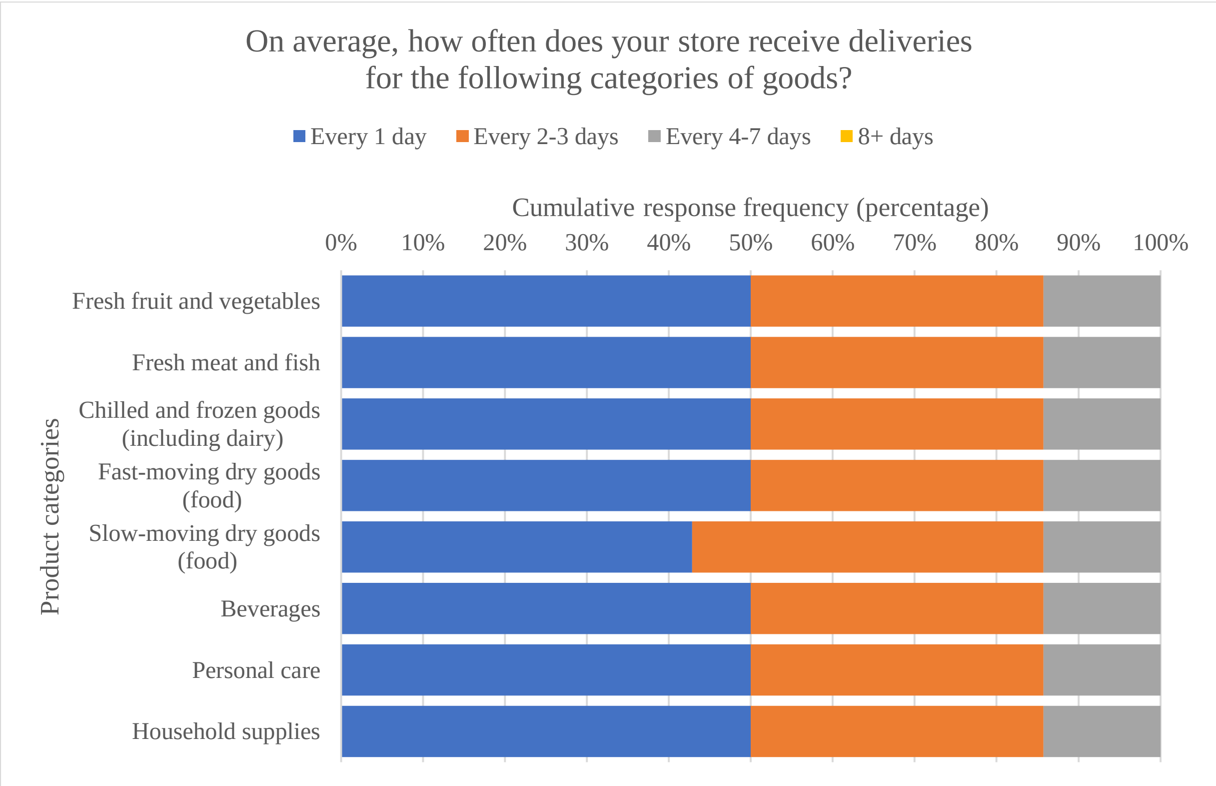

Figure 2. Restocking Interval by Product Category

Buffer Stock

As mentioned in the literature review, the carrying of buffer stock is a redundancy practice commonly used in supply chain operations. Respondents were asked to indicate their buffer stock levels for a range of product categories. The data indicates that buffer stock levels vary with product category and perishability. In particular, Figure 3 shows that at least 79% of the respondents maintain seven or fewer days of buffer stock for perishable items such as fresh fruit and vegetables, fresh meat and fish, and frozen goods. 71% of the respondents carry eight or more days of buffer stock for non-perishable items, including slow-moving dry goods, personal care items, and household supplies. Reduced buffer stock levels for perishable goods relative to non-perishable goods is a common retail practice designed to limit spoilage that would result in financial losses and customer dissatisfaction.

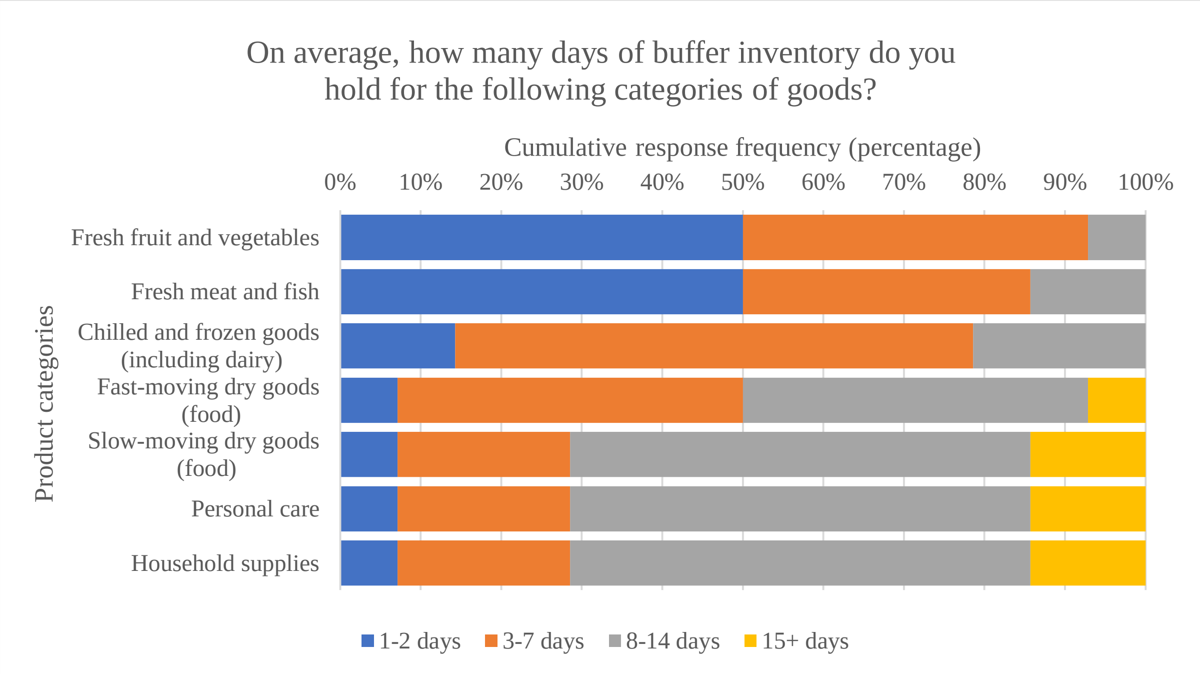

Figure 3. Days of Buffer Stock by Product Category

Nature of the Disruptions in the Wake of the Canterbury Flooding

As shown in Figure 4, the participants experienced inaccessible roads and inventory shortages. 92% of the respondents cancelled some replenishment orders and 83% experienced longer travel times. In addition, 42% of the participants dealt with consumer panic buying and implemented purchase limits.

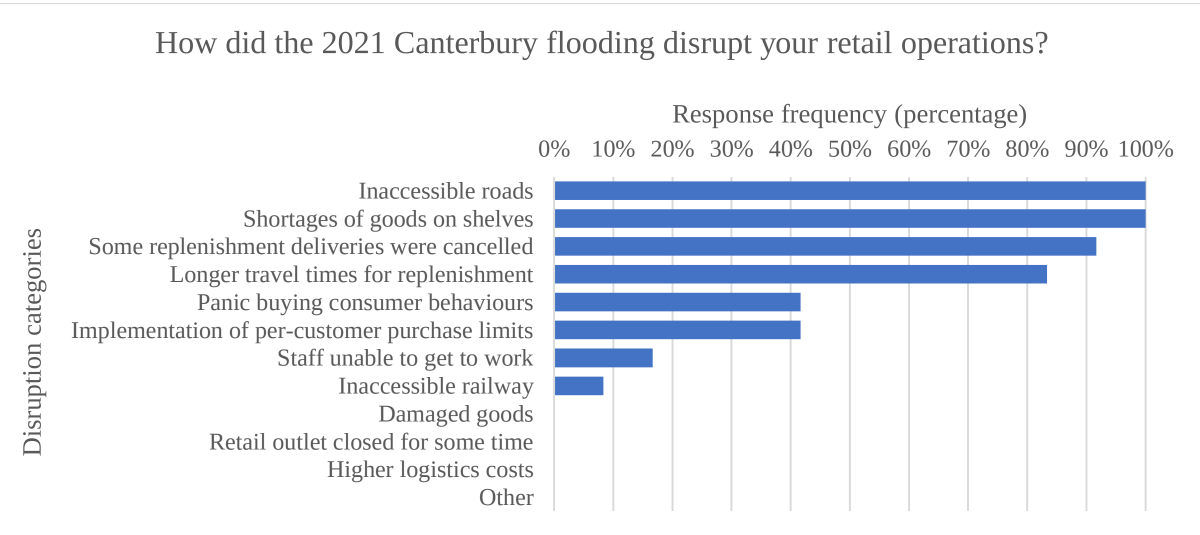

Figure 4. Nature of Disruptions

Duration of the Disruptions

Respondents were asked to indicate the length of the disruptions for a range of product categories. Figure 5 shows some variance between product categories and a clear distinction between perishable and non-perishable goods. Among the perishable goods, fresh fruit and vegetables were the least disrupted (28% of the participants reported no disruption). Across all the categories of perishable goods, up to 83% of the participants were disrupted for two days or less, and none were disrupted for longer than three days. In contrast, non-perishable categories (fast-moving dry goods, slow-moving dry goods, beverages, and personal care items) were the most disrupted.

This variance between perishable and non-perishable goods was unexpected, particularly when considering the buffer stock levels for these products (see Figure 3). Although the data does not enable us to identify any explanation at this stage of the research, one possibility is the establishment of restocking priorities. In particular, due to the urgent restocking of critical food items, the replenishment of non-perishable goods may have been rescheduled, pushing back delivery dates.

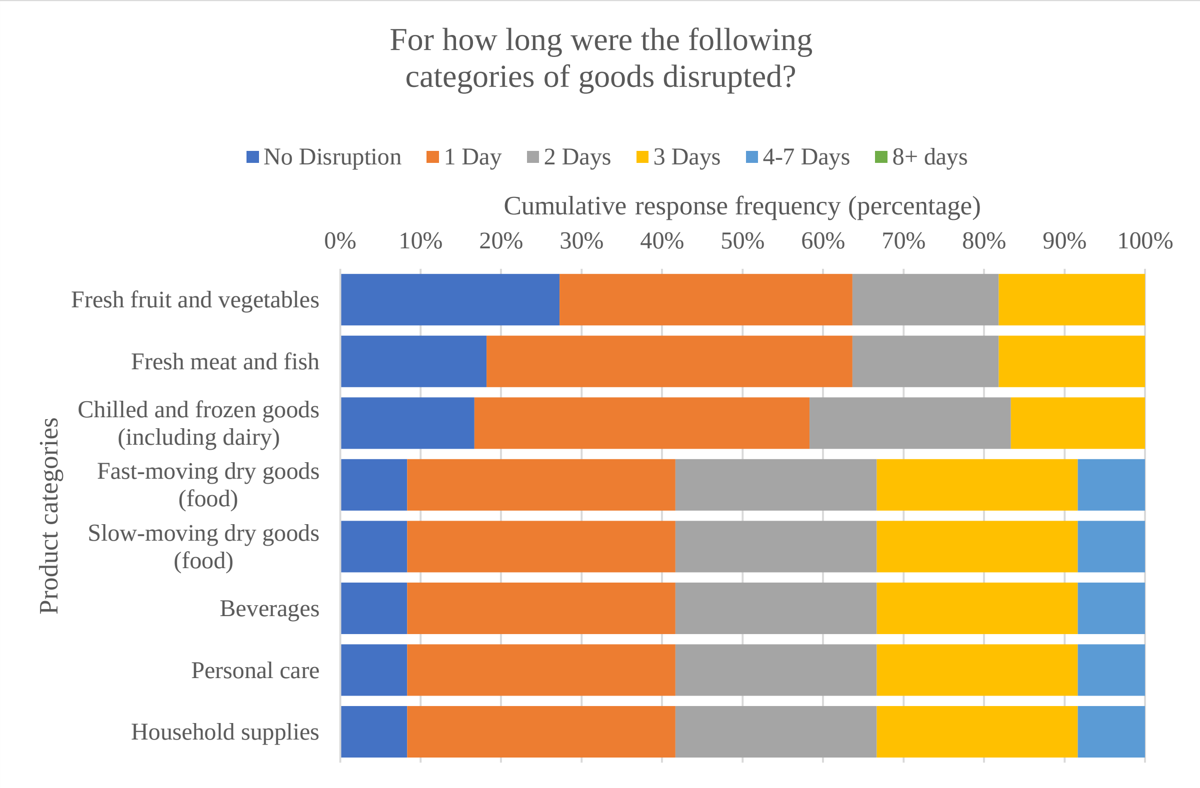

Figure 5. Duration of Disruptions by Product Category

Disruption Mitigation

The participants were asked to indicate how they mitigated disruptions in the wake of the Canterbury flooding. As illustrated in Figure 6, 58% of the participants used alternative roads. 50% increased orders with routinely used distribution centres and 42% with direct suppliers. 29% arranged deliveries from alternative sources (alternative distribution centres, alternative direct suppliers, or both). 8% of the respondents indicated that they could not adapt their replenishment operations.

Figure 6 also shows that no participants stockpiled inventory in anticipation of the disruptions caused by the Canterbury flooding. The participants' existing buffer stock levels and the expectation that the flooding would not disrupt operations for more than a couple of days may have influenced this outcome.

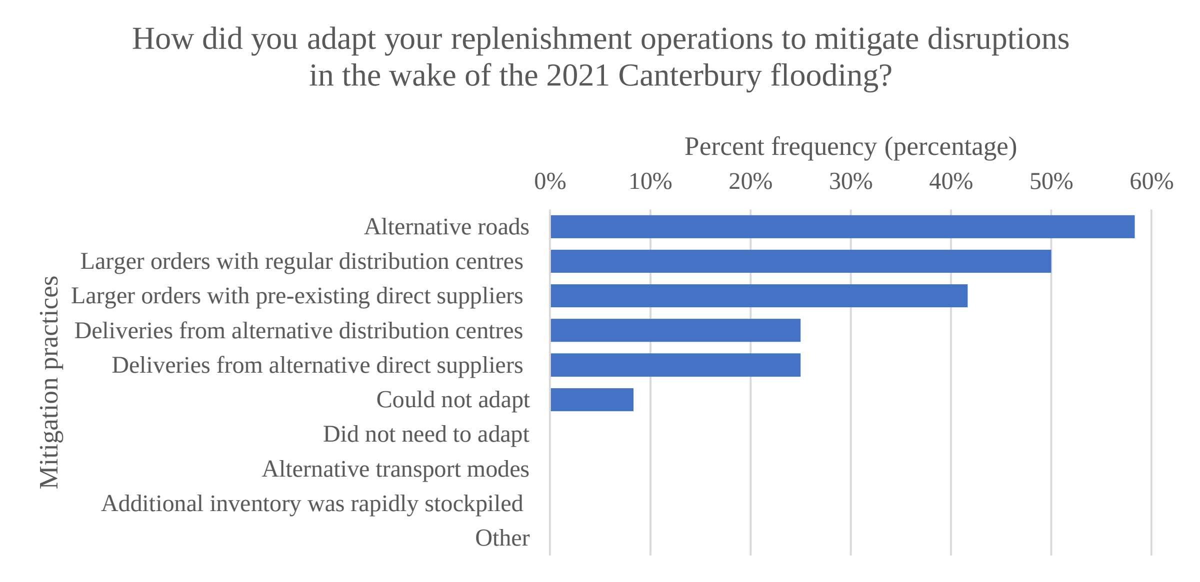

Figure 6. Mitigation Strategies Used in the Wake of the Canterbury Flooding

Impact on Resilience

Given the variety of possible mitigation options, the survey sought to understand the significance of these practices beyond the specific context of the Canterbury flooding. To this purpose, respondents were asked to indicate the extent to which various risk mitigation practices enhance resilience in the wake of a disaster (in general). As shown in Figure 7, the availability of alternative roads and alternative transport modes, as well as the ability to place larger orders with distribution centres are perceived as the factors having the strongest impact. The use of buffer stock has a strong to moderate impact, and the ability to arrange deliveries from alternative direct suppliers has a strong to little impact. Since NZ's road infrastructure has been damaged by multiple disasters in recent years and given NZ's overreliance on trucks for the movement of freight, it is not surprising that alternative roads and modes are ranked high and perceived as significantly contributing to the resilience of grocery retail operations.

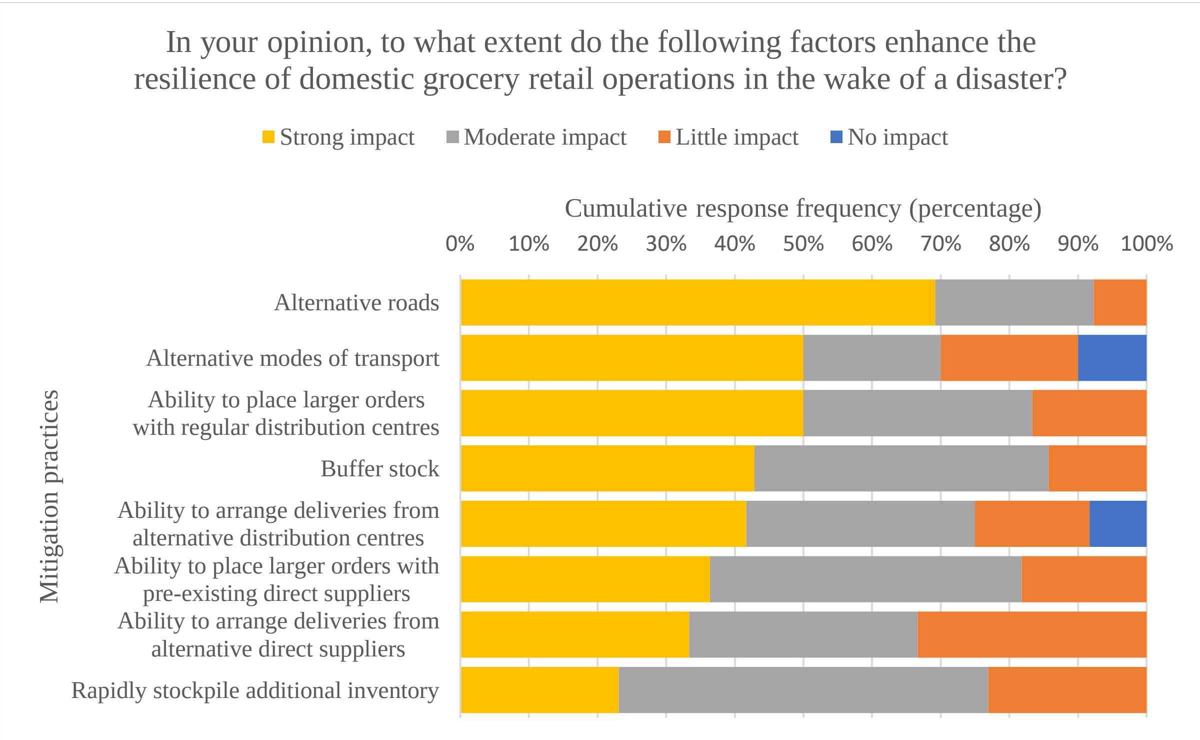

Figure 7. Perceived Impact of Mitigation Practices on Resilience

Availability of Mitigation Factors

The perceived impact of the various mitigation practices is separate from the ability of grocery retailers to use them. Therefore, respondents were asked to indicate the availability of mitigation factors in NZ. A comparison of Figure 7 and Figure 8 reveals multiple imbalances between potential impact and availability. For example, while Figure 7 showed that 69% of the respondents perceive that the availability of alternative roads strongly enhances the resilience of grocery retail operations, only 23% consider that alternative roads are actually strongly available (as illustrated in Figure 8). The imbalance is even greater for alternative modes of transport. While 50% of the respondents perceive that alternative modes of transport strongly enhance resilience (Figure 7), only 8% consider that alternative modes are strongly available (Figure 8). An imbalance between the impact and the availability of decentralised distribution centres is also reflected in the data. While 42% of the participants perceive that the ability to arrange distribution from alternative distribution centres strongly increases resilience (Figure 7), only 9% consider that this option is strongly available (Figure 8).

Figure 8 also shows that buffer stock is viewed as the most available option (it is strongly available for 36% of the respondents and strongly to moderately available for 79% of them). This seems to indicate that respondents resort to building buffer stock to compensate for the lack of flexibility in the NZ distribution system, i.e. the lack of alternative roads, transport modes, and decentralised distribution centres.

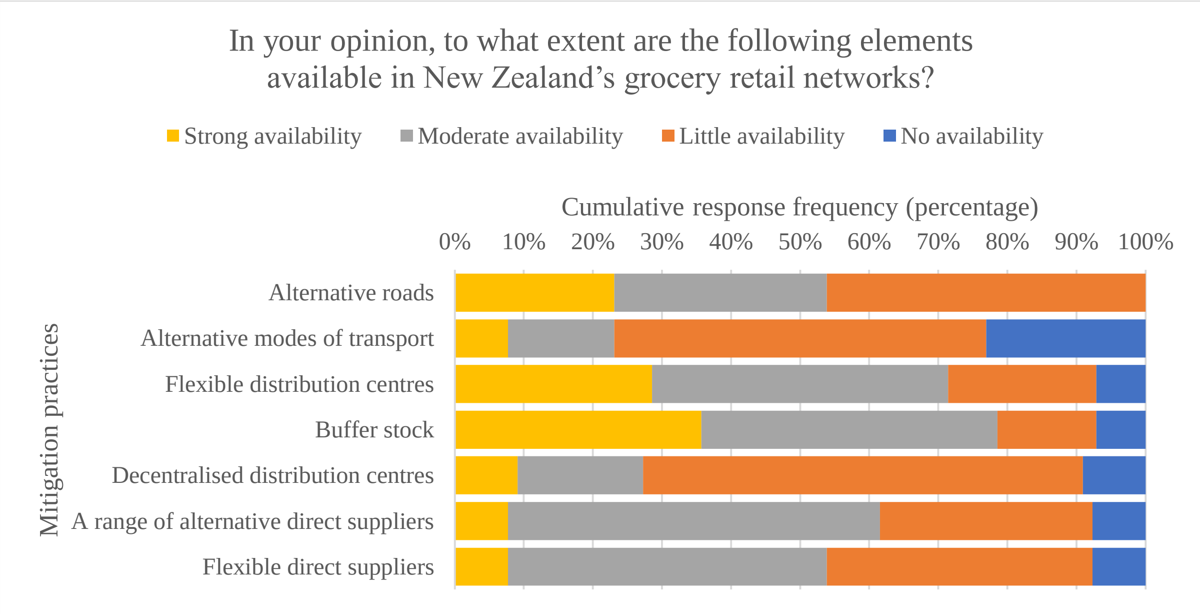

Figure 8. Perceived Availability of Mitigation Factors in NZ

DISCUSSION

This research discusses a range of redundancy and flexibility practices that enable FMCG retailers to increase their supply chain resilience and ensure that goods are available on store shelves when and where needed by consumers. It also investigates the extent to which these practices are used in the NZ context. The above findings show some aspects of redundancy and flexibility in the FMCG distribution system in NZ. For example, most participants used redundant inventory, alternative transport routes, and alternative distribution centres to mitigate the disruptive effects of the Canterbury flooding. However, the resilience of the NZ FMCG distribution system is limited as each of these elements' perceived importance far outweighs its availability.

Flexible Replenishment: Decentralised Distribution Centres

As indicated in the literature, the ability to place larger orders with distribution centres (volume flexibility) and the access to alternative, decentralised distribution centres increase resilience (Agigi et al., 2016; Sheffi, 2019). The findings of this study match the literature. And yet, more than half of the participants have access to only one distribution centre. NZ's relatively small population and lower density in the South Island may explain this disparity (a small market financially inhibits extensive distribution networks). Even so, centralised distribution negatively affects the resilience of FMCG retail operations in NZ.

Flexible Freight Movements: Alternative Roads and Modes

This research illustrates the disruptive impacts of losing access to key transport roads in the aftermath of a disaster. Without these roads, trucks cannot replenish retail stores, travel times are extended, and ultimately, retailers experience shortages of goods. Therefore, a robust road network with adequate secondary options is critical to ensure supply chain continuity in the wake of a disaster. This argument is supported by empirical research (e.g. Sreedevi and Saranga, 2017) showing that resilient road infrastructure contributes significantly to good delivery performance.

Going one step further, this research highlights the vulnerability of the NZ freight system that primarily relies on roads and trucks and is, therefore, prone to disruptions. Resilient transport operations call for alternative modes of transport that increase the number of route options available, a well-documented aspect of flexibility (Tang, 2006; Chen and Miller-Hooks, 2012). The above results indicate that participants are aware of their lack of modal options. In a country with long coastlines like NZ, the development of coastal shipping (that offers unencumbered sea access bypassing inaccessible roads) would significantly increase transport resilience.

Inventory: The First Line of Defence

As discussed in the literature, buffer stock is a form of redundancy commonly used to increase resilience. Buffer stock is often described as the first line of defence against disruptions (Sheffi, 2020). The above results confirm this point and suggest that redundant inventory is used in FMCG retail operations to compensate for the lack of flexibility in the NZ transport system (e.g. the lack of adequate secondary roads, alternative modes of transport, and decentralised distribution centres).

While redundant inventory increases resilience, the benefits are relatively short-lived (Sheffi, 2019) as holding sufficient stock to manage prolonged disruptions in the wake of a severe disaster event would be too costly. Even though the benefit of high buffer stock levels is a poor substitute for adequate transport infrastructure and the flexibility it enables, carrying redundant inventory seems to be the primary option that NZ FMCG retailers currently have to build resilience.

Overall, we argue that the NZ FMCG distribution system needs to be more actively designed to absorb supply variability not only by building redundancy (buffer stock), but also by enabling flexibility with secondary roads, alternative modes of transport, and decentralised distribution centres. While some of these elements are within the control of grocery retailers (e.g. building stock and decentralising distribution), the role of the government agencies in charge of infrastructure development through long-term public investments should not be underestimated. Creating a resilient freight system calls for a holistic and integrated approach involving both public and private stakeholders, which in turn would require public funding and generate extra operational costs for grocery retailers. Although investments can be seen as an insurance policy (as discussed earlier), the question of whether they are realistic in a country with low-population density (as is the case of NZ) is critical and can only be addressed with robust cost-benefit analyses identifying the most influential investments.

LIMITATIONS, CONTRIBUTION AND CONCLUDING COMMENTS

As previously mentioned, the survey was administered when retailers had a seasonally high workload, which reduced the number of responses received. Due to the low level of participation, the collected data is not statistically representative of the whole NZ grocery retailer population. Additional data needs to be collected in order to increase the sample size and, ultimately, improve the reliability of the results.

In addition, this study's focus on NZ and the 2021 Canterbury flooding generates contextual findings that are not generalisable. Similarly, the focus on a specific retail sector (FMCGs) and on a specific supply chain segment (the replenishment of retail stores) limits the applicability of the findings beyond the setting of this study. As a consequence, additional investigations should expand the research to other retail sectors (e.g. durable consumer goods) and take a more comprehensive supply chain approach (e.g. from manufacturers to retailers).

Despite the above limitations, this study contributes a better understanding of the FMCG replenishment operations in NZ and provides an initial assessment of the impacts of natural hazards on NZ's domestic freight operations. It also highlights that the lack of flexibility in the NZ freight network increases the vulnerability of replenishment operations. In particular, the lack of an adequate secondary road network and of alternative modes of transport, as well as the centralised distribution practices in place and the limited sources of supply are discussed.

This work-in-progress research is part of a broader project investigating the concepts of redundancy and flexibility and their contribution to supply chain resilience in the wake of a disaster. It is expected that, ultimately, this project will highlight the importance of a holistic approach to the building of freight resilience in NZ. In particular, freight resilience not only requires supply chain practitioners to reconsider the way they operate and manage their supply chain operations, it also calls for the development of a robust national infrastructure that includes alternative modes of transport. In the context of the increased exposure to highly disruptive events and their negative impacts on supply chain operations, discussing inherent fragilities in freight operations and raising risk awareness have become more critical than ever.

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ICT Adoption for Tourism Disaster Management: A Systematic Review

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ABSTRACT

The tourism sector is not new to disruptions from natural disasters or human induced crises and has been recalibrating the way they operate and sustain. The scale and impact of the COVID-19 pandemic has highly impacted global tourism and the economies that rely on tourism. It has brought phenomenal challenges to humankind and many tourism organisations are on the brink of collapse and this will have a cascading effect on countries and their citizens for years to come. This paper presents the systematic literature review on the adoption of ICTs in tourism when preparing for and managing disasters. This review was conducted using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Flow diagram. Out of 585 articles from four databases, 35 peer-reviewed journal and conference articles were included for analysis. Research on potential adoption of ICT and associated tools for tourism disaster management, remains scarce. With the world coming to terms with the "new normal" of social distancing and increased use of ICT tools such as virtual reality, virtual guides, chatbots, social media and contact tracing apps due to pandemic, the investigation of adoption of such tools is long overdue. Within limited empirical studies, this review shows some trends and opportunities for the development of a critical research agenda in this area. Other innovative tools such as AI, GIS, IoTs, and visual story telling have been adopted for managing disasters related to tourism. This research demonstrates the potential adoption of ICT tools for effective disaster management and the subsequent support of global tourism. To counter the catastrophic effect on the tourism industry from COVID-19 pandemic, it is paramount to recognise cultural sensitivities and study how advancement in technology can be harnessed in all contexts. In addition to this, further exploratory research should be conducted to better understand crisis as an opportunity to develop and adopt foundational and critical ICT systems for the tourism industry.

Keywords

Tourism, ICT Adoption, Disaster Management, COVID-19.

INTRODUCTION

Over the last few decades we have seen the tourism industry develop a strong dependence on information communication technology (ICT). ICT has supported and allowed accelerated development of many aspects of tourism businesses from booking, advertising, managing, and recommending (Koo et al., 2015, Neuhofer, 2016) to introducing market competitiveness and ease of access to services. Information need is profound in tourism enterprises (Sheldon, 1997). Underscoring the proficient and efficient dissemination of information and services, ICT is core to tourism activities and to rapid interactions with tourists and other stakeholders, supporting communications with targeted stakeholders, personalized information exchange, availability of real-time information, faster settlement for booking and payments etc. (Zelenka, 2009; Jovanović, 2019), which also leads to the digital convergence of tourism value chains.

The tourism industry, however, is also vulnerable and subject to a wide range of disasters and crises which occur haphazardly, from time to time throughout history. Disasters can be unforeseen like natural calamities e.g., earthquakes, hurricanes, bushfires, floods, cyclones etc., whereas crises are also unexpected but could be self-inflicted (Faulkner, 2001, Ritchie, 2009) such as terrorism, political unrest etc. Whether a natural disaster or a human induced crisis, both types of events can have a colossal impact on the economic activities of the travel and tourism industry (Ritchie, 2008). Considering the heavy reliance of tourism on infrastructure, transportation (Ye et al., 2020) and interdisciplinary relationships to a wide number of industries (Faulkner, 2001), tourism complexity and sustainability during a time of disaster or crisis needs careful planning and management. The ubiquitous nature of ICT has immense potential in facilitating tourism sustainability and supporting complex interactions.

Emerging ICT technologies such as geographical information systems (GIS), internet of things (IoTs), mobile applications (apps), location-based services, geo-tag services, virtual reality (VR), augmented reality (AR), artificial intelligence (AI), social media and smart devices (Ye et al., 2020) provide many opportunities for exploration and adoption of ICT for development of tourism and mitigation tourism crises and disasters. The complex fusion of technological innovation, resources, infrastructure and data to improve operational and process automation and visualization to improve tourist experience is commonly referred to as smart tourism (Buhalis & Buhalis, 2013; Femenia-Serra, 2018). In this study, we have used the term, disaster informatics to refer to the collection, aggregation, sharing, integration, and transformation of data with the use of ICTs during and after disaster and crises. In broader terms, a knowledge-based crisis management system encompasses the use of new technologies and disaster informatics to provide warnings and monitor emergency/chaotic situations during various stages of the crisis: pre-crisis, during crisis and post-crisis stage. Embedding ICT technologies in the management of tourism knowledge acquisition, creation, storage, and propagation can aid strategic planning at national, local and regional levels for quicker information dissemination during a disaster or crisis as well as in the tourism recovery process (Jia et al., 2012).

Due to the nature of unpredictable disaster or crisis events, tourism disaster management research has focused on some popular theories. For example, Faulkner and Russell (1997) adopted chaos theory and complexity perspectives to analyse tourism disasters. Theory of image restoration (Benoit, 2000) has been employed to attract tourists during and after major crises such as the Gulf oil spill (Muralidharan & Dillistone, 2011) Arab Spring (Avraham, 2015) and Nepal Earthquake (Ketter, 2018; Lama & Pradhan, 2018). Some scholars have combined the theory of image restoration with situational crisis communication theory to analyze their study in tourism. The latter i.e., situational crisis communication theory was focused more on developing strategies to overcome reputational threats (Coombs & Holladay, 2002) of tourist destinations. According to Park et al. (2019), the informational needs of tourism stakeholders vary depending on the situational context of the crises. Post-crisis communication through social media provides assurance, support and trust to tourists who are planning their travel amid the disaster/crisis situation (Huertas & Oliveira, 2019; Schroeder & Pennington-Gra, 2015). The effective use of ICT helps promote confidence and transparency to make informed decisions and choices about safety by the individual tourist and to mitigate risks to their future travel experiences. Coupled with this, journalistic media coverage of celebrity and social media influencers generate tourism interest for reinvigorating inbound tourist arrivals in post-disaster recovery (Rucińska, 2014) This salient feature of online media in conjunction with other ICT applications like GIS and IoTs helps to continuously attract potential tourists and maintain the sustainability of tourism businesses and resources of the areas that have suffered from recent and far-reaching disasters.

TOURISM AND THE IMPACT OF COVID-19

Nonetheless, the recent unprecedented coronavirus (COVID-19) crisis has drastically hit the tourism industry worldwide, with a decline of 72% and 71% in international tourist arrivals in 2020 and 2021 respectively, in comparison to 2019 (UNWTO, 2022). For the tourism industry, the situation is bleak. As Gretzel et al. (2020) pointed out; it is important to relate to the historical theory and practices before the pandemic to understand how to envision processes on the other side of the crisis. Our understanding of tourism operations and practice prior to the pandemic will allow us to better apply and adopt ICT to tourism operations and practice post pandemic.

The tourism industry is highly impacted by COVID-19 as it relies on human resources for service delivery. Various governments have imposed different kinds of movement restrictions, and many tourism businesses, including airlines, permanently closed their business. It is evident that ICT has been widely used during the COVID-19 pandemic, however, applied in areas such as contract tracing apps, chatbots, drones, VR and AI. As suggested by Garfin (2019), the thoughtful use of ICT effectively mitigates the negative impacts of and improves people's lives during a crisis. Seyitoğlu and Ivanov (2021) and Lau (2020) also predicted that the collaboration between ICT developers and the travel and tourism industry could help to minimise the COVID-19 stress and enhance the chance of business survival. Many studies on ICT usage in tourism during the COVID-19 pandemic primarily focused on potential use and advantage of virtual reality or virtual tours (Ilkhanizadeh et al. 2020; Fennell, 2021; Viñals et al., 2021), using social media for interactions as well as examining the possible use of innovative tools such as AI and chatbots to enhance the virtual tour experience (Hasan et al., 2021). Sánchez and Palos-Sanchez (2021) looked at whether virtual reality could help promote small tourism businesses during the pandemic. Similarly, Fennell (2021) investigated the impact of virtual tours during the pandemic and found that such tools can be effective. Research on the use of location-based games and contact apps found that such tools could help minimise the people gathering during pandemic (Ide, 2021). Mardhiyani et al. (2021) implemented the visual storytelling model through Instagram to increase tourists in a destination and found that such efforts helped in branding and raising awareness for tourists. Obembe et al. (2021) examined the key factors that have impact on public sentiments and the role of social media during a crisis by analysing tweets and news articles in tourism.

A few studies (Lemy et al., 2021; Perić & Vitezić, 2021) have been conducted to understand the consumer behaviour and intentions before and after the pandemic. Kock et al. (2020) argued that the COVID-19 pandemic could create a paradigm shift on tourists' behaviour, perceived risk and decision making. Amidst increased discourse on ICT usage for tourism disaster management, studies investigating the readiness and preparedness for the digital transformation of various stakeholders during and after the pandemic have also been conducted (Sorooshian et al, 2021, Sorooshian, 2021).

Considering the potential usefulness of ICT adoption by the travel and tourism industry to support a range of activities for tourism disaster and crisis management, as indicated by its use throughout the pandemic we conducted a systematic literature review to answer the following questions:

- What is the status of ICT adoption in the context of tourism disaster management?
- How is ICT assisting in planning and managing disaster events i.e., response and recovery for tourism?
- What future research agenda or direction could be developed for travel and tourism ICT adoption?

The term 'e-tourism' refers to the overall use of ICT in tourism and is an established field of research. As discussed by Gretzel et al. (2020), e-tourism should be adopted on two emerging fronts: 1) the rapidly changing new reality and prospects for change in the long term; and 2) a focus on transformative research.

This literature review aims to highlight research conducted in ICT adoption for tourism crises and disasters. The remainder of our paper is structured as follows: First, we describe the methodology of the literature review, which includes a description of data collection and data selection of relevant papers. Then, we present the results obtained from the systematic literature review, which includes a description of what was found in papers. Finally, implications, limitations and future direction for tourism disaster research are briefly discussed.

METHODS

The purpose of our paper is to investigate the state of ICT adoption research for disaster management within the tourism industry. Systematic literature reviews have been recognized by the research community as an important mechanism to identify research gaps by searching, identifying, synthesizing, evaluating, and combining the results from published articles for a topic (Shafiee et al., 2019). Moher et al. (2009) developed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Flow diagram, which provides clear guidelines for conducting systematic literature reviews and meta-analyses. The diagram categorises the research process into three simple steps: initial search of literature, selection of relevant articles and review of selected articles to synthesize information accurately and reliably. Figure 1 below shows the results for this paper.

Initial search

To investigate the use of ICTs in the context of disaster management for tourism, we have used some of the largest and most used databases to search for the relevant research articles in this study. They are: Scopus, Web of Science, EBSCOHost and Google Scholar. Most of them allow searching for a wide range of sources from interdisciplinary areas. Our review was conducted in December 2021.

The adoption of ICTs in tourism is broad and multi-faceted. Boolean operators were therefore used to capture and filter relevant articles on tourism and disaster management. For example, Boolean operator 'OR' is used to capture any of these terms related to ICTs, 'technology', 'online', 'internet', 'social media', 'ICT', 'digital' in either titles, abstracts, or keywords. Similarly, another 'OR'' is used to incorporate both words 'disaster' and 'crisis' in either titles, abstracts, or keywords, with 'AND' to join the main search term 'tourism' in titles. The word tourism is truncated to 'touris*' to capture both tourism and tourists. Google Scholar does not have flexible features and so included all of these terms in research paper titles. By using these search terms, the selected databases exhibited a total of 585 results (227 by Scopus; 188 by Web of Science; 105 by EBSCOhost and 65 by Google Scholar) as shown in the figure below.

The search results from the databases were exported to MS Excel using the Zotero application (zotero.org). This application helped to arrange the results from different databases to a single format for further processing.

Selection

An explicit set of inclusion and exclusion criteria was then employed to assure the extraction of the data was relevant to tourism and disaster management. In addition to the exclusive search terms, research articles published only in the English language were extracted. Similarly, only papers published in peer-reviewed journals and international conferences were included and non-peer-reviewed articles, book chapters, news articles, editorials, personal comments and opinions were excluded.

Search terms were carefully chosen to capture and filter relevant papers and were consistently used across the databases. The aggregated data in the MS Excel Spreadsheet had many headers such as 'Item Type', 'Publication Year', "Author(s)', 'Title', 'Publication Title', 'DOI', 'Abstract', 'Date', 'Issue', 'Volume' etc. In the first round of screening, the data was sorted based on paper titles of all 585 results, however, 216 of these papers were duplicates. Most duplicate papers appeared in more than two databases. Although we intended to exclude non-peer-reviewed articles, some of the databases we used did not specify this in the search process. Therefore, in the second round of screening, any articles which were not peer reviewed in journals or book chapters were removed manually. There were 42 articles in that category as shown in the figure below.

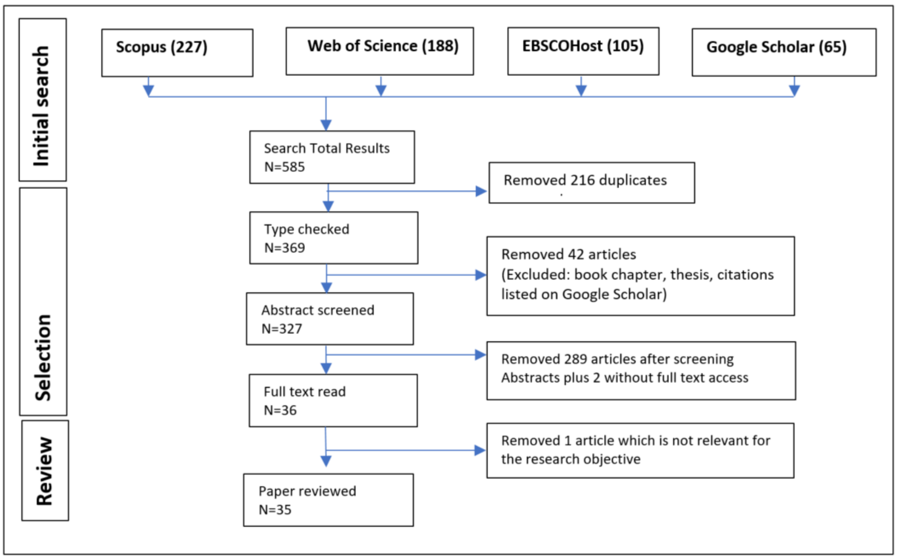

Figure. 1. PRISMA Flow Diagram – Literature search and selection process.

If an article appeared in both Google Scholar and any other databases, the record extracted from Google Scholar was removed (abstract are missing at first glance in Google Scholar, without downloading the paper). For the remaining articles found in Google Scholar, each link was manually checked to extract abstracts to populate our spreadsheet for the third round of screening.

The first two authors screened abstracts of all 327 articles separately in the Excel spreadsheet. Author 1 and Author 2 selected 34 and 37 papers respectively for the next round of analysis, as most of the articles were not relevant to the research topic. There was a high degree of similarity between two authors' selections, except three. The inter-rater reliability was more than 95%. Papers which were mismatched between two authors were screened again (collaboratively) and a consensus was reached to remove these papers. 289 articles had been removed in this stage, as they were not related to the topic of investigation i.e., using ICT for disaster management in tourism. The majority of rejected papers did not address the use of ICT or disaster management in tourism primarily but included ICT or digital in their abstracts. Additionally, 2 articles were also removed as their full-text versions were not publicly available.

Review

The remaining 36 papers were distributed between two of the research team and the content was analysed through close reading. By mutual agreement we removed one paper as it was not totally relevant to the topic under investigation. The remaining 35 papers were discussed in detail by the research team to identify, categorise and code topics related to disaster management themes in the tourism industry. The list of selected papers is shown in Appendix A. A Google Spreadsheet was created, shared and populated collaboratively with identified themes as the review and analysis of papers progressed. Theme codes changed minimally over the course of the analysis, as inter-rater agreement and reliability increased over time.

RESULTS

Across the selected databases, initially a total of 585 articles were identified using our search criteria. After several rounds of screening, we identified 35 research articles to review closely. Table 1 below shows the comparison of the number of research articles initially found and finally selected across the four databases.

Table 1. Comparison of research articles found and selected

Databases	URL	Initial Search Results	Final Selection
Scopus	scopus.com	227 (39%)	9 (26%)
Web of Science	apps.webofknowledge.com	188 (32%)	16 (46%)
EBSCOHost	ebscohost.com	105 (18%)	7 (20%)
Google Scholar	scholar.google.com	65 (11%)	3 (8%)

Academic studies on how ICTs have been adopted for disaster and crisis management in tourism only commenced less than 2 decades ago. From the selected papers, the oldest article published was in 2009. The number of publications on this topic only grew in the last 5 years from 2017. More than 90% of the selected papers were published in the last 5 years (2017 to 2021). The number significantly increased due to the impact of the COVID-19 pandemic. Figure 2 shows the summary of research paper distribution over the last 12 years.

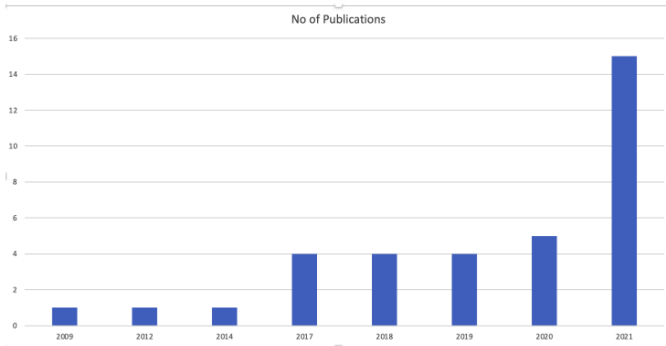

Figure. 2. Distribution of selected research articles across last 12 years.

The selected papers were from research studies in many different countries but were mostly focused on Asia. For example, 5 studies were conducted in Japan, 3 in Indonesia, 2 in China and 1 in India, Nepal and Phillippines. Others were from other countries including Australia, Fiji, Spain, Sweden, and USA.

About two thirds of the selected papers were published in journals and the rest in international conferences. The Tourism Management journal published three of these papers, the Journal of Sustainable Tourism published two and the rest of the selected papers were published in different journals and conferences.

We have also analysed research methods used by the selected papers. Table 2 (below) shows the distribution of research methods used. Less than 40% of the selected papers (13 out of 35) conducted empirical studies, out of which only nine had collected primary data with tourism stakeholders.

Table 2. Distribution of selected articles based on research methods

Research Methods	No. of Studies	Percentage
Mixed (Quant and Qual)	5	14%
Quantitative	4	11%
Review and content analysis	12	34%
Qualitative	4	11%
System development	10	29%

Papers were also divided into several broad categories based on the type of ICT applications for disaster management in the tourism context. Table 3 below shows the top five ICT tools that have been researched in selected articles. Most of the selected papers (15 out of 35) conducted their studies on social media. Other ICT tools such as IoTs, AI, GIS, VR and web applications have also been used for disaster management in tourism.

Table 3. Top five ICT related applications in selected articles

ICT Applications	No. of Studies	Percentage
Social Media	15	43%
Internet of Things (IoTs) / AI / sensors	4	11%
Web applications	4	11%
Geographical Information Systems (GIS)	3	9%
Virtual Reality	3	9%

12 out of 35 papers were relevant to the COVID-19 pandemic and other good proportion of papers were related to other natural disasters such as earthquake, hurricane, tsunami, flooding, and landslides. Five papers were related to human induced crises such as crime, political unrest, or terrorism. There were six, which were general papers in tourism disasters.

DISCUSSION

The tourism industry is susceptible to various disasters i.e., both natural and human induced crisis. Some disasters have a longer lasting impact on tourism enterprises with a potential to cause tremendous loss to global and local economies for decades, changing the attributes and attractiveness of tourist destinations. Most disasters which impact locally cause serious impacts to local people, communities, and their tourism industries, while others have a global impact in many countries in the world. The recent COVID-19 pandemic is a humanitarian crisis of epic proportions, and it has already caused havoc for the global tourism sector that is continuing. Although there is scant empirical research that shows the relationship between adoption of disaster informatics and its implications for tourism, a few studies have shown how various ICT applications have been adopted for all three stages: pre-disaster, during and post-disaster.

Social Media

One of the ICT applications, which has been widely used in tourism, is social media. Many aspects of tourism business have been influenced by social media such as searching and finding information related to tourism destinations, tourism promotions, interaction between tourism providers and tourists [Schroeder & Pennington-Gra, 2015, Zeng &Gerritsen, 2014) to name a few. Likewise, social media has changed the communication processes and interactions among stakeholders at the time of disaster from what used to be a top-down direction of information flow (Luo & Zhai, 2017) to bottom-up communications as information is sourced from users and the communication is now dynamic and multi-dimensional. Moreover, individual users can gain insider information quickly (Schroeder & Pennington-Gra, 2015). This has significant repercussions in tourism businesses both positively and negatively (Zeng &Gerritsen, 2014). For example, volunteer tourism is promoted to disaster zones via social media for recovery work or to boost the local economy (Fukui & Ohe, 2020; Wearing et al., 2020). However, an Indonesian study (Erdiana et al., 2019) highlights the negative impact, whereby images of a localized incident affected and limit tourist activity in that region. Moreover, social media is also seen to facilitate discussions of local events like recent bushfires in Australia to highlight the complex linkage of climate change to tourism (Schweinsberg et al., 2020).

Besides so many different ICT applications, social media has a potential to shape social discourse globally and dramatically re-frame the landscape through the accessibility of information, in both text and image (Fukui & Ohe, 2020). Social media users can also trigger a series of positive or negative connotations to a crisis by commenting, sharing, or forwarding posts, commonly known as secondary crisis communication. For example, a Hong Kong study shows how the secondary crisis communication of 'Occupy Central', which started as a political topic on Weibo (social media platform - Chinese version of Twitter), morphed to a tourism boycott, causing a new crisis (Luo & Zhai, 2017). Similarly, another study Zhai et al. (2020) illustrated that social media also facilitates the evolution of a personal incident into online collective action and influences offline behavioral intentions of other users of the platform. Thus, the behavioral pattern of netizens on social media linked with emotions can develop into new challenges for crisis management in tourism destinations (Park et al., 2019; Huertas & Oliveira, 2019; Luo & Zhai, 2017; Zhai et al, 2020). In contrast, secondary crisis communication in social media can also be a blessing in disguise with an ability to empower and inform tourists during emergency, disaster, and crisis situations (Rucińska ,2014, Möller et al., 2018). Social media can sometimes embody a crucial role in building resilience and increasing awareness (Möller et al., 2018) by bringing together both local and virtual communities during different stages of a disaster. A sense of belonging to a broader global community inspires people to contribute either directly or indirectly through volunteer tourism and funding or donations (Fukui & Ohe, 2020).

Geographical Information Systems (GIS)

Another ICT application that is widely used for the context of disaster management for tourism is Geographical Information Systems (GIS). Most of the applications related to GIS have been used for disaster planning and mitigation: pre-event and prodromal phases (Faulkner, 2001). Several opportunities have been developed for tourism planning such as visitor flow management, tourism resources investigation and prediction of impacts from tourism (Ting & Qiao, 2010). Two Indonesian studies utilised a GIS application to map earthquake-hit areas in Padang (Marizka & Afnarius, 2019) and a tsunami evacuation route for tourists in Lebak (Handawati et al., 2020). Similarly, geotagged social metadata was used in the Bohol earthquake and Haiyan typhoon in the Philippines (Yan et al., 2017) to monitor and assess post-disaster tourism. Whereas in India, pilgrim tourist flow is managed by integrating RFID with GIS in vulnerable disaster areas (Pal & Jain, 2014). Web applications were developed by integrating Web-GIS, disaster risk evaluation technology and host identity protocols to effectively evaluate and manage risk for tourism disasters (Tsai, 2017). Thus, GIS applications are widely used in various types of tourism platforms to plan, manage, and mitigate potential risks for tourists in real-time.

Internet of Things (IoTs)

Furthermore, other emerging technologies such as IoTs are also gradually making their presence felt in e-tourism and smart tourism developments. Takahashi et al. (2019) proposed an IoT surveillance system to assure safety and wellbeing of vulnerable residents and tourists after the tsunami in Japan. In South Korea, cultural heritage sites such as temples are protected from fire danger using a ubiquitous sensor network (Joo et al., 2009). There are many other areas IoTs can be used for assisting tourism operators during disasters, for example tracking tourists' location, relaying traffic congestion information, suggesting alternate routes etc. The omnipresence of mobile phones with cameras, video, microphones, and sensors (Kaur & Kaur, 2016) together with the ability to connect to the internet has provided access to information and advice for many tourists. The convenience and quick access to social media platforms has enabled speedy sharing of information about local incidents, crises etc. making mobile devices an unconventional form of disaster sensing and situational awareness (Harrison et al., 2010). Sensors have been used with mobile devices to capture images and aid maintenance, repair processes and rescue operations. In pre-disaster scenarios, sensors can be used to limit the number of visitors, track location of tour buses (in case of disaster-prone areas) etc. Similarly, adoption of interactive help desks, kiosks, and social networks can be used as tools to assist tourists at the time of a disaster or crisis. Tourism organisations can benefit from virtual tours and augmented reality (AR) to enable tourists to experience the characteristics of the tourism destination / history, even after a disaster (Gutiérrez et al, 2013).

Digital Tours

The studies on ICT use for challenges within tourism disaster management highlight that ICT plays an essential and positive role in investigating existing issues and potential benefits to help the revival of the tourism industry. It is expected that a positive trend of interest in digital tours in the post-COVID era will be seen, and interactive digital experiences may have comparable tourism recovery impacts to physical experiences (Sorooshian, 2021). The virtual ICT tool adoption such as virtual tours and the use of digital avatars provide enhanced interaction and personalisation (Viñals et al., 2021), for online services to increase tourists' engagement and enhance brand competitiveness (Buhalis and Sinarta, 2019; Viñals et al., 2021). Virtual personalised immersive tourism experiences have also created opportunities to develop new tourism services or products and provide a new form of promotion (Sánchez & Palos-Sanchez, 2021). The virtual tours are not only enabling interactive and personalised tours which are comparable to conventional tours in generating more visits during pandemic, but they also enable people who are unable to travel due to infirmity or illness to visit and enjoy the experience of tourist sites. Increasing ICT capabilities for tourism service providers and tourists are enabling such interactions and are better connecting the people and tourism settings (Fennell, 2021). Using ICT in disaster management also supports tourism rehabilitation enabling tourists, service providers and policymakers with better decision making over reopening destinations (Yan et al., 2017) and helps investigate changing traveller behaviour and needs considering a disruption created by a disaster. Lemy et al. (2021) argue that consumer behaviour during COVID-19 has changed and modified the use of ICT for tourism services.

Artificial Intelligence (AI)

AI tools can also help to explore tourists' intention or readiness to use tourism services post-pandemic considering things like safety-related concerns (Perić & Vitezić, 2021). Similarly, social photography sites such as Flickr and Instagram enable visual storytelling at a relatively lower cost to help in destination brand promotion and awareness, increasing tourist visits during the pandemic or in the current tourism revival process (Mardhiyani et al., 2021) (Yan et al., 2017). Such visualisation also enables monitoring and assessment of post-disaster recovery for tourism stakeholders (Yan et al., 2017). Such platforms are also being used to examine visitor/tourist perceptions and sentiments of a return to a destination, which plays an important role in a revival of tourism (Martínez-Hernández et al., 2021; Obembe et al., 2021).

ICT Adoption for Tourism Disaster Management

Consumer behaviour during the pandemic has changed (Lemy et al., 2021). Considering the present context and volatile post-pandemic situation, more studies on this topic are necessary to better understand how to effectively adopt ICT for disaster management in tourism under a variety of contexts. Despite increased ICT adoption and studies investigating technology use during the pandemic, Sorooshian (2021) asserts the need for assessing digitalisation readiness and preparedness for digital transformation of various sectors and stakeholders. ICT is expected to play an important role in tourism not just during the crisis when tourism is adversely impacted, but also in the post-crisis phase for local and global economic revival (Sorooshian, 2021).

Although the travel and tourism industry has been challenged on numerous occasions by disaster and crisis, the COVID-19 pandemic has brought an unprecedented impact and global halt to the industry. With travel restrictions placed across borders both nationally and internationally and the prevailing uncertainty of the pandemic, there has been a major restructuring of many tourism sectors such as airline business. Deep job cuts and/or reduced work patterns were seen across almost all European airlines (Albers & Rundshagen, 2020) and the second biggest airline in Australia, Virgin Australia was forced into voluntary administration (Gao & Ren 2020). Similarly, with the enforcement of social distancing measures, lockdown and shutdowns, the hospitality industry has had substantial impact with changes to their operations, staff lay-offs and closures (Gössling, et al., 2020). Despite the multitude of crisis response strategies being used globally, the uncertainty of the pandemic still persists, and it is difficult to ascertain the damage and time it will take for economies to heal and recover. As demonstrated in the examples outlined previously, ICT tools can be used to minimise impacts on the tourism industry brought about by this exceptional pandemic situation (Viñals et al., 2021).

IMPLICATIONS AND RESEARCH DIRECTION

Our review has also identified several research gaps. Studies related to ICT tools adoption in this research area are still at an early stage. With the advancement in technology, ICT applications have been increasingly adopted for planning, managing and recovery of tourism disasters, yet there are only a handful of research studies which document these efforts. Clearly more research can be conducted to better understand the ICT adoption barriers, processes, outcomes and lessons learned in tourism disaster management.

It is also evident that there are minimal studies on ICT adoption of the latest technologies like big data analysis and AI. The impacts to both tourism providers and tourists should be studied on a large scale to identify ways to help both parties to these ICT applications. Another future research direction could be in developing monitoring or evaluation systems for the adoption and use of ICT for tourism disaster management. This would assist us to better understand current success or failure of these systems to better deploy them in the future.

Our review of the current research literature shows that many researchers are investigating the potential adoption of ICT for COVID-19 disaster management related to tourism industry. Most of these studies, however, focused on social media. Future research should consider adoption studies of more diverse ICT tool sets covering the use of other innovative tools, in various geographic locations using different research methods. With the increasing adoption of ICTs during the COVID-19 pandemic, future researchers focusing on tourism disaster management can also investigate the market and consumer's readiness and security-privacy concerns for the tourism industry through the adoption of such tools.

CONCLUSION

Both natural and human induced disasters have a serious impact on the tourism industry. Adoption of ICTs have a significant role to play for assisting tourism operators and tourists both before and in the aftermath of any disasters or crises. This review highlights the very few studies conducted on the adoption of ICT applications in planning, managing and recovery operations both during and post disaster. This review clearly highlights that there is a lack of research which needs to be increased to better understand and strengthen the adoption of ICT for tourism disaster management. This review also highlights the opportunity to utilise a crisis, such as the current COVID-19 pandemic, to develop, adopt and study foundational and critical ICT systems for the tourism industry.

One of the limitations of our study is that the data for this review was extracted from four selected databases and then filtered to only peer-reviewed papers from journals and conferences. During the search, only research articles having touris* in titles and any study which did not mention tourism or tourist(s) in its title was eliminated. The resulting papers that were reviewed were relatively low in number because of the topic of focus i.e., ICT adoption strictly within a tourism disaster or crisis. Furthermore, we were not able to retrieve the full text of some articles in the list from the selected databases for this review. Most of the articles reviewed were country specific and so may lack generalisability to other contexts. This provides another opportunity to conduct further research to expand studies to other geographical locations. Similarly, for the information intensive nature of a tourism operation, it is apparent that the collection, retention, and curation of data will become more prevalent over time and there will be a growing need to consider potential risks to tourism stakeholders, especially the need to address data security, privacy, consent, access and cloud-based storage systems. Such studies will enhance the awareness of government and sector policymakers to incorporate ICT tools for strategic planning, maintenance, and management of the sector.

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Appendix A

S. No.	Selected Articles
1	An, T. T., Hanh, L. N., Izuru, S., Minh, T. P., Minh, V. V., Thoa, N. T. K., and Long, N. V. (2021). GIS-based Assessment of Coastal Tourism Vulnerability to Climate Change-Case Study in Danang City, Vietnam. *42nd Asian Conference on Remote Sensing, ACRS 2021*.
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The Effectiveness of Social Media Engagement Strategy on Disaster Fundraising

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ABSTRACT

Social media has been a powerful tool and integral part of communication, especially during natural disasters. Social media platforms help nonprofits in effective disaster management by disseminating crucial information to various communities at the earliest. Besides spreading information to every corner of the world, various platforms incorporate many features that give access to host online fundraising events, process online donations, etc. The current literature lacks the theoretical structure investigating the correlation between social media engagement and crisis management. Large nonprofit organisations like the Australian Red Cross have upscaled their operations to help nearly 6,000 bushfire survivors through various grants and helped 21,563 people with psychological support and other assistance through their recovery program (Australian Red Cross, 2021). This paper considers the case of bushfires in Australia 2019-2020 to inspect the role of social media in escalating fundraising via analysing the donation data of the Australian Red Cross from October 2019 - March 2020 and analysing the level of public interaction with their Facebook page and its content in the same period.

KEYWORDS

Social media, Disaster donations, Disasters, Facebook, Donor advocacy.

INTRODUCTION

The Bushfires in Australia (2019-2020) are considered enormous scale destruction in the modern record in New South Wales. Its significance is due to the record number of deaths and longevity from Nov-2019 to Mar-2020 (Smith, 2021). The bushfires have destroyed 3,094 houses and burnt over 17 million hectares of land across various states in Australia (Smith, 2021). The widespread fires have perished over 1 billion animals causing wildlife devastation (Green, 2020). Nonprofit organisations like Australian Red Cross have played a crucial role with certain governments in minimising the damage caused by this natural disaster by mobilising a certain amount of financial and human resources to help people or communities in need with a presence in metropolitan, rural and remote areas (Tanveer et al., 2020). The Australian Red Cross is a part of the world's most significant humanitarian movement, operating in over 190 countries and has over 17 million volunteers worldwide, and has raised the highest donations with more than a quarter-billion in the Australian bushfire crisis season. Recently, social media had an important role in promoting and amplifying the community's passion for climate change (Schweinsberg et al., 2020). Similarly, nonprofit organisations have been using social media to spread important events like earth day to raise awareness of critical concerns like global warming. As social media evolves, nonprofit organisations have more flexibility to conduct online events that can positively impact society (Tsai et al., 2019). Large nonprofit organisations like the Australian Red Cross have a significant social media presence.

During the 2019-2020 bushfires, huge social media interaction was observed where internet users communicated and expressed their emotions about the disaster. Social media is emerging as an effective tool to generate social awareness, spread official advisories, and raise relief funds (Adhikari et al., 2022). The Australian Red Cross employed its Facebook page to generate awareness among social media users and raise donations by indulging users in posts and videos (Rajora et al., 2018). The donation amount rose during the bushfire period, which seemingly influenced social media interaction. However, no study has analysed such a relationship to establish its concreteness.

This paper provides descriptive-analytical insights of the Australian Red Cross Facebook post interactions and donation patterns in bushfire season and discusses the role of social media during Australian bushfires (2019-2020).

RELATED WORK

Social media engagement has established a crucial role in emergencies and disaster response. However, research focusing on such technological employment is relatively limited (Haworth & Bruce, 2015). The widespread increase in different diseases after the disaster hits also causes alarming situation (Kabade et al., 2021). Government and non-government organisations communicate through social media to target large populations, strengthening disaster response capabilities (Poblet et al., 2018). The disaster management cycle involves four critical steps: prevention, preparedness, response, and recovery, which are eminently supported by social media platforms. Houston et al. developed an architecture depicting various dimensions of social media usage towards disaster management (Houston et al., 2015). The framework allows the stakeholders to undergo the disaster management cycle by encompassing preparedness, warnings and advisories, and disaster predictions. Organisations responsible for incident response actively engage social media users to communicate disaster warnings, directions, and advice (Erfani et al., 2016; Whitelaw & Henson, 2014). Haworth et al. established the importance of social platforms and Volunteered Geographic Information (VGI) sharing through a survey of 154 Tasmanian participants demonstrating significant potential of bushfire communication through online platforms (Haworth et al., 2015). A system proposed for classification of data extracted from disaster crises management websites by implementing some classification models. Implementation was conducted in two modules one for extraction of data and other for classification of data related to disaster or not. Domala et al. used bags of words and TF-IDF vectors as a feature extraction technique along with the well-known classifiers named as linear and logistic regression to achieve best accuracy (Domala et al., 2020). Perera et al. proposed a real-time approach using satellite imagery and remote sensing to proliferate bushfire-related warnings to the general public using social media such as Facebook and Twitter (Perera et al., 2021). The proposed framework allows social media users to contribute geographical information through images generating advanced bushfire warnings. The indulgence of social media users aims to disseminate the maximum possible information, warnings, and preventive methods and reach rural and semi-rural communities to mitigate bushfire impacts. (Abedin & Babar, 2018) emphasised the usefulness of microblogging on the Twitter platform, suggesting that the tweets were more informative than directive. They also characterise Twitter usage by formal institutions and non-institutional volunteers during a natural calamity concluding that individual users greatly influenced information dissemination during Australian bushfires. Anikeeva et al. suggested that Twitter can be used as a broadcasting tool to deliver frequent updates to the citizens, whereas Facebook can be used for establishing online communities, for instance, the Australian Red Cross page (Anikeeva et al., 2015). During the disaster (Sufi et al., 2022) extracted location-oriented data and implemented Artificial Intelligence (AI) and Natural Language Processing (NLP) based algorithm for sentiment analysis. They designed an approach having vast knowledge of responses collected from social media related to disaster in 39 different languages by using AL and NLP for analysis and detection of anomaly, regression and applied Getis Ord Gi∗ algorithms. It was found that 70% of the tweets collected were live location-oriented from different location effected by disaster. The accuracy calculated at last was about 97% on the data set. Roshan et al. investigated the use of Facebook and Twitter for crisis communication by similar organisations by performing qualitative content analysis and gain essential insights into usage patterns and motives (Roshan et al., 2016). They concluded that organisations are not fully utilising the social media potential for communication during natural disasters.

MATERIALS AND METHODS

Data

We have extracted the time series bushfire donation data of the Australian Red Cross from 2011-2021 and social media engagement time series data of the Australian Red Cross Facebook page from October 2019-March 2020. Out of the large donation dataset, we only used data from October 2019- March 2020 aggregated by each month to analyse the dependence of social media factors on the donation amounts. After receiving the data, we have removed personally identifiable information (PII), geographical and additional data from the datasets. Data with no relevance is identified and not used for analysis purposes. The features analysed in this study from the aggregation of donation and social media data are listed in Table 1.

Table 1. List of features in the dataset and their explanation

Abv.	Feature	Explanation
DA	Donation Amount	The total amount of donation collected through fundraising
F1	Likes	Total number of likes on the posts of Australian Red Cross Facebook page
F2	Shares	Total number of shares of all posts on the page during the study period
F3	Comments	Total number of comments on all the posts generated during the study period on the Facebook page
F4	Reacts	Total number of reactions (like, love, care, haha, wow, sad, angry) obtained on all the posts
F5	Impressions	Total number of times the posts from the Australian Red Cross page was displayed on users' timeline (Reach)
F6	Seconds viewed	The number of seconds a video was viewed
F7	Duration (Sec)	The total duration of a video in seconds
F8	3-second video views	The total number of views where the users watched a video for 3 seconds
F9	60-second video views	The total number of views where the users watched a video for 60 seconds
F10	Averaged seconds viewed	The average number of seconds for which the users watched a video
F11	Unique 60-second video views	The total number of views from unique users who watched the video for 60 seconds
F12	60-second views from Recommendations	The total number of views on the videos where a user watched the video upon recommendation for 60 seconds
F13	60-second views from Shares	The total number of views on the videos where a user watched the video shared by a friend for 60 seconds
F14	60-second views from Followers	The total number of views on the videos where a follower of the Australian Red Cross page watched the video for 60 seconds
F15	Seconds viewed from Recommendations	The number of seconds a video was viewed upon recommendation
F16	Seconds viewed from Shares	The number of seconds a video was viewed when shared by a Facebook friend
F17	Seconds viewed from Followers	The number of seconds the page's followers viewed a video

F18	Average Seconds viewed from Recommendations	The average duration a video was viewed upon recommendation (in seconds)
F19	Average Seconds viewed from Shares	The average duration a video was viewed when shared by a Facebook friend (in seconds)
F20	Average Seconds viewed from Followers	The average duration a video was viewed by the page's followers (in seconds)

Methodology

Social media is conducive to managing crises in terms of issue monitoring, framing crises, and reinforcing relationships with stakeholders while strengthening relationships with the online community in challenging times (Jiang et al., 2016). According to this study, liking a post shows the user interest in a particular post. It builds a connection with other users who also like the same post on social media, which gives a sense of community that shares similar interests. Facebook updates the user network when a user likes a page or donates to a fundraiser; that particular action acts as a user endorsement and acceptance of that specific brand or organisation (Lee, 2021). This user endorsement might also lead to the user network engagement or views of that organization (Sawhney et al., 2019).

User engagement is the critical metric for a digital organisation (Aldous et al., 2019). According to this study, there is four user engagement with level 1 as views, level 2 as likes, level 3 as shares and comments, and level 4 as external postings. Each level indicates some user actions representing a certain measure of engagement with a lower to higher level as most basic to advanced engagement (Agarwal et al., 2020). Views indicate a more private level of social interaction where the longer a user sees a post, the more interested the user is in that post. Liking, commenting, and sharing is a public expression that can be visible to a user's network (Aldous et al., 2019). views, likes, shares, and comments can be considered primary and standard metrics to determine user interaction with a page or a post (Raj et al., 2021). Reach is an attribute used in this analysis that defines the number of people who read any content from a page or about a page (Facebook, 2021). The impression is another attribute used in this analysis that defines the number of times the content from a page has entered a person's screen (Facebook, 2021). We have considered five attributes for social media engagement: likes, comments, shares, reach, and impressions. Reach, and impressions are very close to being considered views, but these attributes are different in their ways. These five attributes have quantitative potential to show the degree of user engagement in the Australian bushfire crisis, which can help us correlate with the donation data to understand some patterns between donation and user engagement.

To elevate user engagement, Australian Red Cross Facebook page regularly publishes videos on their page. These videos aim to impact users, raise their concerns about disasters and generate fundraising significantly. We extract these video analytics to understand how users respond to such social media posts and how such interaction influences disaster fundraising.

The analysis procedure primarily involves identifying the correlation between the donation amount and social media engagement factors. We plot a confusion matrix for all the features in the aggregated dataset. The implementation is carried out on Google Colab using Python 3. Google colab also known as Collaboratory is a free online service, provides a platform for performing different operations by using machine learning and artificial intelligence techniques for research education. It is based on Jupiter notebook where users can do some programming and run the code. Collaboratory also provide python 2 and 3 runtime pre-defined libraries service such as TensorFlow, MxNet, and PyTorch to perform various tasks. After completing the task data file can be saved by exporting to google drive or system hard drive and Google cloud is hosting the Collaboratory service (Carneiro et al., 2018). The inferences yielded through the correlation matrix were considerably few, following which we plotted the graphs for all the social engagement features with respect to the donation amounts in a monthly fashion. The results obtained and their analyses are discussed in the next section.

RESULTS AND ANALYSIS

Australian Red Cross has an extensive volunteer and donor base across various parts of Australia (Smith, 2021). The extracted bushfire donation data from mid-October 2019 to March 2020 is shown in figure 1. We observe a gradual increase in donations from the mid of November 2019. Aggregated and average amount donated per month from October 2019 to March 2020 is shown in Figure 2 and Figure 3. The minimum amount donated in this period is AUD 0.01, whereas the maximum amount donated in this period is approximately 7 Million AUD. The total amount donated from 10-2019 to 03-2020 is approximately 200 Million AUD.

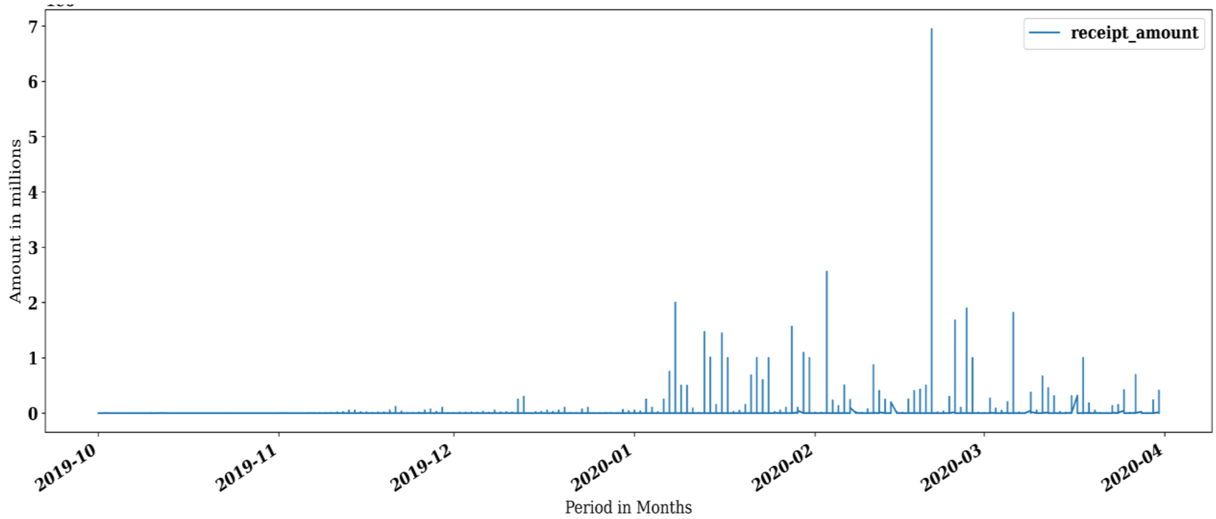

Figure 1: Donation amount ranging from October 2019 to March 2020 (Australian Bushfire crisis period)

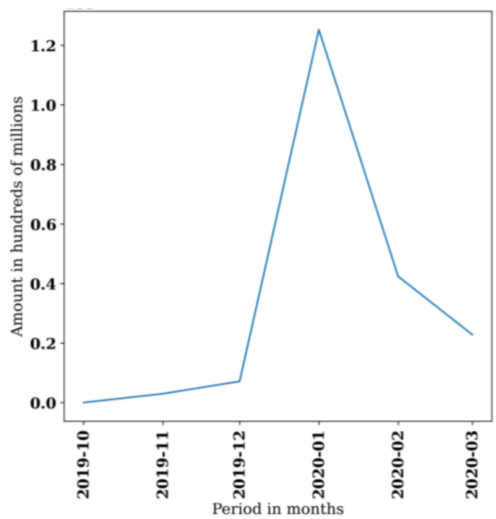

Figure 2: Monthly aggregated donation amount

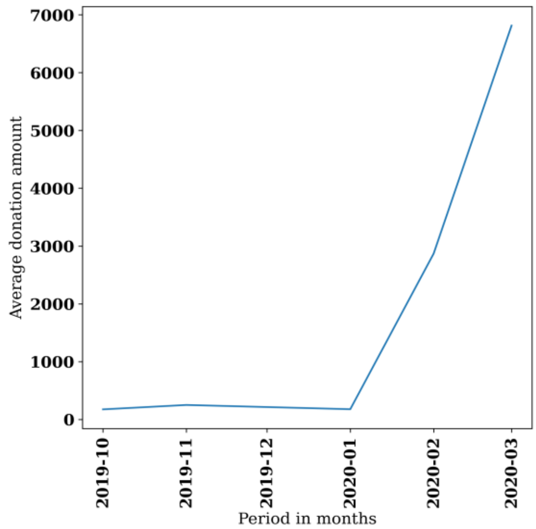

Figure 3: Monthly average donation amount

Australian Red Cross has a significant social media presence with about 253,000 followers, and 248,000 page likes on Facebook. Along with several followers, the Australian Red Cross Facebook consists of various types of content in the form of photos, videos, groups, fundraisers, and online events. We have extracted user engagement data from the Australian Red Cross Facebook Page from Oct-2019 to Mar-2020, including likes, comments, shares, Reach, Impressions and Seconds views of any content originating from the Australian Red Cross Facebook page or the page itself. Likes, comments, and shares of the Australian Red Cross page and its contents are shown in Figure 4. Reach, Impressions of the page and its content are shown in Figure 5.

From Figures 4 and 5, we can see that the user engagement has been steady from Oct 2019 to Nov 2019, whereas the spike of user engagement began in Nov 2019 lasted until Jan 2020. Although the intensity of the user engagement is different among likes, comments, shares, reach, impressions, and seconds viewed, they all show similar trends in that period. We also have extracted a correlation matrix among social media engagement attributes, as shown in Figure 6. We have used Pearson correlation to extract any attribute dependencies. We can see that there is a high correlation among various social media engagement attributes.

Figure 7 illustrates a correlation matrix for all the features employed in the exploratory analysis. It demonstrates a positive relationship between the donation amount with average seconds viewed, 60-second views from followers, seconds viewed from recommendations, followers, average seconds viewed from recommendations, shares, and followers. The highest correlation displayed is 96% between the donation amount and seconds viewed from the recommendation. This extreme value establishes a conclusive effect of social media recommendations. People are more likely to watch a video upon recommendations from their friends and acquaintances. Moreover, such recommendations are highly capable of convincing people to contribute towards disaster fundraising. 76% correlation observed between the donation amount and the average seconds viewed from recommendations reinforces this relationship. Another important conclusion drawn from the correlation matrix highlights that the video views received from the Australian Red Cross Facebook page followers drew massive donation amounts, with a positive correlation of 84%. Followers of a page or profile represent a concern to the cause and the community. Social media videos are more likely to influence the immediate followers of a page. Seconds viewed from followers also hold a 62% correlation with the donation amount. Similarly, a 63% correlation is observed between the donation amount and the average seconds viewed from shares, implying that the views generated upon sharing a Facebook post also significantly increased the donation amount. However, the correlation matrix failed to display any association of the donation amount with the rest of the features.

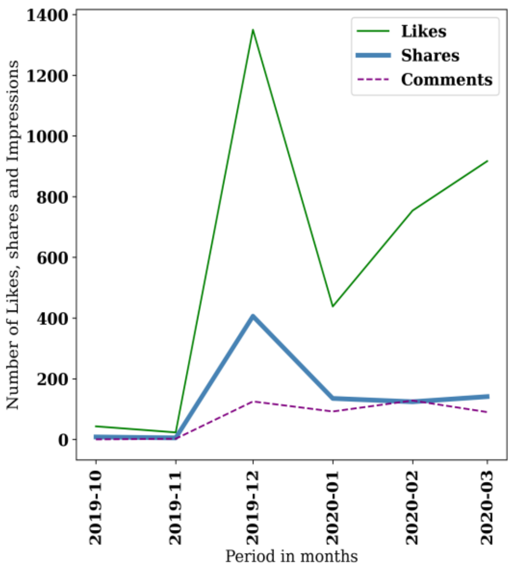

Figure 4: Likes, shares, comments in bushfire period

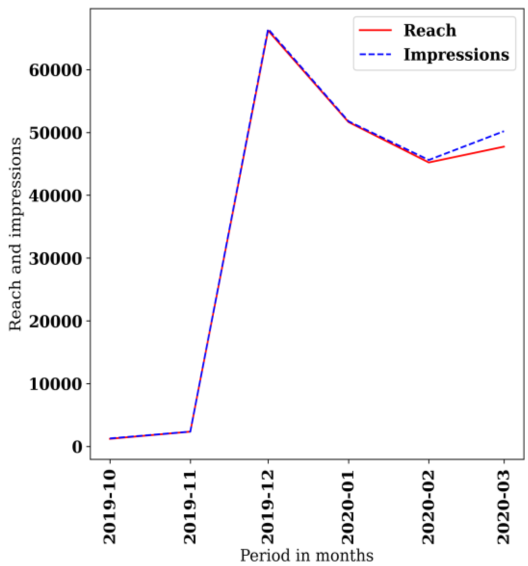

Figure 5: Reach and impressions in Bushfire period

Figure 6: Correlation matrix among social media engagement attributes

Figure 7: Correlation matrix for social media engagement and video features with the donation amount

Figure 8 demonstrates a normalised plot observing the donation revenue trends concerning user engagement on social media. The October to November phase during 2019 shows very gradual progress in the engagement features. The engagement escalates during November when all the social media features, likes, shares, comments, reach, and impressions are observed to rise steeply till the peak. The beginning of December, however, decrements the engagement differently for all engagements. Likes and impressions demonstrate an approximate 65% decline, whereas shares, comments, and reach have reduced by ~20-25% since November. Analysing the donation amount alongside, it gradually increased between October and December, but a boom is demonstrated with a similar trend as the engagement factors during the December month. Following the graph, it is observable that the increment in engagement has a delayed, but direct impact on the donation amount as graphs demonstrate a similar slope for all the trendlines during this period. After reaching the peak donation amount in January 2020, it steadily reduces, following the trend of likes and impressions until February 2020. Post-February, the engagement factors demonstrate an irregular rise and fall, maintaining an engagement above ~35%. However, the donation amount steadily declines after this period.

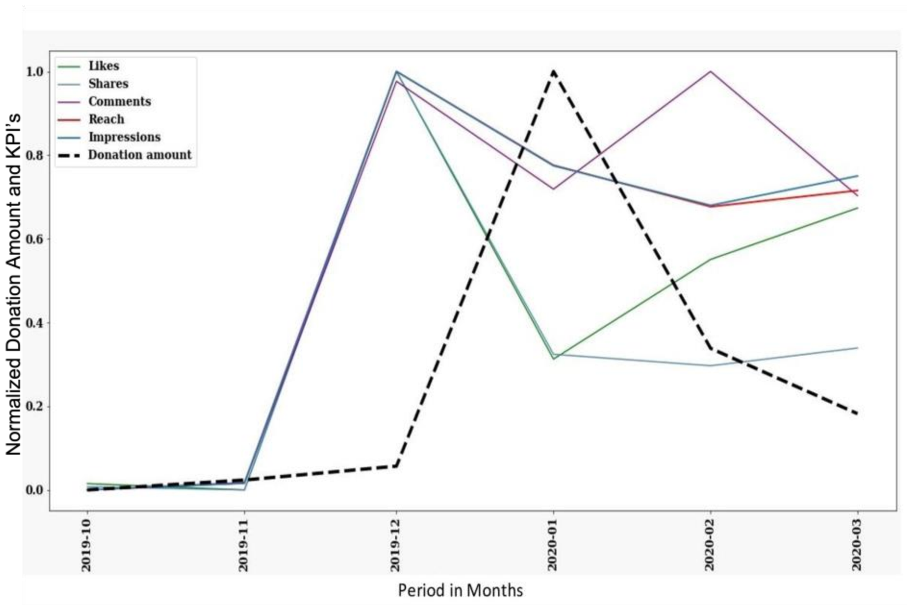

Figure 8: Donation amount with respect to likes, shares, comments, reach, and impressions

Next, we plot the donation amount with respect to the duration (Figure 9) and the average duration (Figure 10). The videos were watched due to unique factors- recommendations, shares, and followers. The video-viewing duration has risen throughout November 2019, with the steepest and maximum rise in the duration watched by shares. People who encounter a shared post in their news feed appear to watch the videos longer than follower or recommendation views. Followers watched the videos for an above-average duration (nearly above ~65% of the video's length). However, recommended videos were watched for a shorter duration of approximately 25% of the video's length. During December, the watching duration rose for views from recommendations and followers but experienced a fall for shared videos. Overall, the donation trendline follows the pattern of watching duration from shares, experiencing similar but delayed peaks and lows.

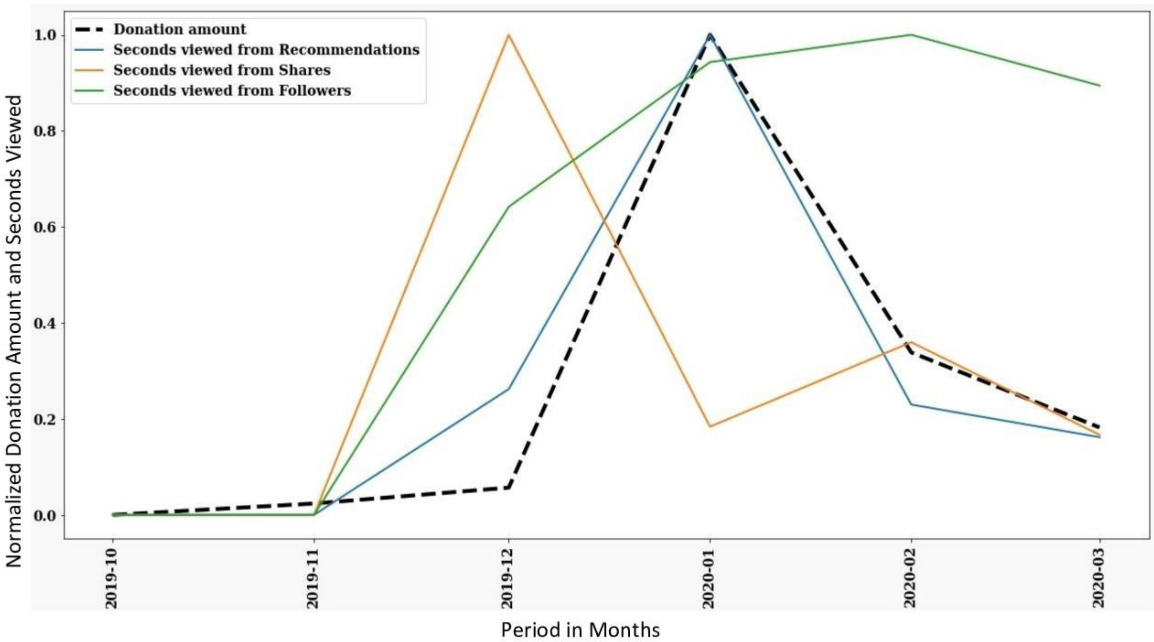

Figure 9: Donation amount with respect to seconds viewed from recommendations, shares, and followers

Averaging the watching duration from these views brought the trendlines closer for views from recommendations, followers, and shares, as illustrated in Figure 10. The average video-viewing duration continually rises for two months during November and December 2019, after which they experience a decline. The donation amount seemingly rises more steeply a month later. The spike is observed in average video viewing duration. This reestablishes the finding that video viewing had a direct but delayed response in disaster fundraising.

Figure 11 plots the donation amount against five key factors: video duration, video seconds viewed, 3-second views, 60-second views, and average seconds viewed. The donation amount rise during December 2019 is likely to be the effect of video duration. It is observed that increasing the length of the video has resulted in higher donation amounts. A similar trend is observed by the number of seconds viewed by social media users, the average number of seconds viewed, and the number of 3-second video views. All of these show a delayed impact, causing the donation amount to rise during December month. However, the rise in the number of viewers who watched the video for 60 seconds impacts the donation amount instantly. The number of views rises to nearly 30% while the donation amount peaks (~100%). Although during January, when the donation amounts begin to decline, the 60-second views are still rising, meaning that users are still engaging into watching the Australian Red Cross page videos, it is not generating any fundraising. Similar to other video viewing patterns and the donation amount, the 60-second views fall gradually after January.

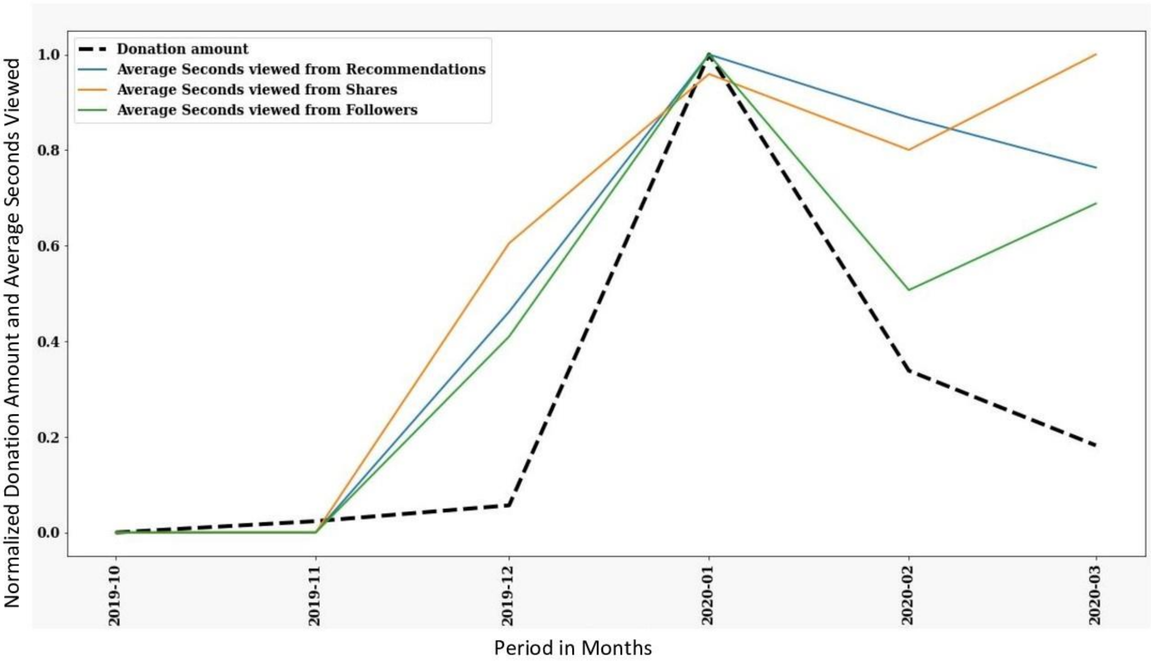

Figure 10: Donation amount with respect to average seconds video viewed from recommendations, shares, and followers

Figure 12 further breaks down the trend of 60-second video views into unique factors. Since 60-second views displayed an immediate response towards fundraising, it is essential to consider the constitution of these views. It is observed that the most views of the most prolonged duration were obtained from the page followers. Thus, highest engagement and impact were observed amongst the page followers, followed by the views from recommendations, unique views, and views from shares. The trendlines for unique video views and the views from recommendations move very close to each other, suggesting that the viewers who watched videos from recommendations were mostly unique viewers, with a marginal percentage of them being the existing followers of the page. The number of views from shares is the least among the 60-second views suggesting that sharing a video on a user's timeline brought substantially lower views and donations. During January 2020, the video views continued to rise, but the donation amount experienced a fall thereafter even if the number of views kept rising. Altogether, a drop is experienced during February 2020, suggesting that the users were uninterested or concerned after a particular time. This could be the case where the post experienced maximum visibility, and thereafter it was circulating among the same people who already viewed the videos or fundraised towards the cause.

Key Findings

1. Social media engagement displayed a direct but delayed relationship with the donation amount during the Australian bushfires.
2. The donation amount displays a positive correlation with the number of views on the Australian Red Cross Facebook page videos.
3. The six social media engagement attributes, namely, likes, shares, comments, reach, impressions, and seconds viewed, demonstrated a high positive correlation (>75%) amongst each other.
4. The rise in social media engagement through likes, shares, comments, reach, and impressions during November 2019 caused a similar increment in the donation amount during December 2019.
5. The decrement in social media engagement in December 2019 caused a similar decline in donation amount during January 2020.
6. As users were watching a video for longer durations, the donation amount also hiked.
7. Recommended videos gained longer views from fellow users and reached a peak by November end.
8. The donation amount increased with the increase in video duration.
9. Videos watched for 60 seconds influenced donation amounts in the same month, immediately impacting the viewers.
10. The earliest video views from followers were to ascend, followed by recommendations, unique views, and

views from shares.

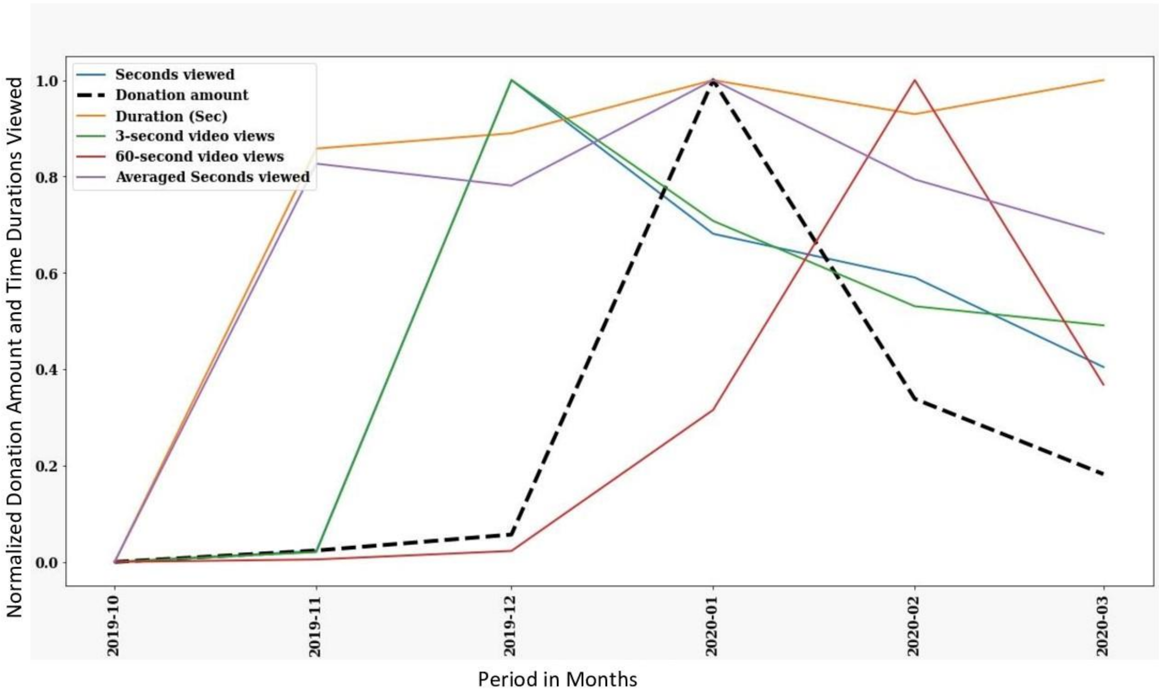

Figure 11: Donation amount with respect to video duration, video seconds viewed, 3-second views, 60-second views, and average seconds viewed

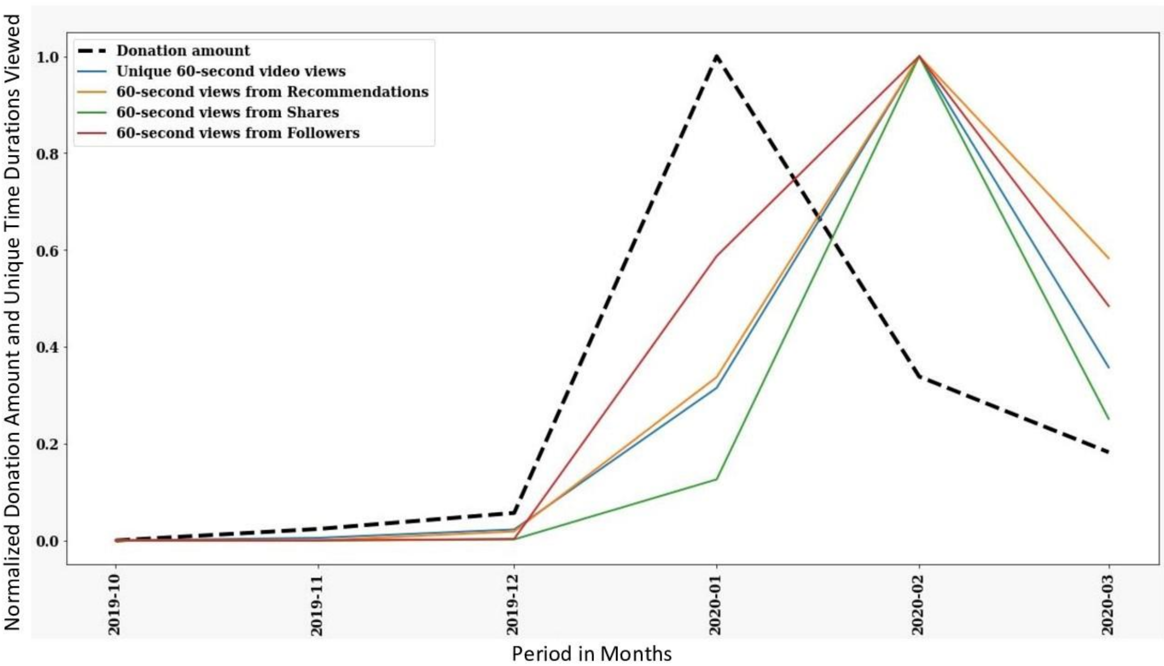

Figure 12: Donation amount with respect to 60-seconds unique video views, views from recommendations, shares, and followers

CONCLUSION

In this exploratory research, we have investigated novel and unique Australian Red Cross bushfire donation trends in accordance with social media engagement. This analysis offers an opportunity to explore disaster donations and Facebook interactions in a relevant way. The social media engagement attributes (likes, shares, comments, reach, and impressions) are highly correlated. This suggests that user involvement is high with respect to all levels of engagement. The correlation between likes, shares, and comments suggests that more than private engagement, user advocacy via sharing and commenting posts in that period might have played an essential role in the revenue growth of donation. We observed a similar trend in donation revenue and social media engagement at different times of the year. The spike in user engagement before donations also suggests that social media's level of user engagement might have acted as a catalyst in generating the donation revenue. Additionally, Facebook video watching behavior leads to meaningful insights towards optimum video length and engagement routines to fundraise massive amounts during natural disasters such as bushfires.

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Crowdsourcing and the COVID-19 Response in China: An Actor-Network Perspective

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ABSTRACT

Crowdsourcing, serving as a distributed problem-solving and production model, can help in the response to a disaster. The current literature focuses on the flow of crowdsourced information, but the question of how crowdsourcing contributes to physical disaster workflows remains to be addressed. Based on a case study of China's response to COVID-19, this research aims to explore the role of crowdsourcing stakeholders and how they acted to respond to the outbreak. Actor network theory is applied as the lens to elucidate the roles of different heterogeneous actors. The preliminary results indicate that socio-technical actors activated, absorbed, associated, and aligned with each other to combat the pandemic. We suggest ways to augment the actor network to address potential future outbreaks.

Keywords

Disaster, crowdsourcing, actor-network, social media.

INTRODUCTION

The frequency and scale of disasters across the globe have continued to increase in recent years (United Nations, 2021). Effective response to disasters requires the coordination of a complex set of workflows, including disaster information, physical delivery of relief supplies, the flow of human resources and financial aid, posing serious challenges under huge time pressures (Long and Wood, 1995). In this respect, traditional response systems that tend to involve hierarchical organizations that may not be flexible and agile enough to meet the multifaceted, uncertain, and complex needs that emerge in chaotic environments such as those encountered during a disaster (Nan and Lu, 2014).

Some information systems (IS) practitioners and scholars have suggested crowdsourcing to tackle the challenges faced by authorities during and following disasters. Crowdsourcing is a mechanism that incorporates three stakeholders: the *crowdsourcers* (for example, public emergency management agencies in this case) who outsource tasks they have traditionally performed to the *crowd* (e.g., a group of individuals) via an open-call format through Internet-based *platforms* (Howe, 2006; Schenk and Guittard, 2011). There has been increasing research interest in the use of crowdsourcing in disaster relief, with individuals acting as data sensors in disaster-affected areas by creating, posting, disseminating, and discussing information on online platforms. The relevant authorities collect, organize and analyze these crowdsourced data and develop appropriate relief measures (Ogie et al., 2018; Sheth, 2009). However, there are at least two gaps in the research at the intersection of crowdsourcing and disasters. First, existing research focuses on the flow of crowdsourced information in the aftermath of disasters, but little attention has been paid to understanding the crowdsourcing of material, financial, and manpower flows in disaster response. Such flows are typically taking place in parallel with, or as a result of (crowdsourced) information. However, the heterogeneity of the crowdsourcing stakeholders involved in disaster response makes collective action challenging. Therefore, a second gap requires research into the role played by crowdsourcing stakeholders in disaster response workflows, and how they interact to form effective disaster response networks. To fill these gaps and contribute to our knowledge of how crowdsourcing can best be used in disaster management, our research aims to address the following question – *What are the roles of crowdsourcing stakeholders in disaster workflows?*

We chose the case of the COVID-19 response in China to explore this question. Due to the lockdowns and social distancing requirements implemented in China, crowdsourcers have primarily relied on internet platforms to mobilize crowds and connect with each other, while subsequently investing in practical actions concerned with prevention and control of outbreaks. We conducted semi-structured interviews with 32 participants, including civic volunteers, community workers, social workers, and school community volunteers, to gain insight into the perspectives of different groups helping with the response to the COVID-19 outbreak.

We elaborate the theoretical lens for this research in the next section. After this, the research methodology is introduced, followed by a brief description of the preliminary results. In the final section, we discuss the limitations and potential contributions of the research.

THEORETICAL FOUNDATION

The term crowdsourcing was first coined by Howe (2006) to describe "*the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call".* Since then there has been widespread official recognition of crowdsourced engagement as an important element of disaster relief and resilience building (e.g., UNDRR, 2015) because of its benefits for accessing large amounts of resources, obtaining cost-effective results, and exploring new discoveries (Brabham, 2012; Kanhere, 2013; Wazny, 2017). For a variety of reasons, such as spatial and temporal distance from the disaster site, delays in decision making, or disasters that exceed response capabilities, formal authorities may not be able to act immediately following a disaster. As a result, government and other agencies sometimes make public appeals for help from the crowd. Individuals and communities close to affected areas are often the first responders, reporting the disaster and helping those who are at risk or suffering (Leong et al., 2015). Online intermediary platforms such as social media are used to reach out to users to participate in disaster relief (Kim et al., 2018). However, how these socio-technical forces (i.e., crowdsourced stakeholders) interact to increase the responsiveness of disaster workflows is under-explored in the current research literature.

Hence, this research explores the interaction amongst heterogeneous networks actors during a disaster. We do so through the lens of actor-network theory (ANT) (Callon, 1984; Latour, 2005; Law, 1992). ANT has interdisciplinary methodological and theoretical strengths that offer potential for understanding socio-technical aspects of IS research (Walsham, 1997). ANT treats both human objects (e.g., organizations and individuals) and non-human objects (e.g., laws and technologies) as actors. These heterogeneous components generate connections that form networks in which the nodes are actors (Bosco, 2006; Latour, 2005; Law, 1992; Walsham, 1997). Central to ANT is the process of translation by which the focal actor defines, negotiates, and arranges the interests, roles, functions, and status of other actors through four moments: problematization, interest, registration, and mobilization (Callon, 1984).

We employ ANT to explore the role of crowdsourcing in disaster response for the following reasons. First, ANT provides a framework for understanding the roles of social and technological actors and their interaction, while avoiding the limitations of technological and social determinism (Latour, 1984; Law and Callon, 1988). This fits our research context, in which our aim is to explore how crowdsourcing stakeholders create and maintain disaster relief networks with aligned interests. Official crowdsourcers act as the focal actors, interacting, negotiating, coordinating, and ultimately facilitating disaster relief efforts with other crowd members through the technical resources provided by nonhuman actors (i.e., platforms). Second, the ANT translation approach enables us to reveal the process of human–technology interaction. This helps achieve our research aim of exploring how different crowdsourcing stakeholders contribute to disaster workflows, and, how the focal actor encourages, manages, and mobilizes other actors to build a network for disaster relief. Third, ANT highlights the dissidence in the network. It provides a suitable perspective from which to analyze the claims of various heterogeneous actors, thereby revealing the challenges encountered in disaster response and shedding light on critical disaster management issues. In short, we will use ANT as a sensitizing device to understand the roles of different crowdsourcing stakeholders and the efforts made to form a disaster response network. We will also explore the dynamic interactions among actors, including how they respond to resistance in the process of forming the actor-network.

RESEARCH METHODOLOGY

We decided to use case study research given the exploratory nature of our research project (Eisenhardt, 1989; Siggelkow, 2007). Our case is based on the COVID-19 response in China because it provides sufficient evidence on the crowdsourcing phenomenon in the response to a disaster (Mason, 2002; Myers, 2019). China was the first country to report a confirmed case of COVID-19 and the first to implement a lockdown, hence offering an excellent opportunity to explore and better understand the role of crowdsourcing in disaster response.

The primary data were collected from semi-structured interviews, conducted from February to April 2022. Eligible participants were those who had participated in or organized prevention and control-related efforts after the COVID-19 outbreak. We approached key informants from volunteer groups and the local community in which the first author was involved. Subsequently, a "snowball sampling" strategy was used, which helped us to obtain a total of 32 interviewees, covering fifteen provinces in China, including Hubei province (Myers and Newman, 2007).The interviewees were from a variety of backgrounds, including nonprofits, civic volunteers, college students, community workers, and grassroots government agencies. Each interview lasted an average of 30 minutes. To understand the potential characteristics of the roles of different stakeholders in post-disaster response, we invited the interviewees to share their experiences of anti-epidemic from early 2020 onwards, including motivations for participation, actions taken, challenges encountered, and reflections[1]. In addition, ancillary data were collected from archival sources, including posts related to the outbreak on the interviewees' personal public social media accounts, reported interviews, WeChat posts from their communities or organizations, short videos, and related news coverage. This additional data facilitated an in-depth understanding of the phenomenon of interest (Klein and Myers, 1999).

Due to the exploratory nature of this study, the process of data analysis was inductive and iterative (Walsham, 1995). We followed the temporal bracketing strategy devised by Langley (1999) to identify recurring theoretical mechanisms over time. The logical sequence of translation from ANT (i.e., problematization, interessement, enrolment, mobilization, maintenance) was adopted and extended. We then applied the concept development process described by Gioia et al. (2013) to develop a multi-stage coding scheme with first-order codes, second-order themes, and aggregated dimensions (see Table 1). We conceptualized the process of network formation by heterogeneous participants in each respective time period as activation, absorption, association, alignment, and augmentation (the 5 As).

Table 1. Excerpt of Coding Scheme

1st Order Concepts	2nd Order Themes	Aggregated Dimensions
Purchasing and donating PPEs	Emergent spontaneous response	Activation
Traveling to Hubei to support the fight against the outbreak		
Spontaneously guarding at transportation stations		
Assembling on standby		
Setting up a team for pandemic prevention and control services	Official response	
Arranging manpower based on the number of administrative residents		
Calling for crowd power		
Defining the goal of collective action to resolve the crisis		
Services like PCR testing require short-term and large numbers of helpers	Identification of needs	Absorption
Epidemic services have become routine work that requires stable forces		
Absorption through word of mouth from social connections	Diversification of channels	
Social media and website subscriptions and retweets		
Offline posts of announcements		
Monetary rewards	Stimulation with incentives	
Non-monetary rewards such as souvenirs and thank you letters		
Volunteering activities credited for curriculum		

[1] The details of interviewees and interview questions are placed in a cloud repository. Visit via https://doi.org/10.17608/k6.auckland.20819941.v1

Inspired by the efforts of frontline workers		
To help people in need		
Top-down notification of work requirements	Duty configuration	Association
Bottom-up reporting on work progress and social feedback		
Governments invite social organizations with experience and resources	Collaboration	
Emergent groups join with each other to act collectively		
Group leaders act as bridging coordinators across levels or organizations	Coordination	
The key is problem solving through negotiation of benefits		
Team leaders play a pioneering role	Demonstration of credibility	Alignment
Continuously calling for people around them to action		
Guidance on public opinion to reduce social panic		
Unified deployment and vertical management	Effective governance	
Inspection of grassroots efforts		
Official recognition of the work of social organizations and individuals		
Conducting professional training and qualification exams	Training	Augmentation
Advocacy education as invisible training		
Recording volunteer hours and implementing a time bank mechanism	Ways on innovating	
Community and corporate partnerships to absorb participants		
Use of social media campaigns to express appreciation for donating companies and to stimulate more donations		

PRELIMINARY RESULTS

Using the ANT perspective, the crowdsourcing stakeholders involved in the disaster relief in China can be classified into different categories of actors. We defined the focal actors as having more resource advantages, greater authority and stronger organizational, management and dispatching capabilities than other actors. Due to the resource advantages and leadership granted by the administrative system, the various government agencies were the focal actors, initiating the outbreak response network and actively involved in the implementation of relief measures. The main actors in building the network were spontaneous social voluntary groups. In our case study, these were not only the active responders to the call from the focal actors, but also the network expanders who put the call out for broad crowd involvement. They assisted officials in integrating information, interfacing with communities, disinfecting and sterilizing, providing psychological support, and raising and allocating resources, amongst other efforts. Volunteers and social workers from all walks of life were important supporters and task performers for the crowdsourcers. As in previous research, internet-based crowdsourcing platforms remained important co-actors in the relief network, serving as an effective and viable crisis information intermediary between the crowdsourcers' appeals and the crowd's response. In China, popular mobile applications such as WeChat and Alipay have taken on the function of an emergency pandemic service, with officials and developers releasing a "three codes and one record" (health code, itinerary code, vaccination code, and COVID-19 test feature). Social media groups are used by community workers to identify the health status of residents in their jurisdictions and by residents to obtain local outbreak policies.

Problematization Stage: Activation. The actor-network responding to the pandemic began with problematization. In the face of the sudden outbreak, government sector agencies, as the focal actors, identified the need for the country to work together to resolve the crisis and maintain social order as quickly as possible. It was imperative in this stage to clarify the status of the pandemic and mobilize the materials and manpower needed to launch relief efforts, as well as set up traffic control points as appropriate to prevent the spread of outbreak. The government call activated a broad set of actors to participate in pandemic control and rescue efforts. In this stage, the pre-established relationships between the public sector, business, and administrative organizations provided an important base from which these focal actors could activate networks and define their roles.

Interessement Stage: Absorption. After some consensus on the pandemic response had been reached, the focal and main actors sought to define and stabilize the identity of the other actors by reasonable vesting in interests, so as to absorb more actors into the network (Callon, 1984). The most popular channel for absorption was online platforms. Almost all respondents mentioned the role played by WeChat in delivering crisis information and appealing to the crowd. This occurred in two main ways. The first was updates from the official accounts to which crowd members were subscribed, and the other was through the proliferation of online social circles (community, work, school, business contacts) to recruit more actors. In terms of incentives, along with monetary subsidies, the government and other crowdsourcers rewarded the other actors in the form of honorary certificates, public reporting of their good deeds, and so on. In addition, many interviewees indicated they joined the relief network through self-interessement, i.e., rather than being driven by external factors, they aimed to realize their instrumental value through taking control of reality, out of a sense of guardianship of social morality, law, and responsibility.

Enrolment Stage: Association. Enrolment occurs after successful interessement. In this stage the focal actors attempted to identify and coordinate the roles they had assigned to others. Due to the heterogeneity of actors, enrolment involves the coordination and cooperation of various actor nodes to reach a stable network of aligned interests (Callon, 1984; Madon et al., 2004). Our case demonstrates three processes for linking the network nodes. The first is duty configurations, that is, through top-down notification (i.e., cascading arrangements from central government to the local level, or within organizations) or bottom-up reporting (i.e., grassroots actors reporting to higher levels). The second is cross-organizational collaboration. In China, collaboration between government and emergency social groups was largely driven by the former with the aim of improving efficiency by inviting actors with skills and resources to participate in outbreak services. Here, official credibility and unofficial resources complemented each other in a win-win situation. In contrast, collaboration between social groups was the result of joint efforts. Such organizations are nodes where strengths and donations converge, originating from and spreading care and support to the social community. The third is coordination, where the regional directors acted as coordinators between participants across levels or organizations, resolving problems on both sides by negotiating interests.

Mobilization Stage: Alignment. During this phase, the focal actors were widely recognized as representatives of the network (Callon, 1984). Other actors were mobilized and aligned in the pandemic response network. Our case highlights two approaches used by focal actors to achieve successful mobilization. The first was demonstrating credibility. The focal actors not only took the lead in the front line of the action, but also guided the direction of public opinion and secured the credit accumulated by their actions to gain reputation. Officials used social accounts to report on the progress with patient treatment and the implementation of pandemic policies, so that others would be convinced that an effective disaster response was being led by the focal actors. The second was effective governance, as reflected in the following aspects: 1) vertical management by a dedicated pandemic prevention and control center to arrange the work of other functional departments; 2) effective supervision on the work by other actors, based on public evaluation and accountability mechanisms in grassroots communities; 3) official recognition, especially for social groups and emergency individuals, whose efforts are recognized to enhance gratification and active participation.

Maintenance Stage: Augmentation. Given that temporary regional lockdowns in response to imported cases of COVID-19 have become the norm in China, our interviewees provided insights on ways of enhancing the actor network to respond to potential localized outbreaks. The first step is retaining current actors through training. In addition to skills training, the civic education they receive is an intangible form of training that facilitates the development of moral and ethical qualities, which then further promotes the retention of these groups as an investment in future public service activities. The second step is expanding the actor network through innovative approaches. Many interviewees suggested governments, communities, businesses, schools, and public welfare organizations should introduce time bank volunteering. This involves volunteers depositing their time for public service into a time bank, from which they can withdraw time served when needed. This mechanism not only calls for the crowd to participate in the outbreak response but also serves as a reserve for potential future actor networks. Seeking community and corporate partnerships and leveraging the power of social media to stimulate action are other methods for expanding the network of actors.

CONCLUSION

This paper has presented the preliminary results of research into how crowdsourcing can help in the response to a disaster. Our case study focused on the response to the COVID-19 pandemic in China, revealing how different actors activated, enrolled, connected, and formed interest alliances to fight COVID-19. The next step of our project is to focus on the resistance crowdsourcing stakeholders encountered in this process and how they responded. There are of course limitations in our research. For example, the results of our study may not be generalizable to other countries or other disasters. However, we hope that this study will contribute to research at the intersection of crowdsourcing and disaster management, through identifying the potential of crowdsourcing not only in relation to crisis information, but also in broader disaster workflows. The study also extends the applicability of ANT by delving into the interaction and coordination process of socio-technical actors in dynamic disaster contexts.

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Insights from a Decade of Twitter Monitoring for Emergency Management

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ABSTRACT

The Emergency Situation Awareness (ESA) tool began as a research study into automated web text mining to support emergency management use cases. It started in late 2009 by investigating how people respond on Twitter to specific emergency events and we quickly realized that every emergency situation is different and preemptively defining keywords to search for content on Twitter beforehand would likely miss important information. So, in late September 2011 we established location-based searches with the aim of collecting all the tweets published in Australia and New Zealand. This was the beginning of over a decade of collecting and processing tweets to help emergency response agencies and crisis coordination centres use social media content as a new channel of information to support their work practices and to engage with the community impacted by emergency events. This journey has seen numerous challenges overcome to continuously maintain a tweet stream for an operational system. This experience allows us to derive insights into the changing use of Twitter over this time. In this paper we present some of the lessons we've learned from maintaining a Twitter monitoring system for emergency management use cases and we provide some insights into the changing nature of Twitter usage by users over this period.

Keywords

Crisis Coordination, Disaster Management, Situation Awareness, Social Media, System Architecture, Twitter

INTRODUCTION

The Emergency Situation Awareness (ESA) tool provides all-hazard situation awareness information for emergency managers using tweets obtained from the public Twitter API. It collects and processes tweets in near-real-time, enabling effective alerting for unexpected incidents and monitoring of emergency events as they progress with results accessible via an interactive website.

ESA was developed in close collaboration with partners from emergency management agencies in Australia to ensure fitness-for-purpose for the tasks they perform. ESA processes large volumes of tweets and identifies trends and unusual topics using language models (Cameron et al., 2012). A burst detector generates alerts for unexpected high frequency words that are filtered using text mining techniques and machine learning algorithms to identify tweets of interest to users (Yin et al., 2012).

The ESA tool was initially developed as a research prototype in late 2009 and by the end of 2011 we had deployed an online, web accessible operational system that was available 24/7 and is still in operation today over a decade later, see https://esa.csiro.au.

In order to maintain this tool, over the past 10 plus years we have had to deal with normal business as usual activities expected from supporting an operational software system (for example managing scheduled downtimes and unscheduled outages, responding to hardware faults, migration of servers to new IT infrastructure, maintaining regular software updates and third party software patches and upgrades), managing user engagement (responding to user enquiries, providing help desk functions, engaging with high profile clients during emergency events) as well as ensuring its longevity within a research organization amongst competing project activities (championing the continued investment of the tool to senior management, providing support outside normal business hours, and 'keeping the lights on' during times of funding shortfalls).

We have also had to respond to changes from Twitter itself. Over this time there have been changes to the Twitter API used to collect tweets, changes in the structure of the JSON data returned by the API, the removal of content from tweets and the inclusion of new elements in the tweet JSON. All these changes have required updates to the ESA software and careful management to ensure continuous 24/7 operation. We have also updated the ESA offering by including new features and upgrading existing functionality over time, such as adopting new machine learning technologies that become best practice, upgrading the text processing third party libraries used and making enhancements to the user interface to maintain an active user engagement.

One of the core functions of the ESA tool is the ability to easily define new tweet collection tasks by defining keywords to search for, users to follow or geographic regions to target. These tweets are then automatically processed in near real-time to find information relevant to specific use cases. We have used this feature in other social media monitoring related projects and as a result the volume of tweets collected over the past decade has expanded beyond our original emergency management scenarios.

The rest of the paper is organized as follows. First background information is presented about the ESA tool, including a summary of how tweets are collected, and an overview of the software elements used. We then review some of the technical challenges encountered in maintaining the tweet collection over this time. Insights into the tweets collected over this period are then presented, including a discussion of some of the trends seen. Finally, we conclude with a summary of our findings.

SYSTEM OVERVIEW

The Early Years

ESA was developed as part of a research platform to investigate how social media content could be used to help the work practices of emergency management agencies in Australia and New Zealand. Our first active case study was in March 2010 when we collected tweets using the search API focused on the impact area as Tropical Cyclone Ului (Wikipedia contributors, 2022) made landfall in Queensland. Similarly, after the two large Christchurch earthquakes on 4 September 2010 and 22 February 2011, tweets from this area were collected and used as test data to refine our tools. Twitter was used since the Application Programming Interface (API) provided a useful and versatile method of obtaining public crowdsourced content and its uptake in Australia at that time had been steadily growing (Digital Marketing Lab, 2010).

These investigations indicated that there was potentially useful information being reported by the public on Twitter. The challenge was to find the information, ensure it was relevant and provide a timely and concise summary to interested people. This preliminary work was encouraging and helped establish a working relationship with the national Crisis Coordination Centre (CCC) in Australia where general-purpose emergency management use cases were defined (Cameron et al., 2012; Power et al., 2014; Power et al., 2015a).

These first tweets were collected using specific keywords expected to be relevant to the incident being monitored. Doing this for the general needs of 'all-hazard' social media monitoring for various events of interest, from anticipated natural disasters (floods, bushfires, cyclones) to unexpected emergency events (flash flooding, public unrest, terrorist incidents), would require an ongoing curation of keywords in order to ensure important information would not be missed.

Therefore, in late September 2011, we established location-based searches using the Twitter search API (Twitter, 2022a) for the regions shown in Figure 1 by providing a search location with geographical coordinates and a search radius. These queries are repeated every twenty seconds to obtain the recent tweets. As tweets are obtained from Twitter, they are processed using text mining and machine learning techniques (Power et al., 2013; Robinson et al., 2013a; Robinson et al., 2013b; Yin et al., 2012). From October 2010 through to the end of June 2022, we have collected over 14 billion unique tweets, approximately 6.6 billion original tweets and 7.7 billion retweets. A profile of the tweets collected is described below.

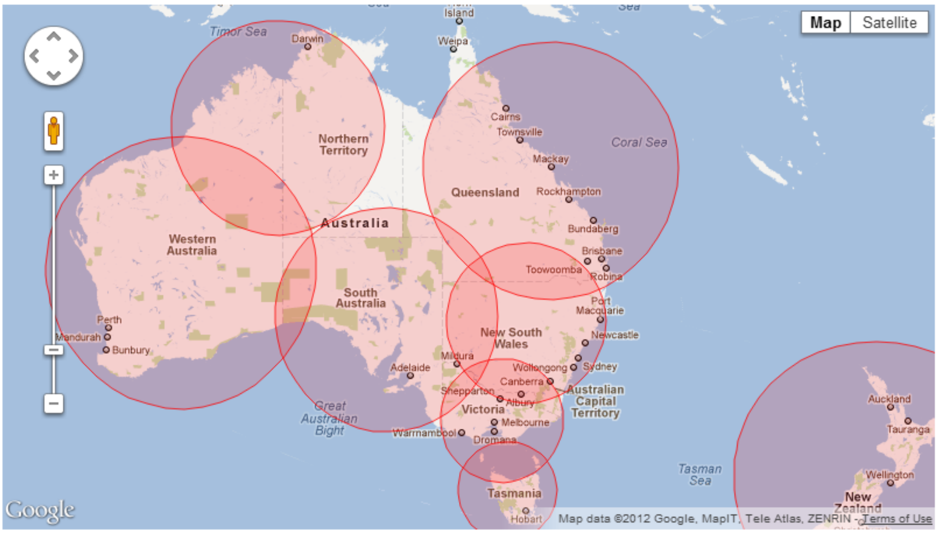

Figure 1: ESA Tweet collection regions.

System Architecture

A schematic of the ESA system architecture is shown in Figure 2. Tweets are gathered from Twitter using various API endpoints and sent to a Java Messaging Service (JMS) instance which makes them available for various backend consumers. The original tweet JSON is filtered with a subset of the contents cached in a database. The tweets are also processed by a Burst Detector which generates alerts that indicate words that have a statistically significant high usage with respect to the Language Model constructed from previous tweets collected (Yin et al., 2012). These alerts are also published to the JMS instance where subsequent consumers store them in a database and process them to target specific keywords of interest which may generate user notifications. Examples are earthquake and bushfire detectors that are triggered when specific alert keywords (for example ‘earthquake’ or ‘fire’) are found (Power et al., 2013; Power et al., 2015b; Robinson et al. 2013a; Robinson et al., 2013b).

In Figure 2, the elements represented as clouds are tools we adopt, ovals are Java software we have written, cylinders are databases we maintain, solid rectangles are processing pipelines (burst detection and event detection) and rounded rectangles are the user interfaces available at the web site https://esa.csiro.au.

There are multiple burst detectors (one for each state/territory in Australia, New Zealand, and Australia and New Zealand) and there are multiple event detectors implemented using machine learning classifiers, currently to detect fires and earthquakes. We have in the past maintained multiple repositories as redundant backups, but the current deployment only has one database instance. This repository acts as a cache of recently collected tweets so the original tweet content can be readily displayed on the various user interfaces as required without the extra overhead of subsequent Twitter API calls.

By early 2012, a comprehensive toolset had been developed that included:

- a statistical language model that characterizes the expected discourse on Twitter.
- a burst detector based on the language model to identify deviations from the expected discourse.
- an alerting system that targets specific bursting keywords which generates user notifications.
- clustering techniques for condensing and summarizing information content.
- interfaces supporting forensic analysis tasks.

A key element of this processing is determining the location of the user. This is the role of the Location Mapper component and is achieved in various ways. When ESA started collecting tweets, the meta data included a time zone and UTC offset which was useful to narrow down the location. A small percentage of tweets are geocoded, so this is used when present. We also investigated extracting location cues from the tweet text but predominantly, the user’s location field in the tweet JSON was used.

Originally, this self-described location text content was sent to Yahoo Geoplanet/PlaceFinder, a service that determined a location from a text string. These locations could range in geographic extent, from ‘Australia’, ‘New South Wales’, ‘Sydney’ down to a specific place such as ‘Sydney Opera House’. We stored the results of the lookup text and location result in a database. This allowed us to progressively build our own cached copy of the Yahoo service results for previously seen locations. This Yahoo service was migrated to a different offering around 2014 based on Yahoo Query Language (YQL) APIs which were then retired around 2019. Since then, we have been using our cached copy of text/location results.

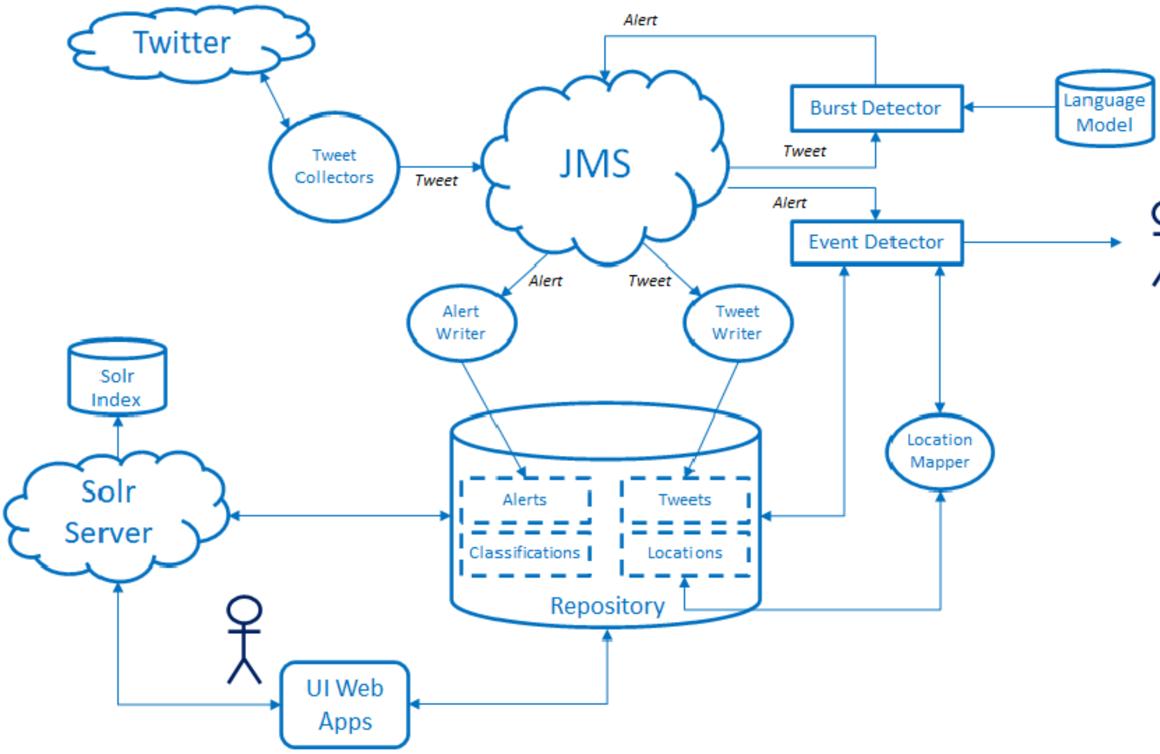

Figure 2: ESA System Schematic

Tweet Collection

Figure 3 shows the number of tweets collected per day for the period 1 October 2011 through to 30 June 2022. In total, 14,381,908,726 unique tweets have been collected during this time with 6,616,304,127 of these being original tweets and 7,765,604,599 are retweets. This period corresponds to 3,926 days and there was only one day where we did not collect any tweets: 16 October 2016, a Sunday.

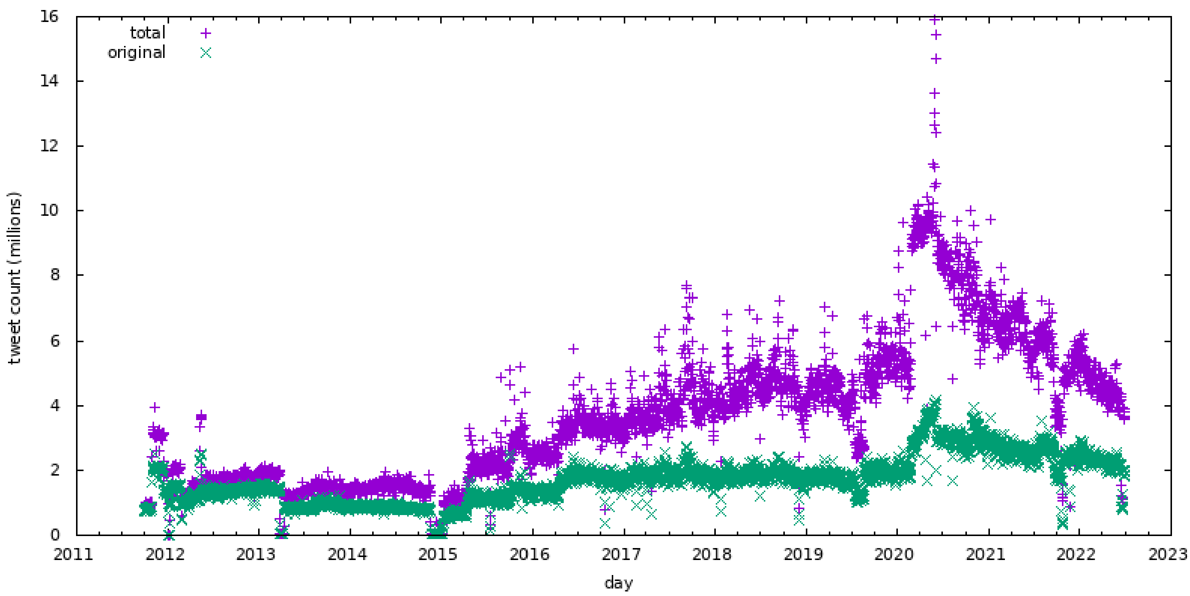

Figure 3: Daily Tweets Collected.

There were a further 56 days where we collected less than 10,000 tweets per day. These days correspond to three periods where we had issues with the location-based search APIs, specifically:

A. 3 January 2012 – 8 January 2012

B. 28 March 2013 – 9 April 2013

C. 22 November 2014 – 4 January 2015.

The location-based Twitter search API, where geographic coordinates and a search radius are provided to obtained tweets from that region, had issues during these periods. In late November 2014 it broke completely. This was discussed on developer forums and Twitter were aware of the problem, but it was not resolved until April 2016, almost a year and a half later.

To maintain the flow of tweets from Australia and New Zealand for ESA, we had to find different ways of collecting content. This was done using other Twitter API endpoints:

- Follow specific users by their id.
  We compiled a list of Twitter accounts managed by emergency services agencies in Australia, news media outlets, politicians, and government departments. This 'authoritative' content is focused on the discourse topics of interest for ESA. We also reviewed our previously collected tweets to curate a list of relatively prolific tweeters and followed these users as well.

- Track keywords.
  Collect tweets using the filter stream that include given keywords. A list of the keywords used for specific emergency events by ESA can be found at: https://esa.csiro.au/aus/help-public.html.

- Geotagged tweets.
  Collect geotagged tweets for specific bounding boxes.

The impact of this change in tweet collection strategy can be seen in Figure 3. There is a dip in tweet volume at the end of 2014, which lifts in early 2015 after we established the new collection methods. When the search API resumed operation in April 2016, the tweet volume lifts again. The volume of original tweets then remains steady through to mid-2020 when there's a noticeable increase, which corresponds to the arrival of COVID-19. Our tweet collection use cases had expanded from emergency management to include health (Sparks et al., 2017) and this resulted in an increase of tweets being collected. There is also a downward trend from the peak of mid-2020 onwards as the COVID-19 discussion abated.

Table 1 provides an overview of the main tweet collection strategies we have used in the past decade, noting the volume of original tweets and retweets collected. This table reflects both the need to use different Twitter API endpoints and the changing use cases of focus for ESA, such as politics, sport, news media, agriculture, science and health. In a couple of instances, we also established tweet collectors for high profile events, such as the Lindt café siege in Sydney and tropical cyclone Maria in Queensland.

As well as focusing on keywords and topics of interest, we also filter out tweets and retweets that are not of interest. Examples are international pop stars such as Justin Bieber, Cody Simpson, Harry Styles, BTS, 5SOS, 1D. We also aim to remove spam and adult content however this has been difficult to achieve and requires constant attention to refine the exclusion filters.

Since we are using multiple collection methods, we can obtain the same tweet multiple times. When including these duplicates, the total number of tweets collected by ESA has been 15,575,816,806 which means we retrieve approximately 8% of duplicate tweets from Twitter. However, in terms of downstream tweet processing we only process unique tweets, for example for alert detection and event notification.

TECHNICAL CHALLENGES

The following sections provide an overview of some of the technical challenges we've overcome in maintaining the tweet processing pipeline and operational system for ESA.

Blacklisting

One of our early explorations to collect tweets was done by modifying a publicly available Twitter client on GitHub, called TwitterClient (Gist, 2010). We changed the code to use the sample stream (the original code used the filter stream) and we ran it for a month to collect tweets and it one day suddenly stopped working. Investigations revealed that the program would no longer work from a specific machine: its IP address had been blacklisted. When we contacted Twitter support, they indicated there was an issue with multiple simultaneous connections being open in violation of the Twitter Rules (Twitter, 2022b). A review of the code changes we made to the original software confirmed that we were doing the wrong thing, which was remedied.

This was an important lesson learnt early: follow the rules or you could be banned. Although the Twitter API is a publicly available resource, its use can, and will be, revoked by Twitter if you do the wrong thing.

Table 1: Tweet collection summary

Num collectors	Started	Finished	Description	Tweets (millions)	Original (millions)
8	Sep 2011	-	Australia/NZ region collectors	3,749	2,546
1	Oct 2011	-	Emergency Management users	187	55
1	Aug 2013		Australia Mexico/Cuba	440	262
1	Dec 2014	Jan 2015	Sydney Lindt Café siege	0.9	0.4
5	Jan 2015	-	Stream collection keywords: fire, flood, earthquake	3,622	1,349
1	Feb 2015		Health keywords	2,207	690
1	Feb 2015	Mar 2015	Tropical Cyclone Marcia, Queensland	2	1
8	Apr 2015	Aug 2019	Following high volume users by state	792	364
3	Sep 2015	-	Stream keywords topics: politics, sport, transport	2,745	1,088
1	Oct 2015	-	Australia/NZ sample stream using time zone	74	32
1	Dec 2016		Australia Day	633	230
1	Feb 2017		Australian media organizations	129	59
1	Sep 2017	-	Australian agriculture	101	36
1	Apr 2018	-	Science topics	24	9
1	Apr 2020	-	Geocoded tweets from Australia and NZ	101	101

Twitter API Changes

Unsurprisingly, the Twitter API has undergone several changes over the past decade. New features have been introduced, new meta data has been included in the tweet JSON and some elements have been removed. Importantly for us in terms of trying to determine the location of the tweet user, the UTC offset and time zone fields were disabled in 2018.

As part of tweet processing, we check for new fields in the tweet JSON and note new ones as they appear. This allows the data to inform us of changes as they occur and highlights new data elements that could be useful. The last time a new JSON field was introduced was recorded on 25 May 2018. The two previous times new fields were introduced, as recorded by our system, was in August 2017 and October 2016. It seems the tweet content has been stable for the last four years, although we have been using API version 1.1 and version 2 is out now and may contain more or different content.

Detecting Earthquakes

One of the early successes of the ESA system was earthquake detection. We developed an email notification system that was activated when tweets were identified from people experiencing an earthquake (Robinson et al., 2013a). This system was based on the combination of tweet heuristics and a machine learning text classifier which had an F1 score of 0.881 and accuracy of 96.85% (Robinson et al., 2013b). We also developed a similar classifier for tweets discussing bushfires, however this was less successful partly due to the ambiguity of language: when people discuss 'fires' they may not be referring to natural disasters or an emergency event. However, when people are discussing 'earthquake' they are more likely to be referring to an actual earthquake. Or so we thought.

Initially, the main task of the earthquake classifier was to distinguish tweets from people experiencing an earthquake as opposed to a general discourse about earthquakes, for example referencing past events. We did this by manually curating tweets in classes of positive and negative examples and training a machine learning text classifier to distinguish the two classes (Robinson et al., 2013a; Robinson et al., 2013b). The heuristics used were to check that the tweets were sent by people geographically close together (when it is possible to determine the location from the tweet) and that the tweets were sent around the same time. The classifier used several features including the text length, the use of punctuation and the number of retweets. Tweets about an earthquake usually contain few words, include exclamations and are not retweets.

The ESA earthquake classifier was operating successfully for over 12 months until we had two notable incorrect notifications. There was a racehorse called 'Earthquake' which was tweeted about in February and April 2014. These tweets generated two false positive earthquake notifications from our software. We considered the first event a one off but after the second, we needed to revise our classifier by including these false positive tweets as negative examples of earthquake related tweets. The classifier hasn't generated a horse related earthquake detection after this. Table 2 shows a selection of tweets that contributed to these incorrect notifications.

Table 2: Example False positive earthquake tweets in 2014

Tweet text	Date
Favourite Earthquake draws 15. #bluediamond	18 Feb
Earthquake barrier...15 ouch	18 Feb
Barrier 15 for Earthquake! #ouch	18 Feb
Earthquake draws barrier 13. Barrier 13 has had no winners #GoldenSlipper	1 Apr
Earthquake - barrier 13 - wow - makes it tough	1 Apr
Racing: #Slipper Draw:Fav Earthquake draws 13 & eases Mossfun 11; Ghibellines 2; Unencumbered 14; Risen From Doubt 6; Oakleigh Girl 10;Law 7	1 Apr

These tweets are similar in structure to tweets posted by people experiencing an earthquake: they are from people geographically close together around the same time, in this case proximity to a horse racing event.

Tweet Identifiers

Tweet identifiers are numbers consisting of 18 digits in length. When working with some tools, for example Excel, these tweet ids are truncated if they are represented as numbers. For example, a common task in building a text classifier is to curate tweets for human review to allocate them to positive and negative classes as part of the classifier training process. We would export a CSV file that would include the tweet id, text and possibly other information and do the labelling process using Excel. Unfortunately, the tweet ids would be truncated and so the link back to the tweet source would be lost.

As an example, the tweet id '435566610384822272' is truncated to '435566610384822000' and '435568602423373824' to '435568602423373000'and so on. The solution is simply to treat the ids as strings by enclosing the ids in quotes and prefixing with text, for example: 'id: 435566610384822272'. Putting quotes around the number is not enough to resolve this problem. This was probably an issue with other applications and programming languages as well since Twitter introduced the field "id_str" in the tweet JSON. For example, such large integers can cause problems with JavaScript[1].

Hashtags

As noted above, one of the reasons we adopted a tweet collection strategy of 'collect everything' was that it is difficult to know beforehand the language people will use when describing an event of interest for emergency management use cases. This is also true of hashtags before they become established. Soon after the Christchurch earthquake of October 2010, various hashtags were used by those tweeting about it, such as: #earthquake, #quakenz, #nzquake, #nz, #christchurch, #chch. One hashtag started to dominate: #eqnz and this became the hashtag of choice from then on for all earthquakes in New Zealand (Potts et al., 2011).

How the community converge on a given hashtag for a specific event or for an event category is difficult to

[1] https://developer.twitter.com/en/docs/twitter-ids

anticipate. For example, when Tropical Cyclone Marcia struck Queensland in 2015, it was discussed extensively on Twitter. For the approximate 4-week period over February and March 2015 several hashtags were used to describe the impact of the cyclone across the state. The most popular was #TCMarcia. This is a common format used by the community in Australia: prefix the cyclone name by 'TC' for tropical cyclone. However, #CycloneMarcia was also a popular hashtag as were the major town names impacted by the event, such as #Rockhampton, #Mackay, #Gympie, #Gladstone, #Bundaberg. The general hashtag #weather was also used as well as a less serious one: #thisisqueensland.

Location Ambiguity

The initial location-based tweet collectors were focused on the Australian states and New Zealand as shown in Figure 1. When reviewing the content of the location field of the tweets being collected, a notable absence were locations with the text 'Australia'. This was a common location setting for Twitter users from Australia, but we weren't getting these tweets from the location-based tweet collectors. After investigating this, we discovered that searching for tweets in Mexico collected tweets with a location value of 'Australia'. It turns out there is a suburb in Mexico in the region of Saltillo called Australia!

To obtain these tweets, we established a location-based collector with coordinates and radius for this location in Mexico and included a language filter for English tweets. This is shown in Table 1 with the description 'Australia Mexico/Cuba' since Twitter again changed where it thinks Australia is from somewhere in Mexico to Cuba[2]. This location ambiguity is a consequence of the opaque geocoding method Twitter uses to determine the location of tweets. This process is occasionally updated and needs to be reviewed periodically to ensure the tweets being collected correspond to the expected outcome.

TWITTER INSIGHTS

As noted above we have collected and processed over 14 billion unique tweets for the period 1 October 2011 to 30 June 2022 with over 6 billion of these being original tweets and the remainder retweets. Here we present further analysis of the tweets collected to provide an insight to the trends over the period.

Twitter Users

The tweet JSON includes a user id and a screen name of the Twitter user who made the tweet. The screen name can change over time, but the user id remains the same. This allows us to note the number of users who have made tweets collected by the ESA system. This is shown in Figure 4 below where we distinguish between users who have made original tweets and all tweets including retweets.

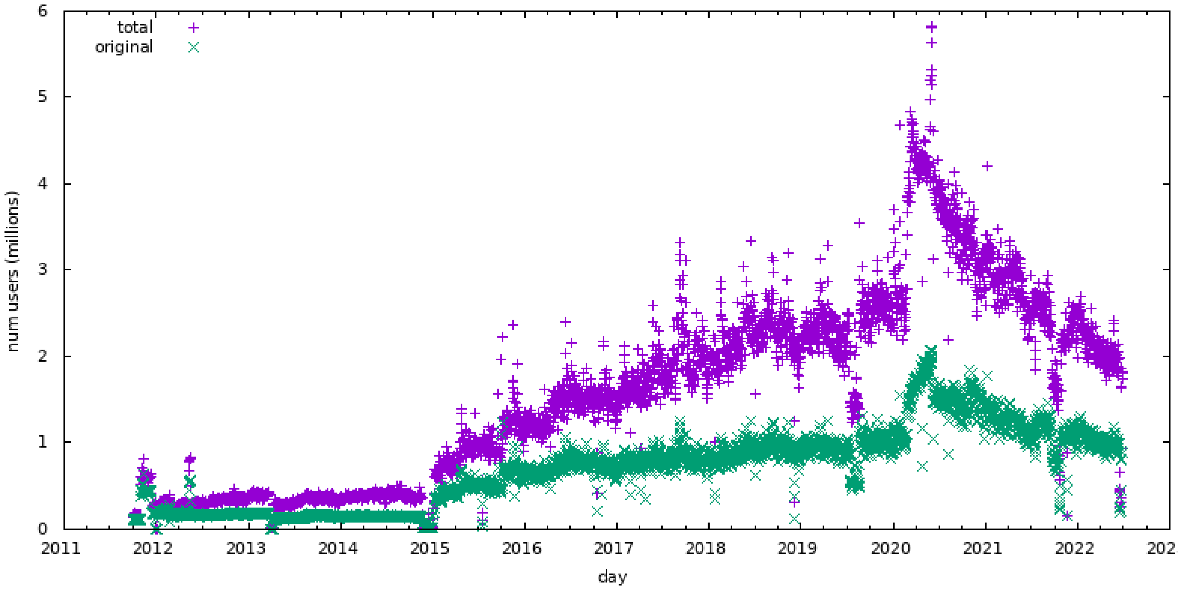

Figure 4: Number of users per day.

[2] This can be seen on Google Maps at: https://www.google.com/maps/place/22%C2%B030'02.9%22N+81%C2%B008'10.0%22W

Figure 4 shows that there are more users who simply retweet rather than provide original content. The impact of the different tweet collection strategies can also be seen in this plot. After the search API broke in late 2014, we switched to a different tweet collection strategy focused on keywords and specific users early in 2015. This resulted in more tweets being collected and interestingly, more users who simply retweet over time.

Tweets Per User

Since the number of users recorded by ESA over time depends somewhat on how the tweets were collected, an alternative insight is to look at the ratio of the number of tweets per user collected each day. This is shown in Figure 5, again distinguishing between original tweets and all tweets, including retweets. These ratios need to account for the category of tweet (retweet or not) and so the ratios are: total tweets/total users and original tweets/total 'original users' (the number of users who posted an original tweet on that date).

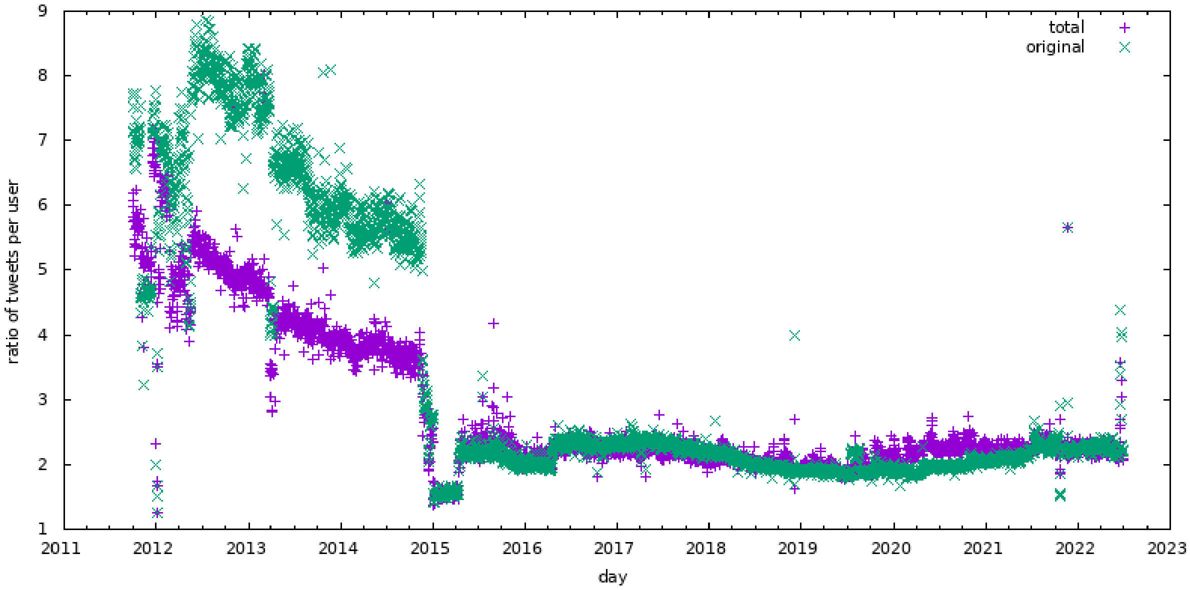

Figure 5: Ratio of tweets per user.

The impact of the different collection strategies is significant in this plot. After April 2015, the tweets per user have been steady and is similar for original tweets and all tweets. Prior to this however, there was a significant difference. The people posting original content on Twitter were doing so more often that those retweeting however this was in steady decline leading up 2015.

Tweet Length

In November 2017, Twitter doubled the character limit from 140 characters to 280 characters. In the tweet JSON object obtained using the Twitter API, the tweet text can be found in the field labelled 'text'. We originally assumed the longer tweet text would simply appear in the same JSON field. This was not the case. A new field called 'full text' was introduced containing the longer tweet text. We didn't discover this initially and it was a few weeks until we made the necessary changes to our tweet collection software to extract the full text.

Figure 6 shows the average tweet length per day for original tweets. The impact of the doubling of the allowable number of characters from 140 to 280 in late 2017 is clearly seen. This figure also indicates why this change was introduced – the average tweet length was steadily increasing and after the extension it seems to have settled to around an average of 120 characters.

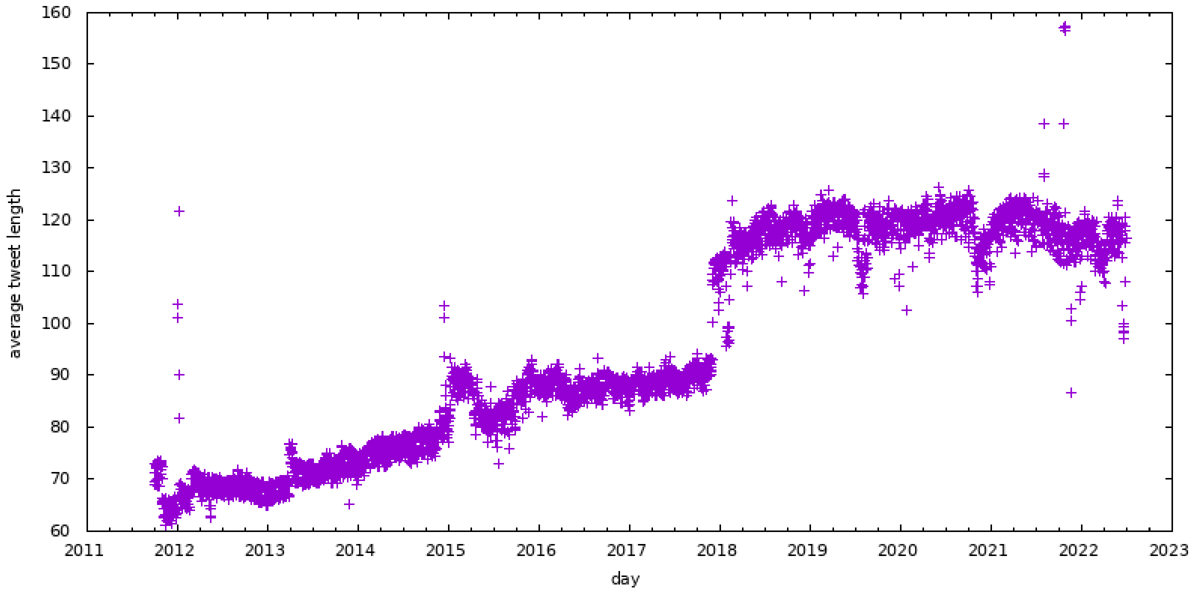

Figure 6: Average (original) tweet character length per day.

CONCLUSION

The ESA tool has been collecting and processing tweets about specific topics, mostly focused on emergency management use cases, for over a decade. Keeping the system running during this time has been a challenge not just from a software and operational systems perspective, but also from a corporate and governance one. A large part of the continued success has been the dedication of those involved. Without them it would not have lasted so long.

This experience has allowed us to reflect on some of the insights and learnings we have accumulated along the way. In summary:

- Know what you're doing, or you may be blacklisted.
- The Twitter developers have been responsive to questions, but fixes may take some time.
- Be adaptable in your tweet collection strategies.
- Review the content you collect to ensure it's what you're expecting.
- It's difficult to know beforehand how people will describe an emergency event.
- Be careful using numeric tweet ids when exporting tweets.
- When using the Twitter APIs, keep up to date with the changes to the Tweet JSON structure.
- Don't rely on third party services to be around forever.

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Analysing Donors' Behaviour in Non-profit Organisations for Disaster Resilience

The 2019–2020 Australian Bushfires Case Study

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ABSTRACT

With the advancement and proliferation of technology, non-profit organisations have embraced social media platforms to improve their operational capabilities through brand advocacy, among many other strategies. The effect of such social media campaigns on these institutions, however, remains largely underexplored, especially during disaster periods. This work introduces and applies a quantitative investigative framework to understand how social media influence the behaviour of donors and their usage of these platforms throughout (natural) disasters. More specifically, we explore how on-line engagement – as captured by Facebook interactions and Google search trends – corresponds to the donors' behaviour during the catastrophic 2019–2020 Australian bushfire season. To discover this relationship, we analyse the record of donations made to the Australian Red Cross throughout this period. Our exploratory study reveals that social media campaigns are effective in encouraging on-line donations made via a dedicated website. We also compare this mode of giving to more regular, direct deposit gifting.

Keywords

Disaster response, social media, donors' behaviour, Australian bushfires.

INTRODUCTION

Nowadays, social media are widely adopted to improve disaster readiness and resilience. Specifically, the utilisation and usage patterns of such platforms have been studied for different aspects of emergency management; for example, organisational decision-making, disaster management, strategic planning for emergency response, as well as the overall influence of social media on relevant organisations and their activities. Among these avenues of inquiry, Non-Profit Organisations (NPOs) are often keen to learn how to acquire new donors and mobilise existing givers to increase the organisational capacity, which is urgently needed during disaster periods. For such

*Equal contribution.

NPOs, the donations collected from *individuals* are usually the lifeline necessary to "survive, sustain themselves, and develop" (Medina-Borja and Triantis 2014). While the number of fundraising agencies has soared in this fast-paced environment, the quantity of donors and donations reaching any single organisation have decreased as a consequence (Ford and Merchant 2010). This is especially true for individuals who – among corporations, foundations and governments – generate a sizeable portion of NPOs' budget through their monetary contributions.

Individual, goodwill donations are a precarious source of relief money managed by NPOs. It is therefore worth better understanding various factors influencing such non-institutional giving. Nah 2009 suggests that the Internet is the most appropriate tool for reaching out to the broader population of potential donors in the connected world. Specifically, this technology allows organisations to publish a website and, more recently, venture into commercial social networking sites such as Facebook and Twitter by creating a page on the former and curating a feed on the latter. NPOs should devise strategies to lead people to those social media accounts and encourage them to actively participate in these spaces. Using the example of Facebook, such interactions are mostly captured by *likes*, *shares* or *comments* attached to posts published thereon by a stakeholder. Engaging with individual donors to encourage active participation across the NPOs' social media portals has the potential to boost the overall outreach of these organisations – via voluntary brand advocacy (Wilk et al. 2018), among others – which can also lead to increased participation in off-line activities such as in-person donating, hosting fundraisers and volunteering (Levenshus 2010).

In this study, we aim to analyse the effects of various activities happening across social media on non-profit organisations during natural disasters. To this end, we investigate the donation data collected by the Australian Red Cross during the 2019–2020 bushfire season.[1] Throughout this calamity, the charity supported 49,718 people affected by the fires, awarded 5,914 people with bushfire grants (AU$187m), and extended the recovery programme to 21,563 people, which amounted to AU$207m throughout that period (Australian Red Cross 2022). Given the overall success of these actions, it is crucial to explore the effects of social media activities on the collected donations to better prepare for the future.

RELATED WORK

Social media can be used to various ends in case of disasters; for example, communication, fundraising and publicising relief efforts (Finau et al. 2018). To formalise these roles, Houston et al. 2015 offered a functional framework for social media use across various stages and aspects of disasters. Among others, the authors identified the important role of such platforms in enabling their users to *donate*, and charitable organisations to *receive donations*, both during and after the event of interest. Specifically for Facebook, Bhati and McDonnell 2020 showed that fundraising success – determined by the number of donors and the value of their donations – is linked to the non-profit's number of likes (network size), posts (activity) and shares (audience engagement). Additionally, Wilk et al. 2018 reported that customers – i.e., supporters of a charity who donate – have more impact on consumer (i.e., donor) decision-making than brand-sponsored marketing messages thanks to a process called *voluntary brand advocacy*. More specifically, people who mention a charity on social media and engage in brand advocacy (on Facebook) are more likely to donate (Wallace et al. 2017; Choi et al. 2021).

Similarly, Mathur 2019 showed that social media brand advocacy and reciprocity are crucial for improving brand equity, formalising this process in a conceptual framework. Okada et al. 2017, on the other hand, scrutinised the effectiveness of social media in encouraging people to donate in view of disasters. In particular, their findings demonstrated that employing social media both *before* and *after* a disaster increases the amount of collected donations. Additionally, the authors found that the use of social media allows to raise more money in comparison to in-house platforms such as websites and blogs. Okada et al. 2017 have also speculated that the *first three months* of a disaster may be the most effective period to collect donations.

BACKGROUND

Before we delve into our results, we define relevant terms and overview key concepts.

Facebook Free-to-use, on-line social networking platform started in 2004 for college students (Lee 2012).

Google Analytics A toolkit that allows website publishers to determine the number of visitors to their sites. Additionally, it can measure the performance of marketing channels, sources of traffic and success of (advertising) campaigns over time.

[1] The data cannot be made available to the public due to their sensitivity.

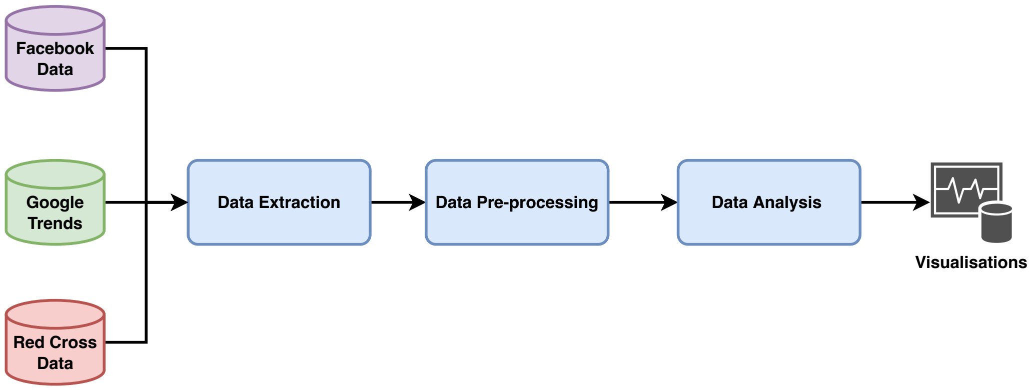


Figure 1. High-level overview of the analysis applied to the 2019–2020 Australian bushfire disaster data.

Non-profit organisations Groups established for purposes other than statutory or profit-maximising, and in which no part of the organisation's income is distributed among its members, directors or officers (Maier et al. 2016). NPOs are also known as *non-profit corporations*, *not-for-profit agencies* or *non-profit institutions*.

Charity organisations A subgroup of NPOs that strives to improve various aspects of life across different communities. These organisations follow strict guidelines for qualification and must be fully registered to be classified as a charity. Achieving this status grants them an authority to issue official receipts for income tax deductions, which allows them to receive tax credits (DiMaggio and Anheier 1990).

Social media Any on-line resource that is designed to facilitate engagement between individuals (Aichner et al. 2021).

The role of social media in NPOs Non-profit organisations can benefit from social media in different ways, such as attracting new volunteers or donors, advertising events or actions to the broader community, and building new relationships. Levine and Zahradnik 2012 have discovered a positive link between on-line media presence and higher market orientation, which may boost financial viability. This dependency could, for example, be observed when Red Cross raised $32 million in donations for Haiti using social media alone (Daniels 2010). Moreover, Feng et al. 2017 reported that social media platforms help to enhance trust and satisfaction in NPOs. This was validated in a study carried out by Goldkind 2015, who found that NPOs using social media were able to increase the interest in their organisations up to 400% over a year, ultimately helping them to boost their brand advocacy.

Natural disasters Natural disasters are sudden catastrophic phenomena that can occur all over the world. The severity level of such an event depends on the strength of the disaster, probability of its recurrence, location, population density, general economic development of the affected area, preparedness of the community as well as its response to the disaster. The destruction caused by such events is often far-reaching, costly to mitigate, and it creates a huge demand for the essential goods and services, all of which require a rapid response. In particular, to effectively overcome such a situation it is usually necessary to seek aid from both governments and the non-profit sector. McKenzie 2011 further corroborated this observation by uncovering that donations from the members of the public tend to be greater than government contributions following the occurrence of a natural disaster. Moreover, the author concluded that the media coverage associated with these events usually generates the most significant increase in donations flowing into NPOs. It is therefore worthwhile exploring how on-line platforms like social media portals and search engines are linked to the behaviour of donors.

METHODOLOGY AND DATA SETS

In this section, first, we discuss the workflow employed to extract the data used for our study. Next, we explain the pre-processing steps applied to these data sets. We then, in the following section, aggregate the resulting data to investigate multiple scenarios throughout the disastrous 2019–2020 Australian bushfire season. An overview of this process is depicted in Figure 1.

In this study we consider three sources of data related to the 2019–2020 bushfire season in Australia; namely, Facebook activity data, Google Trends and donation data provided by the Australian Red Cross. Since our investigation aims to analyse the influence of social media and other on-line presence on NPOs during the

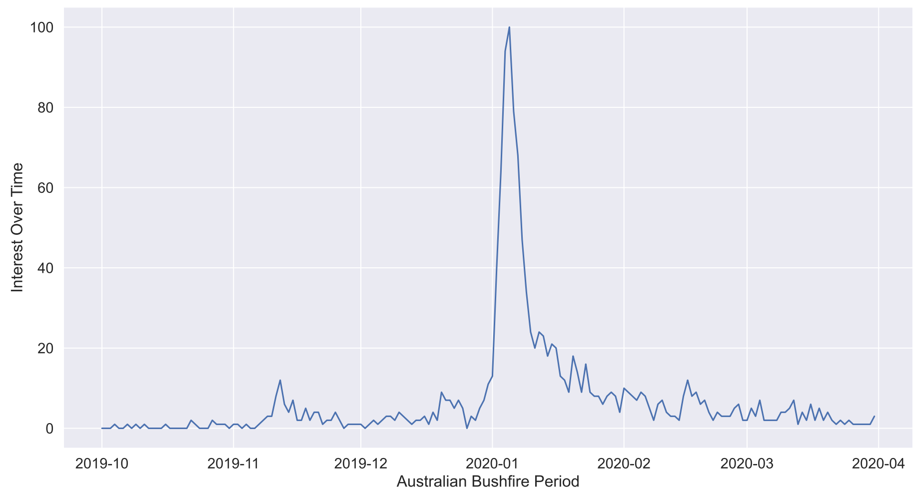


Figure 2. Google search trend for the `bushfire` keyword in Australia during the disaster period. The y-axis represents search interest relative to the highest point visible in the graph for Australia between the 1st of October 2019 and the 31st of March 2020 (shown on the x-axis). A value of 100 signifies the peak popularity of the term. A score of 50 denotes that the keyword is half as popular. A value of 0 indicates lack of (enough) data for this particular term.

aforementioned bushfire season, we consider a period of time when the donation collection coincided with relevant media campaigns. Before presenting the results of our analysis, we discuss the data extraction and pre-processing steps applied to each data source.

Facebook Data To gather insights from Facebook, we focus on various social media engagement metrics pertaining to the Australian Red Cross' Facebook page[2] in the period between October 2019 and March 2020. To extract these data, we use an open source tool called Facepager[3]. We then apply `QUERY = bushfire OR fire` to this time series to extract posts related to bushfires. Before analysing the data, we remove all the `null` and `NA` values. Next, we aggregate the data based on the daily count of reactions, shares and likes. After these steps, we are left with 63 records, which we use to analyse the behaviour of users on social media during the 2019–2020 Australian bushfire season.

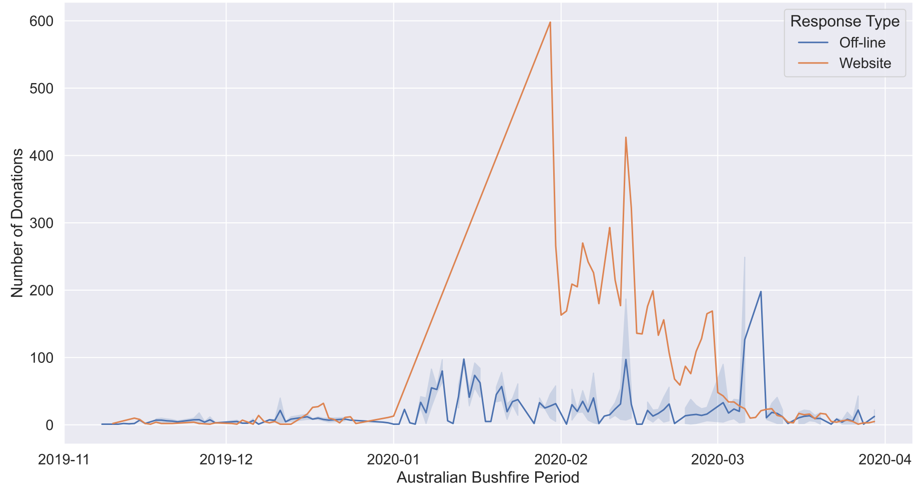
Google Trends We consider Google Trends to understand the on-line awareness of people about the Australian bushfires during the period between October 2019 and March 2020. To perform the analysis we select `Australia` as the country and consider `QUERY = bushfire` as the filtering criterion. Figure 2 shows the search trend for the `bushfire` keyword during the disaster period.

Red Cross Data We consider a time series capturing donation patterns across the bushfire fundraising campaigns organised by the Australian Red Cross between 2019 and 2020. The raw data set consists of instances relating to multiple donation drives. In this analysis, first, we extract the data between October 2019 and March 2020. Next, we use `QUERY = bushfire OR evacuate OR survivors OR fire` to narrow down the scope of the records to the ones pertaining to bushfires. Afterwards, we pre-process the data by removing the `NULL` and `NA` values. We then aggregate the donations into a 24-hour resolution to visualise the daily donation rate and the amount of money collected across the bushfire period. After these steps 703,931 donation records remain and are considered in our analysis. The breakdown of the donations based on the gifting method is shown in Table 1.

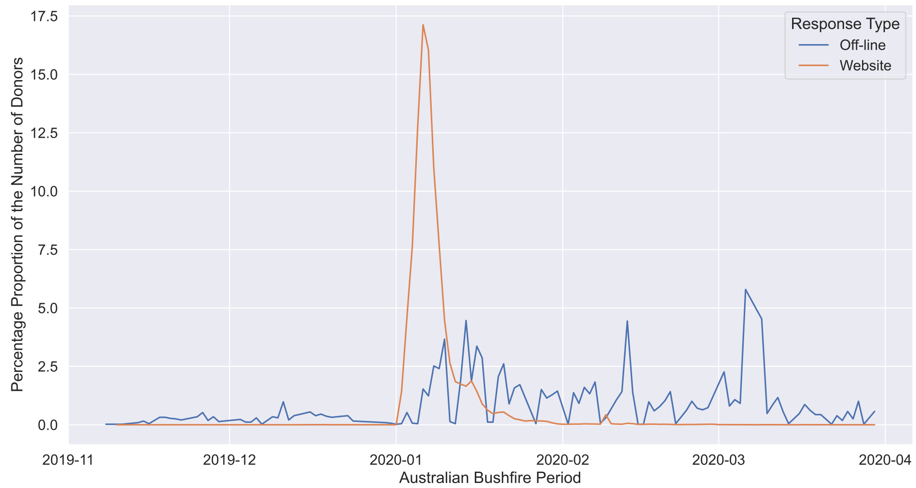
Donation Method	Number of Donations
direct deposit	3,086
mail	1,223
telephone	60
website	699,562

Table 1. Number of donations made via each available route during 2019–2020 Australian bushfires.

[2] https://www.facebook.com/AustralianRedCross
[3] https://github.com/strohne/Facepager



(a) Number of on-line and off-line donations during the selected bushfire period. The orange line indicates the count of donations made via the website, whereas the blue line denotes the number of donations made through off-line means (direct deposit, mail and telephone). We only consider days with fewer than 1,500 donations to better capture the variability of the off-line donations.



(b) Percentage proportion of on-line and off-line donors during the selected bushfire period. The orange line charts the proportion of donors using the website, whereas the blue line shows the proportion of donors using off-line means (direct deposit, mail and telephone).

Figure 3. Visualisation of the (a) distribution of donations and the (b) behaviour of donors.

DATA ANALYSIS AND INSIGHTS

Our study is focused primarily on investigating the number of on-line and off-line donations in relation to various events and activities recorded across Facebook and Google Trends throughout the bushfire period. Notably, the Australian Red Cross considers this particular fundraising drive as a *single giving-tied programme*, which means that *donation pledges* are not accounted for in the analysed data set. Therefore, for *off-line* contributions our study only considers donations made via *direct deposit*, *mail* or *telephone*. Additionally, we analyse *on-line* gifting facilitated through the Australian Red Cross' website.

The behaviour of donors and influx of donations are summarised in Figure 3. More specifically, Panel (a) visualises the *number of donations* made throughout the period of interest; note that the plot only displays the days with fewer than 1,500 donations to ensure the readability of the figure, thus better convey the variability of off-line contributions. Panel (b), on the other hand, illustrates the percentage proportion of the number of donors over the same time period. Figure 3 clearly shows that most of the donations were received via the Australian Red Cross' website, especially so between January and February. Additionally, the distribution of the influx of money over the period of interest – shown in Figure 4 as the percentage proportion of the total amount of donations collected in that time span to avoid revealing sensitive information – uncovers that the value of contributions is higher for *website* donations only throughout January (note that outliers were removed to improve the readability of this chart). Based on the same plot, the Australian Red Cross was able to attract more funding via *off-line* donation routes in the remaining period.

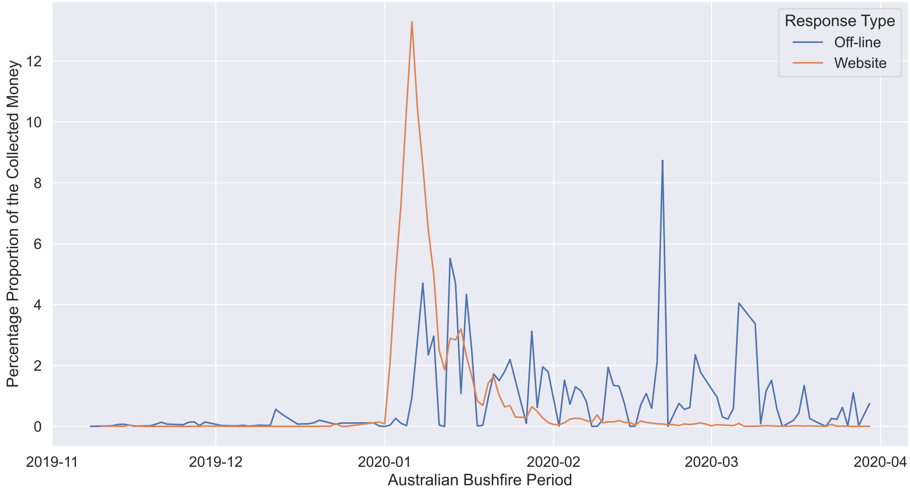
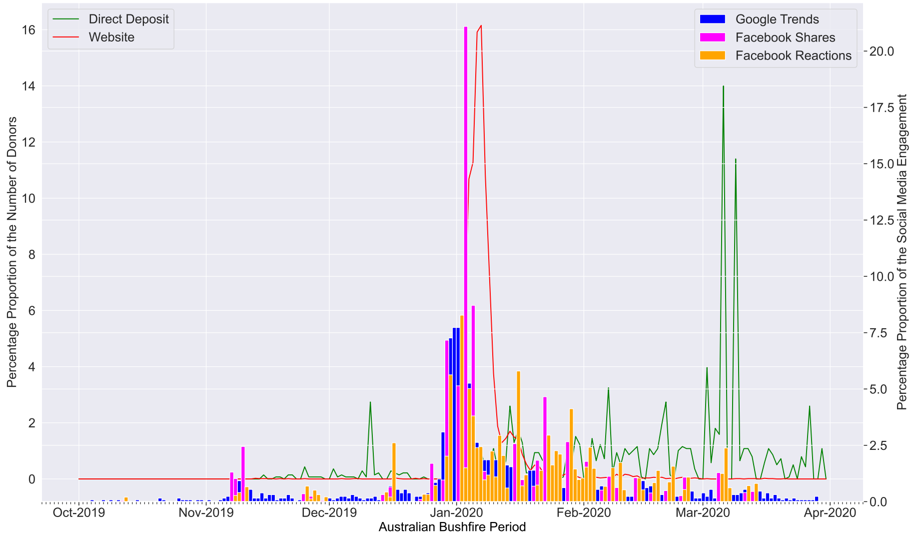
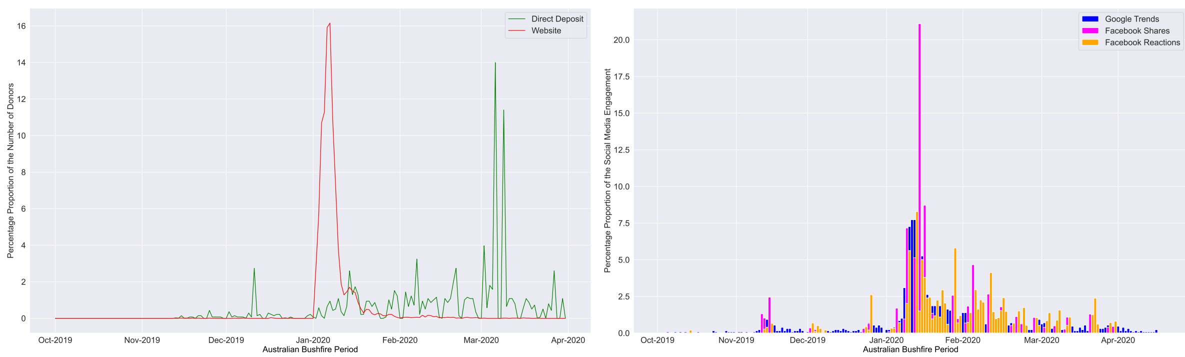


Figure 4. Percentage proportion of the on-line and off-line donation amount across the selected bushfire period. The orange line indicates the proportion of the total collected amount across the displayed time for website donations, whereas the blue line captures the same metric for off-line transactions (direct deposit, mail and telephone).

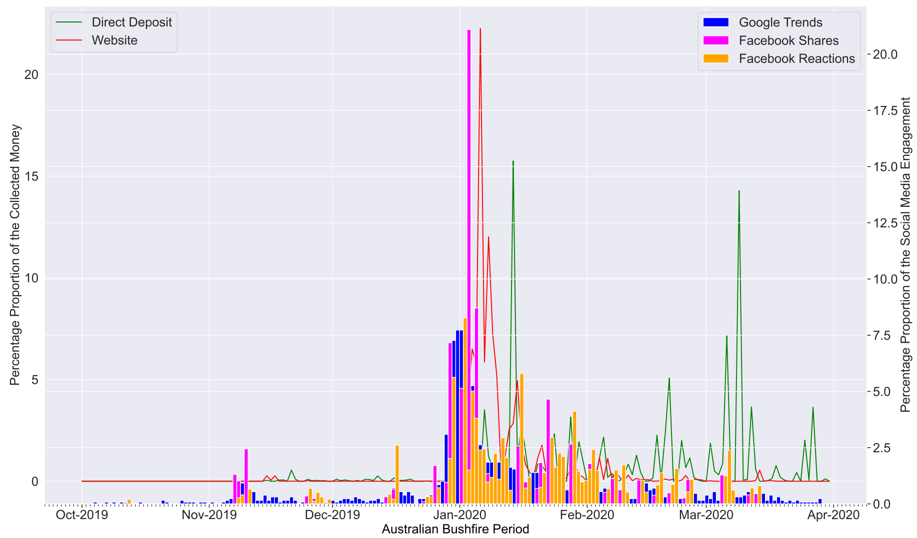


(a) Relation between Facebook interactions and Google searches, and the percentage proportion of the number of donors contributing either via direct deposit or through the Australian Red Cross' website during the selected bushfire period. The bar chart shows the percentage proportion of on-line engagement captured by Google Trends as well as Facebook shares and reactions (the legend and y-axis to the right). The green and red lines indicate the percentage proportion of the number of donors contributing respectively through direct deposit and website (the legend and y-axis to the left).

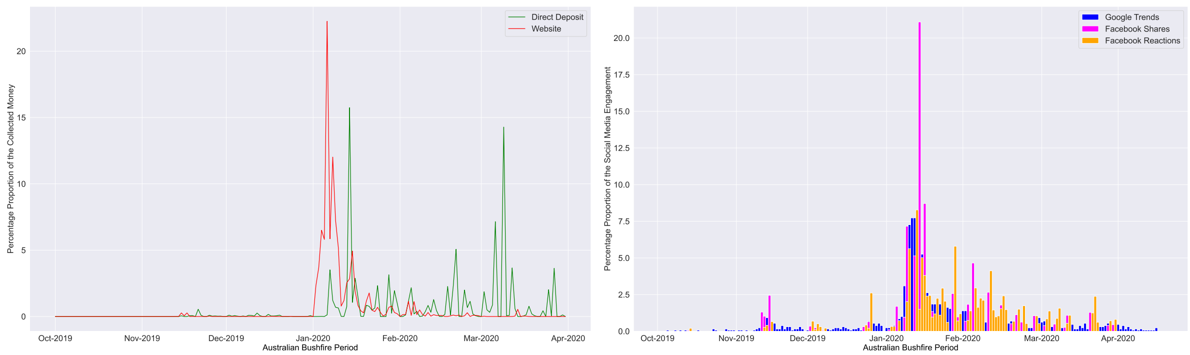


(b) Decomposition of Panel (a) into two individual plots for improved readability.

Figure 5. Relation between Facebook interactions and Google searches, and the number of donors contributing either via direct deposit or through the Australian Red Cross' website during the selected bushfire period.



(a) Relation between Facebook interactions and Google searches, and the percentage proportion of the amount of money collected either via direct deposit or through the Australian Red Cross' website during the selected bushfire period. The bar chart shows the percentage proportion of on-line engagement captured by Google Trends as well as Facebook shares and reactions (the legend and y-axis to the right). The green and red lines indicate the percentage proportion of the amount of money collected respectively through direct deposit and website (the legend and y-axis to the left).



(b) Decomposition of Panel (a) into two individual plots for improved readability.

Figure 6. Relation between Facebook interactions and Google searches, and the amount of money collected either via direct deposit or through the Australian Red Cross' website during the selected bushfire period.

Next, we shift our attention to the sudden spike in the number (Figure 3a) and value (Figure 4) of monetary contributions made through the website across January. According to the schedule of public awareness and fundraising campaigns as well as the calendar of disaster relief and recovery efforts shared with us by the Australian Red Cross, their significant portion was executed between the 31st of December 2019 and the 31st of January 2020. This corresponds to, and explains, the aforementioned rise in donation metrics. Notably, smaller social media campaigns pertaining to the bushfires were run up to the 17th of February 2020; we hypothesise that they may be the reason for a higher number of on-line (website) donations when compared to off-line giving until the end of February (Figure 3a).

Another interesting avenue of inquiry is the behaviour of individuals who donate multiple times towards the same cause, specifically bushfire relief efforts coordinated by the Australian Red Cross. In this context, we aim to study how on-line (communication and interaction) media may impact such donors, who contribute via recurring direct deposit. To this end, we examine the pattern of donations made after the first direct deposit payment, all of which originate from a single person. Moreover, we look into the possible influence of on-line media on multiple-time donors who made their first contribution through the website; we consider only the first website-based donation to explore this perspective. In the Red Cross data set, there are 8,637 individuals who donated multiple times, 8,301 of whom used the website, 333 relied on direct deposit and 3 utilised both options. Figures 5 and 6 illustrate the history of Facebook interactions and Google searches in relation to the number of donors and the amount of money collected throughout the period of interest either via the website or direct deposit.

A dominating phenomenon in these plots is the aforementioned soaring number of Facebook *shares* and *reaction* attached to entries published on a page curated on this social media platform by the Australian Red Cross, as well as Internet *searches* captured by Google Trends throughout January 2020. As explained earlier, these events – and the co-occurring steep increase in the number and value of on-line (website) donations – are likely a consequence of the coordinated social media campaigns executed between the 31st of December 2019 and the 31st of January 2020. This rise in the engagement of Internet users, especially in terms of Facebook shares, can be interpreted as growth in the NPO's brand advocacy. Interestingly, direct deposit donations peak around March 2020, lagging behind more responsive website donors as shown in Figure 5. This shift illustrates the *delayed effect* of Facebook marketing campaigns on generation of more sustainable, and possibly regular, off-line donations. The sudden increase in the value of off-line donations immediately following the series of social media campaigns visible in Figure 6, on the other hand, suggests that these communication efforts were likely to nudge some regular donors to additionally contribute with a one-off donation.

In summary, social media campaigns appear to be a viable and effective route to mobilise donors and encourage them to contribute for the first time or, in case of active benefactors, offer additional monetary support, as well as create new and convert on-off donors to regular givers, all of whom are particularly important to NPOs responding to (natural) disasters. Based on our findings, goal-driven Internet presence allows non-profit organisations to boost their brand advocacy and revenue within a short window of time, especially so via on-line donations collected through the NPOs' websites (in contrast to more traditional direct deposit gifting that may be slow to build up). More broadly, any social medium and communication platform – whether on-line or off-line – seems to benefit the (financial) capability of a non-profit organisation to respond to a calamity by informing the population how to help with or contribute to relief efforts.

CONCLUSIONS AND FUTURE WORK

In this study, we explored the relationship between social media engagement as well as other on-line interactions, and the behaviour of donors who contribute money to non-profit organisations during natural disasters. Our analysis confirmed that NPOs can benefit from employing social media for various fundraising activities and campaigns; additionally, the use of such platforms can stimulate public awareness while also increasing brand advocacy. Our investigation considered the disastrous 2019–2020 Australian bushfires, for which we analysed the behaviour of people donating via different routes (on-line, direct deposit, mail and telephone) to the Australian Red Cross. Specifically, we compared the patterns of their contributions to user activity on the Australian Red Cross' Facebook page and Google search trends throughout this calamity.

Our study found that the higher user engagement recorded across social media and other Internet platforms is linked to a greater number of donations made on-line via means such as NPOs' websites. More precisely, the social media campaigns executed by the Australian Red Cross during the monitored disaster period helped it to boost the users' on-line engagement, which in turn increased the number of donations made through its website. This case study is a prime example of social media's positive influence on NPOs' brand advocacy. For off-line donations, on the other hand, it is worth observing a lag between publishing social media campaigns and the donors' response, which is captured by the delayed influx of direct deposit contributions. While such donations arrive late, they are still essential for relief efforts during and after a disaster period, especially that they may become regular, hence steady, source of revenue for NPOs. Even though on-line donations (made via a website) are more immediate, our analysis revealed that they tend to be unreliable (in contrast to off-line contributions). We hypothesise that this pattern arises due to the website donations being mainly driven by social media campaigns and the ensuing engagement of on-line users, which possibly relies on the spontaneous enthusiasm spurred by the content published by NPOs. Importantly, social media campaigns help to increase both the number and value of donations received by non-profit organisations throughout disaster periods regardless of the transaction origin.

In this study we focused exclusively on the relation between on-line platforms, spanning social media as well as other interaction channels available on the Internet, and two effectiveness criteria crucial to any non-profit organisation responding to a (natural) disaster: the behaviour of its donors and viability of its brand advocacy. However, it is important to note that traditional media – such as television and radio broadcasts as well as newspapers – can influence the aforementioned benchmarks as well. In future work, therefore, we plan to expand our investigation to relevant off-line channels, thus offering a more accurate picture of how each communication or interaction medium affects the performance of NPOs during disaster periods. Additionally, we envisage validating the insights uncovered here for natural disasters other than bushfires, as well as increasing the granularity of our analysis by separating such periods into three stages – pre-disaster, disaster and post-disaster – thus allowing us to understand changes in the behaviour of donors and the engagement of social media users in finer detail. All of these findings should inform non-profit organisations how to better manage, utilise and optimise both their on-line and off-line presence, therefore increasing the number and amount of (possibly recurring) donations, and enhancing the NPOs' brand advocacy.

ACKNOWLEDGEMENTS

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Parler, Capitol Riots, Alt-Right and Radicalization in Social Media

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ABSTRACT

Social media platforms have risen in popularity since their inception. These platforms have since then come to be at the forefront of controversies, from being accused of election interference to, more recently, disseminating fake news and campaigns to sway political behavior. One such episode took place on January 6 when a group of individuals stormed the United States Capitol, and the social media platform Parler came under scrutiny. The platform was accused of being a place for right-wing extremists and Trump supporters who claimed the 2020 election was fraudulent. Initial reports suggested these individuals used Parler to organize and call others to action. This paper explores the feasibility of using social media to detect alt-right radicalization and examines its possible relation to the Capitol Insurrection and Parler. Moreover, we examine if those events could have been detected and averted through the investigation of the platform.

Keywords

Social Media, Parler, Sentiment Analysis, Alt-Right.

INTRODUCTION

Lewis defines social media as "a place for people to connect, interact, produce and share content" (Lewis 2009). Social media houses a wide variety of discussions and thoughts. They range from content aimed at comic relief to political dialogue (Miller et al. 2016). In this work, we delve into one such incident. The incident in discussion occurred on January 6th 2021, when a group of individuals assaulted the Capitol of the United States. To this day, their intentions are under scrutiny, and nothing has been corroborated. Nonetheless, it was safe to assume they were not seeking a peaceful resolution to their political concerns. This assault culminated after the 2020 presidential elections, one of the most talked-about in the history of the United States [1]. However, this was the result of a broader issue after November 3 and a clear victory of Joe Biden, the former president Donald. J. Trump decided never to concede.

What is more, President Trump did not believe the election results were valid, leading him and his allies on a campaign to smear and overturn the election results. To this end, they used slogans, antagonized people, and spread fake news and disinformation across social media [2]. All this culminated in what is now known as the Capitol Insurrection. As a result of this, a social media platform came to light. The platform, branded as a medium for right-wing extremists and sympathizers, allowed these individuals to incite the insurrection and organize. Hence *Parler* came under the scrutiny of the public eye. Parler was not too different from other social media platforms. Like Reddit and Facebook, users can post, comment, and share content they upload. In some regards, it resembles a micro-blogging platform. The platform was launched in 2018 and was said to have served as a refuge for individuals who did not find comfort in other social media platforms. Ultimately, it made the platform a safe harbor for Trump

[1] https://apnews.com/hub/capitol-siege
[2] https://www.npr.org/sections/insurrection-at-the-capitol/2021/01/07/954671745/on-far-right-websites-plans-to-storm-capitol-were-made-in-plain-sight

supporters and right-wing individuals. Moreover, it became a pit of conspiracy theories such as QAnon (Dinulescu 2020). QAnon is a global, wide-reaching, and remarkably elaborate conspiracy theory that has taken root within some parts of the pro-Trump movement. It is a combination of old and new theories that may or may not be well established, with marked undertones of antisemitism and xenophobia [3]. However, Apple and Google removed the app from their stores after the Capitol Insurrection. Twenty-four hours later, Amazon Web Services (AWS) dropped its hosting services for the platform, rendering its access impossible.

However, it is not the first time social media platforms have been under scrutiny due to accusations of inciting individuals to commit acts of violence according to their religious beliefs or political ideologies (Chatfield et al. 2015). Over the last few years, social media has been used to organize, plan, and incite people to protest or riot. However, the data generated from social media can be used as a window into past events and discover how things truly unfolded (Anwar 2020). This data allows us to analyze how people could have become radicalized and to what extent the platform aided and catalyzed the actions of the individuals.

Consequently, this paper examines the extent to which this event could have been detected and how radicalization and alt-right behaviors can be easily recognized and targeted on social media. To do so, we analyzed a portion of Parler's data extracted by the Twitter user known as *@donk_enby*. Through our research, we aimed to find signs of radicalization and evaluate whether the Capitol Insurrection could have been averted with social media investigation. In specific, the research questions we aim to address are:

- *How detectable is alt-right radicalization on a right-wing dominated social media platform like Parler?*
- *Can we approximately detect the events of the Capitol Insurrection before January 6 by leveraging social media (in our case Parler) data alone?*

LITERATURE REVIEW

Radicalization in Social Media

Radicalization is a topic that has been extensively studied (McCauley and Moskalenko 2008), specifically in social media. However, its definition remains muddy, and there is a lack of consensus on what it entails (Greenberg 2016). The general agreement states that radicalization brings *radical behavior* (Kruglanski, Gelfand, et al. 2014). By this definition, one can assume that acts of extreme violence or terrorism could classify as such. The issue lies in that social media has created an environment where this kind of behavior flourishes, and that is because the users have access to the platform at any time they want (Thompson 2011). It is why cases of radicalization through social media have increased, as its use has permeated every aspect of society. However, as Thompson et al. put it, social media is insufficient to group individuals towards riots, revolutions, or dissent. In addition, looking at McCauley and Moscalenko's (McCauley and Moskalenko 2011), which places individuals on a pyramid-shaped scale based on their participation in terrorism, we will see that consumption and support of radicalized content through social media do not lead individuals to action.

If this is the case, what moves individuals to be radicalized or commit acts of *radical behavior*? Among others, Kruglanski et al. (Kruglanski, Bélanger, et al. 2013; Kruglanski, Chen, et al. 2009) explain the presence of a motivating force that runs deeper and leads people to commit these acts. They named it the *Quest for Significance*. This Quest for Significance explains how some individuals act out the need to create respect for themselves and a sense of value (significance). Furthermore, there is also the argument that the different ways to explain radical behavior are just different forms of the *Quest for Significance*. Hence, using this approach and phenomenon to explain why people commit acts of radical behavior would help clarify why individuals without a past background in radical behaviors begin to engage in these seemingly out of nowhere.

Understanding an issue helps with the solution-seeking approach. In the case of radicalization, developing a knowledge bank about how it spreads and grows on social media might hold the key to stopping it in its roots. As we have established in the discussion of past literature, different methodologies can be used to counter online radicalization. For example, one approach is to counter radicalization efforts through the cooperation of governments and companies (Thompson 2011). Furthermore, reactive means and proactive measures can be taken to combat online radicalization (Winter et al. 2020). When talking about proactive methods, data-driven techniques that use linguistic methods to identify radicalization in its nascent stage have proved helpful in the past. In our scenario, this would mean giving the government a certain degree of access and leverage over social media platforms to disrupt the services these individuals use (Greenberg 2016). However, as we have seen in the last few years, it is a complex issue to tackle [4]. Nonetheless, during the year 2013 YouTube and Facebook attempted to crack on propaganda sites by using disrupting the access to these sites (Greenberg 2016).

[3]https://www.adl.org/qanon
[4]https://www.theguardian.com/technology/2022/apr/04/us-law-enforcement-agencies-access-your-data-apple-meta

Detecting Radicalization in Social Media

Understanding how radicalization occurs can give us insight into detecting it. The two are different processes and come with their challenges. Detecting radicalization in social media is a problem that past literature has tried to address (Araque and Iglesias 2022). Detecting radicalization is a complex issue. There are many proposed and proven strategies to detect signs of radicalization on social media platforms (Alvari et al. 2019; Rekik et al. 2019). We rely on previous literature to better understand how modern approaches manage the detection of radicalization so we can position our study within the boundaries of those studies. To do so, we first review *HateSonar*, an open-source hate speech detection tool based, which was created and developed upon previous work by Davidson et al. (Davidson et al. 2017). This tool is widely used (Grover and Mark 2019; Gallacher 2021), and can detect words and sentences that fall within the boundaries of hate speech and offensive language. However, the tool is limited in that hate speech or offensive language or not sufficient signs of radicalization by itself. Furthermore, it lacks flexibility and customization as its parameters cannot be modified or suitable for all types of texts.

A second approach to detecting radicalization is using LIWC (Linguistic Inquiry and Word Count) (Pennebaker et al. 2015). LIWC is a state-of-the-art algorithm that calculates the different types of words in a text and classifies [the text] into predefined categories. These range from positive and negative tones to social words and more. Like HateSonar, LICW is a proven tool for discovering the meaning and intent behind the text. However, its limitation resides in its price as it might limit its accessibility by institutions or individuals.

After these two methods, we step into the domain of the different machine learning models used to detect radicalization. The first example is the model created by Saif et al. (Saif et al. 2017). Their approach worked by identifying the word's semantics used by social media users to identify possible signs of radicalization. Their approach improved upon previous work in the field and outperformed other approaches such as HateSonar and LIWC. Following a similar pattern, again, Rowe and Saif (Rowe and Saif 2016) focused on detecting signals that could suggest pro-ISIS behaviors. Other approaches have focused instead on comparing different machine learning models to detect handles and usernames that radicals could have used (Madarash-Hill and Hill 2004). Despite their usefulness and success, these approaches suffer from a high specificity that sometimes renders them unusable for widespread use (Agarwal and Sureka 2015). Our efforts focused on using different ”over-the-counter' methods to examine Parler. Specifically, our effort resides in examining the feasibility of detecting radicalization and alt-right behavior using highly accessible methods.

PARLER DATA SEARCH AND RETRIEVAL

While platforms similar to Parler, like Twitter, have defined rules and permissions required (employing Developer accounts), Parler had no such Privacy Policy. The poor security of Parler made it possible for a researcher to scarp and share the data publicly. The data collection was possible by using part of the data retrieved by the Twitter user @*donk_enby*. Like Twitter, Parler had (at that time) a proprietary API that allowed its users to collect the data shared on their platform. As the Capitol Insurrection took place, the news of AWS dropping its support, and all the rumors of the company shutting down, some users decided to save and retrieve as much data as possible. One of those users was @*donk_enby*. This user managed to retrieve all platform's data due to a vulnerability in their API, as it did not restrict the amount of data that could be collected from the platform. Hence @*donk_enby* managed to download all of Parler's data. The entirety of the data accounted for a total of 50 Terabytes. However, we retrieved our data from a literature-validated source (Aliapoulios et al. 2021). All the data collected at the time of collection was publicly available. This data was divided into two separate zip files, one consisting of user information and the other with general data (posts, messages, likes, and similar), which we deemed to be the main file for our study. The main file consisted of 34 Gigabytes divided into 166 NDJSON files. However, we used only a subset of 10 randomly selected NDJSON files from the main file as computing power and time partially limited our study.

METHODS

We relied on different approaches found throughout modern literature to explore and examine for any possible signs of radicalization or inciting for violence that could have led to the Capitol Insurrection. First, we selected a date range to run our analysis, which ranged from December 6 to January 6, assuming that any organizational efforts or signs of radicalization could have been more visible a month prior. With that date range in mind, we randomly selected 10 NDJSON files (using a Python randomizer). Once we combined those files into one, we filtered the data to ensure it fell within our given date range. Doing this yielded a total of 1,200,000 posts. After the data was filtered and pre-processed, we moved on to the analysis. To do so, we relied on proven methodologies found in modern literature.

Data Cleaning and Pre-Processing

Data cleaning is the first essential step toward making sense of a noisy data set. Social media data can be challenging to work with precisely due to its varied nature. The data can come as text, images, audio, and video. However, in our paper, we are interested in the text data we obtained through Parler. Working with text data from a social media such as Parler has its issues, usually related to the ”cleanliness” of said text data. Hence text data usually needs a certain level of pre-processing before it can be used. Most of our pre-processing procedures were done by default by some of the algorithms we used. Among those were HateSonar, and Text2Emotion. However, we relied on the NLTK package to clean and pre-process our data for our N-gram and Keyword analysis.

N-grams

The first of the methods we used to find the more specific message and discover different behaviors and opinions in our data was N-grams. N-grams consist of a sequence of N items found in the text. In computational linguistics, N-grams are used to predict the next item in the sequence (Wang et al. 2007). Prior research (Aliapoulios et al. 2021; Zannettou, Bradlyn, et al. 2018) has shown that N-grams are suitable for understanding the nature of messages shared and published throughout social media environments. We decided to gather three different N-grams *(N = 3 ,4 ,5)*. However, while this approach was not intended for finding individual instances of radicalization, it helped create a picture of the overall conversation in our data.

Sentiment Analysis

The second method we used was sentiment analysis. Like N-grams, sentiment analysis has also been used in modern literature (Dıaz et al. 2018; Guichón Aguilar and Serrat Gual 2011)). Sentiment analysis is usually used to understand the positive, negative or neutral sentiment in a text (Yaakub et al. 2019). However, we were looking for a more specific classification in our case. For this purpose, we used the text2emotion [5] implementation that is available through Python as a package. The rationale for using this package was based on its comprehensive text classification instead of the positive/negative binary results found in other algorithms. This algorithm works by processing textual messages and recognizing the emotions embedded in them. Once the algorithm has processed the text, it gets classified into five categories: *Happy, Angry, Sad, Surprise,* and *Fear*. The algorithm works in a two-stage process. First, the algorithm cleans and pre-processes the text to make it suitable for analysis. Second, it detects emotions find in every sentence and keeps a count. The final output of the algorithm is an emotion score in each category ranging from 1 to 0. A higher score means a higher probability that the message has that emotion. Therefore any message can have a range of emotions, not just one emotion.

HateSonar

The third method used was *HateSonar*, an open-source package built to detect hateful language on social media. HateSonar uses Logistic Regression to classify text into offensive and hateful (Zannettou, ElSherief, et al. 2020). As such, prior work (Grover and Mark 2019; Davidson et al. 2017) has shown this to be an effective method to detect hateful language. Similarly, in text2emotion, the algorithm provides a score range between 0 and 1, where 1 represents hateful speech. While hateful/offensive language detection could help identify anger as sentiment, we cannot say with complete conviction. Pairing the findings from sentiment analysis and HateSonar would be helpful in more accurately determining the nature of the language used. For example, if a statement is categorized as offensive and with a strong surprise sentiment, it may not convey hate as much as it does someone is startled. Thus, coupling HateSonar with sentiment analysis helped us better determine the nature of the language found in our data by letting us see the overall sentiment and present emotions.

Keyword Analysis

Our last method was looking at specific keywords in our text data. The goal was to look for specific terms and words associated with the Capitol Insurrection, radicalization, and alt-right behavior. Examples of these practices can be found through literature showing their effectiveness (Klein 2019). Previous studies such as Rowe and Saif (Rowe and Saif 2016) looked for specific words that could point towards signs of radicalization. In addition, Panizo et al. (Panizo-LLedot et al. 2019) identified keywords commonly used in alt-right circles. Hence, we tried to imitate these methodologies to create a comprehensive approach to identifying the different kinds of behaviors.

[5]https://shivamsharma26.github.io/text2emotion/index.html

Table 1. N-grams Analysis Results

N-grams	Text	Count
3	('looking', 'forward', 'meeting')	1082
3	('forward', 'meeting', 'everyone')	1060
3	('enemy', 'foreign', 'domestic')	291
3	('invoke', 'insurrection', 'act')	285
3	('january', '6', '2021')	202
4	('looking', 'forward', 'meeting', 'everyone')	1060
4	('fight', 'trump', 'congress', 'jan')	123
4	('congress', 'jan', '6th', '2021')	123
5	('parler', 'looking', 'forward', 'meeting', 'everyone')	1060
5	('petition', 'fight', 'trump', 'congress', 'jan')	123
5	('fight', 'trump', 'congress', 'jan', '6th')	123
5	('fightback', 'communist', 'socialist', 'revolution', 'insurrection')	95

RESULTS

N-grams

The first of our results came from the N-grams. During our analysis, we focused on N=3,4,5. We filtered the N-grams to show only the top hundred instances for a clearer picture. We concentrated on the cases that occurred more than a hundred times throughout the data. As seen in Table 1, this yielded some exciting results. The 3-grams seemed the most telling at first as they displayed some sign of a possible call to action. We found the following 3-gram *('forward,' 'meeting,' 'everyone')*. Therefore we were led to believe and think that Parler had the characteristics of a close-knit community in which users had similar ideologies and goals. They were organizing themselves through the platform. In addition, we found instances of January 6 even through our N-gram analysis. However, these cannot be categorized as radical behavior, albeit it suggests individuals were able to coordinate through the platform.

One could argue that *('looking,' 'forward,' 'meeting,' 'everyone')* suggests that Parler was a close-knit community in which users had similar ideologies and goals. The 5-grams reveal the frequent mention of words like *('Trump', 'communist','revolution')* which offer some insight into the type of communication and the topic. It would be safe to conclude that there was a prominent presence of conversations around Trump and banding together. In addition, we can see frequent mentions of a specific date, which can lead us to believe that the planning (at least in parts) took place on the platform. With regards to our first research questions, we can claim reasonably that with the help of n-grams, we can establish a context that is a helpful first step in identifying alt-right radicalization.

Sentiment Analysis

We used all data entries (minus missing data) for our sentiment analysis. Out of roughly a million entries, we average the results in percentages. The results were as follow: *Happy* (9.38%), *Sad* (18.03%), *Angry* (4%), *Surprise* (18.83%), *Fear* (23.65%) and *Uncategorized* (37.8%). These results can also be seen in Figure 1. Our results showed that the most prominent feelings were those of fear and surprise, followed by sadness. Even if our keyword analysis presented an image of anger, the overall trend was fear.

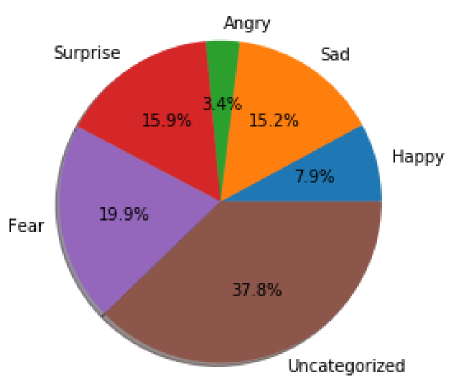

Figure 1. Twitter Sentiment Analysis

HateSonar

We conducted the HateSonar analysis over our data collection (1,232,102 messages). After the analysis, HateSonar reported *4,399* messages classified as *Hate Speech*, *122,385* as *Offensive Language*, and 1,105,315 as*Neither*. This amount of data accounted for 11% of messages classified as hate speech or offensive language. These results would align with our N-grams analysis as language did not seem particularly offensive or hateful. While we know that hateful speech leads to increase radicalization (Love 2016), the results did not suggest many cases of radicalization or extreme behavior based on the language analysis we conducted.

In the context of HateSonar, it is essential to understand that it assigns the label with the highest probability. That is to say that given that there is a case where the probability distribution is 0.3 (Offensive Language), 0.3 (Hate Speech), and 0.4 (Neither), it still categorizes it as Neither when there is a significant combined hate speech and offensive language component. We attribute the high Neither representation to filler comments and examples of the above kind.

Keyword Analysis

The keyword analysis consisted of multiple stages. The first stage involved a broad overview of the general trends found in our data set. We plotted the total number of comments created each day from December 6 to January 6 for the years 2020-2021 and 2019-2020. The result can be seen in Figures 2 and 3. Surprisingly both figures showed a similar pattern, with a substantial drop in comments during the last week of December 2020. We believe this was caused by some holidays occurring during that same period. However, it is interesting to note that for the years 2020-2021, the number of comments made did not rebound as the previous year. Messages declined when it approached January, suggesting that some users got discouraged by the trend of the platform.

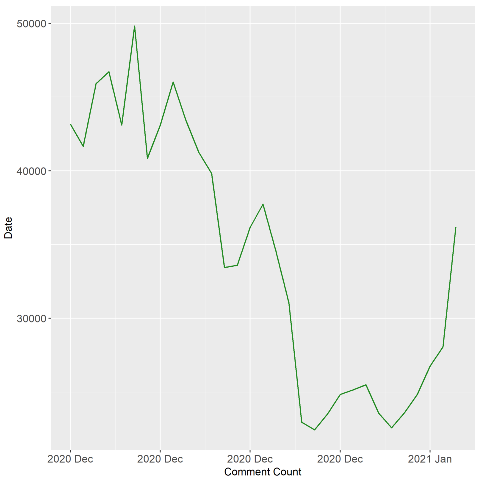

Figure 2. Posts made during the period Dec-2020 and Jan-2021

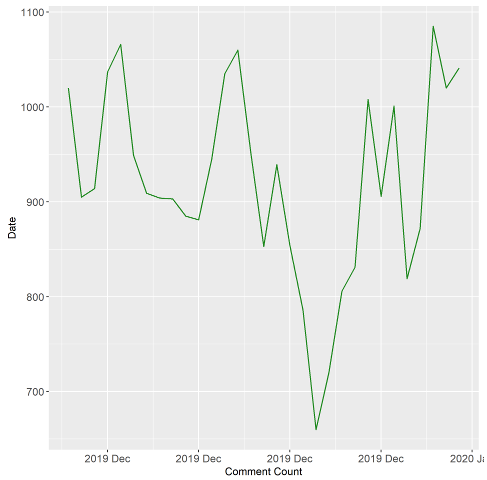

Figure 3. Posts made during the period Dec-2019 and Jan-2020

The second stage consisted of identifying keywords related to acts of violence, alt-right, radical behavior, and hate speech. Some of these words were: *"assault"*, *"kidnap"*, *"white power"*, *"shoot"*, *"insurrection"*, *"proud boys"*,*" violence"*, and *"take over"*. The results from the keyword analysis can be seen in Table 2. We certainly saw a more radical language in this study phase than in the prior stages. However, we were limited by the amount of data collected and the need to parse manually through the entries. Nonetheless, we were surprised at how easy it was to find some instances of call to action on January 6. In some cases, they were not just called to action but also for violence. Some of these messages can be found below.

"*Everyone needs to make plans to be in dc on january 6!*" -U1 (2020-12-20)

"*It will all come down on january 6*" -U2 (2021-01-01)

"*Trump said be there january 6,2021! he said it'll be wild! he's said the word! let's go!*" -U3 (2020-12-24)

"*Jan 6 be in washington dc or your state capitol. the time has come and is now*" -U5 (2020-12-21)

"*I guess raiding the capitol is becoming the likely option every time, these democrats shouldn't be able to serve till the next election, remove them forcibly*" -U6 (2021-01-03)

Table 2. Keyword results

Keyword	Count	Keyword	Count
trump	83057	shoot	2666
riot	27771	meeting	2034
fraud	27316	violence	2019
congres	9897	take over	1364
kill	9693	proud boys	1285
traitors	6631	fight back	1199
rally	4846	capitol	773
6th	3892	assault	731
insurrection	2963	punished	607
Civil War	2803	kidnap	178

"*We can do this on january 6th if you all have the courage to raid the capitol and lock all these traitors up*" -U7 (2021-01-04)

However, not all keywords returned comments and posts about the election results or the meeting in January. In some cases, they were just related to the coronavirus and international news. And in some others, deliberate cases of fake news or disinformation.

"*President trump issues proclamation on national pearl harbor remembrance day, 2020*" -U8 (2020-12-07)

"*Solarwinds noted in the filing that while it has more than 300,000 customers, it believes fewer than 18,000 installed an update that contained the malware, in addition to many gov't agencies.*" -U9 (2020-12-14)

The limitation of this approach was that we had to parse manually through the data entries to find instances of radical behavior. To overcome this limitation (or at least minimize it) and get to understand the data in finer detail, we nested our keyword search. To do this, we filtered comments and posts based on the first set of keywords. Then, we added a second set of keywords from the same list to see what results could still show up. Surprisingly we found a substantial amount of comments that seemed to incite violence and raiding the capitol.

"*If they certify for biden, raid the capitol and take all the traitors away and lock them up*" -U10 (2020-12-23)

"*We can do this on january 6th if you all have the courage to raid the capitol and lock all these traitors up*" -U11 (2021-01-04)

"*Don't forget your 2a gear. blm and antifa are going to be ultra violent that day. also if we have to take over the capitol and start dragging out traitors and communist sympathizers we will need them.*" -U12 (2020-12-25)

During this analysis, we noticed an interesting hashtag and term used throughout Parler to call seemingly and inconspicuously to violence without bringing too much attention. The term was *1776* and acted as a reference when the United States declared independence from the British Empire and began the American Revolutionary War. We noticed this was a somewhat common occurrence, and we believe this allowed people to avoid suspicion from any self-moderating algorithms. We also think this could be why HateSonar showed only a few instances of hate speech. Some of the messages with 1776 can be found below.

"*I vow to dismember him when 1776(2.0) begins next week.*" -U13 (2021-01-01)

" *The number of americans ready to kick ass and have our 1776 are at record high!why don't you report on that!*" -U14 (2020-12-15)

" *I'm right with you brother let me know where and when the time comes which i think is very soon. hopefully they all go to prison and we'll have to resort to bloodshed but that doesn't look like an option in the very near future great man once said the tree of liberty must be soaked with the blood of patriots and tyrants from time to time. freedom isn't free. 1776 is the answer.*" -U15 (2020-12-13)

DISCUSSION

Literature has indicated that it can sometimes be ambiguous when defining the limits of hate speech or offensive language before these become a sign of radicalization. A substantial amount of literature focuses on measuring the accuracy of different "in-house" algorithms instead of what the data means as a whole (Malmasi and Zampieri 2017). However, some of these approaches might suffer from their high specificity as they focus their effort on a particular domain or platform. Nonetheless, this does not minimize the significant impact this has on discovering new ways to identify and leverage data on social media platforms. For example, we now know Twitter's usefulness during times of crisis.

In the case of Parler, it is all the more challenging due to the alleged relation it had with the Capitol Insurrectionists and how it acted as a medium for these to organize and call others to action. It was later known that its owner contacted the FBI as there were suspicions of radicalized individuals within the platform.

The question we have sought to answer here is: could the capitol insurrection have been prevented or predicted by an investigation of Parler? After our analysis, the initial allegations of Parler being a hotbed for ring-wing extremism seem more plausible. Our results have shown, even with simpler methodologies, that extremism and call to action were spread over the platform. Considering that our sample size was limited, it is worth considering that the platform could have harbored a more significant extremist base. We believe that early action could have helped dissuade some individuals or groups. Nevertheless, there are still variables that we cannot account for in these analyses, such as the impact of traditional news and other individuals.

However, detecting these behaviors might be more related to the literature trend than individuals' inactivity to investigate the platform. Modern approaches take time, large amounts of data (which social media platforms have), and some way to validate their results. Here is where these approaches tend to get stuck. Through this paper, we try to present and follow an approach that can provide more identifiable and valid results in a smaller time frame. However, we do not intend to supersede other machine learning approaches but instead offer a first look into our data and explore it with "over-the-counter" methodologies.

To carry out our study, we used four different methods: *N-gram* analysis, *HateSonar*, *Keyword Analysis*, and *Sentiment Analysis*. Combining these methods allowed us to detect other possible signs of radicalization in the platform. N-gram analysis showed us what seems to be a call to action with multiple references to January 6, the Congress, and some mobilization. The second analysis, HateSonar, revealed that roughly 11% of all posts on the platform were categorized either as hate speech or offensive language. That does not necessarily indicate significant indications of radicalization. However, it describes the overall sentiment that was observed on the platform. While these numbers (HateSonar) are on the upper side of what prior literature has found (Gibert et al. 2018), it is still within their limits. Our third method of keyword analysis focused on a more hands-on approach by looking for specific keywords that could be related to these instances of radical behavior or call to action. This method showed clear instances of this behavior with many references to January 6 and a call to action.

In addition, we found how some messages contained the term *"1776"* as a reference to the American Revolutionary War. In the context of the platform, we found that the term was used to mask more incendiary comments that could have been flagged. This type of language leads us to believe they were already trying to use language that could mask their behavior and not raise suspicion. Parsing manually through the text seemed the best method to find clear instances of radical behavior. The limitations of these specific methods are evident; it is impossible to parse large amounts of data promptly and thoroughly. Our last method, sentiment analysis, showed us that among all our data, negative sentiment seemed to be the norm throughout.

Based on our initial analysis of the platform and considering our data-set was a fraction of the size of all data scraped from the website, we believe the platform played an important role in stoking and triggering the capitol insurrection. We detected clear instances of call to action, organization, and some call to violence. We believe the platform helped individuals before January 6 organize and coordinate to carry out the insurrection. However, we are aware that our analysis might lack the depth of some machine learning algorithms. Given its public nature, we believe there need to be more studies to be conducted in this domain and open new venues of research to not only detect but counter-radicalization in social media platforms.

CONCLUSION

In this work, we proposed understanding how radicalization can be identified preemptively on social media platforms. Doing this is a challenging problem in itself. The focus of this work was the Capitol assault and if Parler catalyzed the planning of the same. While we cannot say with absolute certainty, this work presents strong evidence of group planning and radical sentiment build-up. The combination of the three methods (n-grams analysis, keyword analysis, and HateSonar) provided a rounded image of what transpired on the platform between December 6, 2020, and January 6, 2021. Through our work, we not only detected clear signs of alt-right behavior and radicalization but also how the platform served as a medium to organize these individuals for what transpired on January 6.

FUTURE WORKS

This study shows a preliminary overview of the overall behavior and conversation throughout the platform. However, as we tried to use easy and more accessible methodologies, we could not delve as deeply as other approaches. Future work should focus on using automated approaches to gather more evidence of radical behavior and draw a more delicate line between the events of January 6 and the platform.

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