CrashHelp: A GIS Tool for Managing Emergency Medical Responses to Motor Vehicle Crashes

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ABSTRACT

This paper presents the research, design, and development of a comprehensive trauma information system inclusive of 911dispatch, Emergency Medical Services, and hospital trauma information. A proof-of-concept GIS based information system was designed and developed for use by trauma and emergency medical practitioners. Methods used include end-user focus group discussions, quantitative and qualitative data analysis, and an iterative system development process. A framework from prior research was utilized; a framework that considers the visualization of emergency medical events across an end-to-end continuum of patient care. Analyses performed provided a multi-layered understanding of the practical and theoretical implications of using an end-to-end information schema for emergency response and trauma health systems.

Keywords

Mashup, GIS, EMS, TCIS, motor vehicle crashes, emergency medical response

INTRODUCTION

Road traffic injuries are a major public health challenge that requires concerted efforts for effective and sustainable prevention (NHTSA, 2007). In 2008 37,261 fatalities occurred in the United States, a result of 34,017 motor vehicle crashes (MVC). The economic cost of MVC's in 2008 is estimated at $290 billion, approximately 2 percent of the gross domestic product. Medical and emergency service costs are roughly 15 percent of this total (NHTSA, 2007, NHTSA, 2008a). Past research demonstrates that timely emergency medical response to MVC's can significantly reduce the likelihood of death, disability, and economic consequences (Trunkey, 1983, Grossman, 1997, Schooley et al., 2008). The literature posits the potential role of Health Information Technology (HIT) in reducing emergency medical response times (Schooley et al., 2008, Peters and Hall, 1999) and improving the care provided to the injured at varying points across the inter-organizational continuum of emergency care (Shapiro et al., 2007, Horan and Schooley, 2007).

Emergency response and public health information consumers need access to accurate, timely, and comprehensible information (Turoff, 2004, Sawyer, 2004). Patient and incident information is used at various points in time by telematics service providers (e.g., OnStar), 911 dispatchers, first responders, ambulance providers, emergency department personnel, trauma physicians, crash analysts, medical specialists, and public health organizations. However, information among these actors is typically not shared across the incident response and care continuum (Joint Advisory Committee on Communications Capabilities of Emergency Medical and Public Health Care Facilities (JAC), 2008). For example, patient care information collected by paramedics at the scene of a MVC is not always forwarded to an emergency room doctor upon patient arrival at the hospital (Institute of Medicine (IOM), 2006). As the patient makes his/her way to the hospital, critical data that could aid in saving life is often misplaced, forgotten, or otherwise not reported (Andrew Stiell et al., November 11th 2003, Ye et al., 2007).

Prior research by the authors indicates that one key aspect to improving clinical decision making for trauma victims is to provide a shared operating picture of the emergency incident and related patients across the continuum of medical care (Schooley et al., 2009 Forthcoming). However, in the United States, such a unified approach is not currently "viewable" across the range of care providers involved (Joint Advisory Committee on

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Communications Capabilities of Emergency Medical and Public Health Care Facilities (JAC), 2008).

This study examines the research, design, and development of an integrated crash trauma information system. The system focuses on incident visualization and related metrics surrounding the "end-to-end" treatment of a crash victim. This study builds upon past case study research regarding multi-organizational information sharing in the Minnesota Mayo Clinic trauma system from the perspectives of Mayo Clinic practitioners and the State level trauma system. We present the socio-geographic data analysis of case study data, qualitative findings from focus group discussions with users, and a prototype design of an integrated crash trauma information system (CrashHelp) as derived through quantitative and qualitative case study research findings.

BACKGROUND : SOCIO-GEOGRAPHICS AND MOTOR VEHICLE CRASH TRAUMA

Demographic, geographic, and individual medical factors play a key role in the discussion of health outcomes for MVC patients. For example, increased utilization of emergency medical services (EMS) and increased vehicle-related mortality has been found among the elderly (Svenson, 2000) and in lower population density regions (Clark, 2001). Nationally, over 60% of vehicle related fatalities occur in rural areas, making up to 80% of all fatalities in some rural states (NHTSA, 2008a). Widespread attention has been given to public health issues associated with adolescent injuries and fatalities due to automobile crashes; the number one cause of death among persons 15- to 20-years of age in the U.S. Per vehicle miles traveled, teenagers are involved in three times as many fatal crashes as all other drivers (NHTSA, 2008b).

Analysis also reveals that elderly drivers are more likely to be injured and die as a result of a motor vehicle crash (Clark, 2001, Evans, 2004, Yee et al., 2006). Some studies indicate that drivers seventy-five years of age and older have higher fatal crash rates per mile than other accident-prone groups (Jun et al., 2000). Most accident prone drivers are teenagers and the elderly (Zhang et al., 1998), and a higher proportion of accidents take place in rural areas. How can communicating these and other important demographic data in a more integrated and visual manner provide for better decision making at the point of care? How can it inform policy and programmatic enhancements to improve patient outcomes?

This research focuses on developing a GIS based tool that is visually oriented, geographically based, web-enabled, and allows for assessing performance of emergency medical response by taking into account important health disparities and outcomes. Within this work, an exploration of how the inclusion of age, emergency response time, rurality, and related "socio-geographic" variables can be utilized in creating integrated, end-to-end emergency response information system. This work examines the potential of such a system in improving the analysis of health outcomes. The research team has previously developed a consumer-based tool for understanding traffic fatalities (SafeRoadMaps.org); this research considers the needs of EMS stakeholders in understanding and responding to traffic crashes.

RESEARCH APPROACH

This research follows general guidance from the Time-Critical Information Services (TCIS) framework (Horan and Schooley, 2007) which was developed to aid in the study of emergency services that are highly time and information dependent. Researchers developed TCIS to allow for a multi-dimensional view of an emergency incident across the continuum of patient care; from one end of service provision to the other (end-to-end). Figure 1, extracted from TCIS, provides a way to frame our analysis through the end-to-end EMS process, beginning with medical onset through definitive care (Horan and Schooley, 2007).

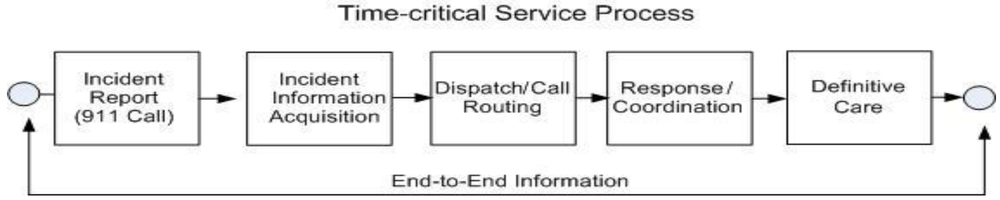

Figure 1. Time-critical service process

One theme of ISCRAM 2010 is Geo-Information Support for Crisis Response and Management - geospatial information and technologies as critical elements of effective emergency response systems. The CrashHelp tool is being designed to consider these elements.

METHODOLOGY

The research approach utilized is an action-design research methodology for assessing the end-to-end EMS response of trauma incidents. A software tool was designed from the perspective of the stakeholders within a targeted case study location. The action-design methodology has emerged as a transdisciplinary approach to studying socio-technical systems in a manner that gives attention to both analysis and design aspects of the research endeavor (Baskerville and Meyers, 2004). As such, it is dedicated to the development of knowledge useful to both research and practice (Cole et al., 2005). The goal of this action-design research is two-fold: to reduce the negative health impacts of motor vehicle crashes while extending scientific knowledge. Specifically, it features multiple methods, including quantitative and qualitative analysis of the problem, design-research and development of GIS-based tools to understand and affect the problem, and qualitative stakeholder assessment of the value and feasibility of implementing such tools to enhance emergency response. These methods were also aimed at contributing to the body of knowledge on emergency response systems research and evaluation (Marottoli et al., 1994).

Secondary data was merged and analyzed from 911 call centers, emergency medical services (EMS), and trauma center databases from a case study entity in Minnesota. Qualitative data were also collected through interviews and focus groups with public health and emergency response practitioners who participated in the action-design and evaluation of an GIS-based analytical software tool and purposeful IT artifact (Hevner et al., 2004). Application of findings are aimed at improving the manner in which emergency health practitioners analyze, characterize, and assess a patient and related performance. Further details on methodology are discussed in the sections below.

CASE STUDY OVERVIEW

Researchers conducted a case study of the local Rochester Minnesota Mayo Clinic trauma information system in Olmsted County, Minnesota between March 2007 and June 2009. The Mayo Clinic service area is largely rural, covering a land mass that includes portions of three states: southeastern Minnesota, western Wisconsin, and northeastern Iowa. The population of the communities served range in size from under 1000 to more than 60,000.[1] The Mayo Clinic is located in Rochester, Minnesota, which has a population of 94,950. The data collected, and context discussed herein, focused on emergency responses in the southeastern Minnesota region.

Building on prior collaborative research with the Mayo Clinic, the aim of the case study was to explore the needs, requirements, challenges, and benefits associated with implementing and using an end-to-end information system across the inter-organizational emergency medical response process. Researchers collected emergency response data sets used across the emergency response process (9-1-1 call center, ambulance service, trauma center), merged and analyzed the data, and then held a series of focus group discussions with emergency medical practitioners. These discussions were designed to aid in the development of a prototype application to visualize end-to-end information. Analysis and findings are discussed below.

Case Study Quantitative Data Analysis and Findings

Quantitative data analysis focused on a set of 172 adult (15 years of age and older) victims who were involved in a motor vehicle accident (MVA), transported by ambulance to St. Mary's Hospital in Rochester, MN in 2006 or 2007, and who had identifiable data recorded both by first responders (including dispatch and EMS) and the trauma center. Several steps were taken to derive this sample. A more detailed discussion is provided in following sections (Schooley, Nov. 14-18, 2009). Initially, two unique datasets were obtained from the Mayo Clinic. The first included information from reports completed by EMS agencies, n = 6,885. The second included information from reports completed at St. Mary's Hospital (Mayo Clinic), n = 4,657.

Data from patients whose treatment was necessitated by their involvement in a MVA were selected, *EMS n* = 639, *St. Mary's n* = 925, yielding two smaller datasets. The combination of these two datasets resulted in the final sample (172) and was achieved by matching similar attributes across datasets; specifically, date, time, age, gender, and the zip code of where the accident occurred. This single dataset comprised information from 26.9% of the EMS-MVA reports and 18.6% of the St. Mary's MVA reports.

Relationships between patient age, EMS response time, and health outcome measures Injury Severity Score (ISS), and Length of Hospital Stay (LOS) were examined (Table 1). ISS is a relatively comprehensive index of the overall extent of injuries recorded by trauma center health practitioners. The LOS, recorded in days, served

[1] http://www.mayohealthsystem.org/mhs/live accessed on January 19, 2008.

as an additional measure of trauma as well as a rough measure of recovery ease. Quantitative analysis consisted of Pearson correlation and linear regression techniques, although tests of differences between means (e.g., *t* tests and analyses of variance) were also used.

Two notable findings were identified through this research. First, a positive correlation between age and LOS was observed - as age increased, the number of days spent in the hospital did as well. This suggests that age may be a critical factor in predicting how long it will take for individuals to recover from injury.

	Injury severity score	Scaled length of stay
Injury severity score	--	.65**
Patient age	.05	.32*
Total EMS response time	.23**	.16*
EMS dispatch and transit	.24**	.17*
EMS time on scene	.05	.04

** $p < .01$. * $p < .05$.

Table 1. Pearson correlations and variability between health outcomes, age, and EMS response

Second, analyses revealed a positive correlation between EMS response time and both ISS and LOS - the longer it took for victims to be transported to the hospital, the more severe were the victims' injuries, and the longer it took to recover.

EMS response times in the sample ranged from 5 to 230 minutes, and averaged about 44 minutes per incident (Table 2). EMS time-on-scene ranged from less than 1 minute to 101 minutes. The average response was approximately 16.5 minutes per incident.

	Min time	Max time	Mean (*SD*)	Median	Mode
Total EMS response time	5	230	43.88 (*28.58*)	37.00	26.00
EMS time on scene	< 1	101	16.56 (*10.57*)	15.00	13.00

Table 2. Case Study EMS response times in minutes

It is important to note that these findings serve to validate past research and literature on the topic, support current research on developing frameworks and IT artifacts that can be useful to practitioners, and support the need for improved data quality from public health and EMS practitioners. Accordingly, these analyses and findings were utilized as inputs into the design and development of the prototype system.

These findings are not intended to serve as an evaluation of emergency medical services, or of the quality of services at St. Mary's trauma center. Certainly an important limitation in this analysis is the quantity of data (or rather, the number of cases not captured in these analyses due to inconsistent data tracking).

Case Study Qualitative Data Analysis and Findings

Validating the importance of patient age, response time, response distance, and trauma outcome provided much needed context for conducting qualitative focus group discussions with practitioners. Participants were asked about their perspectives on the value, need, and use of clinical and performance information. Focus group discussions were held with trauma practitioners at both the local and state levels between March 2007 and January 2008. At the local level, 14 practitioners participated across the pre-hospital and hospital domains including emergency call center staff, paramedics, nurses, ED physicians, trauma surgeons, and hospital and IT administrators. The state level focus group was comprised of 16 state level EMS and Trauma decision makers. Participants represented the following organizations: Emergency Medical Services Regulatory Board (EMSRB), the Health Department (State Trauma System and State Trauma Advisory Council), Department of Transportation (Intelligent Transportation Systems Program and Office of Traffic Safety), and the Department of Public Safety (Traffic Safety).

A detailed discussion of qualitative findings has been presented in Schooley et al. (Schooley et al., 2009). In sum, participants expressed the need to have both pre-hospital and hospital data systems integrated to enable faster and more pertinent information exchanges, reduce data collection time on scene, and push forward much needed information to the trauma center for more accurate and timely patient treatment.

Findings from focus group discussions helped elicit the meanings, needs, issues, and benefits of an open, standardized, integrated, secure, and private information sharing environment. Key architecture design features were identified including (Schooley et al., January 6-9, 2009):

1. End-to-end operational process considerations for providing emergency medical care as seen through the eyes and experience of a patient (Horan and Schooley, 2007).
2. A multi-organizational view of the system architecture.
3. Dynamic information sharing considerations by a range of user types including dispatch, EMS, trauma, and public health oversight organizations.
4. Visualization of a range of data, images, video, and audio from a range of devices (e.g., mobile phones, computer aided dispatch software).
5. End-to-end performance reporting capabilities across organizations and information systems
6. Additional enterprise architecture characteristics are illustrated including:
    a. Security/Privacy
    b. Patient tracking system
    c. Directory and Access Services

Information needs included: (1) assimilation of data from heterogeneous sources, sites, and devices, (2) "mashing up" these data to produce a composite geographic based display, (3) visualizing MVA incidents, patient records, voice, video, and images collected on-scene on a composite page, and (5) visualizing aggregate clinical and performance information. These design features and information needs were employed in the design of the CrashHelp system.

CRASHHELP PROTOTYPE DESIGN

A prototype was built using information learned from the needs assessment performed during the focus group meetings and several predictive factors identified in the quantitative analysis,. An initial review of existing systems was first performed to become familiar with current state-of-the-art systems. These included several health-related GIS-based websites. Functions were identified and analyzed in an iterative agile development manner using pre-factoring and model-driven refactoring (Rosenberg et al., 2005).

CrashHelp Prototype Overview

The CrashHelp prototype was designed to integrate information about EMS responses and hospital treatment of MVC patients within the Mayo Clinic trauma jurisdiction. CrashHelp can be used to enhance decision making, help reduce emergency response times, and improve the quality of healthcare. The system was designed to 1) aid health care practitioners with real-time resource and patient care decision making 2) provide retrospective analysis of system performance for oversight and quality improvement initiatives. Unified patient information and performance reporting across emergency response and trauma care, derived from the operational level findings in prior research, (Schooley et al., January 6-9, 2009) were applied to this prototype.

The system was developed utilizing a range of current and emerging concepts and technologies including Web 2.0, geographic information system (GIS) Mashups, web services, dashboards, and multi-media mobile applications.

DATA FLOW DIAGRAM

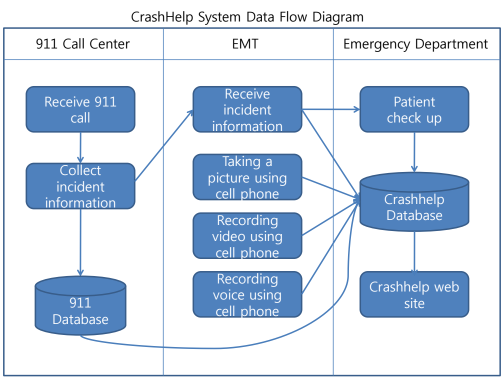

Figure 2. Data Flow Diagram

The CrashHelp System initiates when the 911 call center receives a call and collects incident information. Following receipt of the call emergency medical sevice providers (EMT) are dispatched sent the information collected from the 911 call center. The information is also saved in the 911 database. When the EMT reaches the incident location they 1.) take a picture of the scene, 2.) record audio notes, and 3.) capture video for the incident via cell phone to be sent to the CrashHelp database. After arriving at the trauma center where the patient is admitted, a nurse in the emergency department reviews patient and incident information provided by the EMT. The patient record is also saved in the CrashHelp database and the incident information, including the patient care record, is displayed on the CrashHelp system map.

Data Used in Prototype Development

For the prototype design, a number of data classes were assessed and considered across pre-hospital and hospital (trauma center) care settings. These included:

- Pre-hospital event times (time stamps) for: receipt time of the 911 phone call, time of ambulance dispatch, time of ambulance arrival on-scene, time of ambulance departure to the hospital, time of ambulance arrival at the hospital
- Resources deployed and type of transport: Basic Life Support, Advanced Life Support, Ground Transport, Air Transport
- Pre-hospital impression, assessment, and procedures including: the initial complaint reported by caller/patient as well as the EMT primary and secondary impression of the trauma patient
- Images and video of a trauma incident scene and/or patient
- Crash information including: Incident type (motor vehicle accident), use of extrication by emergency crews, Automatic Crash Notification information.
- Basic demographic data on the patient, including age, gender, and ethnicity
- Location information including: Location of the incident, location of the receiving hospital
- Trauma Center (registry) data including: Facility name, facility type, date and time of arrival, discharge date, basic demographic data, alive- or deceased – on - arrival status, injury severity score (ISS), length of stay at hospital (LOS), hospital disposition, discharge diagnosis.
- Fire station and hospital data including: name, address, longitude and latitude.

CrashHelp Prototype Requirements

Through a series of iterative design and development sessions, the following themes were identified as key to communicating EMS and Trauma issues related to emergency response:

- Visual Display – It is critical to portray EMS response in a manner that is both comprehendible to a wide range of users and that simultaneously brings together a range of related disparate data.
- Human – It is important to humanize the EMS response. Past research indicated that EMS personnel want to know what happened to the patient they treated. CrashHelp offers personnel a holistic view of the emergency response for a particular patient.
- Integrated Analysis – A wide range of users need a performance profile of EMS responses at both individual and aggregate levels, allowing for development of local and regional system-wide improvements with policy leaders, health, and safety professionals.

From these themes, the following functional requirements were defined:

- Map – visually display spatial data and key clinical indicators (age, response time) required for situational awareness and decision support as derived from statistical analysis.
- EMS Incident Profile – visually display pre-defined queries of EMS events, including EMS responder and patient information.
- EMS Response Statistics – enable drill-down (query/filter) through various data sets to facilitate extracting information about specific EMS incidents as needed by end-users.
- Real-time incident and patient status – provide indicators and dashboard gauges that allow visualization of EMS performance and patient status across a range of defined EMS incidents. Gauges represent specific injury related data such as age, response time, Traumatic Brain Injury (TBI) score, Glasgow Coma Scale (GCS), and Spinal Cord Injury (SCI) score.
- Graphical display of patient status – allow the capture of video and display of pictures by EMTs on-scene, through a mobile device, in a real-time incident status window.

CrashHelp Prototype Application Components

The CrashHelp prototype (Figure 3) displays two frames within a web browser. The left frame displays views of incident status, data layers, GIS tools, and resources. The right frame displays the incident map view. These views enable a range of user types to receive end-to-end EMS response and trauma care information.

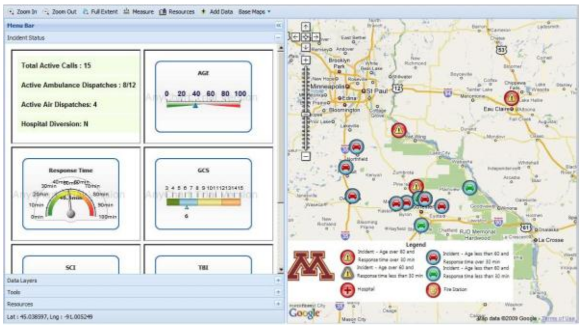

Figure 3. CrashHelp Prototype

Incident Status

The “Incident Status” page (Figure 4) displays current (real-time) aggregate incident information using graphical gauges. Users are able to view information such as the average age of incident participants, the average response time of EMS personnel, and the average GCS, SCI and TBI of injured participants.

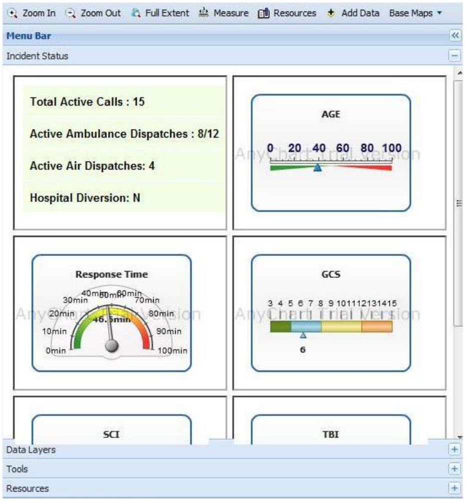

Figure 4. Incident Status Page

The current version of the CrashHelp prototype does not collect “live data”, but the intent is to implement this capability in a future version of CrashHelp.

Crashes - Map View

The “Crashes – Map View” page (Figure 5) displays the locations of current incidents and related resources (e.g., hospitals) in the Rochester, Minnesota region. A user may select an icon to view more detailed information about each resource. Several different Google or Microsoft map views can be selected by a user as the base map.

When the user selects an incident icon, the system allows for a “drill down” to display detailed incident information including photos taken on-site, streaming video, a Microsoft Virtual Earth map, and a Google Street View (Figure 6).

Similarly, when a Fire Station or Hospital symbol is selected, detailed information about that resource, such as name and the street address, are displayed.

The indicators discovered in the statistical analysis phase of this research were implemented into the GIS interface. Four separate icons for incidents indicate various combinations of age and response time. For example, one icon indicates that an incident has exceeded 30 minutes from the time of emergency notification. Another icon indicates that a crash patient is over age 60. Another icon indicates combined age and response time factors. In sum, the various icons represent "alerts" to practitioners based on clinical indicators for probable or likely injury.

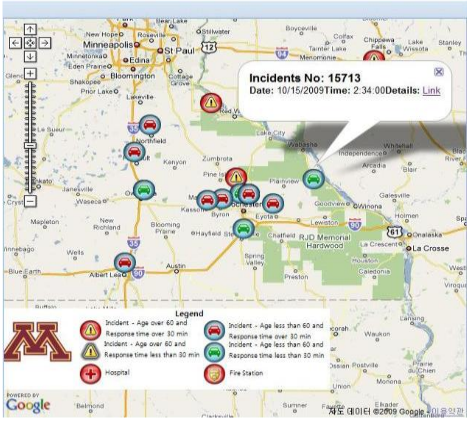

Figure 5. Crashes - Map View Page

Crash Profile Page

Another feature of CrashHelp is a detailed view of an incident. A drill down on an incident from the GIS interface will result in the display of detailed incident information on the Crash Profile page (Figure 6). Incident information is divided into several categories. The "Patient & Medical" section includes the patient profile information collected and reported by EMS responders. The "Incident Status" section includes response time data from 911 dispatchers (e.g., arrive on scene, depart to hospital, etc.). Incident location information is displayed on the Microsoft Virtual Earth map and the Google Street View. Gauges provide indicators for GCS, total response time, and ISS for that patient. Additionally photo images and video, taken at the incident scene with a mobile phone application, are included on this page.

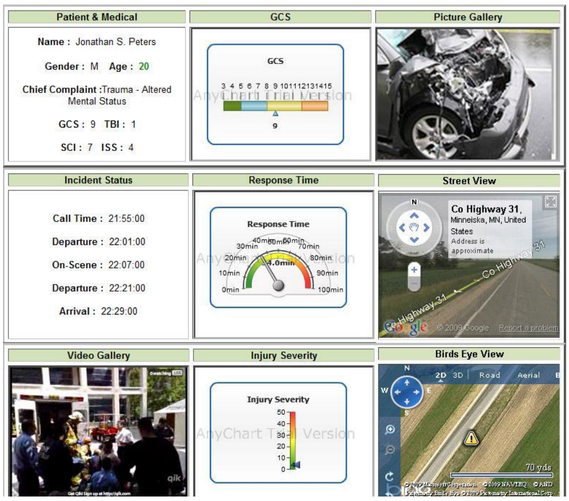

Figure 6. Crash Profile Page with Microsoft Virtual Earth and Google Map View of Incident Location

Data Layers

The "Data Layers" page (Figure 7) provides detailed resource information such as incidents, fire stations and hospitals, cell phone service areas, locations of traffic cameras, fatal crash hot-spot statistics, and current weather information.

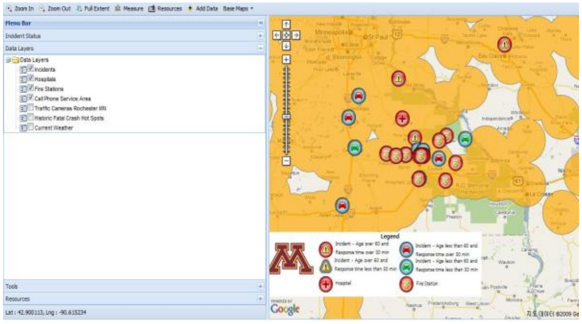

Figure 7. Data Layers Page

When a user selects a view of incidents, hospitals, fire stations or traffic cameras, the CrashHelp system displays a resource icon on the map. When a user selects a view of cell phone service areas, fatal crash hot spots, or current weather, the CrashHelp system displays colored area boundaries.

REVIEW AND EVALUATION OF CRASHHELP PROTOTYPE

The CrashHelp prototype was presented to an expert group of emergency practitioners (Russ-Eft and Preskill, 2009, Friedman and Wyatt, 1997) at the Mayo Clinic in Rochester, Minnesota. Through presentation of the prototype, several themes emerged in terms of the perceived value of the various CrashHelp features, needed improvements, and next steps (Hevner and Chatterjee, 2009, Jain, 1991). These are described below.

In general, the GIS graphical display combined with performance indicators and dashboard gauges were viewed as valuable for providing 1) a high level of situational awareness about the overall service demand on the trauma system, 2) potentially important information for making trauma care decisions for individual patients, and 3) a high degree of value for clinical Quality Assurance / Quality Improvement activities for post incident reviews. In addition, the GIS interface was viewed as an intuitive, efficient, and user-friendly platform for accessing needed and useful information.

Participants discussed the importance of having non-invasive technologies available to emergency health practitioners. Paramedics, physicians, nurses, and others that work in highly time-critical environments often view information technology as a distraction from caring for acute emergency situations. As such, the ability to capture and display pictures, video, and voice recordings in a GIS interface was viewed as potentially the most significant feature of CrashHelp. A general challenge for EMS practitioners is handing off patient information across pre-hospital and hospital environments. Data is generally not captured “in the field” fast enough to handoff to an emergency department to be used in a manner that impacts patient care. The use of a mobile application with image, video, and voice capture capabilities was viewed as valuable to 1) enable ambulance teams to “get back out on the street faster” as opposed to waiting around to provide a verbal description of the incident to a physician, and 2) accord trauma teams the capability to determine if and when they should assemble an expensive trauma team. For example, the voice handoff could be reviewed at the convenience of the physician through the GIS interface. The pictures and video could provide meaningful evidence to decide if and when to prepare for trauma surgery. Such an electronic handoff would potentially eliminate the need for a face-to-face handoff between time constrained EMS and trauma personnel.

While past engagements between the research team and case study participants focused on the integration and transfer of a large amount of EMS data, more recent discussions revealed the value of minimizing the amount of manual data capture in the field so as to minimize the burden on emergency personnel. Simply capturing age, gender, name, incident number, and injury level indicators were thought to be “good enough.” This data together with location, image, voice, video, and automated emergency response time stamps were believed to be highly useful. As such, the scope of the CrashHelp system retracted during final evaluation.

Likewise, the iterative design and development process of the prototype initially served to expand the scope of the system considerably, with researchers working to serve the needs of many stakeholders. This final evaluation, however, revealed that the high value features were those that benefited the care providers that work closest with the patient (paramedics, physicians) and required fewer data fields, but richer content.

Finally, participants at the Mayo Clinic discussed their belief that the CrashHelp system could be scaled and developed further and applied as a larger pilot study at the Mayo Clinic.

Discussion: Implications, Expected Benefits, and Next Steps

It is expected that these findings and prototype will lead to new protocols and applications for enhancing emergency medical response by aligning emergency health services to rich voice, video, and image content together with key socio-geographic and crash indicators on a GIS platform. While the specific case of MVC's provided the context for this study, participants felt that the CrashHelp system would be beneficial for all acute emergency medical situations (e.g., trauma, stroke, cardiac). The CrashHelp system could also provide expanded utility for mass casualty incident situations where multiple trauma centers and EMS services across government jurisdictions must collaborate to address the needs of many patients. From a theoretical perspective, this work addresses a significant gap in the literature on inter-organizational socio-technical systems within the emergency health care domain. In short, this work has addresses a societal and end-user need to simplify the design and visualization of a complex array of activities, users, organizations, and information sources into an accessible web based system. Methodologically, this work illustrates action-design research to address visualization, utility, and application of information from an end-user design approach. From a practical perspective, the prototype has been presented to a wide range of EMS practitioners for ongoing and iterative design and development. Uses for the prototype include:

- Patient information handoff. Exchanging patient information (including images, video, and audio) across pre-hospital and hospital domains for more real-time use is believed to have significant impact on continuity of care.
- EMS training and education. The visual display of an incident, the location, and targeted data provides a platform for training EMS professionals.
- Clinical quality improvement. Oversight EMS and Trauma organizations use case examples at regularly scheduled medical advisory and committee review meetings. The system provides a visual basis for discussing the "good" and "bad" cases and scenarios to improve care protocols and processes.
- Feedback Mechanism to Practitioners. A common need described by paramedics, 911 operators, and firefighters is the desire to see what happened to a patient he/she served. This simple tool allows for a quick query of an incident and related patient outcome information.
- Visualization for select user types. Due to the geographical and web-based design combined with end-to-end response information, the potential exists for decision makers within trauma centers and across trauma regions to have a common operating picture (COP) for larger scale decision making, such as trauma center diversion and re-routing in the case of mass casualty incident (MCI) situations.

While much has been discussed about the benefits of integrated systems that cut across traditional data "silos", this research and prototype has demonstrated a proof of concept for an emergency medical domain (i.e., trauma) where timely information makes a difference in the care of a patient. An important next step is to systematically expand the prototype into a working pilot system and test that system in the Mayo Clinic setting. While interactive feedback has been obtained throughout the development, a pilot assessment would provide a set of metrics for determining the value of this or related tools developed in the emergency health services arena.

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