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December 2004

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ABSTRACT

This paper analyzes end-to-end performance of EMS providers. Continually under pressure to reduce disabilities and fatalities, EMS providers need timely and accurate incident related information within the critical "golden hour" of emergency response, especially in rural areas where approximately 60% of all vehicle fatalities occur. In this study, a multi-method analysis was conducted around an embedded case study in rural Minnesota to better understand and evaluate end-to-end performance of emergency response under normal and crisis conditions. Researchers used field interviews and agency data to develop an ontological knowledgebase for EMS data and then used this factual ontology to test end-to-end performance through a simulation software called ARENA. Findings suggest that (1) there is a lack of systematic inter-connected information about rural EMS performance, and, (2) under typical crisis conditions the system is overloaded and that may affect the dispatch performance of the end-to-end process.

Keywords

End-to-end Performance, Mobile Emergency Medical Services, Rural Emergency Response, Crisis Simulation.

INTRODUCTION

There has been a substantial amount of emergency response and crisis management research and literature aimed at improving the effectiveness of the emergency response infrastructure (Davis, 2002; Hale, 1997; Perrow, 2000). Effective response to "unexpected events" (health emergencies, crises) is highly dependent upon timely and accurate information to and from all participating organizations (Arens and Rosenbloom, 2002; Turoff et. al., 2004). An "end-to-end" emergency medical services (EMS) system includes an inter-organizational network of service providers delivering time-information critical (TIC) services. Looking from one "end" to the other "end", a medical emergency response involves multiple government agencies and non-government organizations, from the time an emergency communication (911 phone call) is made, answered by a Public Safety Answering Point (PSAP), dispatched to public agency resource (fire, police, ambulance), and treated at the scene and/or ambulanced to a hospital. Understanding end-to-end performance is essential to understanding how public services are delivered, the timeliness and quality of the services delivered, and the need to improve services under normal and crises conditions. The need to improve EMS services is especially true for rural areas where approximately 60 percent of all vehicle fatalities in the United States occur and the average EMS response time between a rural crash and the arrival of the victim to a hospital is 52 minutes, compared to 34 minutes for an urban crash victim (NCSA, 2002).

This research study investigates the role of information systems in enhancing end-to-end performance of rural EMS systems. The paper reports on empirical findings from the second phase of a multi-year study. During an earlier first phase, an exploratory analysis was conducted on policy, technology and organizational challenges to deployment (Horan

& Schooley 2004). The follow-on phase reported in this paper focused on a multi-method analysis that was conducted around an embedded case study in rural Minnesota. The first task was a series of field interviews and site visits. During the course of these interviews, EMS system performance data was gathered from multiple organizations. These data sets allowed researchers to construct an ontology and knowledgebase populated with performance data. Finally, the case study performance data were used to perform a preliminary simulation of rural EMS performance under normal and crises conditions, utilizing the ARENA business-process modeling program.

This study addresses three questions. First, what are the local contextual factors surrounding inter-organizational end-to-end rural EMS system performance? Second, how can the performance elements described in the rural EMS ontology be represented in the factual ontological knowledgebase for end-to-end performance evaluation? Finally, in terms of end-to-end performance, what do simulations suggest in terms of normal versus crises performance results?

Case Study Setting: Brainerd, Minnesota & MSP-D2800

Brainerd, Minnesota is situated 131 miles northwest of the Twin Cities Metropolitan Area and is the largest city in what is known as the central lakes area.[1] The entire region under study is Minnesota State Patrol District 2800 (MSP-D2800) which includes seven counties: Aitkin, Cass, Crow Wing, Hubbard, Kanabec, Mille Lacs, and Morrison (see figure 1). The area has always been a popular tourist attraction and continues to gain favor with tourists, retirees, and people who are seeking employment in the growing region. The seven counties are home to 3.8 percent of the state's population and they cover 10 percent of Minnesota's land.

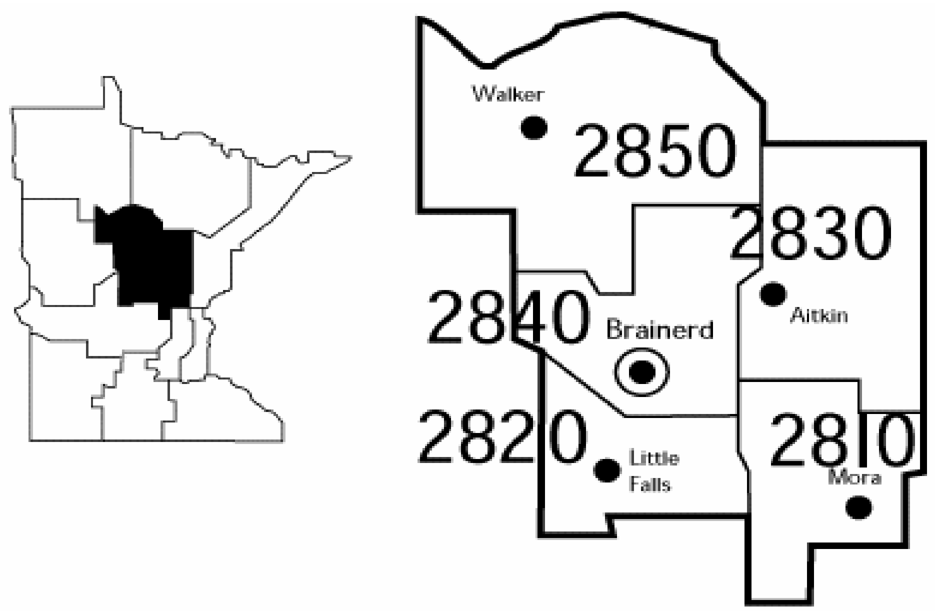


Figure 1. Minnesota State Patrol District 2800

The Brainerd region's population doubles during the summer due to tourists.[2] The most popular weekends include the fishing season opener in May, Memorial Day, Fourth of July, Labor Day, and summer race weekends at the Brainerd International Raceway.[3] The population triples over the Fourth of July weekend and during major race weekends.[4] These special events place considerable stress on Brainerd's (MSP-D2800) EMS system. For example, on a typical Friday night in Crow Wing County, two state troopers are on duty, but on a popular Friday night, there are eight active troopers.

[1] Brainerd Lakes Vacationland. 2003, Midwest Captions, Inc.
[2] Brainerd Lakes Area Chambers of Commerce, 2003.
[3] Dirlam, G., et al., *Meeting with the Baxter TOCC*. 2003: Baxter.
[4] Paxton, L., *Population and Traffic Counts*. 2003, Brainerd Lakes Area Chambers of Commerce: Brainerd.

RESEARCH OBJECTIVES & METHODOLOGIES

As noted in the introduction, this study has three primary objectives (see Table 1). The first is to explore the contextual factors surrounding the Brainerd EMS system. The second is to represent the performance elements described in the general EMS ontology in a factual ontology using data from the Brainerd area. The third is to analyze and simulate Brainerd's end-to-end EMS system performance. Three methods were used to meet the objectives. First, the research team conducted field interviews, site visits, follow-up interviews, and gathered existing data. Next, the researchers constructed a factual ontology with the aid of an ontology and knowledgbase editor (Protégé 2000). Lastly, the researchers performed a simulation using Arena based on available Brainerd EMS system data.

Objectives	Methods
Contextual Factors	Field Interviews and Site Visits
Factual Ontology	Ontology Development with Protégé 2000
End-to-End EMS System Performance	Simulation Using Arena

Table 1. Objectives & Methods

Field Interviews, Site Visits, and Data Gathering

The research team made three site visits, interviewing representatives at each site.[5] During each meeting, the research team provided an overview of the EMS process and asked each interviewee to comment on the organization's role in each step of the process and the availability of data for documenting the performance of their activity in each relevant step. The interviews were important for providing a context to understand the rural EMS process from end-to-end and to understand inter-organizational dynamics and relationships within the end-to-end process. Along with the qualitative interviews, this study used data for the year 2002 from four sources: the national Fatality Analysis Reporting System (FARS), Minnesota FARS, the Baxter Transportation and Operation Communication Center (TOCC), and the Crow Wing County Public Safety Answering Point (PSAP). These data were identified during the field visits and obtained through follow-up connections.

It is important to note the role of TOCCs in the rural emergency response. TOCCs are a recent cooperative effort between the Minnesota Department of Transportation (Mn/DOT) and the Minnesota State Patrol (MSP) for the purposes of sharing resources (buildings, IT systems) and creating inter-organizational efficiencies. TOCCs serve as regional centers throughout the state that provide round-the-clock transportation operation services including incident and emergency response, multi-agency dispatching and fleet management, interagency communications, collection and dissemination of road conditions and closures, traffic management, and potentially, integrated transit operations.[6] They are an integral part of Minnesota's E-911 infrastructure and have a close working relationship with PSAP's to perform coordinated emergency response. TOCCs respond to almost all highway related emergencies and wireless 911 calls coming from motorists on highways, rural roads, and rural areas. In this study, the TOCC examined is located in the nearby town of Baxter, while the PSAP is located in Brainerd.

Conceptual Model for Ontology Development

A second methodology involved creating a factual performance ontology that could be used to define and organize rural EMS data. In an abstract sense, an ontology is an explicit representation of a conceptualization (Grüninger and Lee, 2002). In practice, ontologies provide machine-processable semantics of information sources and a representational vocabulary that can be communicated between different agents (software and humans), "opening the way to move from a document-oriented view to a content-oriented view, where knowledge items are interlinked, combined, and used" (Lima, Fies, El-Diraby, and Lefrancois, 2003). An EMS system ontology provides a simple and visually rich representation of

[5] The three visits were: Minnesota Statewide 911 Program, St. Paul, MN, June 19, 2003; Baxter TOCC, Baxter, MN, June 20, 2003; Crow Wing County PSAP, Brainerd, MN; June 20, 2003.
[6] http://www.dot.state.mn.us/guidestar/projects/tocc2.html. Accessed November 27, 2003.

the EMS process; the EMS ontological knowledgebase distinguishes classes of systems, instances within classes, and the relationships among classes and instances inside the rural wireless EMS domain (Musen, 2000).

As a result of the Phase I analysis (Horan and Schooley, 2004), five major activities and concepts were singled out for inclusion in the ontological classification of wireless EMS. These activities and concepts are the mayday call, call routing, EMS dispatch, response and hospitalization, and related system information. These major components of the wireless emergency call procedure are used as the basis for the conceptual wireless EMS system ontology and are the superclasses of the ontology. The data obtained about Brainerd were organized based on this ontological framework resulting in a "Factual ontology for rural EMS".

Computer Simulation of the End-to-end EMS System

Once the factual ontology was completed, the next methodology was to use this ontology to perform a simulation of rural EMS performance. Simulation allows detailed research into the performance of proposed or existing systems by modeling the behavior of key processes and entities of those systems[7](Kelton et. al., 2004). Computer simulation is particularly useful in modeling complex, dynamic interactions that include both behavioral and technological components such as those in the Minnesota rural EMS system (Sterman, 2000). This approach enables performing relevant detailed sensitivity analyses of various scenarios, such as the potential response of the EMS system to catastrophic conditions. In addition, the dynamic behavior of the EMS system can be modeled and predicted based on the random or stochastic inputs that are seen in processes that include human behavior and other natural phenomena as inputs.

Several major components of the Minnesota rural EMS system were modeled in the simulation, including call generation, the Baxter TOCC, the regional PSAPs, TOCC-activated emergency services, and PSAP-activated emergency services. Figure 2 illustrates the end-to-end performance information systems evaluation for rural wireless EMS systems showing the context factors that translate into conceptual ontology, knowledge acquisition, knowledgebase, and simulation development.

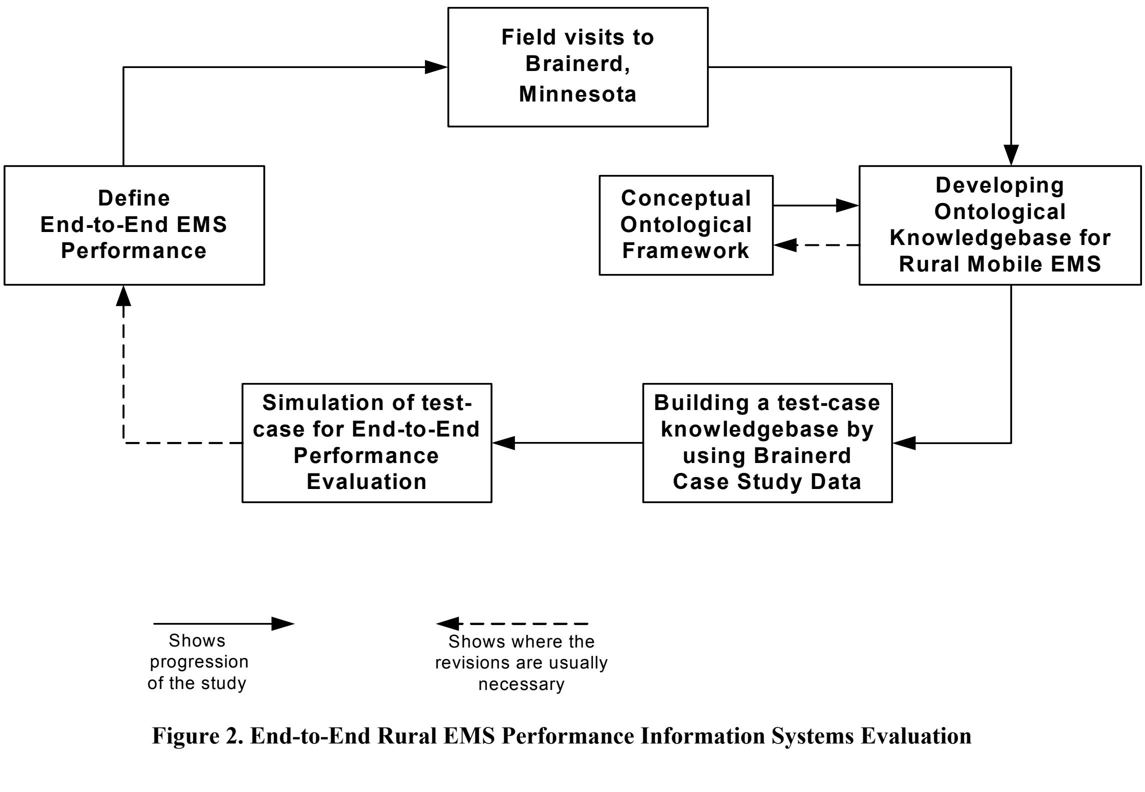


Figure 2. End-to-End Rural EMS Performance Information Systems Evaluation

[7] The Rockwell Software Arena Simulation program was used in all EMS simulations.

FINDINGS

Contextual Factors

Management Information Needs

Baxter TOCC and Crow Wing County PSAP representatives expressed a need for quality information management systems so that good management decisions can be made. For example, representatives noted that it would be helpful for TOCC management to know the number of calls that the TOCC received over a given time period that were managed there or transferred elsewhere. In addition, information on call volume, calls for service, and the outcome of 911 calls would be welcomed at the Baxter TOCC. This TOCC is in the process of upgrading to a CAD system, but the implementation of the system has taken more time than was anticipated straining the record-keeping capabilities of the current system. In this sense, there appears to be a disconnect between information systems coordination and service coordination whereby the former is lagging behind the latter.

Inter-organizational Cooperation

The Minnesota State Patrol (MSP) was once a division of Mn/DOT, but was moved under the Department of Public Safety in the 1970s. Regardless, these two organizations are inextricably linked formally and informally and they are in constant communication with each other. MSP and Mn/DOT share the same main goal – safe highways. Mn/DOT expects MSP to provide them with real-time information and MSP expects Mn/DOT to be proactive. For example, when MSP notices a maintenance problem on a road they call Mn/DOT for emergency repair. Implementing TOCCs provides a physical locale for agency and service coordination; however, limited staff, resources, and formal policies that guide inter-organizational cooperation curbs the effectiveness of collaboration between the two organizations. An added level of organizational and jurisdictional complexity arises as MSP-D2800, Mn/DOT District 3A, and county boundaries do not align.

Organizational & Policy Factors

Responses in the interviews noted the budgetary constraints confronting EMS in Minnesota. These concerns were also reflected in the recent Annual Report of the Department of Administration (2002). This report found three financial threats to the Minnesota Statewide 911 Program. First, if the call volume is greater than projected, program funding will be inadequate. Second, the costs of implementing enhanced 911 services are great. Third, maintaining and improving 911 services is prohibitive due to increasing costs. It was stressed during interviews that there needs to be a strategy and vision for financing TOCC operations in the long-run, especially considering the rate at which technology is changing. Despite an increase in call volume, the Baxter TOCC has the same number of radio operators that it had five years ago and new E-911 dispatching technologies have not been fully implemented.

Factual Ontology

A major effort of the study was to identify the data need for the factual ontology (see Table 2, far right column). Figure 3 and Table 2 present this data from an "end-to-end" perspective, that is, from the initial emergency call through response and hospitalization or fatalities. The following section provides supplemental data, where available, on the process as it occurs in Brainerd for fiscal year 2002. It is important to note that this available data is an assembled "puzzle" from different data sources and experts; it is not available from any one location.

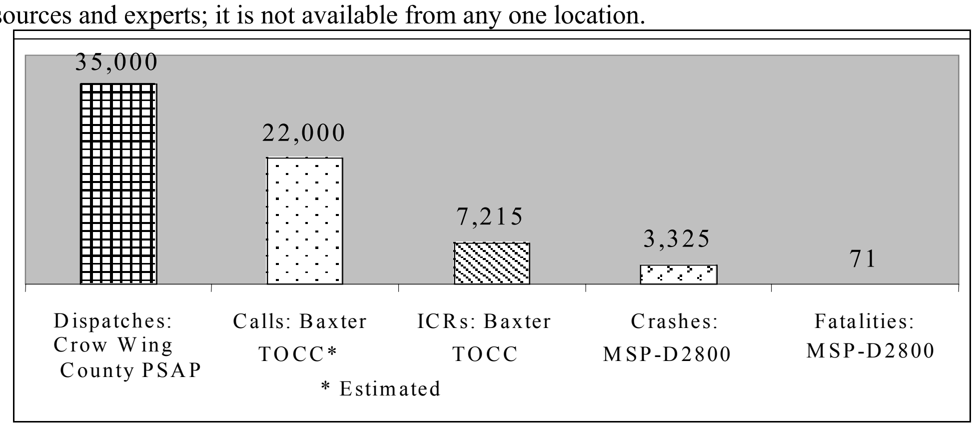


Figure 3. Factual Ontology and Knowledgebase Data (2002)

Wireless EMS Process	Conceptual Wireless EMS Ontology	Factual Ontology Brainerd, 2002
Mayday Call	➢ Mayday Call ○ *Cellular phone call* ○ *Automatic crash notification* ○ *Radio communication*	Around 9000 wireless calls in 2002 at Baxter TOCC
Call Routing	➢ Call Routing to EMS Dispatcher ○ *Routing delay* ○ *Third party routing (GM OnStar)*	Two of seven PSAPs in MSP-D2800 accept all local wireless 911 calls
EMS Dispatch	➢ Response to Mayday Call ○ *Response delay* ➢ Dispatch ➢ Data Management	Crow Wing County PSAP made 36,488 dispatches
Response & Hospitalization	➢ Response to Incident ○ *Response delay* ➢ Response Coordination ➢ Hospitalization ➢ Fatalities	71 Fatalities in MSP District 2800.
Related System Information	➢ E-911 Technology ○ *Network based* ○ *Satellite based* ➢ Wireless Coverage ➢ E-911 Deployment	Phase I – 100% complete Phase II – 33% complete

➢ Subclass – 1st level.
○ Subclass – 2nd level.

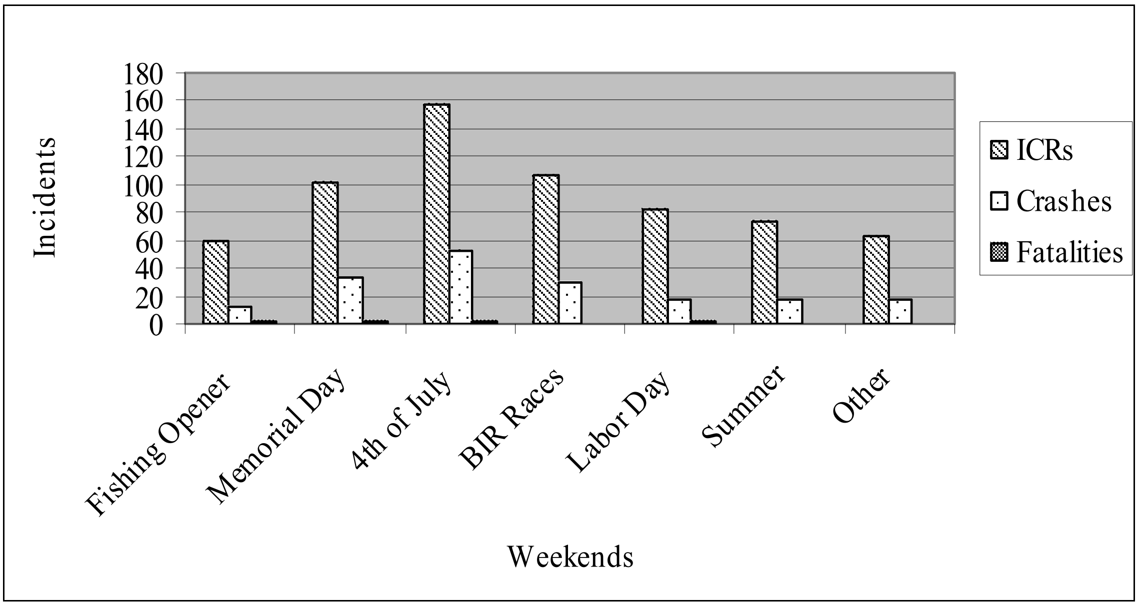
Table 2. Conceptual & Factual Wireless EMS System Ontology

Mayday Call

In Phase I of wireless enhanced 911 systems (E-911), when a wireless subscriber initiates a call the closest tower picks up the signal. The wireless service provider's network has a switching center that works much like the switches on wireline calls, reading the digits and forwarding the calls accordingly. The wireless service provider must first program its tower to immediately send any 911 calls to the appropriate 911 tandem. In addition, the wireless subscriber's callback number is sent along with the signal in the case of wireless E-911 phase I. In the case of deployed wireless E-911 Phase II, the call taker is provided with the subscriber's callback number and latitudinal and longitudinal location within a few hundred feet.

From the emergency response providers' perspective, the emergency begins when a call is received. Only calls that result in an Initial Complaint Report (ICR) order are stored in the system at the Baxter TOCC, therefore there are no data on total E-911 calls received. In 2002, there were 7,215 ICRs. Representatives from the Baxter TOCC noted that each ICR is associated with between one and 20 calls. However, the total number of calls that the TOCC receives is unknown, as the system tracks calls once a response is initiated. The Baxter TOCC and county PSAPs in MSP D2800 mutually decide which agency responds to which calls. In 2002, the Baxter TOCC responded to 33 of the 71 fatalities in MSP-D2800.

As previously mentioned, the Brainerd area's population surges during special events in the summer. As a consequence, the number of crashes and other incidences also increase. Figure 4 shows the number of ICRs, crashes, and fatalities for the following weekends: the fishing opener, Memorial Day, Fourth of July, the average number of crashes for four major race weekends, Labor Day, the summer weekend crash average, and the crash average for all other weekends. Of note, there are 35 more crashes over the Fourth of July weekend than during an average weekend.



Source: Baxter TOCC, 2003.

Figure 4. MSP-D2800 Weekends, 2002

For the month of August 2003, there were 1,545 wireline and 310 wireless ALI requests at the Crow Wing County PSAP. A PSAP official said that almost 90 percent of the wireless calls that the PSAP receives are inadvertent or non-emergency calls. The official explained that dispatcher protocol differs significantly between wireline and wireless calls. Because E-911 Phase II deployment has not been completed, a dispatcher must first vocally take location information from a wireless caller. Table 3 summarizes some of the Crow Wing County PSAP's call and dispatch statistics.

Wireless Calls (monthly)	**200 (estimate)**
Wireline Calls (monthly)	1,200 – 1,500
Total Dispatch Calls by Agency	35,640*
Total Dispatch Calls by Activity	35,410*

***Grand Total - System Crash**

Source: Crow Wing County PSAP, 2003.

Table 3 Crow Wing County PSAP Call/Dispatch Statistics, 2003

Call Routing

The Baxter TOCC responds mostly to highway related emergencies. The TOCC responds to all wireless 911 calls that are not taken by PSAPs, filling in wireless 911 gaps for the district's PSAPs. In Crow Wing County, wireless calls are routed to either the PSAP or the TOCC. The call is sent to one of the two organizations depending on the location of the originating call's cell phone tower. The PSAP designated some towers as PSAP responsibility, and others as State Patrol responsibility. The PSAP takes calls from cell towers that are in close proximity to towns, whereas cell tower areas near state highways are the State Patrol's territory.

EMS Dispatch

For the years 2000 and 2003, the Baxter TOCC made 7,100 to 7,200 ICR dispatches to the Minnesota State Patrol annually. In 2002, the Crow Wing County PSAP made 36,488 dispatches. The majority of these dispatches were to police departments (21,151), sheriff's offices (10,881) , and ambulances (2590). In 2002, the Crow Wing County PSAP made 10,800 traffic and vehicle related dispatches (see Table 4). The most common type of dispatch was for a traffic stop.

Type of Call	Total
Abandoned Vehicle	73
Driving Complaint	876
Fire-Vehicle	41
H&R No Injury	193
Parking Complaint	326
Personal Injury Accident	532
Pursuit	18
Suspicious Person/Vehicle	696
Traffic Stop	8,045
Total	**10,800**

Source: Crow Wing County PSAP, 2003.

Table 4. Crow Wing County PSAP Traffic & Vehicle Related Dispatch Calls, 2002

Response & Hospitalization

According to the Minnesota FARS data source, there were 71 crash-related fatalities in MSP-D2800 during 2002.[8] Almost 15 percent of all of Minnesota's rural fatalities in 2002 occurred in MSP-D2800. Table 5 compares EMS notification and response time intervals between urban and rural Minnesota, and MSP-D2800 (i.e., the average number of minutes and the range of minutes that passed between the accident and the notification of EMS, the accident and EMS arrival on the scene, and the accident and EMS arrival at the hospital).

	Urban Areas		Rural Areas*		MSP-D2800*	
Interval (in minutes)	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Accident/EMS Notification	2.1	0-28	5.8	0-275	4.9	0-61
Accident/EMS Arrival at Scene	10.3	1-73	21.3	1-285	20.8	2-94
Accident/EMS Arrival at Hospital	33.0	5-86	51.8	12-197	60.5	17-197

*Outliers omitted.

Source: FARS & Minnesota FARS, 2003.

Table 5. EMS Notification &Response Intervals in Minnesota, 2002.

Building the Knowledgebase

Following the formation of ontology class schema, data obtained through field interviews and subsequent analyses were entered into the knowledgebase as instances within classes and/or subclasses (see Figure 5). For some classes, data were not available so no instances are recorded for them. Nevertheless, since the ontological construction of Protégé is in place, data may be entered at any time. Moreover, this data provided the basis for a simulation of end-to-end performance using ARENA.

[8] There is a discrepancy between the number of fatalities reported by the Baxter TOCC (33) versus the number of fatalities reported by Minnesota FARS (71), because the TOCC tracks only those fatalities that the Minnesota State Patrol responds to whereas Minnesota FARS tracks all fatalities.

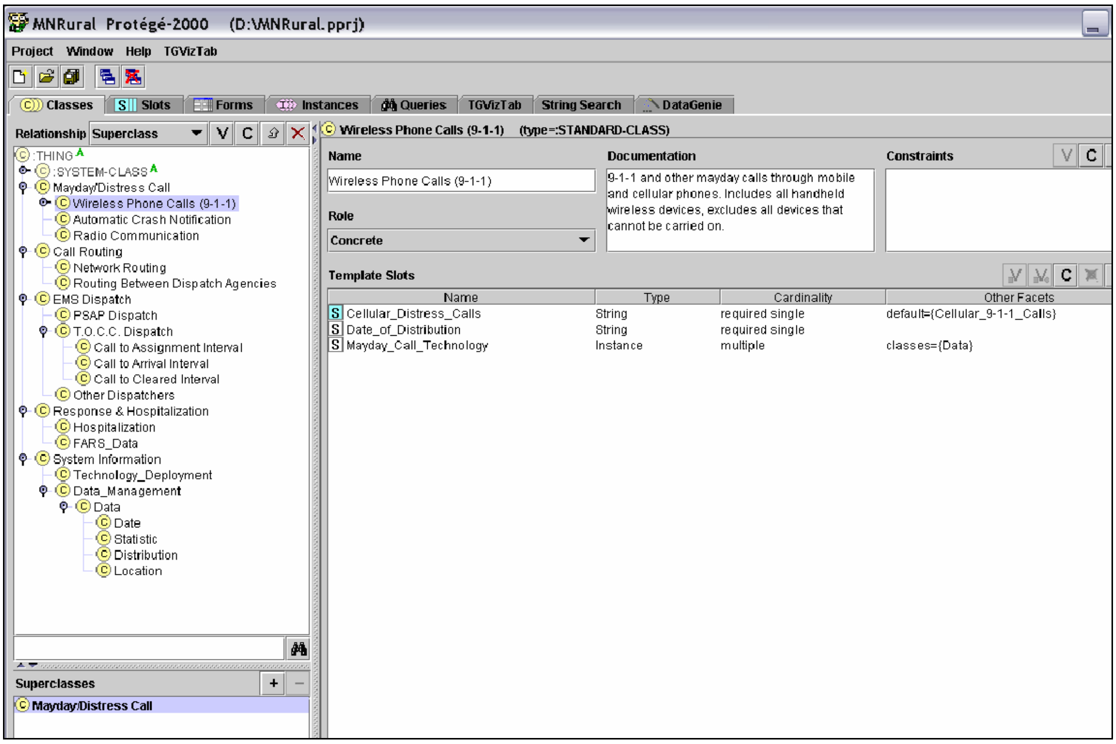


Figure 5. Protégé 2000 Interface Showing Classes of the Ontology.

End-to-End Simulation

Choosing Sample Data

A judgmental sample of ICRs was extracted from the raw data for 2002, beginning with 36 days sampled at 10-day intervals to limit overrepresentation of specific weekdays. In order to fully capture the expected range of daily call frequencies, data from several days with expected high emergency activity (e.g, December 31, July 4) were included in the sample. This sample yielded a range of eight to thirty-four incidents per day, with a mean of approximately 14 incidents per day. The distribution of call times was examined for the entire data set of 7,210 incidents, yielding an approximately uniform distribution of calls throughout the day, with the exception of markedly decreased incidence from approximately 3:00 a.m. to 6:00 a.m.

System to be Simulated

The Baxter TOCC simulation modules represent dispatchers and their activities (see Figure 6). A single dispatcher is normally present in the Baxter TOCC, with an occasional second backup dispatcher added between the hours of 3:00pm and 3:00am. Although the Baxter TOCC has three incoming lines, normally only one or two are staffed. If dispatcher phone capacity is reached, callers hear a continued ring tone or are placed on hold.

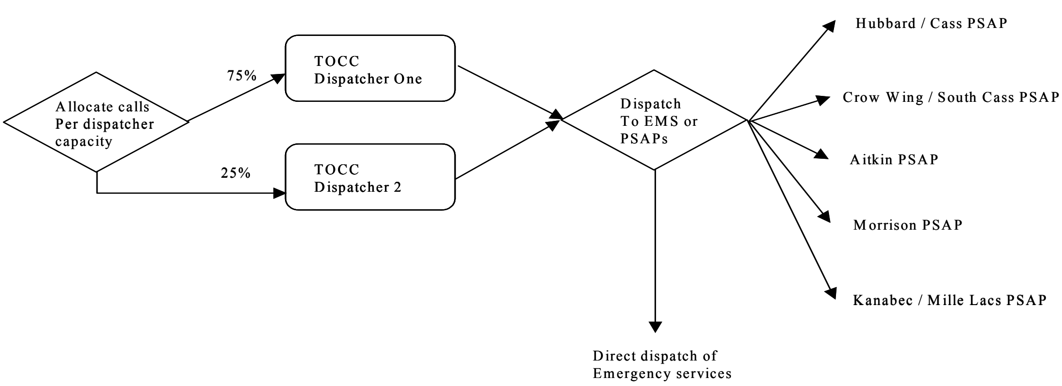


Figure 6. Baxter TOCC Dispatcher Activity

Dispatch Sequences

The Baxter TOCC dispatchers may dispatch emergency services directly, or they may redirect the dispatch task to regional PSAPs based on the geographic location of the incident, emergency service availability and other variables. Redirected calls may be sent to the Hubbard / Cass PSAP, the Crow Wing / South Cass PSAP, the Aitkin PSAP, the Morrison PSAP, or the Kanabec / Mille Lacs PSAP.

The Baxter TOCC can directly dispatch the County Sheriff (2 units cyclically available), Minnesota State Patrol (2 units), Mn/DOT (for roadway repair or maintenance – 4 units), and tow truck services (2 units). It is assumed that all incidents will require at least one of these services, and that each service is equally likely to be used. Table 6 defines emergency service durations.

Service	Min	Mean	Max
County Sheriff	0.5	1.0	2.0
City Police	0.5	1.0	2.0
Ambulance	0.5	1.0	2.0
Fire Services	0.5	1.0	8.0
Towing Services	0.5	1.0	2.0
Mn/DOT	1.0	2.0	8.0

Table 6. Emergency Service Durations in Hours (triangular continuous distributions)

Typical & Disaster Simulation Results

Each of the regional PSAPs will directly dispatch ambulance, fire, city police, or tow trucks, following the same rules employed by the TOCC emergency services. During the typical scenario, events and calls are generated according to the rules in the preceding discussion of the typical case. Key results of this simulation scenario run for a 14-day period and are included in Table 7. A disaster scenario was created to simulate the effects of crises situations on the EMS system, with insurgence of an additional incident every hour for a 48-hour pulse. The disaster simulation scenario covered a 14-day period (see Table 7).

Several preliminary observations can be drawn from these results. First, a number of system bottlenecks can be clearly identified. In the model, TOCC dispatchers spend a minimum of 1.2 minutes handling a dispatch, and an average of 4.8 minutes per dispatch. The Baxter TOCC dispatcher may be able to begin dispatching the necessary services immediately, but the *Typical Case* may take nearly an hour to dispatch the needed services. Moreover, in the visual model, it becomes clear that this dispatching event is tightly coupled with response service, as demonstrated by subsequent queues in Morrison Ambulance. Conversely, the long queues in dispatching Department of Transportation vehicles (MN/DOT) is not coupled to any subsequent events.

Second, it is clear that the *Disaster Case* has a dramatic impact on the overall performance of the EMS system, leading to extended periods of non-response or delay. The *Disaster Case* led to a 21 percent increase in total emergency calls over the *Typical Case*, which may be considered typical of what may result from a two-day crisis such as a series of highway catastrophes. Each *Disaster Case* emergency response service spends 20% more time processing each incident than in the disaster case. However, the *Disaster Case* shows delays of up to 90 minutes for the actual emergency request to be logged and dispatched. Emergency service provision show similarly extended delays in the *Disaster Case*, with maximum wait times for towing services increasing from about an hour to over seven hours, and maximum wait times for Mn/DOT services increasing from 3.5 hours to more than a day.

	Typical Case – 14 days			Disaster Case – 14 days (a)		
Emergency Calls – TOCC Dispatcher 1	883			1029		
Emergency Calls – TOCC Dispatcher 2	264			353		
Total Incidents	187			228		
	Typical Case (hours)			**Disaster Case (hours)**		
Activity / response unit / incident	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Baxter Dispatcher 1	0.02	0.08	0.16	0.02	0.08	0.16
Crow Wing County Sheriff	0.54	1.16	1.90	0.63	1.37	2.20
Baxter Tow	0.61	1.18	1.95	0.63	1.39	2.28
Mn/DOT	1.31	3.64	7.61	1.62	4.58	9.09
Morrison Fire	1.83	3.47	7.09	1.95	4.22	9.07
Morrison Ambulance	0.63	1.01	1.56	0.71	1.42	2.31
Queue	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Baxter Dispatcher 1	0.0	0.20	0.92	0.0	0.25	1.33
Baxter Tow	0.0	0.06	1.18	0.0	0.27	7.64
Crow Wing County Sheriff	0.0	0.11	2.19	0.0	1.90	11.35
Mn/DOT	0.0	0.15	3.54	0.0	6.18	26.26

Note (a): The Disaster Case includes a 48 hour disaster period of one additional incident per hour.

Table 7. Representative Outcomes of Typical & Disaster Cases

DISCUSSION

This embedded case study has highlighted several important features of rural wireless EMS systems and the flow of information from end to end. First, the availability, type, and use of performance data vary from agency to agency and from place to place. Second, while organizations collaborate to deliver emergency response and management services, these providers are loosely affiliated with each other. Inter-organizational systems such as rural EMS do not have integrated systems for monitoring performance. At the micro level, this study coupled an ontological knowledgebase with a computer simulation as an information system to search for possible bottlenecks in the rural EMS process under crisis conditions. Simulation, fed with structured knowledgebase data, proved to be promising for better understanding the entire EMS performance. While the principle motivation for conducting the simulation was to conduct a "proof of concept" in terms of the ability to simulate rural EMS performance based on extant data, the results do raise items for further analysis (including simulation). For example, the simulation raises issues about how to manage queues in dispatching during both normal and disaster scenarios, especially for "tightly-coupled" queues such as in dispatching. From the case study, it appears that innovative approaches are needed to handle this surge without major staffing increases. One issue to consider may be remote surge assistance (that is, not necessarily located in Brainerd) that could be offered to rural areas during predictable peak periods as well as on-demand for emergencies. Such an avenue could be explored both qualitatively as well as through simulation analysis.

In summary, the case study reveals that while local EMS providers may have an intuitive understanding of how the entire system performs, there is a lack of systematic data to support, confirm or refute perceptions about overall performance. This research provides a step towards explicating "end-to-end" assumptions into a bonafide information system that can be used to monitor, plan and simulate performance. While some research strands have investigated performance measurement and evaluation in "private" inter-organizational business processes for the purposes of process improvement, very little research has been conducted along these lines for *public* inter-organizational networks such as EMS. This is an important gap to fill for future inter-organizational, time-critical performance research and could be investigated by expanding this study to collect additional data at a national level.

ACKNOWLEDGMENTS

The authors express their appreciation for U.S. Department of Transportation and Minnesota Department of Transportation grant support provided through the ITS Institute and State and Local Policy Program, Humphrey Institute, University of Minnesota.

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