A SaaS-Based Early Warning Information Fusion System for Critical Infrastructure Safety

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ABSTRACT

Maintaining the critical infrastructures, such as Drinking Water Treatment Plants (DWTP), transportation, power generation and communications systems, in a safe state is a complex problem. The effective collaboration, as well as the collection aggregation and dissemination of early warning information among the stakeholders of the Safety Management System (SMS) responsible for the safety of these critical infrastructures are some of the challenges that need to be addressed.

This paper argues that the Software as a Service (SaaS) deployment model can offer new ways of enhancing the fusion of early warning information during the operation phase of critical infrastructures. It presents the requirements, the architecture and a number of features of a working prototype SaaS-based early warning information fusion system for DWTP safety issues in the Republic of Ireland. It is the first time that a SaaS-based working prototype system is reported of providing early warning information fusion services in the literature.

Keywords

Early warning system, software as a service, SaaS, drinking water treatment plants safety.

INTRODUCTION

The provision of safe drinking water to the general public in the Republic of Ireland is accomplished by the means of a complex SMS. As Figure 1 shows, among the key components of this system are the DWTPs, which are engineering facilities responsible for the purification of the water to the appropriate quality standards. Additional elements of the SMS are the Water Service Authorities (WSA) and state agencies, such as the Environment Protection Agency (EPA) and the Health Service Executive (HSE). The WSA are special departments of the local authorities of the country, which are responsible for the day-to-day operation of DWTPs and, among other responsibilities, should notify the EPA, whenever a drinking water quality parameter exceeds its accepted quality threshold value, and consult the HSE on the enforcement of potential mitigation actions. The EPA regulates the WSA and conducts audits at the DWTPs of its jurisdiction. In essence, DWTPs are elements of a complex socio-technical SMS and, thus, their performance and safety is affected by many factors, including environmental disturbances and technical failures, as well as, by the dysfunctional interactions among the elements of the SMS.

The SMS described above is experiencing problems in meeting the drinking water standards set by the European Council. For instance, it was reported that a third of all water supplies in the country is on the list of identified vulnerable water supplies, which is known as the Remedial Action List (RAL) (Irish Environmental Protection Agency, 2011). In 2010 alone, 43 boil water notices and seven water restrictions notices (serving approximately 65,000 persons) were put in place by 16 WSA. The most notable consequences of not supplying safe drinking water to the general public are those related to public health. For example, the most serious drinking water outbreak recorded to date in the Republic of Ireland is the cryptosporidium (a bacteria that is an indicator of whether human or animal waste has entered a water supply) outbreak on Lough Corrib, County Galway that occurred in March 2007, which affected water quality in the city of Galway. More than 200 cases of people with confirmed cryptosporidiosis were reported at the time.

A reason for the unwanted performance of the SMS is that a relatively small number of DWTPs are equipped with sensors capable of detecting the presence of harmful agents in the water. Indeed, private and HSE-owned laboratories periodically conduct sensitive analyses of water samples from different DWTP. However, the laboratory tests cannot be delivered immediately to decision makers due to technological limitations and budget restrictions. Unfortunately, the alerts from the sensors and from the laboratory tests are usually revealing the symptoms (i.e. that a drinking water contamination event has occurred) that emerge by a dysfunctional SMS.

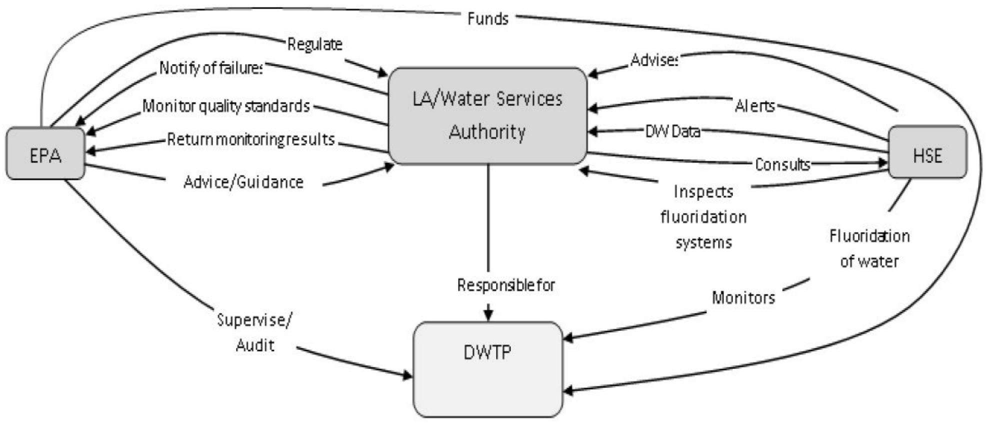


Figure 1. The SMS for the Provision of Drinking Water in Ireland

Ideally the warnings that indicate in a timely manner the presence of, but most importantly, the "concurrency" of the complicated set of contributing factors that together may turn a drinking water contamination scenario in to a reality must be accessible by those who have the power to act in order to avoid the worst case scenarios. These warnings may be perceived by agents that belong in to many if not in all levels of the SMS and not just by agents at the operational level of the DWTPs. Thus, mechanisms and systems that aim to enhance the collection and aggregation of the perceived, by either humans and/or automated agents, early warning signs in the different hierarchical levels of the SMS and their dissemination to the proper stakeholders are important tools for a proactive risk management. These tools need to combine data from multiple sources, aggregate the data and present them properly, in order to support and enhance the awareness of the decision makers about the safety levels of the DWTPs. These systems are referred in this paper as *early warning information fusion systems*.

Currently, there are only "soft" procedures in place aiming at enhancing the situation awareness of the stakeholders of the SMS. For instance, in the case of an exceedance of a microbiological or indicator parameter in one DWTP, the manager of that DWTP is legally required to inform the EPA and the HSE by 11 o'clock on the following working day by email of by fax. In addition to that, the RAL is only updated quarterly by the EPA. This paper argues that Web technologies and in particular the SaaS deployment model, which allows many users to use one instance of a software application through their Web browser, may provide novel ways of collecting, aggregating and disseminating early warning information about the safety of DWTPs and of critical infrastructures in general.

Specifically, the paper presents the requirements, architecture and some features of a working prototype SaaS system, which was developed in order to provide to all actors, in all levels of the SMS responsible for the provision of safe drinking water to the consumers in the Republic of Ireland, a single "platform" for reporting and receiving early warning information about the safety health of the DWTPs in the country. The web based system provides the necessary interfaces so that sensors, users and other agents to report early warning signs. As result it collects a stream of early warning input data from many sources coming from different hierarchical levels and different geographical locations. The system fuse the early warning data according to their relevance to the safety of each and every DWTP registered in to the system. In this prototype version, the fusion of the early warning data is accomplished by Bayesian belief based algorithms, which represent cause and effect models of possible hazardous behaviors for each DWTP registered in to the system. It can also disseminate early warning messages to the appropriate stakeholders informing them about the deterioration of the safety health of the DWTPs. The paper continues with a description of previous relevant research works. It then describes the SaaS deployment model and explains the concepts of "tenant" and "multi-tenancy". The basic requirements and the architecture of the SaaS based early warning information fusion system are presented next. The paper continues with a walkthrough of a use case scenario of the SaaS based early warning system, where different views and features will be presented. The paper finishes with a summary and discussion section.

PREVIOUS WORKS

Guidelines, like the water safety plans (Davison et al., 2003) proposed by the World Health Organisation's provide a framework on how to define "soft" procedures for the collection and dissemination of early warning information. These guidelines, however, are applicable only on the hierarchical level of the SMS where the

DWTPs belongs to. On the other hand, early warning information about DWTP safety issues can be perceived by many agents in different hierarchal levels. Inspectors from state agencies for example, who conduct periodic audits in DWTPs, are another source of early warning information. The challenge, which has not yet been addressed, is to provide an effective “interface” where all the agents, located in different hierarchical levels of control within the SMS of DWTPs, will be able to disseminate any perceived early warning signal and retrieve those which have been perceived by other agents in different hierarchal levels of the SMS and in different geographical locations.

The most relevant application to the SaaS based system described herein is the WaterSentinel system (U.S. Environmental Protection Agency, 2005), The term “contamination warning system” was used by the U.S. Environmental Protection Agency instead of the term early warning system for describing this system after recognizing that a reliable system providing early warning of a contaminant prior to human exposure with public health impacts using today’s technologies may not be possible.

The conceptual architecture of WaterSentinel (U.S. Environmental Protection Agency, 2005) was defined in 2005. Some components of the system are:

- Online water quality monitoring, which use data from sensors and SCADA systems are used first to define the expected “normal” levels of monitored parameters. Then, any changes from these expected “normal” levels of the parameters being monitored are interpreted as warning signals of potential contamination.
- Sampling and analysis of water at a predetermined frequency, which are used to detect contaminants that cannot been detected by the Online monitoring system. In addition, water samples are collected in response to triggers from water quality monitors or other information streams to identify the potentially unknown contaminants in the sample.
- Enhanced security monitoring, to monitor, collect and document security breaches, witness accounts, and notifications by perpetrators, news media, or law enforcement.
- Consumer complaint surveillance regarding unusual taste, odor, or appearance of the water are often reported to water utilities, which document the reports and conventionally use them to identify and address water quality problems.
- Public health surveillance which can make use of data from existing syndromic surveillance conducted by the public health sector, from emergency medical service logs, emergency call centers, and poison control hotlines.
- A consequence management plan that detail the treatment plant's response actions, along with those of the related local, state, and federal agencies that should respond to a drinking water contamination incident .

The main difference of the prototype system described herein compared to the drinking water systems that compile data from a variety of disparate sources, typically in a GIS platform, is its SaaS based deployment, which allow the users to run the application inside their Web browser without the installation of further plugins. There are only two previous works discussing some aspects of the potential use of a SaaS based system as an early warning information fusion system for DWTPs. The first paper (Dokas et al., 2009) has presented the results of a feasibility study. It has concluded that an early warning collection and distribution system for DWTPs could be developed by combining technologies, such as SaaS, Bayesian believe networks and business activity monitoring. The second paper proposed a possible architecture for a SaaS based early warning collection and dissemination platform for DWTPs safety issues (Foping et al., 2009). In addition, the authors described some of the technologies which will be using in order to impellent their designs. This paper is a continuation of the two previous works. It presents the final design of the working prototype SaaS based early warning information fusion system and some of its views and operating features and provides some evidences that accord with the concussion reported in (Dokas et al., 2009).

SAAS

The increasing popularity of the Web has paved the way for a new breed of software characterized by the fact that both the ownership and the maintenance of the software are outsourced by the service provider and not by the user who now does not need to install it in his computer. With the new model the software features are provided to end-users as services and are accessed via a Web browser. In essence, the software runs from a remote server, while the users can access and make use of its features via a Web browser. This category of software is named in the literature as SaaS, on-demand software or subscription software (Turner et al., 2003).

One important technology necessary to build and deploy a SaaS application is known as multi-tenancy. A Web application is said to be multi-tenant if it allows its users to share the same hardware resources, by providing only a single instance of the application and its underlying database that is shared between all users. Throughout the execution of the application, users are allowed to customize the application to meet their needs. Finally, the mechanism behind multi-tenancy should be completely transparent to users. These users are also known as tenants (Bezemer and Zaidman, 2010). A tenant is the organizational entity that uses a multi-tenant application on-demand. A tenant usually consists of a plethora of end-users which are part of the organization (Bezemer and Zaidman 2010).

For example, referring to the problem of DWTPs safety in the Republic of Ireland the EPA, HSE, WSA and DWTP can be represented as different tenants within a SaaS based early warning information fusion system where each tenant can have different roles. For instance, the EPA is represented in the SaaS system presented in this paper with two roles: the administrator and the inspector. The administrator is responsible for the creation of new users and DWTPs in the system and he may perform the following tasks: add users, update their personal data, remove them from the database, add new DWTP in the system, and assign EPA inspectors and HSE health officers to a newly defined DWTP. On the other hand, the EPA inspector due to his responsibilities within the SMS for the provision of safe drinking water in the country is free to interact with the RAL, is able to see the changes of the hazard levels which are calculated by the early warning, Bayesian belief-based, fusion algorithms of each DWTP with time in a graph representation, and he can request the list of "emerging issues" (i.e. those events or states of the DWTP, which when perceived by the caretaker, have been classified as "out of the ordinary") for a DWTP in the system. The HSE is represented into the SaaS based early warning information fusion system with two roles: the HSE Laboratory Technician and the Health Officer. The HSE Laboratory Technician is responsible for carrying sample analysis of the water and disseminating the results using the SaaS based system. The results will need to be validated by the HSE Health Officer before being made accessible to the other users.

SaaS applications run inside a Web browser and usually do not require the installation of further plugins. They are particularly suitable for distributed applications with users living in remote locations (Foping et al., 2009). Thus, a SaaS-based solution for the collection and dissemination of the early warning, which may be perceived by agents and stakeholders in different hierarchical levels of an organisation, located in different geographical locations, like in the case of the organisation responsible for the provision of safe drinking water in the Republic of Ireland, may offer a valuable service at a reduced cost compared to on-premises applications such as legacy GIS systems. SaaS applications are entirely hosted and maintained on the provider's data center. Therefore, SaaS users are not required to purchase additional hardware to run the application. This looks also appealing because coordinating the agents/users that belong in such complex SMS in accomplishing the tasks of updating and maintaing the early warning information fusion software in to their own computers seems very hard to be achieved. Finally, as the number of agents and users connected to the system will increase through the addition of more DWTPs in to the system, so does the need to increase the computing power and data storage capabilities. The SaaS model, which is a form of cloud computing (Zhang et al. 2010), "inherits" the attribute of scalability that characterise cloud computing solutions. Scalability in this case could be achieved by adding more devices to the servers of the system or by adding more servers to an application server cluster.

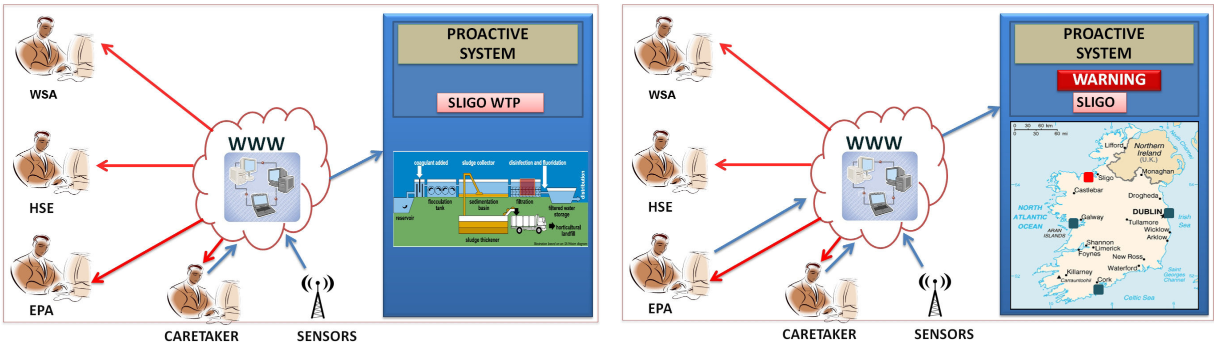
SAAS BASED EARLY WARNING INFORMATION FUSION SYSTEM REQUIRMENTS

The high level requirements of the SaaS based early warning information fusion system first presented during its conceptualisation phase in (Dokas et al., 2009). The final high level requirements of the working prototype early warning information fusion system are presented herein. The system should be accessible by all stakeholders of the SMS, which are scattered in Ireland and it should:

- make important and relevant early warning information accessible to each stakeholder;
- allow the "definition" or "registration" of new DWTPs in to the system;
- allow users/domain experts to model and represent scenarios of possible accidents;
- allow the task of updating the knowledge related to the contributing factors and early warnings of accidents;
- provide an estimation of the likelihood of accident occurring in the DWTPs, given some evidences and/or early warning signs;
- notify stakeholders by email or text messages when receiving important early warning information and/or when the assessed likelihood of an accident occurring exceeds its threshold value;
- allow as input real time sensor data as well as to allow updates of the status of the components of the DWTP by their personnel;
- allow users to report conditions and safety related issues that are not ordinary (i.e. emerging issues).

Specifically, referring to Figure 2 (a), the caretaker of a DWTP will be able to log on in to the SaaS based early warning information fusion system (represented in to Figure 2 (a) with the letters "WWW"). The system will recognise him as the caretaker of a specific DWTP and it will display his dedicated view that he can use to report any perceived early warning information and emerging issue, which may be related to one or many accident scenarios. The system will be able to collect near real time sensor data from the sensors of the DWTP. If, given the warnings provided by the caretaker and the sensor data, the assessed likelihood of an accident occurring exceeds a predefined threshold then it will dispatch early warning massages to the associated EPA, HSE and WSA personnel (red arrows).

In addition, the EPA inspector, or the HSE health officers, or the senior engineers of the WSAs, as Figure 2 (b) shows, can log on in to the SaaS based early warning system. The system will recognise them as personnel of the state agencies, or of the WSAs and it will display them a view which will be appropriate to their role. The view of each role may have different features and functionalities depending on their responsibilities assigned to each role. For example, some functionalities available into the EPA inspector view, such as the inclusion of a DWTP in to the RAL, will not be available to the health officers of the HSE. Through their view each user can report the perceivable early warning signs like, for instance, in the case of the EPA inspector, any warnings signs identified through a periodic audit in a DWTP and they can see and browse the early warning information which were distributed by other stakeholders.



(a) (b)

Figure 2. Two Use Cases of the SaaS Based Early Warning Information Fusion System

ARCHITECTURE

The architecture of the SaaS-based early warning information fusion system follows a layered model containing, as shown in Figure 3, the presentation, the business logic, the security, and the multitenant database layers. The presentation layer contains the following modules: Hazard Visualization to visualize the hazard levels over a period of time; the View Switcher that is responsible of the rendering of the appropriate view given the currently connected user; and the Web-based Hazard Editor used by the safety and risk analysts of the SMS to represent potential hazardous scenarios to the DWTPs registered in to the SaaS based system using on line a fully integrated Bayesian belief network-based hazard analysis editor. The security layer contains sub-modules that were created to deal with potential security vulnerabilities such as eavesdropping acts, SQL injections and Cross-site Scripting Attacks. The business logic layer contains the Validator; the AI Engine; and the Warning and Alert Dispatcher modules. The Validator, ensures that the work flow of the application is strictly followed by users. This is achieved by defining a set of rules that must be met by the users during the interaction with the objects of the application. The AI module aims at computing the hazard levels giving a set of input data received from the users of system, from the sensors, and other agents. The reasoning engine provides a wrapper around the actual computational model. The reasoning is executed based on Bayesian belief network technology.

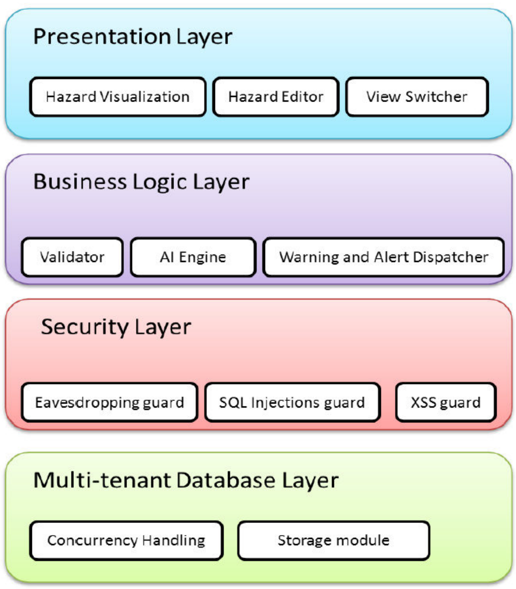


Figure 3. System Architecture

The computation of the hazard levels requires the system to: 1. Load the Baysean belief algorithms that fuse the perceived early warning data and assess the hazard level of the facility; 2. Get the list of early warnings supplied by the agents and treat them as evidences to the Bayesian belief model; 3. Apply those evidences to the Bayesian model; 4. Update the beliefs of the network; 5. Return the Hazard level of the network.

Step 1 is achieved by loading the model of the Byesian belief network of each hazard for each DWTP from an XML file located in to the database of the system. Listing 1 shows part of an XML representation of a Bayesian belief model of a pollution hazard in a DWTP. Due to space limitation the listing does not reflect the complete model. The complete model contains as nodes the events “Flooding”, “Colour”, “Chlorine Drop”, “Ammonium Level”, “Turbitity Level”, “Dissolved Oxygen”. Step 2 is achieved by fetching from the server of the application the list of evidences which are provided by the uses of the system and by the sensors or by other web services. For example, the values or the evidences of the Turbidity Level, Ammonium Level, Chlorine Drop, Dissolved Oxygen events for the Bayesian model shown in Listing 1, are provided by the appropriate sensors located in the DWTP, whereas the Flooding event may be entered by a user (i.e the Caretaker of the DWTP) if it is perceived. This is done via Asynchronous JavaScript And XML (AJAX) calls. Step 3 The system applies the previously retrieved list of evidences to the Bayesian belief model. Step 4 also known as Bayesian updating or probabilistic inference, is based on the numerical parameters captured in the network. The structure of the model, that is, an explicit statement of independencies in the domain, helps in making the algorithms for Bayesian updating more efficient.

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        </cpt >
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                0.5 0.5 </probabilities >
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Listing 1. Part of a Bayesian Belief Model

Each DWTP registered in to the system has its own customised Bayesian models for its potential unwanted events. That was done intentionally because each DWTP has different design and it is equipped with different sensors, as well as with different purification processes. Furthermore a DWTP may be affected by different environments compared to other plants. The creation of customised cause and effects models for each DWTP is feasible via the Web Hazard Editor component of the proposed architecture. That feature of the proposed system gives freedom to the risk analysts of the SMS to decide to use the most useful data sources that are available in each case.

The Warning and Alert Dispatcher component is responsible of dispatching warnings in certain situations. For example, when the resulting hazard level has exceeded its threshold, this component is engaged in order to dispatch the warning messages to the stakeholders associated to the DWTP.

A STRUCTURED WALKTHROUGH

Due to space limitations it is not possible to describe in this paper all the functionalities available in the dedicated views of each user of the SaaS-based early warning information fusion system. Therefore, a structured walkthrough of a use case scenario involving some of the functionalities available into the dedicated views of the caretaker of a DWTP, the senior engineer of the local authority where the DWTP administratively belongs to and the HSE health officer will be presented in this section.
In this scenario:

1. the caretaker, through his dedicated view, reports an emerging issue,
2. the senior engineer receives the emerging issue, which was reported and validates/approves it as an issue that needs to be transmitted in to the officers of the state agencies (i.e. higher to the hierarchy),
3. the EPA inspector and the HSE health officer become aware of it,
4. the HSE health officer advice the senior engineer to issue a boil water notice,
5. the senior engineer accepts the advice from the HSE health officer and enforces the notice,

6. The marker in the map available in all views representing the DWTP changes its colour and shape from green to red indicating that the status of the DWTP has changed.

DWTP Caretaker's View

After logging on to the system the caretaker can see in his monitor an interface similar to that shown in Figure 4. This view allows him to enter any predefined/sound warning signals and any emerging issues or weak warning signs that have been perceived by the caretaker during the DWTP operations. At the left hand side of his view it is a table that contains the sound early warning signals, that is the early warning signs that have been identified after the implementing a hazard analysis approach. At the right hand side a text box could be used by the caretaker to specify any emerging issue related to his DWTP. In this walkthrough scenario the caretaker reports the presence of e-coli in a routine sample test of the water entering the DWTP.

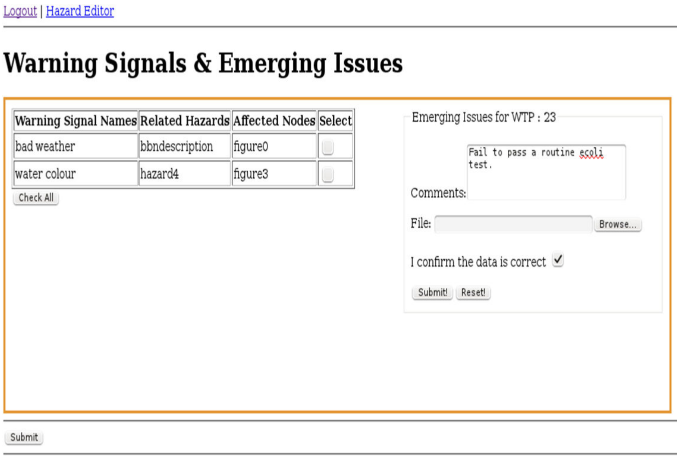

Figure 4. Aspect of the Caretaker's View

The WSAs Senior Engineer View

Figure 5, depicts a snapshot of the WSAs senior engineer view. In the middle of the view a map is showing the area served by the WSA. The markers on the map indicating the DWTP managed by the WSA. Each marker contains information related to the DWTP. At the left hand side there are boxes containing widgets that allows a senior engineer to apply a number of actions such as lift a restriction and lift a notice. At the top right corner there is a button with the label "emerging issues" that displays the emerging issues which have been submitted by the caretakers of the DWTPs that belong in to the WSA of the senior engineer. Figure 6 for example shows the pop up window that contain the emerging issue which, as mentioned previously, was reported by the caretaker in this use case scenario. If the senior engineer presses the "update" link in the pop up window, the emerging issue is deemed by him as important and therefore it will be automatically visible to the EPA inspectors and to the HSE health officers. If, however, the senior engineer considers the emerging issue as of being not important then he can "hide" it by pressing the hide link. In this walkthrough scenario the senior engineer has pressed the

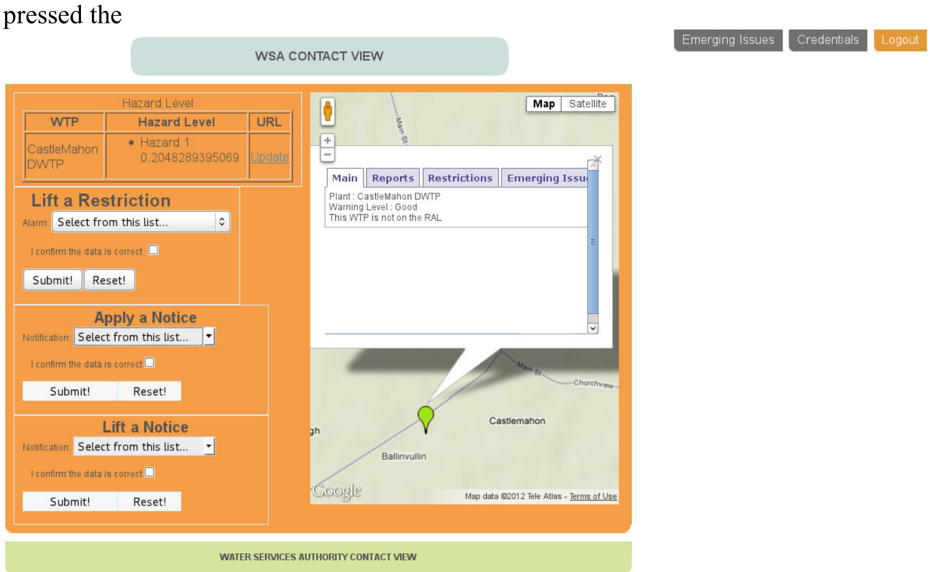

Figure 5. The Senior Engineer View

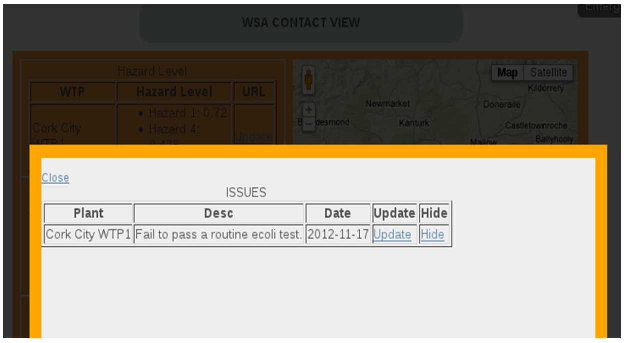

Figure 6. A Pop Up Window With the Reported Emerging Issues

The HSE Health Officer View

After receiving the emerging issue which was deemed as important by the senior engineer, the health officer can use the SaaS based system in order to "formally" advice the senior engineer to issue a water boil notice. The HSE health officer view is depicted in Figure 7. On the left hand side there is a map and the markers on the map indicate the DWTPs. On the right hand side there are boxes with widgets that can use to complete some tasks. In this walkthrough scenario the health officers uses the widgets on the "Report and Incident" box to "formally" send an advice for a boil water notice to the senior engineer of the WSA. As result the senior engineer and the EPA inspector will receive his advice. Up to now, the warning level for the DWTP is in the "Good" level because, as per the regulations that govern this case, in order to change the warning level to a different level the senior engineer must first accept the advice by the health officer. Nonetheless, with the SaaS based system presented herein all key stakeholders are aware of the information which has been exchanged.

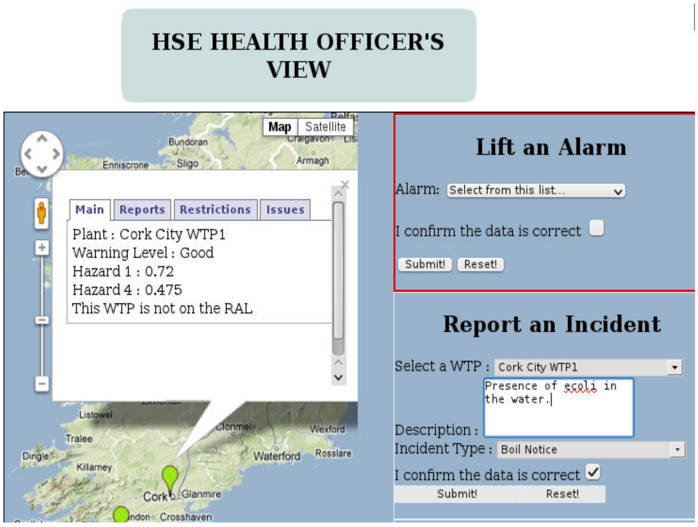

Figure 7. The Health Officer's View

Change of the Warning Level

In this walkthrough scenario the senior engineer has accepted the advice given by the health officer by applying a boil water notice using the widgets located in his view inside the box entitled "Apply a Notice". As result, the SaaS based system has dispatched emails with a warning message to all stakeholders and has changed the warning level of the DWTP from good to poor in all views. This change can be recognised visually by every user via the marker that represents the DWTP in the map, which, as shown in Figure 8, has changed from green to red with an exclamation mark.

SUMMARY AND DISCUSSION

Maintaining the safety of critical infrastructures like DWTPs is a complex task, which requires the collaboration, coordination and the effective exchange of early warning information among different agent groups that are scattered in different geographical locations and reside into different hierarchical levels of a complex SMS. Early warning information about the safety of critical infrastructures, in particular, may be perceived by many agents in different hierarchical levels. The challenge is to create a system that will provide an effective "interface" for the fusion of perceivable early warnings signs by different agents, regardless of their position in to the hierarchical complex SMS that is responsible for the safety of the critical infrastructure.

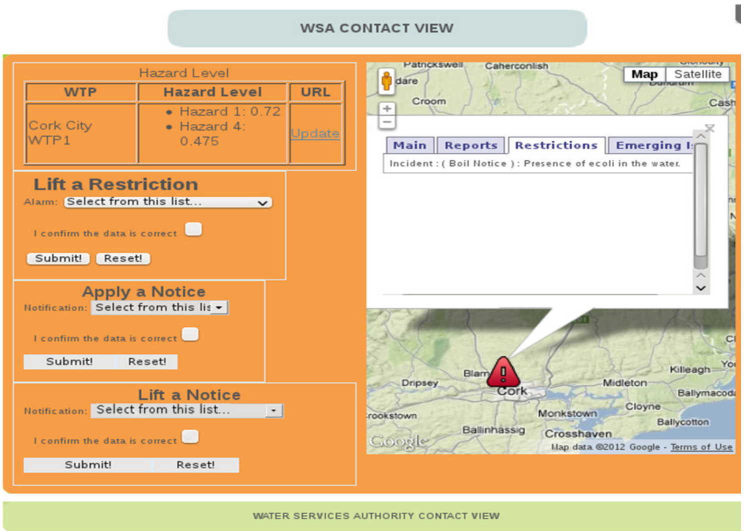

Figure 8. Change of the Warning Level

This paper has presented one possible way to address this challenge. Specifically, it has presented the architecture and a number of features of a working prototype SaaS-based early warning information fusion system for DWTP safety in the Republic of Ireland. It is the first time that a SaaS-based working prototype system is reported of providing early warning information fusion services for critical infrastructures in the literature.

The testing and evaluation phase of the system consists by three steps. This phase begun right after the development of the first working prototype version of the system and it is currently underway. During the first step, a number of demonstration meetings with representatives from the key stakeholders of the SMS for the provision of safe drinking water for the Republic of Ireland were organised in order to obtain an initial feedback about the potential usefullence of such a system. At the second step, the system will be used by the caretaker of one DWTP and by its associated senior engineer/WSA and EPA, HSE personnel in real conditions for a period of six months. After that, in the third step, the goal is to submit questionnaires to its users from the previous step in order to assess its usability.

Some thoughts from the practitioners and experts who participated into the demonstration meetings will be presented into the following paragraphs. In overall, the experts found the idea of using one tool for the dissemination of early warning information quite practical and useful. During the meetings the experts recognised the usefulness of disseminating perceivable early warnings to other agents into the SMS. They have mentioned also that they are using “homemade” / legacy systems to record the early warning signs, which are defined by the legislations and the official procedures. However, these systems are not “connected” with the systems, which other stakeholders are using. Furthermore, they cannot report with these systems other – non predefined early warnings - and as result they agreed on that such a system has the potential to provide a useful service. Thus, they were convinced that such a SaaS-based tool has the potential to provide a useful and practical service.

On the other hand, the experts thought about the potential of data overflow, which the ability of the caretakers to report emerging issues may generate to the stakeholders of the SMS. Data overflow which this feature may produce could generate new threats. As result, they proposed to include some sort of validation procedure before the emerging issues that are reported by the caretakers will be visible to other stakeholders. This comment has forced us to make some addition and few changes into the validator module within the business logic layer of the architecture of the system.

In addition, common issues which have been reported that hinder the deployment of SaaS business models in the literature, such as service availability, privacy, liability and security issues, were discussed during the meetings with the experts. For example, the experts were concerned about the availability of the service. Specifically, they pointed that it wouldn’t be a positive experience if the system will be down due to maintenance when an expert will perceive a warning sign that needs to be disseminated via the system. They were concerns also about privacy issues. For example, they were interested to know whether third parties are monitoring their activities. Some experts for example were discussing whether a court of law will have the potential to use the recorded data of the system during a court case after the occurrence of an outbreak. As they mentioned, if such potential exists then a number of agents of the SMS may not be intimated to use the early warning information fusion system. This is something that cannot be assessed with certainty right now and it is something which needs a very careful consideration. However, it is technically possible to address a possible future requirement of deleting some data from the database in an automatic manner. Furthermore, they were concerns about web security issues. This is a very dynamic area of research and implementation and obviously a satisfactorily solution to this can be given by group of experts in this field.

All experts agreed that such a solution has the potential of saving resources and money. They were asking, however, questions about the maintenance of such a system in practice. As the SMS is structured, the most appropriate organisation to host and maintain such a system is the Irish EPA. Indeed, at the end of this research work the source code of the entire system will be a deliverable to the Irish EPA.

Overall, from these meetings the potential of using a SaaS-based approach for the provision of early warning information fusion services into the domain of critical infrastructure safety seemed quite promising. There were some praises about the way information was presented. The expert for example liked a lot the box associated to each marker that contained all early warning information available from different sources for each DWTP. In addition, they pointed out that the different markers indicating different warning levels is on its own a good filter of information that can contribute at enhancing the situation awareness of all stakeholders.

However, more work is needed to fully comprehend all aspects of the potential benefits of such a service. This paper described some functionalities of the first working prototype example of such an idea. The near term goal is to finish the rest steps of the evaluation phase of the system described herein and to improve as we can its functionalities based on the feedback which will be received. The long term goal is to systematically study how SaaS-based early warning information fusion systems could be integrated into complex SMSs for different types of critical infrastructures as proactive risk management tools.

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