

Devising an Architecture for Time-Critical Information Services: Inter-organizational Performance Data Components for Emergency Medical Service (EMS)

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ABSTRACT

This paper reports on a case study analysis of a county-wide emergency medical services (EMS) system striving to implement information technology across service provider organizations (e.g., fire, ambulance, dispatch center, hospitals) to enhance e-governmental emergency response performance. An analysis of performance data and supplemental interviews from emergency response organizations are used to inform this study. From these data sources, researchers performed process and information flow analysis across a chain of dispatchers, responders, and health care facilities to understand barriers and challenges to accessing and linking time-critical data across service organizations. The analytical lens is a socio-technical framework developed from prior e-government research on time-critical information services (TCIS), or public services highly dependent upon time and information (e.g., emergency response, law enforcement). Findings include inter-organizational gaps in data access across pre-hospital and hospital information systems, the need for patient tracking across organizations and systems to enable end-to-end analysis, and time and quality of care benefits to inter-organizational data access and use. The National Intelligent Transportation System Architecture is applied to the case study location to validate the functionality of the TCIS framework and to provide strategic guidance for the case study locale. Recommendations are provided on how the architecture can be adapted to enhance end-to-end performance of EMS systems.

Categories and Subject Descriptors

H.4 [Information Systems Applications]

General Terms

Performance, Design.

Keywords

architecture, e-government, emergency medical services, emergency response, performance, time-critical information services.

1. INTRODUCTION

An important goal of e-government research is to enhance understanding about how information access and use across multiple agencies improves the performance of end-to-end services to the public to better serve the needs of citizens. Perhaps one of the most illustrative examples of this phenomenon can be found in ‘time-critical services’ to the public, where service performance can have life and death implications [1]. Time-critical public services include law enforcement, homeland security, fire, emergency medical services (EMS), hazardous material (HAZMAT) response, disaster response, and humanitarian aid assistance. The time-critical dynamic of these services introduces complexities to multi-organizational information sharing, including the need for timely information in a form that can be trusted and used by emergency responders [2, 3]. Information systems developers need to understand what components and elements are needed to facilitate inter-organizational data access and integration in order to identify the functional requirements for the larger socio-technical EMS data management system.

This paper builds on a recent set of e-government analyses that have identified the need and value of examining inter-organizational systems (IOS) and process improvement concepts in e-government generally and time critical services specifically [2,4,5,6]. It follows suggestions by [6,7,8], who identify a need to further explore public sector inter-organizational information sharing and its performance implications. More directly, this study extends research conducted by [2,9,10] who present a general framework for understanding and studying a type of inter-organizational e-government information system – one that must support a highly time-critical process and end-to-end service.

Past research has been conducted in multiple phases, encompassing field visits, interviews, focus groups, and performance data analysis and simulation. More recently, the team conducted an expert workshop (sponsored by the National Science Foundation) to further refine the conceptual model and methodological approach. Their research findings have been used to construct a framework for understanding and studying

Time-Critical Information Services (TCIS), or information systems that support time-critical public service delivery from end-to-end (see Figure 1).

In preliminary work, researchers found that organizations seem limited in their ability to access pertinent and valuable data relative to end-to-end EMS service. Yet, inter-organizational access is essential to measuring service performance from end-to-end. These findings have also been confirmed in recent studies by [11] and [12]. While these studies have described the need for access and integration of EMS data from a range of cooperating EMS entities, they have not empirically studied issues related to access in the EMS domain. An important purpose of this case study is to understand what data is exchanged across EMS organizations, why service organizations do or do not have access to end-to-end data elements, how this links to patient-centered performance, and how the analysis could be extended into an IT architecture for inter-organizational EMS information sharing.

As stated previously, the TCIS framework will be used to guide the analysis. While the framework has been constructed from research literature and peer-reviewed in conference proceedings and journals, it requires validation as a tool for conducting real-world case analyses including how the analytical findings could be used by an existing framework to construct a useful solution. A theoretical purpose of this study therefore, is to understand how findings from TCIS analysis could be used to map to an established architecture, designate data access points for system improvement, and to essentially validate the TCIS framework as a tool for end-to-end EMS systems analysis and design.

This study utilizes the TCIS framework to analyze the EMS service process of a county wide EMS system. Specifically, it focuses on the first three levels of the framework – to understand the process, the organizations involved in the process, the performance indicators, and the multiple dimensions of inter-organizational performance information exchange (see Figure 1). The TCIS framework was developed to aid in the study of Time-Critical Information Services (TCIS), or public services that are highly time and information dependent. The researchers have developed this framework in a manner that allows for a multi-dimensional view of “end-to-end” system performance, and information sharing therein, for time-information critical services such as EMS. While the TCIS framework has been refined through conferences (e.g., DG.O 2006), professional publications (e.g., Horan and Schooley, 2007), and a National Science Foundation (NSF) supported workshop on the topic (see Horan, Marich, and Schooley, 2006), the case study reported below has provided an important opportunity to further validate this approach through examination of a real-life time-critical service as well as application to a well established system architecture.

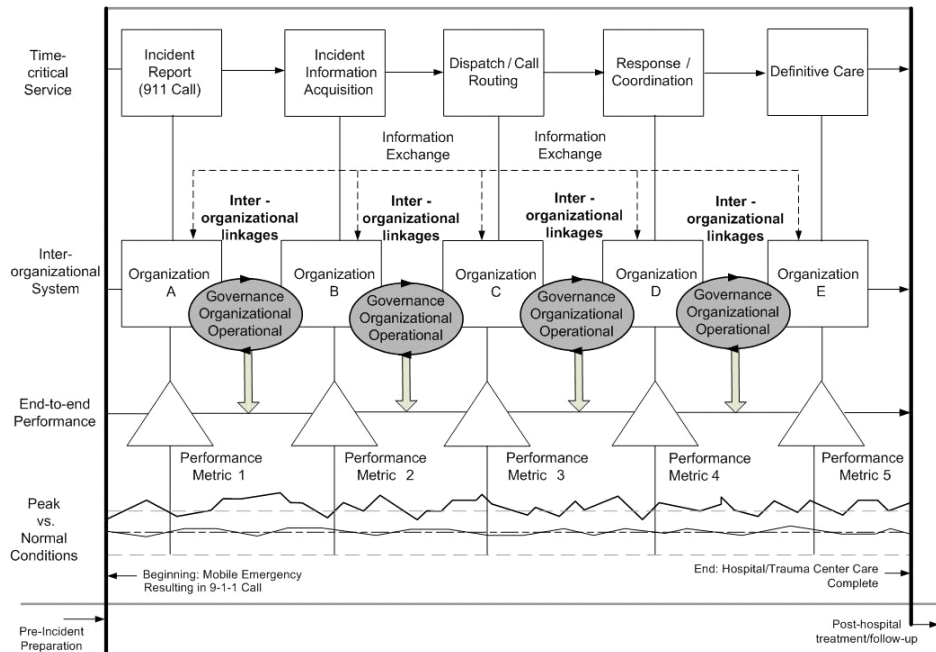


Figure 1. TCIS Framework

This paper builds on the San Mateo case study analysis that has been summarized in [8]. Here, we focus attention on the information and data elements and architectural implications. First we examine the specific information handoffs across an inter-organizational, end-to-end service process to analyze issues and challenges associated with information access. Furthermore, the authors conduct a “process analysis” that is then regularized into a general system architecture for EMS specifically, and e-government services more generally [9,10].

2. RESEARCH APPROACH

Our case study effort examined inter-organizational information exchange and data access through three overlapping phases. The first phase investigated the operational and technical levels including what performance-related information is/is not collected, communicated, and/or exchanged across organizations. It examined the technical information systems, business processes, and information flows. The types of data that were collected for this analysis are as follows: business process documentation, performance data for the year 2005, technical information system documentation, management reports, performance reports, inter-organizational agreements including formal and informal contracts, as well as field notes from observations and interviews.

This data was collected through field visits on location at each participating organization as well as through follow-up phone and email conversations. During field visits, researchers interviewed staff and management personnel, observed both demonstrations and real-world operations, including sitting with emergency dispatch operators and riding along with fire/paramedic and ambulance crews. During this phase, the researchers asked those being interviewed to describe the end-to-end EMS service process, to provide details related to the information that is passed between organizational components, and what information technologies are used to support information exchange.

The second phase examined contextual issues about the performance-related information exchanges. Semi-structured interview questions sought to understand issues surrounding the access and linkages to performance data from the perspective of each organization. Specifically, researchers asked why each service organization has or does not have access to data elements identified in phase I. As in the first phase, researchers took detailed field notes, and summarized observations. Inter-organizational “linkage” issues were categorized by the three focus areas posited in the TCIS framework: operational, organizational, and governance.

The final phase included analysis of first and second phase findings to assess, from a systems architect standpoint, how the findings could be applied to an architecture for supporting the San Mateo EMS system. The criteria for analysis was the National Intelligent Transportation Systems (ITS) Architecture and associated documents [13], a well established and widely used architecture for large-scale socio-technical systems development.

2.1. Performance Measures for EMS

In order to explore performance implications of inter-organizational information access, it is important to further describe the concept of performance as it relates to this study.

This study utilizes the view of a recent Institute of Medicine (IOM) (2006) study where the critical performance features of the system are those that matter most to a patient: *timeliness*, and *quality of care*. Time has long been used in EMS to measure inter-organizational system performance (IOM, 2006). It is measured by recording time-stamps at specific points in service delivery, from notification (9-1-1 call), to arrival at an incident, to delivery of a patient to a health care facility. A significant finding from the recent IOM report was that quality of care performance measurement is largely lacking and significantly differs across local EMS systems. It is safe to say that unlike the nature of the “time” metric, the quality of care metric is more multi-faceted. This study explores information access across organizations and how a greater degree of access influences the general notion of quality care EMS performance. Specific quality of care performance metrics are embedded in the information types that have been labeled “treatment provided” and “patient condition” in the case study analysis (see figure 5).

3. SAN MATEO CASE STUDY

The research setting for the study was San Mateo County, CA. San Mateo County is located between the Pacific Ocean on the west, San Francisco Bay on the east, San Francisco County on the north, Santa Cruz County on the south, and Santa Clara County on the south east. While the majority of the population of approximately 700,000 live along a narrow corridor along the 101 freeway, the majority of the land mass is located in rural and remote mountain and coastal areas.

The San Mateo County EMS Agency formed an innovative public/private partnership to provide more efficient and effective emergency medical services to its citizens throughout the county. The partnership was established in 1999 after a four-year planning process that involved nurses, physicians, paramedics, city managers, fire agencies, ambulance providers, consumers and county staff as well as an RFP process with ambulance providers. The partnership includes the County Health Services Department’s EMS office, American Medical Response (AMR) ambulance service, a Joint Powers Authority (JPA) made up of all 17 fire service agencies in the county, and the County Public Safety Communications Center. Oversight for the EMS system, both operational and medical, is provided by the EMS office of county Health Services, which holds the master contract with AMR for both ambulance service and paramedic first response. AMR has subcontracted paramedic first response service to the JPA and communications dispatch service to the County Communications Center (see Figure 2 for partnership arrangement). The 11 independent health care facilities throughout the county are not formally included in the partnership, but collaborate with each of the major partners. This collaborative arrangement was the county’s first “performance based” contract system, and it has received a number of awards from the National Council for Public-Private Partnerships, International City-County Management Award for Outstanding Partnerships, the League of Cities Helen Putnam Award for Excellence in Public Safety, and the International Association of Fire Chiefs.

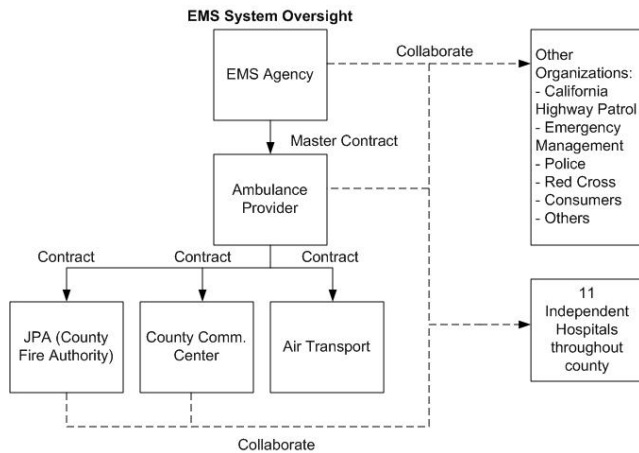


Figure 2. San Mateo Governance Structure

The EMS system consists of a single consolidated dispatch center that performs all dispatch services for fire departments and ambulances within the County. The dispatch center also provides dispatch services for the County Sheriff's department and five other local law enforcement agencies in the county. It does not dispatch for the state-run California Highway Patrol (CHP) or for the remaining 18 local law enforcement agencies in the county. However, due to the need for local agencies to save on costs, several of these law enforcement agencies are in the planning stages to outsource dispatch to the County Communications Center.

The system dispatches the closest fire engine and ambulance to every medical incident regardless of local fire agency boundaries. The previous system provided paramedic ambulance response with a 9-minute response time standard in the more populated areas. In the current system, fire engines with paramedics on board respond within 7 minutes (with >90% compliance). Emergency ambulances continue to be staffed by paramedics but have a response time standard of 13 minutes (with >90% compliance). The cost savings to AMR for the extended response time is used to subsidize the fire departments for providing the paramedic first response service. The partnership has also standardized such functions as training, communication protocols, quality improvement, equipment, supplies, and record keeping across organizations.

The system features a single e-patient care record (PCR) per patient that includes data assimilated from the Communication Center's computer-aided dispatch (CAD) system, the first responders (Fire/Paramedic crews), the ambulance service, as well as the receiving health facility's emergency department. Ambulance crews utilize laptops with wireless connections to transmit data to the centralized PCR system server, which feeds data to anyone logged into the system, including the eleven health care facilities in the county. Though the web based system is accessible by each organization, it is primarily used by the ambulance service, with some usage by the Fire department and rare use by the health care facilities largely due to the equipment

costs to access the system (mobile PC's/handheld computers on board all fire engines and for all ED physicians in hospitals). The EMS Agency's vision for the information system includes a single electronic patient care record (PCR) system that can share appropriate data elements with every organization in the service process. This system would utilize a suite of XML-based schemas and protocols in the transfer of its data to and from other disparate systems (law enforcement, hospital, emergency management, etc.).

4. ASSESSMENT OF EMS SERVICE PROCESS

The following section provides an overview of the case study findings. As stated previously, the first phase of research sought to document performance-related information exchanges that take place across the EMS service process. Figures 3 and 4 show a high-level overview of the types of performance-related information collected and transmitted across organizations during an emergency service process and the major data collection and repository systems that are utilized.

4.1 Information Types and Data Linkages

The progression of information across the EMS service process represents key information exchange linkages across service organizations. In general, as seen in Figure 3, the EMS service process is sequential, starting at a 9-1-1 phone call (or equivalent notification) and continues through a series of organizations through to delivery at a hospital. Generally, most real-time information travels across the service process following this sequence of events, with adjacent organizations exchanging information asynchronously. Information types used by each organization are depicted in the top section of the diagram. Information about an emergency incident increases across the service process in terms of the number of information types needed by emergency professionals to make informed decisions. The information within each information type may also change and increase as the service progresses in a dynamic manner. For example, depending on the original accuracy of an incident report, location information could change or be added upon.

While the majority of information exchanges happen in a sequential manner, there could be several opportunities to exchange data in a non-traditional manner that is "out of sequence." For example, one exception to the traditional information sequence in San Mateo is the hospital availability information sent from the hospitals to the communications center. This data is used by the communications center to make recommendations to the ambulance service about which hospital to transport a patient depending on the needs of the patient and the available resources and skill sets at each care facility. This "out of sequence" data provides emergency professionals with valuable data to better serve citizen needs and improve performance, demonstrating that the traditional sequence of information handoffs may not provide the best performance benefits. There exists an opportunity to explore how data could be utilized in such a non traditional way to enhance end-to-end performance for EMS.

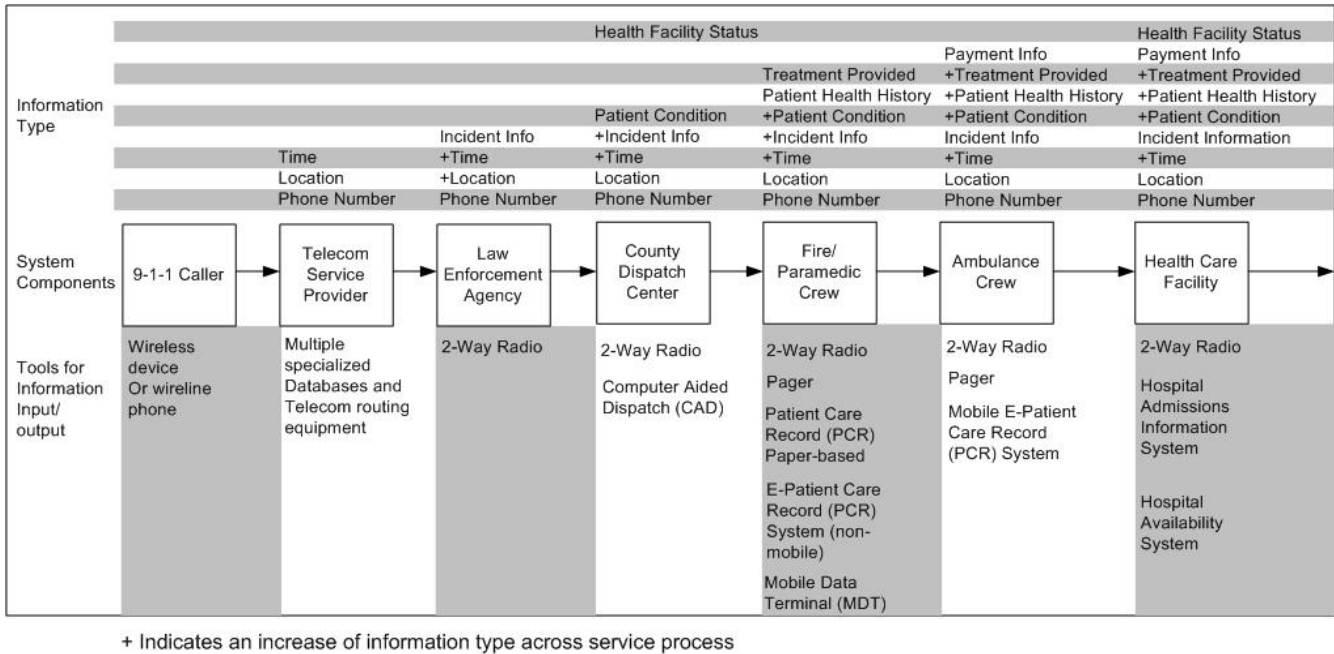


Figure 3. Information Types across EMS Service Process, Components, and Information Systems

4.2 Tools for Data Input/Output

The bottom section of Figure 3 lists the primary information systems used by each organization to collect and transmit emergency incident data. While the cell phones, 2-way radios, pagers, and mobile data terminal (MDT) are primarily used to communicate and transfer information, there are three major systems that collect and aggregate incident data. The first is the Computer Aided Dispatch (CAD) system that is controlled by the County Communications Center. Caller information, location data, and initial health problem data are entered into the CAD system. Time-stamp data from fire and ambulance crews are also reported to the Communications Center and key-stroked into the system. The second system is the Patient Care Record (PCR) which is controlled by the County EMS Agency. Patient information including health condition and treatment data are entered into wireless mobile laptops by paramedics in the field and recorded at a centralized server. Some CAD data is also sent to the PCR system, including response time data. Finally, the hospitals collect and record an array of treatment data from the time a patient is admitted in the emergency department until his/her release from the hospital. This data is located within independent and disparate hospital information systems (HIS). In general, there are very few interfaces between these three systems (CAD, PCR, HIS) and data utilization (e.g., analysis) is largely retrospective rather than real-time. A significant challenge rests with how to appropriately integrate these systems in a way that is acceptable to each organizational stakeholder. But currently, end-to-end performance analysis cannot be conducted because of a lack of integration. In other words, patient outcomes cannot be

linked to service interventions at any stage of EMS service delivery.

4.3 Information Flows

Figure 4 shows the exchange of voice and data information flows across organizations. It should be noted that the information flows depicted in this diagram are “performance information” related as opposed to all types of information. It shows the “voice centric” nature of the information flows as two-way radio is utilized across the process including the emergency department at hospital and trauma centers. While the communication is “voice centric”, many of the voice communications are recorded, through key strokes, into either the CAD or PCR systems for later analysis. In most cases, when data is used to transmit information, it is supplemented with voice radio communications. For example, the communications center dispatches fire and EMS crews sending a text message to pagers with location, phone number, and priority level data. But the crews are also provided a dispatch message over their two-way radios. For the purposes of this discussion, figure 4 supports the comments made previously and was used to understand issues related inter-organizational data access. For example, information flows into the health care facilities but not out of them.

In sum, there currently exists a flow of information across EMS service processes and information systems used. Challenges exist in terms of identifying and eliminating communication redundancies and using more data-centric systems in a way that could enhance service delivery rather than detract from it.

The current challenge to utilizing data in new ways to provide real-time data dashboards and retrospective analysis now rests with the lack of technical human resources to create interfaces across all organizations and information systems. Funding does not exist at either the Communications Center or the EMS Agency to support such a technical effort.

The largest data access barriers in the EMS system stem from the health care facilities. Interviewees named the reasons that hospitals do not grant access to data or provide selected data sets to the EMS Agency including 1) privacy concerns (e.g., HIPAA), 2) lack of trust, 4) lack of incentives, 4) insufficient technical staff to create interfaces, and 5) high costs associated with building interfaces to legacy systems.

Interview respondents described their concerns regarding HIPAA requirements. There still exists a lack of understanding about what HIPAA means. And in an effort to comply with HIPAA, health care organizations have become highly resistant to sharing any level of data. The hospitals do share data however with other agencies. But the majority of these data sharing activities are required at the state level. For example, hospitals are mandated to send hospital admissions data to the State of California. This addresses the issue related to a lack of incentives for sharing data. The EMS Agency director explained how the County of San Diego had been working on legislation that would mandate hospitals to send hospital admissions data to the county before sending it to the State level. Such legislative action will be pursued by San Mateo County as well. But beyond mandated incentives, there is a need to understand other models for creating information sharing incentives for health care facilities, such as the potential decision support benefits that could be realized to improve hospital performance.

5.1 End-to-End Performance Implications

As alluded to in the above discussion, participants in the San Mateo EMS system discussed performance benefits due to performance information access and integration. These include reduced response times and increased quality of care due to 1) the ability of the EMS Agency to evaluate system wide behavior through analysis of pre-hospital ambulance response activity, 2) the ability of communications dispatchers to monitor the activity of paramedics in real-time and provide information for decision making, such as hospital availability and directional data, and 3) the ability of paramedics to conduct reporting in the online PCR system during and directly after an incident, as opposed to the end of the day.

Information access barriers to achieving enhanced levels of timeliness and quality of care include 1) the lack of patient data prior to or immediately upon arrival at a scene (e.g., demographic data, medications, pre-existing conditions, health care provider, etc.) to eliminate verbal information gathering on the scene, 2) the lack of automated data collection systems (e.g., vital signs data) that stream data directly to the PCR to eliminate manual data entry, and 3) the lack of data structure for tracking patients across pre-hospital and hospital environments that would allow for end-to-end performance analysis and system improvement.

Understanding current performance benefits and barriers allowed for participant discussion about overarching governance issues that exists for the San Mateo EMS Agency specifically and

county EMS Agencies more generally. Participants discussed a lack of an overall strategy and structure to guide organizational and information technology access and integration improvements to allow for more prevalent data and information. The following section utilizes an architectural approach to explore how a commonly accepted architecture (the National Intelligent Transportation System (ITS) Architecture), could be utilized to inform such a strategy for San Mateo.

6. APPLICATION TO EMS ARCHITTECURE

The National Intelligent Transportation System (ITS) Architecture “provides a common structure for the design of intelligent transportation systems” and prescribes a general framework that supports the development of many different designs [13]. Contained within the National ITS Architecture, there is a logical architecture and a physical architecture. The logical architecture presents a functional view that consists of process specifications that are used to perform user services. In this view, the functions are represented in a set of data flow diagrams. The physical architecture divides the logical architecture functions into a number of high level classes and many lower level subsystems. Further details of the National ITS Architecture can be found in [14] and on a website¹.

The National ITS Architecture provides considerable support in the area of EMS – the Emergency Management Subsystem is one of the many subsystems contained within the physical architecture. Because of the complexity and enormity of the National ITS Architecture, many transportation system architects represent their designs in the form of a market package. A market package is a diagram that focuses on the specific details of the architecture for a particular interest group, which for the purposes of this paper would be those persons interested in EMS.

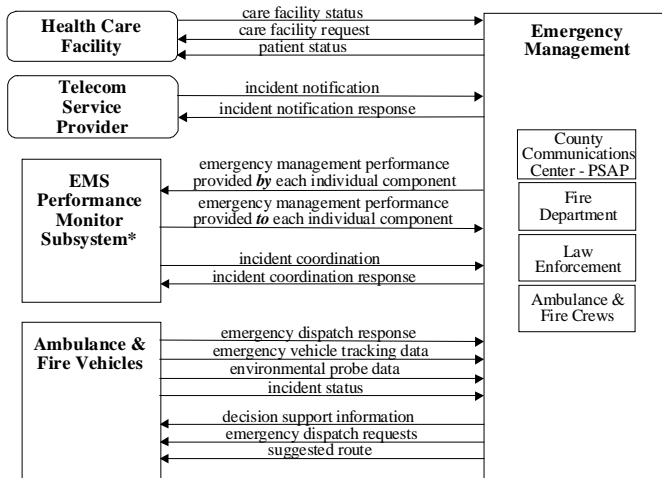
Based on the material gathered from the San Mateo case study, as outlined in the previous sections and figures, a mapping of the EMS entities was performed with respect to the National ITS Architecture. This mapping is shown in Table 1.

Table 1. Resultant Mapping of San Mateo Entities

National ITS Architecture Entities	San Mateo Entities
Emergency Telecommunications System	Telecom Service Provider
Emergency Management	County Communications Center—PSAP
Emergency Management	Fire Department
Emergency Management	Law Enforcement
Emergency Management	Ambulance & Fire Crews
Emergency Vehicle Subsystem	Ambulance & Fire Vehicles
Care Facility	Health Care Facility

¹ <http://www.iteris.com/itsarch> accessed on February 18, 2006.

The entities that reflect the San Mateo case study were then configured into the market package diagram shown in Figure 5. Additionally, as explained in [15], the entities are coupled with an EMS Performance Monitor Subsystem. The EMS Performance Monitor Subsystem is roughly equivalent to what the National ITS Architecture makes available as the Archived Data Management Subsystem. However, rather than merely archiving the data for later retrieval, the Monitor facilitates the near-real time movement of emergency response messages throughout the system. Its chief function is its ability to collect the data that is generally isolated within each of the elements and move it to where it can then be used for the benefit of each entity. Thus, by managing the system entities in near-real time, the Monitor would allow for immediate feedback to each of the organizations and provide the potential for improving end-to-end performance.



* The EMS Performance Monitor Subsystem replaces what the National ITS Architecture refers to as the Archived Data Management Subsystem.

Figure 5. Regional Market Package that Includes Performance Monitoring

7. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

We have examined a specific case study for the San Mateo County EMS system that was guided by the TCIS framework. That is, the framework was used to investigate the service process, data access issues across organizations, and performance barriers and benefits to inter-organizational data. As a result of this examination, we have observed the challenges associated with linking the various information systems and organizations, such as the PCR, CAD, and care facilities. We have also observed that there is a need to enhance the end-to-end performance of the time-critical information services provided by the system. Our solution was to first create a regional ITS architecture by mapping the entities of the case study location into the National ITS Architecture. This supported the creation of a framework in which previously disparate entities were now organizationally and technologically coupled. Finally, the concept of employing an

EMS Performance Monitor Subsystem that captures and disseminates performance information throughout the system was illustrated. The solution provided a practical solution for San Mateo County and is the applied contribution of this paper. As a result of the analysis, the EMS agency gained new insight into their service process and the use of IT to facilitate services. The San Mateo EMS Agency has recently initiated a county wide EMS system redesign effort based on case study findings. As

From a theoretical perspective, the major contributions of this paper were to demonstrate the utility of the TCIS framework including how it could be applied to an existing inter-organizational EMS system. The case analysis showed how end-to-end performance could be evaluated. The application of a common and well-defined National ITS Architecture to case findings was used to validate the TCIS framework for inter-organizational end-to-end performance analysis for e-government time-critical systems.

EMS represents inter-organizational e-government information systems where cooperation is central for enhancing performance. The work conducted by [16,17] is similar in its relationship to e-governmental analysis of emergency response systems in identifying information flow dimensions to organizational relationships. Whereas these authors identify multiple levels of interactions, we extend TCIS concepts, including e-government IOS and end-to-end performance improvement therein, into the architectural dimension. In this respect, information flows are considered not just in a descriptive sense, but also set the stage for a normative description of potential dynamic information flows and exchanges.

Of course, the goal is not just to improve information flow, but to improve the consequences on performance as it affects the e-government service. Specifically, how the two domains, response and quality, effect service performance. Response (efficiency) is articulated elsewhere in the e-government literature as a recurring theme of e-government services. The “quality” domain, however, is critical in terms of health outcome to the patient. To the injured patient, the interactions and cooperation of service providers “behind the scenes” is less important than the perception that the service is both seamless and effective.

Future research directions should focus on how an architectural view could be utilized in understanding the effects of information technology on end-to-end performance, specifically how IT could be utilized to improve the quality of patient care.

8. ACKNOWLEDGMENTS

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