December 2006

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Implications of Time-Critical Information Services on Emergency Response ITS Architecture: Scenario-Building and Market Package Analysis

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ABSTRACT

Previous emergency medical services (EMS) research has established a foundation for conceptual and empirically based tools that improve the scientific understanding of the interaction between information and organizational systems. Recent research has introduced the time-critical aspect into the delivery of EMS by examining end-to-end performance through a chain of dispatchers and responders. Within the United States, work is currently underway at a national level to develop the next generation of 9-1-1 services that integrate voice, data, and video. However, there still exists a challenge in that no single organization is responsible for managing end-to-end system performance. Knowledge of the performance across the system will benefit stakeholders and organizational elements responsible for facilitating service level agreements between the service providers. Based upon an examination of the Intelligent Transportation Systems architecture and the Next Generation 9-1-1 Concept of Operations documents, the authors provide recommendations for integrating performance metrics into emergency response architecture.

Keywords

Architecture, emergency medical services, performance, time-critical information services.

INTRODUCTION

If you were involved in a life-threatening medical emergency, wouldn’t you like to know that throughout the entire service delivery process, each of the organizations responsible for your health care work as a tightly coupled team using the latest technology? The United States Department of Transportation (USDOT) has developed the National Intelligent Transportation Systems (ITS) Architecture that, among other things, includes the logical and physical architecture for emergency services (National ITS Architecture, 2006). Recently, the USDOT has launched the Next Generation 9-1-1 (NG 9-1-1) Initiative for the purpose of upgrading existing public emergency services from a “voice only” system to one that handles voice, text, data, images, and video, which have become common in a wireless and mobile society (NG9-1-1 RFI, 2005). However, nascent research has shown that there exists a challenge to ensure that the information relating to the end-to-end system performance is captured (Horan and Schooley, 2005a). This is significant, since at the present time, each organization that plays a part in EMS is chiefly concerned with their individual performance, rather than the performance of the system as a whole. Knowledge of performance metrics across the system will be of paramount importance not only to each of the stakeholders, but also to the organizational elements that are responsible for facilitating the service level agreements between the service providers.

The authors have evaluated the Preliminary NG9-1-1 Concept of Operations (ConOps) document proposed by the USDOT (NG9-1-1 ConOps, 2005) for EMS and have developed a scenario that highlights the architectural characteristics necessary to achieve real-time, end-to-end performance. This new scenario can be used to augment the existing set of scenarios that are currently in the NG9-1-1 ConOps document. In addition, the authors have examined the National ITS Architecture and have developed an architectural approach that includes performance metrics and elements of the newly developed NG9-1-1 scenario. This approach will be useful in identifying the information to be gathered in real-time from the various elements that make up the National ITS Architecture. Essentially, the concept of end-to-end performance is reified in the scenario and the architecture. These proposed enhancements can then be readily applied to the existing National ITS Architecture and the
Preliminary NG9-1-1 ConOps document, where, together they will be beneficial to the U.S. government sector as it begins development of the NG9-1-1 system.

The remainder of this paper is composed of five main parts. First, an explanation of the concept of time-critical information services and the need to include performance metrics in end-to-end emergency response. Second, an overview of the National ITS Architecture and next generation 9-1-1 systems. Third, the methodology for incorporating end-to-end performance metrics into the national architecture and the NG9-1-1 ConOps document. Fourth, an analysis in the form of a new scenario for the NG9-1-1 ConOps and modifications for the National ITS Architecture. Finally, implications from this research as well as future research directions.

IMPLICATIONS OF TIME-CRITICAL INFORMATION SERVICES

This section introduces the concept of time-critical information services and the need to include performance metrics in end-to-end emergency response.

Time-Critical Information Services

Time-critical information services (TCIS) combine the aspects of time criticality and information criticality with regards to EMS. The time critical portion involves rapid delivery of emergency services, which are dependent upon accurate and timely information from multiple organizations (Horan, Marich, and Schooley, 2006). The delivery of these emergency services are also information critical in that they have become greatly dependent upon information, such as the type of incident, the incident location, and the medical needs of the injured citizens (Arens and Rosenbloom, 2002; Hale, 1997; Turoff, Chumer, Van de Walle, and Yao, 2004). The effectiveness of the time and information service elements are dependent upon the cooperation of each organizational element and the effective use of information technology (Mayer-Schonberger, 2003).

The Need for Performance Metrics

The notions of Just-in-Time (JIT), Supply Chain Management (SCM), Business Process Reengineering (BPR), and more recently Business Process Management (BPM), refer to the business need to improve business processes and services using information technology. Beyond the popular discussion of JIT, however, is the idea that “takes into account individuals’ interdependent work patterns, the macro context in which they work, and the interconnections between this context and their work patterns” (Perlow, 1999, p. 80). One goal of SCM is to bring about end-to-end performance improvement as it increases customer satisfaction through business efficiency (Bose and Pal, 2005). BPR emphasizes “achieving improvements in critical measures of performance, such as cost, quality, service and cycle-time reduction” (Hammer and Champy, 1993, p. 32). TCIS extracts these and other improvement concepts from the business world and introduces them into public services related to emergency management. This paper serves to highlight specifically how the National ITS Architecture and the ConOps being developed for NG9-1-1 can benefit from these improvement concepts in terms of performance.

For TCIS, end-to-end performance is what matters to an injured citizen (Horan and Schooley, 2005b). Performance metrics are defined as those parameters within and across the organizational elements that can be measured from initiation of a 9-1-1 call until arrival of the patient at a hospital. For instance, if a dispatch operator answers a 9-1-1 call immediately and notifies an emergency vehicle within the allotted time, but the ambulance takes a long time to arrive or goes to the wrong location, the resulting performance metrics across the entire system are adversely impacted. The measurement of performance metrics is essential to understanding the following three issues. First, how public services are delivered to the public. Secondly, the levels of service (i.e., timeliness and quality) with which they are delivered. Finally, how the network can be improved to deliver better services in an information-critical and time-critical manner.

OVERVIEW OF NATIONAL ITS ARCHITECTURE AND NG9-1-1 CONOPS

The National ITS Architecture is classified as a collaborative, large-scale, evolutionary, socio-technical system, having a highly distributed, yet heavily interconnected architecture (Maier, 1997, Maier and Rechtin, 2002). ITS’s are collaborative in that they are built and operated through voluntary choices of the participants (Maier and Rechtin, 2002). Flexibility has also been recognized as a critical feature of the National ITS Architecture, allowing easy adaptation to future changes as well as accommodation to regional differences (Weissenberger, Lo, and Hickman, 1995). A more detailed explanation of the National ITS Architecture can be found in (USDOT, 1994).

In essence, the National ITS Architecture “provides a common structure for the design of intelligent transportation systems”; rather than a system design or design concept, it prescribes a “framework around which multiple design approaches can be developed” (NITSAES, 2003). For the purposes of this paper, it is important to understand the term “market package” and
its relationship to the logical and physical architecture, as described in (NITSAES, 2003). The logical architecture provides a functional view made up of process specifications that are used to perform user services, with the functions represented in a set of data flow diagrams. The physical architecture breaks down the logical architecture functions into several high level classes and many lower level subsystems. Emergency Management is an example of one of many subsystems within the physical architecture. The National ITS Architecture is enormous in breadth and depth. Due to this enormity, the concept of market packages has been devised. Market packages focus on specific portions of the Physical Architecture and are used as a means of breaking down and targeting a variety of user services to a particular interest group, for example, people interested in EMS. The market package is represented as a combination of subsystems and terminators, the combination of which is referred to as entities.

The NG9-1-1 Preliminary ConOps document “provides a user-oriented vision of the NG9-1-1 within the context of an emergency services internetwork that can be understood by the stakeholders with a broad range of operational and technical expertise” (NG9-1-1 ConOps, 2005). The ConOps document contains an operational description, operational needs, system overview, operational scenarios, and references. For the purposes of this paper, an understanding of the operational scenarios is important. The operational scenarios are textual descriptions that are used to describe NG9-1-1 concepts from the point of view of key users. The current ConOps document provides three different hypothetical scenarios involving telematics, interactive text, and system overload.

**METHODOLOGY FOR INCORPORATING END-TO-END PERFORMANCE METRICS**

TCIS are dependent upon the cooperation of the organizational elements that are used to produce and distribute information and services in a timely fashion. Since the overall performance of the EMS system is what matters to an injured citizen, rather than the individual performance of a particular organizational element, the cooperation of the elements is vital. The methodological approach selected for this research attempts to apply TCIS features to the National ITS Architecture, which is chiefly characterized as being collaborative, large-scale, evolutionary, and socio-technical.

To exhibit the benefits that would be obtained through the collaborative nature of the organizational elements, a new scenario to augment the Preliminary NG9-1-1 ConOps document was developed as part of this study. The scenario is based upon case study data that was gathered from actual EMS systems (Horan and Schooley, 2005b). Guidance on the document structure, including the technological capabilities of the NG9-1-1 system was provided in the Transportation Management System CONOPS Primer (TMC PFS, 2005). The new scenario was then validated by two experienced EMS practitioners and the Program Advisor for the National Association of State EMS Officials. The NG9-1-1 Initiative is currently in its formative stage, with the Preliminary ConOps document being one of the first documents being released to the public. Adding a scenario that emphasizes collaborative features will help provide direction as the system requirements are generated in the near future.

As previously stated, the National ITS Architecture involves socio-technical issues. The evaluation of an architecture based on “socio-technical issues is difficult because it is unclear how to take an organized and rational approach to issues that are so difficult to rigorously model” (Maier, 1997, p. 615). Previous literature has applied heuristics to architecture evaluation and selection, especially with regards to ITS (Maier, 1994, 1996, 1997; Maier and Rechtin, 2002). A compilation of collaborative system heuristics is captured by Maier and Rechtin (2002, p. 126-135) and two that seemed especially suitable for the purposes of this paper are:

“The greatest leverage in system architecting is at the interfaces.”

“If a system requires voluntary collaboration, the mechanism and incentives for that collaboration must be designed in.”

To exhibit the benefits that would be obtained with regards to the socio-technical issues, a market package was developed to specifically show the various interfaces involved. As previously mentioned, the use of a market package allows a focused view of the elements contained within the National ITS Architecture, which in this case will be centered around EMS systems. Throughout the development of the market package, the authors were mindful of the above heuristics. Specifically, we developed a set of message sequence diagrams that show each of the components that were highlighted by the scenario. In the course of generating the sequence diagrams, we became aware of the many data flows associated with EMS performance and the need for collection and dissemination of the performance metrics among the subsystems involved in EMS. Our approach to showing the messages sequences between the organizational elements allows one to see how an evolutionary approach might be undertaken since these large-scale systems, as contrasted to small- to medium-scale systems, are typically built out over the course of time.
After generating the message sequence diagrams, we then translated the components in the scenario to their corresponding entities within the National ITS Architecture. It was at this point it became apparent that in order to achieve successful integration of the entities within the architecture, a much more active performance management role must be present. From our scenario we have identified this dynamic performance management role as the EMS Performance Monitor. We have, in essence, transformed the current Archived Data Management Subsystem as it exists in the National ITS Architecture to something that is more “real-time” in its ability to gather and provide useful knowledge to the EMS subsystems. Based upon the scenario component translation, a new market package was developed for the National ITS Architecture. Existing ITS market packages were used as models for the new market package. This new market package is chiefly focused on introducing performance metrics into the Emergency Response Subsystem. After development of the sequence diagrams, translation, and market package, a practitioner possessing extensive experience with the National ITS architecture validated the artifacts. Each of these analytical elements follow.

**ANALYSIS**

“The architect’s core role is to assist the system’s client in the making of key technical decisions” and to “use models and methods that communicate with the client” (Maier and Rechtin, 2002, p. 233). Therefore, a scenario was first devised for NG9-1-1 in a similar format to the scenarios that are presented in the Preliminary NG9-1-1 ConOps document. The scenario was circulated to several NG9-1-1 experts for commentary and refined for presentation below. Subsequent to this scenario development, a market package analysis was conducted using the National ITS Architecture. The results of this analysis are also presented here.

**NG9-1-1 Scenario Devised**

The following scenario was developed to demonstrate the characteristics of an architecture that captures end-to-end performance metrics. This new scenario reflects many of the concepts currently being promoted for the NG9-1-1 system.

**Scenario: End-to-End Performance Metrics for NG9-1-1**

The Brown family makes the yearly trip in September from their home in Canada to the United States to see the automobile races held in rural Minnesota. Traveling on a rural highway in Northwestern Minnesota during heavy rain showers, the Brown’s are involved in a vehicle crash. Unfortunately, the Brown’s have an old vehicle that is not equipped with a vehicle telematics system.

Realizing that the other occupants are in need of immediate medical assistance, Cindy uses her cell phone to dial 9-1-1. Fortunately, the Brown’s vehicle is not located in a cell phone coverage dead zone. Although the cell phone number is neither local nor U.S., the multinational IP-based communication system employed by NG9-1-1 allows her to access a third party emergency call center.

From the Third Party Emergency Call Center, the call is automatically forwarded to the nearest available Alternate Public Safety Answering Point (PSAP) over 60 miles away, since the performance data in the system indicates that a high volume of calls is currently overwhelming the two Call Takers at the Local PSAP. The performance data automatically acted upon by the system consisted of: PSAP locations, number of calls in queue at the PSAPs, number of Call Takers actively taking calls, and total call response time and average call duration per call at each PSAP.

The Alternate PSAP receives the call and Cindy describes the situation and the nature of the injuries as well as she can to the PSAP operator, who inputs the description into the system. The alternate PSAP then notifies the closest available Emergency Medical Service (EMS) Provider, also based on the performance data in the system. The performance data automatically acted upon by the system consisted of: incident location, nature of the injuries based on caller description, location of EMS Bases, availability of resources at each EMS Base, skill levels of on-duty staff, and current road conditions.

Before departing the EMS Base, the ambulance is determined to be properly equipped for the incident based upon the performance metrics in the system, but another ambulance will be required because there are multiple patients. Because the incident occurred in a rural area, an Air Medical Helicopter has been placed on alert. The performance data automatically acted upon by the system consisted of: number of patients with injuries, nature of injuries based on caller information acquired by the PSAP, types of equipment, tools, and medical supplies needed to effectively respond, and skill levels of the EMS responders.

Upon arrival at the scene, the initial EMS Crew finds no life-threatening injuries. They automatically send video of the injured occupants from head-mounted mini-cams into an information system that can be accessed by all parties involved in this particular patient care episode. They also input patient status and injury description text into the system by speech-
recognition technology, images from portable ultra-sound and other imaging devices, and data from vital signs and cardiac monitors by wireless transmission. All of this data is input during the course of patient assessment and can be pulled by other care providers as they need the information (e.g., the emergency room physician at the receiving hospital, the second arriving ambulance crew which is en route). The physician and emergency medical technicians are able to share data and video without disturbing the flow of their work but also communicate by voice when necessary.

Just as the ambulances are ready to leave the scene with the patients, the performance data that the EMS Crews automatically receive suggests that they redirect to a different hospital over 25 miles further than the closest hospital. The performance data automatically acted upon by the system consisted of: nature of patient injuries as described by the EMS Crew upon arrival and examination at the scene, time duration from the original 9-1-1 call until departure to the hospital, hospital location, current availability of hospital to receive patients, estimated hospital wait times to receive additional patients, types of services that the hospital provides (e.g., trauma, advanced coronary care), and skill sets and availability of hospital staff. With this information, the EMS Crew and emergency physician are able to select the most appropriate hospital to treat the Brown family’s injuries.

The on-board information system in the ambulances automatically update the driving directions on their GPS receiver system so that they avoid the traffic congestion caused by road debris from the storm, which they would have encountered on their “normal” route to the hospital. The performance data automatically acted upon by the system consisted of: current location, destination location, weather conditions, and traffic incident reports.

Finally, the emergency physician at the alternate hospital begins to pull the stored video, speech-recognition entered text, monitoring device and imaging information as the previous hospital staff signs off. The additional Brown family members that were not transported with the injured family members are transported via a State Patrol vehicle and are kept up-to-date on the condition of the injured family members.

Analysis of Scenario in Terms of Market Packages

As shown in Figure 1, we envision the NG9-1-1 system as one in which all components of the system provide performance metrics on a periodic basis. In this diagram, each of the system components is shown providing performance metrics to the EMS System Performance Monitor. It should be noted that this figure, as well as subsequent figures in this paper are used to illustrate architectural perspectives and are therefore abstract representations. As such, they do not infer a specific implementation. Along these lines, the EMS System Performance Monitor appears as a single entity, but this is not to imply that its implementation would necessarily be realized as a single entity.

In addition to providing performance metrics to the EMS System Performance Monitor, each component of the system receives performance metrics from the other components on a periodic basis. The message sequence diagram in Figure 2 provides an illustration of this concept. The message sequence diagram that was developed for the new NG9-1-1 scenario is illustrated in Figure 3. In this figure, it is assumed that each of the components is periodically providing and receiving performance metrics (as shown in the previous two figures). This figure is limited to showing only those sequences that are specific to the scenario.

Table 1 provides the mapping of users listed in the scenario to the entities listed in the National ITS Architecture. The resulting market package graphic, shown in Figure 4, was developed to demonstrate the characteristics of an architecture that captures end-to-end performance metrics. As such, this market package is based upon the new scenario and portions of the existing ITS Architecture.

The market package identifies key points of integration between care facilities, emergency telecommunications systems, and emergency management. The emergency management subsystem represents various government and private agencies that provide emergency medical services to the public. Much of the information sharing associated with this market package is coordinated internally within the emergency management subsystem. Another major portion of the information is gathered through the use of the archived data management subsystem acting as an operational data store. The archived data management subsystem is used to collect performance metrics from each of the components contained in the emergency management subsystem and distribute the performance metrics among each of the components. The archived data management subsystem also has access to the performance metrics from each of the emergency management components. It can therefore provide a management service to coordinate the timely activities between emergency management components. This service is labeled incident control on the market package graphic. The emergency management components provide a response back to the archived data management subsystem, which is used to indicate the ability of the component to meet the requests of the archived data management subsystem. This response is labeled incident control response in the market package graphic.
Figure 1. System Components Provide Performance Metrics

Figure 2. System Components Receive Performance Metrics
Figure 3. New Scenario Sequence Diagram

<table>
<thead>
<tr>
<th>User Names from Scenario</th>
<th>Entities in National ITS Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-1-1 Caller</td>
<td>Emergency Telecommunications System&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Party Emergency Call Center</td>
<td>Emergency Management&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>PSAP Call Taker</td>
<td>Emergency Management&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>EMS Provider</td>
<td>Emergency Management&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>EMS Base</td>
<td>Emergency Management&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>EMS Crew</td>
<td>Emergency Vehicle Subsystem&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hospital (Emergency Room Physician)</td>
<td>Care Facility&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>State Patrol</td>
<td>Emergency Management&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>EMS Performance Monitor</td>
<td>Archived Data Management Subsystem&lt;sup&gt;1&lt;/sup&gt; (used here as an Operational Data Store)</td>
</tr>
</tbody>
</table>

Notes: 1 indicates a subsystem; 2 indicates a terminator.

Table 1. Scenario to Architecture Mapping
CONCLUSION
The authors have provided a new scenario for NG9-1-1 that demonstrates how performance metrics will affect the architecture of future systems. Additionally, we have mapped the NG9-1-1 users listed in the new scenario to the entities in the National ITS Architecture. This mapping technique will be useful for future work on NG9-1-1. From the resultant mapping, a new market package was developed for the National ITS Architecture that introduces performance metrics into the system. Distributing performance information among the presently isolated subsystems is a crucial step to bringing just-in-time, supply chain management, and business performance management characteristics to EMS. The authors have developed the scenario and market package with the hope that NG9-1-1 systems become known not only for voice, video, and data, but for their seamless integration of end-to-end performance as well.

Research Contributions
The research presented here has provided an initial examination into three important dimensions related to EMS architecture associated with NG9-1-1 systems. Namely, how public services are delivered, the level of service provided, and how the network of providers can be improved. In the following paragraphs, we have drawn out a number of lessons through the development of the scenario and market package. These lessons are not only applicable to e-government practitioners, policy makers, and academicians involved the USDOT National ITS Architecture, but can also be applied by e-government personnel throughout the world as they consider upgrading existing 9-1-1 services.

Since current 9-1-1 services are delivered by isolated organizations, the scenario has attempted to show how the integration of services will result in vast improvements in capability and the level of service provided. Through the scenario, the sharing
of information among the organizations has resulted in the injured persons being taken to the hospital in a very expeditious manner as the various EMS elements seamlessly deliver their services. The data that beforehand had resided solely within the organizations can now be shared with others, and thus, transforms the services to become much more customer focused.

The market package provides a high level view of how the organizational elements will interface with one another in their delivery of integrated services. The market package diagrammatically shows the particular information that each element of the system can exchange with the other elements. For implementation purposes, this diagram is most useful in allowing one to visualize how a system can be transformed in stages. Interfaces can be added in a sequential fashion over time, rather than building the entire system at once, which may allow for more cost effective implementations for many communities. In addition to cost, there are also considerations to the human/business change aspects to be considered. By developing the system in stages, communities can work through the difficulties that often occur when people are faced with change, especially with change that not only affects professionals that may be reluctant to change, but changes to life-saving processes that are deeply engrained within the service organizations.

**Future Directions**

As a result of this research, the authors plan to present their new scenario to the USDOT for consideration as an update to the ConOps document. EMS systems are valued for their importance to save lives. We believe that the contribution that we have provided in this paper will help to shape the architecture upon which future EMS systems will be based and, in doing so, increase the number of lives that are saved.

This research has exposed a number of issues that could provide avenues for further work. For instance, it is envisioned that as more data is passed through these large-scale systems, many critical decisions will be made autonomously based upon the data. Because people’s lives are at stake, the quality of the data will need to be assured. Additionally, with the increased information available to EMS personnel such as PSAP Operators, EMS crews, and Emergency Room Physicians, a balance must be maintained in order to prevent information overload.

Future research is planned to validate the proposed end-to-end performance metric through an examination of how real-life performance would be enhanced through the inclusion of elements such as those described in this paper. EMS systems, like most other systems, do not come into being from a baseline of zero; they evolve over a period of time through their usage. We intend to determine in what ways the near real-time capture of performance information affects the services rendered by an EMS system. Our goal is to conduct a comparative case study between one case study location that has not implemented a performance management system and another location that has either partially or fully completed implementation.

**ACKNOWLEDGMENTS**

We sincerely thank the following people for their contributions to this document. Kevin McGinnis, MPS, EMT-P, and Program Advisor for the National Association of State EMS Officials and Glen Youngblood, MICP and EMS Program Specialist at the San Mateo County EMS Agency, for their review and comments on the scenario. Ron Ice, of ICE and Associates and a member of the National ITS Architecture team, for his review and comments on the market package. The anonymous AMCIS reviewers and track chair, Professor Tony Elliman of Brunel University, for their thoughtful review and insightful comments. We also thank the State and Local Policy Program, Humphrey Institute and the ITS Institute, University of Minnesota for the research funding support. Several of the interviews as well as exploratory analysis was based on work supported by the National Science Foundation under grant number 0508938.

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