Modeling Effective, Efficient and Sustainable Emergency Medical Services Systems for Rural Areas

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DISCLAIMER

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EXECUTIVE SUMMARY

Many challenges face Emergency Medical Services (EMS) today. Among these are sub-optimal distribution of pre-hospital care providers by both number and level of training, lack of payment incentives, delays in offloading patients at the hospital and ambulance diversion. It remains unclear as to whether EMS is a health care, public safety or public health program. Research in the pre-hospital phase of the emergency care system has been limited and largely focused on specific clinical interventions rather than system design issues. The goal of this research was to identify variables, constraints and approaches to developing model response systems for EMS in rural areas that meet the Institute of Medicine's vision of systems that are “regionalized, coordinated and accountable” and which are, additionally, sustainable.

A literature review found that the connection between economic and workforce consideration and the allocation of EMS resources has not been examined or developed to date. It was also evident that much of the work to date had focused on the urban context of the facility location and allocation problem, ignoring rural needs. Much of the work conducted to date has focused on the problem of EMS vehicle/facility location. Past work employed generalized data inputs, namely number of vehicles, call demands (historical or probability-based), prospective facility/vehicle sites, and generalized response/travel times to optimize service coverage and identify facility locations. These efforts did not take into account many other factors which have an impact on the EMS system (economic, personnel, etc.). The modeling approaches that were developed focused on a limited range of variables so that they did not require excessive calculations.

Interviews with rural EMS providers in Gallatin County, Montana supplied the critical “reality check” for a prospective rural EMS model. Practitioners identified and lent a practical perspective to potential model variables, components, and constraints. With respect to modeling, a number of issues were identified which were taken into later consideration. These included the potential for servicing rugged and remote terrain, environmental factors (e.g., winter weather conditions), experience levels of volunteers, road conditions, gaps in communication coverage and infrastructure constraints (e.g., bridge weight limits).

In addressing the lack of a comprehensive approach to modeling rural EMS service, the researchers developed a conceptual framework. This high-level approach will require a more comprehensive future research effort to implement. The modeling discussion presented in this report focused on different variables and constraints that could be incorporated into modeling efforts, assuming the availability of various pieces of data. Model variables were generally grouped into a series of categories, including past call data, system priorities, EMS system data, funding, network and population. Similarly, model constraints were categorized as provider, funding, staffing, priorities, traffic, and weather.

Once the variable and constraint groups were developed, prospective model components were identified. These components included several individual, standalone models intended to produce outputs which provide answers to specific aspects of EMS service that may be of interest. Individual component models identified during the course of this work covered the Econometric, call volume, dispatch/protocol, coverage/response, personnel, and equipment aspects of EMS service. The individual component model results would be employed in a unifying approach which models EMS service for an area. The approach employed in developing this unifying model could potentially include simulation, Bayesian, or other models.

This approach could be used to produce an optimized output (after iterations) which accounts for various factors which affect EMS service in a given area. In addition, the compartmentalized nature of the overall modeling approach would allow for different factors to be employed and changed on an individual basis yet still interact with others overall. Collectively, the individual models and the simulation would produce a number of outputs, including performance metrics, budget information, resource needs and allocations, and data to support GIS mapping, among other items.

Based on the work presented in this report, a series of potential barriers have been identified which could present challenges to the eventual implementation of a modeling approach based on the conceptual framework developed. These include cost, data availability, agency goals/needs, and general reluctance of models. From a development standpoint, the proposed modeling approach will require significant effort to identify the appropriate modeling approaches to employ when examining the various data and constraints identified during the course of the work.

The primary recommendation drawn from this work is that a follow-up phase to this project should be pursued to identify the proper modeling techniques to employ for each of the model components identified in this report. Each of these models is likely to take on a different type/form based on the input variables and constraints of interest. Once the appropriate models are constructed, they should be tested and refined, preferably using data from a geographic area of limited size scope. This will allow for problems to be identified and corrected prior to more large-scale testing and implementation.

1. INTRODUCTION

Many challenges face Emergency Medical Services (EMS) today. Among these are a sub-optimal distribution of pre-hospital care providers by both number and level of training, lack of payment incentives, delays in offloading patients at the hospital and ambulance diversion. It remains unclear as to whether EMS is a health care, public safety or public health program. Best practice models have not been well documented and/or replicated. Research in the pre-hospital phase has been limited and largely focused on specific clinical interventions rather than system design issues. The goal of the research project discussed in this report was to identify variables, constraints and approaches to developing model response systems for EMS in rural areas that meet the Institute of Medicine's vision of systems that are “regionalized, coordinated and accountable” and which are, additionally, sustainable (1).

1.1. Background

While the roots of organized responses to emergencies can easily be traced back to the Napoleonic wars, a more practical view would suggest that the birth of modern day emergency care systems revolved around two relatively recent convergent events. The first of those was the development of an emergency response system to treat cardiac arrest. While descriptions of resuscitative techniques are evident in the eighteenth and nineteenth century medical literature, the fundamental beginnings of a systems approach to the treatment of cardiac episodes began in Belfast, Ireland, in 1966 (2). In the Belfast model, physicians and nurses responded to the scene of an individual suffering from heart attack symptoms. This extension of the hospital to the field added an additional component to the health care "system" of the day and resulted in increased survival from acute cardiac events by decreasing the amount of time from the onset of symptoms to the initiation of definitive care. The limitations of the Belfast system were the expense associated with having this level of medically trained personnel responding to the scene of an incident, and that personnel were unable to attend to cases occurring far away from the hospital base, resulting in unchanged rates beyond the immediate hospital response area. The Belfast model has evolved over time and, in the United States, is a more complex system whose primary goals are to 1) prevent cardiac events from occurring initially, and 2) when such events do occur, responding to those events in a planned and efficient manner.

At roughly the same time the second converging event occurred. The National Academies of Science (1966) published Accidental Death and Disability: The Neglected Disease of Modern Society. That work described the epidemic of injury, particularly from motor vehicle crashes. “Accidents are the leading cause of death among persons between the ages of 1 and 37; and they are the fourth leading cause of death at all ages” (3). The lack of an organized emergency care system was noted by the panel. “Expert consultants returning from both Korea and Vietnam have publicly asserted that, if seriously wounded, their chances of survival would be better in the zone of combat than on the average city street” (3). Among their recommendations, the following specifically pertains to ambulance or Emergency Medical Services (EMS):

> Adoption at district, county, and municipal levels of ways and means of providing ambulance services applicable to the conditions of the locality, control and surveillance of ambulance services, and coordination of ambulance services with health departments, hospitals, traffic authorities, and communication services (3).

Arguably, the existing status of the emergency care system in the U.S. has not been more clearly stated than in the preface to the Institute of Medicine's (IOM) EMS: At the Crossroads (1). The committee notes the remarkable achievements of the system:

> Emergency care has made important advances in recent decades: emergency 9-1-1 service now links virtually all ill and injured Americans to immediate medical response; organized trauma systems transport patients to advanced, life-saving care within minutes; and advances in resuscitation and life-saving procedures yield outcomes unheard of just two decades ago (1).

More revealing than the statement of general accomplishments is the description of the challenges still facing the system. From the committee's perspective, the current status of the system is critical:

> Yet just under the surface, a growing national crisis in emergency care is brewing. Emergency departments (EDs) are frequently overloaded, with patients sometimes lining hallways and waiting hours and even days to be admitted to inpatient beds. Ambulance diversion, in which overcrowded EDs close their doors to incoming ambulances, has become a common, even daily problem in many cities. Patients with severe trauma or illness are often brought to the ED only to find that the specialists needed to treat them are unavailable. The transport of patients to available emergency care facilities is often fragmented and disorganized, and the quality of emergency medical services (EMS) is highly inconsistent from one town, city, or region to the next (1).

Clearly a discussion on the ills of the health care system or even the emergency care system in its broadest context is beyond the scope of this report. Instead, the remainder of this report will focus on one aspect of the broader emergency care system – the pre-hospital care component – specifically in a rural context.

1.2. Research Goals

The principal goals of this research were to review past relevant literature and identify model variables, constraints, and components in order to develop a conceptual approach to modeling response systems for EMS in rural areas that meet the IOM's criteria of "regionalized, coordinated and accountable" and which are, additionally, sustainable. Meeting these stated goals entailed the following:

- Conduct a literature search of guiding documents and peer reviewed research pertaining to EMS system design and modeling, as well as literature from other health care, public health, and broad system design disciplines.
- Identify critical variables, constraints and components that should be considered in modeling EMS in rural areas.
- Create a conceptual approach and process for modeling rural EMS systems.
- Present the proposed approach to the EMS community for future refinement and application through a final report document.
    - Discuss potential barriers to implementation and strategies for overcoming those barriers.

1.3. Report Overview

Chapter 1 has presented a general overview and background of the research problem being examined, as well as the overall goals of the project. Chapter 2 presents a summary of the relevant literature identified during the course of the work. In a review of the state of the practice, Chapter 3 summarizes the information obtained from a local response agency and the 911 dispatch center in Bozeman, Montana. Chapter 4 provides a discussion of the variables, constraints, components, and outputs for a prospective modeling approach. Finally, Chapter 5 presents a summary of the report document, discusses impediments to future implementation of the approach, and concludes with recommendations stemming from this work.

2. LITERATURE REVIEW

Today, Emergency Medical Services (EMS) agencies are challenged to provide increasingly advanced patient services, as well as expedited transport to hospitals and trauma care facilities. Especially in rural areas, the barriers caused by time and distance, and the limitations of rural economics and available resources exacerbate these challenges. As mentioned in the initial chapter, the goal of this work was to develop a framework and approach for modeling EMS systems. In developing that framework, the researchers initially reviewed guiding documents and peer reviewed research papers pertaining to EMS system design and modeling. The findings are summarized in the following sections. This information was subsequently used to identify variables, constraints, components and outputs of an overall modeling approach.

2.1. Historical Background and Challenges

This section provides an overview of the historical background for Emergency Medical Services (EMS) in the United States, as well as some key issues pertinent to the current EMS system, especially in rural areas.

Many challenges face EMS today. Among these are a sub-optimal distribution of pre-hospital care providers by both number and level of training, improper payment incentives, delays in offloading patients at the hospital and ambulance diversion. It remains unclear as to whether EMS is a health care, public safety or public health program. Best practice models have not been well documented and/or replicated. Research in the pre-hospital phase has been limited and largely focused on specific clinical interventions rather than system design issues.

Challenges facing the pre-hospital phase of the emergency care system in rural America are exacerbated by the nature of the pre-hospital care workforce, the barriers caused by time and distance, rural economics, and a host of other less tangible factors. Exploring two of those factors, in particular, begins to shed light on the issues facing rural EMS.

The first issue is that, in spite of categorical grant funding of the 1970's, ambulance services sprung up organically, without much forethought or planning. When the Emergency Medical Services curriculum became available from the National Highway Traffic Safety Administration in the early 1970's volunteers were expected to take the training and organize ambulance services in their hometown. Fundraisers were held to raise money and state level Departments of Transportation helped with the purchase of new ambulances. Categorical grant funds that followed helped with additional equipment and training. Consequently, we now have ambulances in rural towns a few miles from the next rural town with an ambulance service and so on. Most of those agencies are currently struggling to survive. The reason for those struggles is directly attributable to the second key issue, the voluntary nature of the workforce. Warden in IOM (2006) notes that "EMS, for example, is unlike any other field of medicine, over one-third of its professional workforce consists of volunteers" (1). In rural areas the dependence upon a volunteer workforce is much higher. The IOM report goes on to describe the problem in more detail:

> "Rural areas face a different set of problems, principally involving a scarcity of resources."
>
> "EMS and trauma services are spread out across wide distances, and recruitment and retention of EMTs and paramedics is a pervasive problem. In rural areas, volunteers

> make up the majority of the EMS workforce (4). EMS is the only component of the U.S. medical system that has a significant volunteer component. But in many rural communities, younger residents are leaving while the remaining population becomes more elderly. As a result, the pool of potential volunteers is dwindling as their average age and the demands on their time increases. The closure or restructuring of many rural hospital facilities has further increased the demand on rural EMS agencies by creating an environment that requires long-distance, time-consuming, and high-risk inter-facility transfers" (p. 31).

While the volunteer model has served rural communities well, most experts agree that it is unsustainable. Pressures have been placed on the rural volunteer model in a number of intersecting ways. First the economic challenges facing much of rural America has led to a migration of the workforce from rural areas to larger population areas for college education and employment opportunities. This directly impacts the size of the pool of potential volunteers. The absence of youth has caused a serious graying of the rural volunteer pre-hospital workforce. An additional impact of the economy is the fact that now it is common for both adults in the household to be working. Many business owners may be less willing to allow their employees to leave their stations when the pager goes off alerting them to an emergency. In most rural communities that rely on rural pre-hospital personnel, the most difficult staffing time occurs Monday – Friday, from 7:00 a.m. to 6:00 p.m.

The second issue impacting the volunteer infrastructure is a change in volunteerism itself. The change has not been so much in the numbers of persons within a population willing to volunteer, but rather in how they volunteer. In the 1970's, it was not uncommon for individuals to be willing to carry the pager and respond, literally, 24 hours a day, 7 days a week. Putnam (2001) notes that volunteers now want much greater control over their volunteer time, for instance, volunteering 4 hours per week on Tuesday evening between 6:00-10:00 p.m. (5). EMS agencies who once could comfortably staff their ambulance with 8-10 volunteers have had to double or triple their roster to accommodate this "scheduling convenience" factor.

In some rural areas these challenges are being exacerbated by the migration of urban retirees. Unfortunately, these individuals often bring expectations and demands concerning their emergency medical care that are, largely, unattainable within a rural, volunteer EMS infrastructure. Additionally, these retirees add to the aging population in rural America which may limit the volunteer pool and further add to the increase in demand for services.

The National Highway Traffic Safety Administration (NHTSA) continues to provide leadership to the pre-hospital component of the emergency care system. In the mid-1990's, an expert writing group was convened to draft a vision for the next decade of EMS. Through a series of consensus conferences and iterative drafts, the *EMS Agenda for the Future* (1996) emerged (6). The vision articulated in that document included:

> Emergency medical services (EMS) of the future will be community-based health management that is fully integrated with the overall health care system. It will have the ability to identify and modify illness and injury risks, provide acute illness and injury care and follow-up, and contribute to treatment of chronic conditions and community health monitoring. This new entity will be developed from redistribution of existing health care resources and will be integrated with other health care providers and public health and public safety agencies. It will improve community health and result in more

> appropriate use of acute health care resources. EMS will remain the public's emergency medical safety net (6).

Partially because the *EMS Agenda for the Future* had neglected to discuss the specific need of rural communities in any detail, the National Rural Health Association completed and published the *Rural and Frontier EMS Agenda for the Future* in 2004 (7). Again, an expert writing group and iterative writing process were used. This document clearly focused on the challenges and opportunities facing rural pre-hospital care providers. The vision articulated in the *Rural and Frontier EMS Agenda for the Future* was:

> The rural/frontier EMS system of the future will assure a rapid response with basic and advanced levels of care as appropriate to each emergency; and will serve as a formal community resource for prevention, evaluation, care, triage, referral, and advice. Its foundation will be a dynamic mix of volunteer and paid professionals at all levels, as appropriate for and determined by its community (7).

The authors noted that there are a number of issues facing rural and frontier communities relative to the provision of emergency care. The following list summarizes most of those key issues:

- Staff recruitment and retention
- The role of the volunteer
- Adequate reimbursement and subsidization
- Effective quality improvement
- Appropriate methods of care and transportation in remote, low-volume settings
- Assurance of on-line and off-line medical oversight
- Adequacy of data collection to support evaluation and research
- Adequacy of communications and other infrastructure
- Ability to provide timely public access and deployment of resources to overcome distance and time barriers (7).

As noted earlier, the document describes the mismatch between community perceptions and expectations. The following quote confirms that disparity:

> The presence of an ambulance service in town does not mean that the service is well-integrated into the community. Members of the community at large, and even its leaders, often do not understand the type and level of care that EMS provides. While citizens may expect an advanced level of care in their community because of film and television images of EMS, these expectations are rarely discussed. Tourism and the migration of residents from urban/suburban locales to rural/frontier areas may also import expectations of urban levels and type of EMS response (7).

The disconnect between perception and reality is illustrated in repeated surveys of the state offices of EMS in 2000 and 2004. Not only are there misconceptions about the level of service provided but concerns about being able to get an ambulance to the scene in a timely manner, if at all. This change in perception, over the course of four short years, paints an alarming picture of the health of rural EMS agencies:

> Surveys of state EMS directors in 2000 and 2004, indicated that the greatest need for rural services is the adequate recruitment and retention of staff. In the same surveys, "24/7 coverage" rose from the 22nd most important rural EMS issue in 2000 to the

> second most important in 2004. "Response time" rose from 20th place in 2000 to 5th in 2004 (7).

The IOM report (2006) notes that the six quality aims of healthcare are: safe, effective, patient-centeredness, timely, efficient and equitable. Speaking to the attributes of quality medical care is timeliness, the report notes that it is a relative concept in rural EMS:

> Response times vary widely depending on the location where the incident occurs. Across the large, sparsely populated terrain of rural areas, EMS response times—from the medically instigating event to arrival at the hospital—are significantly increased compared with those in urban areas. These prolonged response times occur at each step in EMS activation and response, including time to EMS notification, time from EMS notification to arrival at the scene, and time from EMS arrival on the scene to hospital arrival (1).

The IOM correctly noted that the most pervasive problem facing rural EMS is recruitment and retention of personnel. It notes that this challenge threatens the survival of many rural EMS agencies based on the following:

> Rural areas face a different set of problems, principally involving a scarcity of resources.
>
> EMS and trauma services are spread out across wide distances, and recruitment and retention of EMTs and paramedics is a pervasive problem. In rural areas, volunteers make up the majority of the EMS workforce.
>
> EMS is the only component of the U.S. medical system that has a significant volunteer component. But in many rural communities, younger residents are leaving while the remaining population becomes more elderly. As a result, the pool of potential volunteers is dwindling as their average age and the demands on their time increases. The closure or restructuring of many rural hospital facilities has further increased the demand on rural EMS agencies by creating an environment that requires long-distance, time-consuming, and high-risk inter-facility transfers (1).

The IOM also notes the high cost of readiness in rural EMS systems. This, in addition to tradition, is the root cause of the heavy reliance on volunteers:

> However, in rural areas, the relatively low volume of emergency calls in relation to the high overhead of keeping a prepared staff results in very high costs per transport. In order to lower those costs, many rural EMS squads rely on volunteers, rather than paid EMS personnel, however this results in a less stable system (1).

Perhaps, most importantly, the IOM articulated a vision around the entire emergency care system as being "regionalized, coordinated and accountable" (1). Strategies to overcome perceived threats to rural EMS agencies who fear the loss of autonomy, concern for local citizens and identity for the local community must be developed.

2.2. EMS System Modeling

A number of studies have examined various aspects of Emergency Medical Systems and response models, particularly the problem of locating vehicles/bases to maximize response coverage. As one might expect, the approaches employed in addressing this issue have gradually progressed in terms of sophistication, paralleling advances in computational processes and power. The following text discusses the research which has been conducted to date regarding the modeling of EMS systems in general. For brevity, the various model equations and formulations are not provided by this text. Interestingly, the focus of these models has remained on the problem of dispatching and location despite the advances in techniques employed; the result is that variables such as economic and workforce considerations have not been considered despite the significant role these play in the development of model response systems.

Fitzsimmons (1973) completed early work in the development of a methodology for ambulance deployment (8). The analytical ambulance response model that was developed in this work used an M/G/∞[1] queuing model as an approximation of the ambulance system. The model only considered response time for a particular call and the number and location of hospitals. Given the limited considerations and focus of the model formulation, it does not appear to be capable of expansion to account for more complex and dynamic data.

Larson (1974) applied the results from an earlier model, named Hypercube, to investigate urban emergency service systems for the Department of Housing and Urban Development (9). Hypercube was a queuing model that incorporated spatial queuing aspects of police patrol and dispatch to compute the performance characteristics of an urban emergency system. The process employed by this investigation was as follows:

- Assume a dispatcher has a rank-ordered list of preferred units to dispatch to calls for a geographic unit (cell) and the most preferred available unit is dispatched first.
- Also assume that the probability of dispatching the j^{th} preferred unit to a call from a cell can be approximated to be proportional to the product of the utilization factors of the first (j – 1) preferred units and the availability factor (fraction of time a unit is busy serving calls) of the j^{th} preferred unit.
- The constant of proportionality is dependent on j and is derived from the simple M/M/N queuing model[2] assuming a situation where j servers are selected randomly without replacement.
- Given the previous, one can generate N simultaneous nonlinear equations relating the N unknowns (utilization factors) to the dispatch policy and call rates from different cells.
- Solve the N simultaneous equations iteratively, yielding estimates of unit workloads.
- Use the values of the utilization factors found through solving the equations to estimate the fraction of dispatches that would send unit i to cell j for all i and j to obtain estimates of desired performance measures (9).

[1] The M/G/∞ is also known as the infinite source Poisson model. In this model, each customer gets its own server and there is no queue.
[2]The M/M/N queuing model is also referred to as the Erlang C queuing model, which establishes that customers arrive at a queuing system having ***n*** servers and *infinitely many* waiting positions.

While this work focused on the problem of police unit dispatch, Brotcorne et al. (10) noted that given an ambulance plan and demand levels, similar probabilities could be estimated using this approach for the case of EMS.

Aly and White (1978) studied the problem of locating emergency service facilities under the assumption that incident locations were random variables (11). The researchers developed the probability distribution of rectilinear travel time between a new facility location and the random location of an incident P_i for the case of P_i being uniformly distributed over a rectangular region. This allowed for the development of probabilistic and deterministic formulations to solve the location problem of interest. It was found that the probabilistic formulation required a higher number of assigned sites than the deterministic approach, with the overestimation obtained to ensure that all sites were covered at a specific service level (11). The model focused on maximizing service while minimizing the number of facilities required. No indication was provided as to whether economic and personnel factors could be incorporated into the model.

Daskin and Stern (1981) developed a modified maximal covering location problem (MCLP) model to locate EMS vehicles in different geographic zones (12). The focus of this model was to make the best use of available limited resources by determining the minimum number of vehicles needed to cover all zones while maximizing the extent of covering all zones. The modeling incorporated hierarchical and multiobjective programming techniques, allowing for the stated objectives to be focused on. No indication was provided as to whether the model could be expanded to incorporate additional inputs for consideration.

Work by Daskin (1983) developed a maximum expected covering location model to analyze locations for public service facilities (13). The approach employed recognized that if M facilities were located on a network, not all facilities would be able to respond to demands at all times. The heuristic solution algorithm employed by the model was based on the observation that for values of p (probability of a facility not working) close to 1.0, the optimal solution was to place all facilities M at the node which covers the greatest demand. The model assumed that probability p was equal for all facilities and that the probability of a facility being busy was independent of whether other facilities were busy (13). No discussion was provided regarding whether (or how) the model might be expanded to incorporate additional considerations relevant to facility location.

Wolfe and Shuman (1988) developed a comprehensive simulation model named RURALSIM to allow planners to examine how their present rural EMS system functioned and how to determine the effects of changes introduced to that system (14). An initial discussion of the model components is provided by Ames et.al (1979) (15). The model was designed to address specific questions, including:

- Are an appropriate number of vehicles serving an area and are they appropriately located?
- Are personnel trained at the appropriate level to serve the area population?
- Are aircraft required for the system and if so, where should they be located (14)?

The model that was developed took a number of factors into consideration, including demand by various patient types, geography, sociodemographic characteristics of the area, the availability of different types of care facilities, the number of EMS personnel and their level of training, available equipment (type, number and location), existing data systems, regional and local organizations (providers) and other factors. For each factor, decisions were made whether it should be handled as a model variable or as a constraint or parameter of the system itself (14). Once these decisions were made, the simulation was developed through the use of the SIMULA programming language, which allowed multiple processes to be active at once and proceed on their own path (15).

The model was broken down into six components including a demand generator, a patient simulator, a vehicle simulator, a communications simulator, a dispatch simulator, and an evaluation module (15). Outputs of the model included vehicle time statistics, patient time statistics and a cost of operations. As a result of this work, it was concluded that while RURALSIM was developed to be generalized, it required extensive modifications depending on the specific analysis case and could not be released for general use. Additionally, the simulation program required use of a mainframe computer, further limiting its practicality for widespread use. However, despite these issues, RURALSIM represents one of the most comprehensive efforts for modeling rural EMS systems, particularly with respect to its inclusion and consideration of demographic and economic factors.

Goldberg, et al. (1990) employed a simulation model to evaluate a set of emergency vehicle base locations (16). The choice of a simulation model was based on the belief that it would perform better when using empirical data of demand and service processes as opposed to fitting a theoretical distribution, as past models employed. The only exception to this was the model that was developed for predicting travel times, as no empirical travel time data was available. While the researchers indicated that the developed model was simple in nature, it was capable of evaluating the effect of adding an additional vehicle, whether base locations should change throughout the day, and alternative dispatching rules that take travel distance and remaining coverage into account. Given that the simulation model developed by this research took more complex information into account (namely dispatching rules), other factors of interest in modeling response systems could also conceivably be incorporated.

Revelle and Snyder (1995) discussed the development of a deterministic, multi-objective model for integrated fire and ambulance siting (17). The model the researchers developed specific to ambulance siting was the maximal covering location problem (MCLP), which sought to cover the maximum population within a specified distance standard given a limited number of vehicles or servers available. The model allowed for ambulances to be sited at free-standing locations, which allowed for the benefit of different placement of servers. In running hypothetical examples, the model indicated that ambulance coverage could be increased for a constant facilities budget (cost to build a station) with little or no loss in fire coverage as ambulances would be stationed free of fire stations (17). While the model that was developed did take into account a limited financial element (i.e., cost to build a station), it primarily focused on service based node demand, potential facility sites, and response distance standards. Consequently, other aspects of the problem, such as work force location, demographics, and so forth, are not considered.

Branas, et al. (2000, 2001) developed a model (TRAMAH – Trauma Resource Allocation Model for Ambulance and Hospitals) which employed a mixed integer linear program and "iterative switching" heuristic to simultaneously locate trauma center and depot resources (18, 19). The iterative switching heuristic was employed to obtain a reduced set of depot and trauma center sites for resubmission to the linear program. It performed the function of a trauma system administrator using subjective judgment in eliminating eligible sites. The model was limited in that it only focused on optimizing the coverage area for assisting severely injured patients. The authors note that future work should incorporate additional measures such as population or call volume coverage, although this modeling approach does not appear to be capable of accounting for non-spatial components (i.e., economic factors).

Brotcorne, et al. (2003) compiled a comprehensive overview of ambulance location and relocation models (10). The authors note that early EMS models focused on static and deterministic location problems with an emphasis on their use in planning. Static models developed solutions which did not consider that coverage is lost when an ambulance responds to a call, while deterministic models yielded solutions in which response demand points were overcovered, but the availability of an ambulance was not considered. These early models could be further broken down by probabilistic (ambulances serve in a queue) and dynamic (ambulances can be relocated throughout the day for coverage) classifications (10). As computational power and advanced search algorithms evolved over time, dynamic models became much more prevalent, with the most recent iterations incorporating Geographic Information Systems to provide additional spatial outputs.

Tavakoli and Lightner (2004) discussed the implementation of a mathematical model for locating EMS vehicles in Fayetteville, North Carolina (20). In this work, the developed model sought to optimize the location and allocation of EMS vehicles and facilities in a manner that would increase the number of calls answered within the cited 8 minute national average. The model was an adaptation of the bicriterion maximal covering location problem (MCLP) model developed by Church et al. (21). From records of EMS calls received, the study county was divided into analysis zones whose structure was based on with travel time, population density, traffic flow and other considerations related to each zone. Results generated by the model indicated that enhancing the degree of coverage relied on the strategic location and allocation of ambulances and facilities. Notably, the researchers cite that qualitative factors not incorporated in their model, including social, regulatory and political consideration, also play a key role in the process, which suggests recognition (not explicitly stated) that these elements should be incorporated into the process during future modeling efforts.

Yang, et al. (2004) recognized that EMS depot and fleet assignment problems were usually solved under simplified assumptions (22). Consequently, the researchers developed a simulation model for EMS vehicle dispatching, with the results incorporated into a genetic algorithm (GA) to solve the depot location and fleet assignment problems simultaneously. The researchers note that the EMS models traditionally constructed were theoretical and simplified (or ignored) many details of the real operational system and were sometimes difficult to solve. As a result, simulation was incorporated in this work to observe the system under different conditions. The approach developed in this work was iterative, in that the location and fleet assignment generated by the genetic algorithm was employed in the simulation program and the output of the simulation program then used in the evaluation of the "chromosome[3]" for the GA to generate the next population of solutions. While the approach employed by this work focused on dispatch, response and coverage, it is intriguing in that it could conceivably incorporate economic, workforce and other considerations (through the chromosome evaluation) which have not been accounted for in other approaches.

[3] A "chromosome" represents the set of nodes N in a coverage area.

Restrepo, et al. (2007) developed two models for static ambulance deployment (23). The first model estimated system performance by using the Erlang loss function[4] embedded in an optimization problem to find desired ambulance allocations. This first model captured the dependence between ambulances that were deployed at the same base but assumed an a priori knowledge of demand. The second model used the Erlang loss function to construct a set of equations that characterized the performance of the system. This model was intended to obtain a performance estimate of the system for a fixed ambulance allocation and did not require a priori knowledge of demand. Given that the model could be adapted to produce performance measures, it may be possible to modify it to incorporate other factors of interest, including economic and workforce, although the researchers did not provide comment on this potential.

Erdemir, et al. (2008) developed a variant of the maximal covering location model to optimize the location of aeromedical base locations in New Mexico (24). The model focused on servicing crash nodes (points) and paths (lines representing roadways) and was originally developed to locate cellular base stations. The researchers noted that the model was limited in that it was static and did not suggest a different set of locations for different periods based on changes in accident distributions and frequencies. They noted that additional factors were not taken into consideration, including geography, topography, jurisdictional issues and coordination between operators. It was not made clear whether the model that had been developed could take these factors into account, although the spatial components (geography, topography) could be, based on the work presented by this reference.

Zhao, et al. (2010) developed a model for an emergency response system based on a partial differential equation solved by an iteration algorithm with a central difference scheme (25). The researchers employed a diffusion equation, which can be used to indicate the spread an interaction of material (e.g., ink drops in a pool) to determine the number and location of scheduling points. With this information, a location model was established based on differential equations to solve for dispatch points. While the model and algorithm solved the target location problem for optimizing an EMS system, the approach that was developed only took into account general aspects of emergency response, namely location and dispatch, ignoring other elements such as travel time.

In an unpublished and undated document, Lightner and Graham examined the use of a genetic algorithm to locate EMS facilities and vehicles to minimize the number of locations that could not be covered in a specific time (26). The algorithm the researchers developed was driven by the fitness of chromosomes generated through a discrete event simulation model. While the approach only focused on coverage based on call volume, vehicle availability and travel time metrics, it appeared to allow for expansion to account for other variables.

[4] The Erlang loss formula expresses the probability that an arriving call is rejected because all N servers are busy.

Additional Modeling Approaches

In addition to the modeling approaches identified specific to EMS, a number of other modeling approaches were identified which may be relevant/applicable to the present project. These were identified primarily through an examination of the citations made by the previously reviewed EMS literature and a general literature search.

Moore and Revelle (1982) discussed the general hierarchical service location problem (27). Specifically, they examined how the maximal covering location problem (MCLP) could be modified and extended to take into account the hierarchies present in service systems. The work sought to find the number of facilities to be allocated at each level and their locations so that the population which had access to all components of service was maximized, given a specific budget for investment (27). While not the focus of the research, EMS clearly fits this framework. Indeed, the MCLP model developed was adapted to use in EMS problems as cited in previous references.

Batta and Mannur (1990) developed covering-location models for emergency situations requiring multiple response units (fire trucks) (28). As part of their work, the researchers examined the set covering location problem (seeks to find the minimum number of units and their locations to cover demand at all nodes) and the maximal covering location problem for use in the modeling framework. While the authors did not discuss the ultimate model that was developed, their discussions of different coverage models does provide insight into different response models that could be developed.

Wears and Winton (1993) employed simulation modeling to examine pre-hospital trauma care systems, noting that these are complex and do not respond predictably to changes in management (29). The model was a discrete simulation that incorporated a continuous model element (physiologic, the type of trauma event occurring). While the researchers noted that their trauma care system consisted of patients, vehicles, receiving facilities, injuring events and a transportation network, it is conceivable to expand the factors accounted for in the simulation model to include items such as economics and workforce.

Acid, et al. (2001) employed Bayesian networks to model emergency medical service (30). The researchers noted that many factors that influence the performance of a health care system are of an uncertain nature. This plays to the strength of Bayesian methods, which are used to make statements about an unknown quantity in a systematic way using what partial knowledge is available[5]. In this manner, Bayesian methods are attractive for use in the analysis of complex problems, including those of health care systems. In this work, an algorithm for a learning Bayesian network was developed to measure discrepancies between the conditional independences represented in any given candidate network and those displayed by the database of variables employed (30). While the learning algorithm was used to develop a network of interactions between study variables, the researchers noted that it could also be used for

[5] Bayesian methods approach data analysis in a different manner than classical statistical methods do. While classical approaches use only observed data in hypothesis tests, Bayesian methods use the observed data along with the knowledge gained in the past about the population in testing the hypothesis. In this manner, Bayesian methods are dependent not only on observed data, but also the history (from experience or expert judgments) of the problem being analyzed. It is this use of historical data which typically make the results of a Bayesian analysis more reliable than that of the classical approach; knowledge gained from past experience is utilized in study of the problem.

predictive purposes as well. Given the structure of Bayesian analysis, it is completely feasible that economic, workforce and other factors can be integrated into a model response system, provided appropriate measures of these variables are developed.

Carley, et al. (2006) developed a scalable multi-agent network numerical model to study the incidence of background and maliciously introduced diseases in an urban environment (31). The model is in essence a simulator using a variety of social, disease, environmental, geographic, weather, communications and other data to model a disease outbreak and response. The authors note that future upgrades would include organizational response and cost models. In the context of this project, the simulation approach and its flexibility to accommodate a number of disparate data types/streams would again appear to be suitable for modeling response systems.

Zhao, et al. (2007) developed an integrated system that incorporated agent-based discrete event simulation, a geographic information system, a rule base, and interactive databases to apply to disaster management planning and training (32). The different modules communicated with each other by exchanging a progression of data and making deductive decisions through embedded algorithms. The agent-based model approach was comprised of "intelligent" entities that were autonomously controlled by perceiving the surrounding environment, compiled predefined rules to make operational decisions, and acted based on those decisions (32). This allowed for the simulation of complex, dynamic, actual systems that were realistic because their operations were highly analogous (32). While developed to aid in disaster management activities, the authors note that future development could incorporate other factors, such as traffic, weather and social behaviors. Conceivably, from an EMS modeling perspective, an adapted version of the model could incorporate many, if not all factors of interest, including workforce and economics.

Huang, et al. (2007) examined the optimal deployment of emergency service resources (fire equipment, ambulances) for critical transportation infrastructure protection (33). This was accomplished through the development of a deterministic maximum expected covering model utilizing a mixed integer linear program. The researchers noted that the model processed input parameters based on a reliability requirement and historical demand rather than employing an explicit probability distribution as older models had done. It was noted that the model did not address several issues, including demand fluctuation due to population changes, which should be explicitly considered.

While focusing on the discussion of embedding Geographic Information Systems (GIS) into a disaster simulation, the work of Wu, et al. (2007) provided many useful insights into a simulation approach that might be considered in modeling EMS response systems (34). The work, which sought to develop a system to simulate the response to emergencies, employed discrete event simulation and a rule-based decision modeling system. The decision modeling system codified standards, training, best practices exercises, and research pertinent to response. The modular nature of the system they employed, as well as the decision model and the factors it took into consideration suggest that such an approach may be transferable to the model response system problem.

Erdemir, et al. (2008) examined location coverage models for cellular network design which addressed point (node) and path (highway) demands (35). The model that the researchers developed was a quadratic maximal coverage location problem that was supported by simulated annealing to locate facilities in a paired fashion at each stage of its solution (35). While the purpose of this work was to investigate cellular coverage for stationary and roaming users, its similarities to EMS service, specifically the randomized (roaming) location of response needs, makes this approach of interest. It is not clear, however, whether non-spatial components (economic, personnel, other) could be incorporated in the overall model. Rather, it might be more feasible to employ a model such as this as part of a larger overall procedure.

Discussion

Throughout this literature review, it is evident that the connection between economic and workforce consideration and the allocation of EMS resources has not been examined or developed. It is also evident that much of the work to date has focused on the urban context of the facility location and allocation problem, ignoring rural needs. Of course, part of this may be explained by the availability of urban data and the larger presence of EMS resources in such areas. In the context of the present project, the parameters employed in examining the location and allocation problem are generally similar between an urban and rural context. In a broad sense for each locale, the concern is to either minimize response time, maximize coverage area or both (depending on the jurisdiction and its priorities). Solving such location and allocation problems requires varying data, depending on the approach, including information on available resources (i.e., ambulances, depots, etc.), the roadway network, call/response volumes by area, and in some cases, travel times on the roadway network. In general, such information is available for rural areas (travel times may not be available). Consequently, the problem becomes defining what is of interest to an agency or community: coverage, response time, a combination of both, or other?

While the previous sections only discussed the overall modeling approaches employed by various researchers, the information presented does allow for discussion to be made with respect to the current project. In reviewing the various models developed in past work, it would appear that the RURALSIM modeling/simulation effort (14, 15) represents the closest approach to date at attempting to examine the complex issues of modeling rural EMS response systems. However, RURALSIM was developed during the 1980's in a mainframe environment and no work since then has transitioned this program to mainstream use, nor has any new effort developed a comparable product. Furthermore, the literature identified in this review found no modeling approach or software package employed by the EMS community that entirely models response, including economic, personnel and other factors.

Aside from the absence of transitioning and development of programs such as RURALSIM for everyday use, much of the work conducted to date related to the modeling of EMS systems has focused on the problem of vehicle/facility location. This work has employed generalized data inputs, namely number of vehicles, call demands (historical or probability-based), prospective facility/vehicle sites, and generalized response/travel times to optimize service coverage and identify facility locations. While these efforts have been worthwhile in progressing the state of the practice and accomplishing their objectives, they have not taken into account many other factors which have an impact on the EMS system (economic, personnel, etc.). This is not necessarily the fault of the researchers or their approaches; indeed, much of the work identified was conducted at a time when desktop computers and their associated computing power were not available. Consequently, the modeling approaches that were developed focused on a limited range of variables so that they did not require excessive calculations. Of course, as time has progressed, recent literature has indicated a shift toward more sophisticated approaches, namely simulation, combined with modeling approaches such as genetic algorithms and Bayesian networks which can adapt as new information becomes available (particularly through initial simulation iterations).

The flexibility of approaches such as simulation is that they allow for the use of multiple approaches in modeling different components and their interaction with one another. In this sense, it may be more desirable to identify different types of models that apply to different EMS components, using their results/outputs as an input into the overall simulation. For example, a simulation could incorporate the output of several models of various EMS aspects (vehicle fleet, historical call volumes and locations, response times, patient types, staffing/personnel, financial aspects, etc.) to serve as inputs. Using the input from various models, the model response simulation would produce an optimized output (after various iterations) which accounts for the various factors which affect EMS service in a given area. In addition, the compartmentalized nature of the simulation approach would allow for different factors to be employed and changed on an individual basis yet still interact with others overall. In this manner, what-if analysis could be facilitated, allowing for a determination of the impacts that changes to one aspect of EMS services might have on the overall system.

As noted, simulation alone is not the approach that should be employed in modeling response systems. Rather, the simulation would employ the outputs of different models of individual aspects of EMS. To this end, the work of Yang, et al. and Lightner and Graham (22, 26) which incorporated the use of genetic algorithms with simulation appears to be a promising approach to modeling response systems. Recall that the approach was iterative in that the output of the initial genetic algorithm is employed in the simulation program, with that output then used in the evaluation of the chromosome (nodes in a coverage/study area) for the GA to generate the next population of solutions. Depending on the components of interest and their data format, this approach is intriguing in that it could conceivably incorporate economic, workforce and other considerations (through the chromosome evaluation components of the GA) which have not been accounted for in other approaches to date. However, further investigation is required to make a conclusive determination as to whether this approach is applicable for use in a model response system.

In addition to the genetic algorithm approach, the use of Bayesian networks in modeling a response system is another possible approach to consider (30). Such an approach could incorporate many factors that influence the performance of a system that are of an uncertain nature (a characteristic of EMS, namely response locations and times). This plays to the strength of Bayesian methods, which are used to make statements about an unknown quantity in a systematic way using what partial knowledge is available. The approach employed in an EMS context might utilize an algorithm for a learning Bayesian network similar to that developed by Acid, et al. (30) that measures discrepancies between the conditional independences represented in any given candidate network and those displayed by the database of variables employed. The learning algorithm could also be used for predictive purposes as well. While further investigation of such an approach would be required, it is again feasible that economic, workforce and other factors could be integrated into a model response system, provided appropriate measures of these variables are developed.

The basic challenge faced by modeling a model response system is identifying an approach which can either incorporate performance, economic and spatial data either as model variables, constraints, or parameters of the system, or separate these aspects from the facility location and allocation problem. From a review of literature, it would appear that the use of simulation appears to be the approach that many researchers are now employing to model EMS and similar systems (14, 16, 22, 26, 29, 31, 32, 34, 35). The reasons for the use of simulation varied by project, but in each case, simulation facilitated an iterative process which allowed adjustments to be made to individual models to produce optimal results. In developing a model response system, the ability to employ an iterative structure would allow for flexibility in changing individual EMS variables/inputs, facilitating what-if analysis and optimization. Of course, simulation combined with one or a number of underlying models for individual EMS variables may be only one available approach that can be applied to the problem. Further discussion with stakeholders and practitioners may reveal alternative approaches that have not been identified during the course of this work.

In addition to the different approaches identified during the course of this review, alternative approaches that have not been considered to date might also present advantages. While one approach to considering economic and workforce components is to incorporate them into a larger overall model of the system, it is also equally valid to consider these aspects separately from the traditional location and allocation problem. For example, one approach might be to determine how existing funding resources and workforce capabilities could be maximized, with EMS resources located/allocated within these corresponding maximized values by treating them as constraints. A second approach might be to determine the optimum location and allocation of EMS resources and then make a determination of how funding and workforce issues might be appropriately addressed.

One final point of discussion is warranted related to Geographic Information Systems (GIS). Many of the more recent (late 1990's and beyond) work cited in this text employed GIS in varying manners. The role of GIS in modeling EMS/response is threefold: data management, data analysis and spatial presentation. Some of the efforts reviewed displayed the results (spatial) of their modeling efforts via GIS. Other work employed GIS to manage a portion of the input data (again, spatial in nature) for subsequent input into a larger process, typically simulation. Finally, GIS does provide some analysis capabilities, such as allowing for the determination of travel times along roadway segments, determining areas of coverage under different scenarios, and other analysis related to spatial data. Regardless of its role, GIS is likely to serve a role in any future response modeling effort that is recommended or results from this work. However, the reader should note that GIS itself is not the modeling mechanism, but rather, one tool used to facilitate an overall modeling effort.

3. STATE OF THE PRACTICE: AN EXAMPLE

3.1. Introduction

For any model to be useful and practical, it must include a "dose of reality." Knowledge of the current system is crucial - how it works, the variables and constraints affecting it, and most importantly, a practical understanding of the goals and needs involved in potential model development. For the purpose of this project, it was important to gain at least a basic understanding of the current processes, protocols, and methods being used to facilitate EMS systems in rural areas. This necessarily included knowledge of the state of the practice in regard to different variables, components, and constraints on rural EMS systems.

Gallatin County in Montana was a logical choice for a study area to develop some insight on the state of the practice for rural EMS systems. The area is diverse in regard to population, demographics, service needs, transportation network, geography, and environmental conditions. This diversity produces a good example of the many challenges faced in providing effective, efficient and sustainable emergency medical services in rural areas. EMS in Gallatin County operate locally and regionally as well. Because of these factors, Gallatin County could generally be considered representative of rural EMS in Montana and potentially other rural areas of the country. Finally, the project team is located in Gallatin County and this proximity to rural EMS providers facilitated opportunities to meet in person and tour facilities. It was not feasible within the scope of this project to visit and interview EMS providers in other locations.

In order to gain some understanding of the important components of a potential EMS model, the project team interviewed personnel and toured the Gallatin County 911 Center and the Sourdough Fire Department. Unless otherwise cited, the information in the following sections is taken from those interviews. Prior to the interviews, a list of potential questions and discussion points was developed and given to the individuals to be interviewed. While not discussed verbatim, the list helped prepare the departments for the meetings and provided a guideline for the interviews. The list of topics and questions can be found in the Appendix.

3.2. Gallatin County Overview

With over 90,000 people spread over 2600 square miles in southwest Montana, even the county seat of Bozeman (population 40,000) has many rural features (36). The County's topography and climate varies from more temperate river valleys to rugged backcountry and snow-capped mountains to open rangelands. Almost half of the land is publically owned and managed by the Gallatin National Forest, State of Montana, Bureau of Land Management (BLM), or the National Park Service (37). However, while most of the land area, both public and private, is within a fire district or fire management area, some privately owned land within the county boundary is not within such a jurisdiction. The varying ownership patterns and jurisdictions are just one example of the challenging factors faced by rural EMS providers.

Gallatin County draws a large number of outdoor recreationists who ski, hike, fish, camp, climb, snowmobile, ride horses or ATVs, and hunt in remote locations. Montana State University draws approximately 13,000 students to Bozeman and the surrounding communities on an annual basis. In addition to the university, agriculture, tourism, a growing high-tech industry and a larger population of younger, active retirees combine to form a very diverse community and associated economic base. The County's population is growing quickly compared to the rest of Montana and the area is experiencing the related effects of growth and suburban sprawl.

These factors affect rural EMS in a number of ways, including:

- Changing expectations and requirements for service;
- Increasing volume and diversity of EMS calls;
- Uncertain and changing funding sources and amount of available funds;
- Recruitment and retention of appropriately trained staff (volunteer, paid);
- Response to calls in rugged and remote areas;
- Collaboration between different jurisdictions and multiple agencies;
- Quality and accessibility of the transportation network;
- Diverse topography, climate and environmental conditions spread over a large geographic area.

3.3. EMS in Gallatin County, Montana

3.3.1. Overview

In a review of the state of the practice for rural EMS systems, the project team briefly explored how rural EMS resources are allocated, operated, maintained, and coordinated in Gallatin County, including those for 911 dispatch, fire and ambulance. The information gathered will help provide the foundation for developing one or more model response systems for EMS in rural areas that are regional, coordinated, accountable, and sustainable.

Over 20 licensed EMS agencies operate in Gallatin County. These include the non-volunteer Bozeman Fire Department, the private American Medical Response (AMR) ambulance service, several community volunteer ambulance and fire departments, ski patrols, and volunteers from local industry (Three Forks). Depending on their type and level of training and available equipment (i.e., ambulance), these EMS agencies are categorized as either transporting or non-transporting. The agencies can be further classified according to the level of patient care that can be provided: Basic Life Support (BL), Basic Life Support with Advanced Life Support endorsements (BA), or Advanced Life Support (AL). Both public and private, these EMS agencies have paid employees, are all volunteers, or operate with a mix of volunteers and non-volunteers. A summary of the different Gallatin County EMS agencies is presented in Table 1.

In addition, the Gallatin County Sheriff's Office coordinates several specialty groups of highly skilled volunteers for search and rescue missions. These groups include the Civil Air Patrol, Gallatin Ham Radio Club, Tactical Divers, and Western Montana Search Dogs, among others (38). Finally, Bozeman Deaconess Hospital is a Level III Trauma Center and the only facility of its type in the county (39). There is, however, no direct air ambulance provider in Gallatin County.

The state and federal agencies that manage land in and adjacent to the County, such as the National Park Service, BLM, Forest Service, and the State of Montana, also have emergency response teams, particularly for wildland firefighting. The Gallatin National Forest, for example, operates the Bozeman Interagency Dispatch Center which coordinates fire suppression activities in the forest. The dispatch center also provides services for Yellowstone National Park, the Montana Department of Natural Resources, and several counties including Gallatin County (40).

While not directly providing emergency medical services per se, since these agencies coordinate with local EMS, they are worth noting here.

Table 1: EMS agencies in Gallatin County, Montana (Source: CITF)

Service Name	City	Service Level	Service Type	Organization Status
AMERICAN MEDICAL RESPONSE	Bozeman	AL	Ground Transport	Non-Volunteer
AMSTERDAM VOLUNTEER FIRE COMPANY	Manhattan	BL	Non Transporting	Volunteer
BIGHORN FIRE CO INC	Livingston	BL	Non Transporting	Non-Volunteer
BIG SKY FIRE DEPARTMENT	Big Sky	AL	Ground Transport	Mixed
BIG SKY SKI PATROL	Big Sky	BA	Non Transporting	Mixed
BRIDGER BOWL SKI PATROL	Bozeman	BA	Non Transporting	Mixed
BRIDGER CANYON VOLUNTEER FIRE DEPARTMENT	Bozeman	BL	Non Transporting	Volunteer
CENTRAL VALLEY FIRE DISTRICT / BELGRADE CITY FIRE DEPARTMENT	Belgrade	AL	Ground Transport	Mixed
CITY OF BOZEMAN FIRE DEPT	Bozeman	AL	Ground Transport	Non-Volunteer
CLARKSTON FIRE SERVICE AREA	Three Forks	BL	Non Transporting	Mixed
FORT ELLIS FIRE SERVICE AREA	Bozeman	BL	Non Transporting	Volunteer
GALLATIN GATEWAY RURAL FIRE DEPARTMENT	Gallatin Gateway	BL	Non Transporting	Volunteer
GALLATIN RIVER RANCH FIRE RESCUE	Manhattan	BL	Non Transporting	Mixed
HEBGEN BASIN FIRE DISTRICT	West Yellowstone	BA	Ground Transport	Mixed
LUZENAC AMERICA - THREE FORKS MILL	Three Forks	BL	Non Transporting	Mixed
MANHATTAN VOLUNTEER FIRE DEPARTMENT	Manhattan	BA	Non Transporting	Volunteer
SOURDOUGH RURAL FIRE DEPARTMENT	Bozeman	BL	Non Transporting	Volunteer
THREE FORKS AREA AMBULANCE SERVICE	Three Forks	BA	Ground Transport	Volunteer
THREE FORKS FIRE DEPARTMENT	Three Forks	BL	Non Transporting	Volunteer
WILLOW CREEK RURAL FIRE DEPARTMENT	Willow Creek	BA	Non Transporting	Volunteer
YELLOWSTONE CLUB SKI PATROL	Big Sky	BL	Non Transporting	Non-Volunteer

3.3.2. Gallatin County 911 Dispatch Center

Gallatin County recently opened a new state-of-the-art 911 Center alongside a new fire hall on a portion of the Gallatin County Regional Park on the west side of Bozeman. Since 1997, the city of Bozeman and Gallatin County 911 response has been a single entity. The Gallatin County 911 Center dispatches public safety resources (police, fire, paramedics) for most of Gallatin County and parts of neighboring Madison County. These resources include the Bozeman Police Department, the county Sheriff's office, the rural fire departments and service areas, American Medical Response (ambulance), and volunteer ambulance crews. It should be noted that the community of West Yellowstone and the Yellowstone Club near Big Sky, in the southern part of the County, have their own emergency response programs and the Gallatin County 911 Center does not directly dispatch for these areas. Because of the distance between West Yellowstone and other municipalities in Gallatin County, the police department in West Yellowstone maintains its own Emergency 911 Center (41). The Yellowstone Club is a private community that operates its own security, fire department, and ambulance services. Interlocal agreements exist with Gallatin County law enforcement to ensure coordinated response as needed.

According to the Gallatin County 911 Center Systems Administrator, the 911 Center received approximately 90,000 emergency calls in 2010. About 45,000 of those were dispatched to the Bozeman Police Department and another 23,000 to 24,000 were dispatched to the county Sheriff's office, with the remaining calls being dispatched to fire departments and EMS providers. Daily call volume varies dramatically, although the first snowstorm of the season regularly produces a larger number of calls. The winter ski season also affects the call volume. Almost all calls result in a dispatch.

For rural EMS response, the dispatch protocols are automatic and based on jurisdictional boundaries. For example, if the Sourdough Fire Department is dispatched to a medical call in its jurisdiction, AMR is automatically dispatched as well. Calls for mutual aid are issued by the responsible department. If mutual aid agreements are not in place, resources must be specifically requested or they are not dispatched.

In regards to technology, the 911 Center's Computer Aided Dispatch (CAD) system went live in February of 2000 and all dispatching is tied to a response plan. The center runs two servers and keeps an archival database. The 911 Center operates on its own fiber network. Three communications lines are designated for the Emergency Operations Center in addition to the three lines for the 911 Center. A reverse 911 system is in place and land-line telephone numbers are automatically included through the 911 database. Community members can also register their cellular and Internet phone numbers and associate them with an address to be included in the reverse 911 system. The wireless enhanced 911 system identifies the call back number of the handset, the tower or sector of the tower hit, and now the approximate location of the handset using GPS coordinates. Land line information including address and caller information can also be collected. This information can all be spilled into the CAD system to help improve the efficiency and accuracy of incident response. The 911 Center can receive and process incoming voice over IP calls, but according to the Systems Administrator, PBX systems can sometimes be a challenge. The CAD program includes Bozeman city and Gallatin county map and GIS data such as all structures labeled with building names and street addresses, water hydrants, and water fill sites with relevant information.

A public safety mill levy add-on fully funded the building of the 911 center, its operations and maintenance. West Yellowstone's 911 center also received part of the mill levy funds. A state fee administered through the Montana Public Safety Services Bureau provides additional funds for 911 infrastructure including hardware, software, and radio sites.

The 911 Center is staffed on two 12 hour shifts, with three to four people per shift. Dispatchers work approximately 40 hours per week, usually three 12 hour shifts and the remaining four hours depending on staffing levels. Training and certification are intense and include classroom type instruction, simulated practice, and work with a mentor. The work is challenging and recruiting and retaining qualified personnel can be difficult.

3.3.3. Sourdough Fire Department

Located south of Bozeman in Gallatin County, the Sourdough Fire District includes 15 square miles with about 1400 homes and 5000 residents. Sourdough Fire Department operates under a very close interlocal agreement with the neighboring Rae Fire Department. The Rae department covers a fire service area while the Sourdough department covers a fire district. A portion of funds for services in a fire service area are collected through fees per structure. Comparatively, funds for a fire district's services are collected through mill levies based on taxable values. Each department has its own station and the two departments share a third station and training facility. Firefighting equipment and vehicles are owned by each individual department. This close working relationship and facility sharing is unique and is driven by the pragmatism of sharing resources, geographical convenience, and a willingness to cooperate. Both departments are volunteer fire departments and are run by an elected board of trustees. The Sourdough Fire Department does have some paid employees, including a maintenance technician and an attorney/administrator. The salary for the attorney/administrator is split through an interlocal agreement between three rural fire departments—Sourdough, Rae, and Amsterdam fire departments (42).

One of the most important challenges for the Sourdough Fire Department is recruiting and training volunteers. The Fire and EMS operations director pointed out that it is a nationwide trend for people who live in a rural fire district to not be the volunteers. He further explained that Sourdough Fire Department is both unique and dependent in that it draws the majority of its volunteers from the university (85 percent of volunteer firefighter roster). Because of the dependence on university students, maintaining the volunteer staffing levels when classes are not in session (e.g., summer,) can be challenging. On average, the college student volunteers stay for two to three years; some might continue to volunteer for up to five years. This means that there is a constant cycle of recruiting and training volunteers. To partially address this, Sourdough Fire requires an 18 month commitment, which allows volunteers to gain the necessary basic skills and provide some return on investment. Volunteers must train one time per week, spend an overnight shift one time per week, and are expected to respond to all calls as possible. College students often find that volunteering is a good lifestyle fit and have many reasons for volunteering, including past experience, giving back to the community, and "doing something fun." Arguably, the most prevalent reason is the value of the experience. To help maintain staffing levels and viability of the department, Sourdough Fire is planning to recruit on campus, establish student services links and maintain a strong Internet presence.

When asked about extremes or particular challenges in terms of rural EMS response, the firefighters mentioned:

- Rugged and remote terrain such as the popular, nearby Hyalite Canyon;
- Environmental factors, particularly winter weather conditions;
- Experience levels of volunteers;
- Poor road conditions;
- Driveways not subject to a building code that inhibit access for EMS response vehicles;
- Gaps in communication coverage;
- Infrastructure such as bridges with weight limits too low for a fire truck.

Sourdough Fire Department is considered non-transporting and does not have an ambulance. However, other rural fire departments in the county do operate an ambulance. As mentioned above, when Sourdough Fire is dispatched to a medical call, AMR automatically goes as well. AMR will cover medical transport needs while Sourdough Fire will coordinate the fire response. One challenge noted by Sourdough Fire was that AMR can be at capacity and frequently stretched thin. The Hospital can also be another "choke point" as it has the capacity for five patients with traumatic care needs and more and more people are going to the Emergency Room for primary care. (Note that the Emergency Room at the hospital is going through renovation that will increase its capacity.) These situations present notable challenges to effective and efficient EMS systems.

When asked about performance metrics, the reply was a question, "What is the desired level of service in our community?" They explained that the answer may be very different depending on the community. Briefly, when someone dials 911, that person expects EMS to show up and be prepared. Sourdough strives to "offer the best customer service with what we have." However, average response time, or number of minutes to respond X percent of the time, is a primary metric used to obtain federal funding or grant monies. Sourdough staffs an incident commander 24 hours a day, seven days a week. A rapid response vehicle is always stocked and ready for immediate deployment by the incident commander.

The point was emphasized that Gallatin County has some of the strongest, most effective mutual aid agreements in the state and arguably the country. These agreements facilitate effective and efficient rural EMS response; the Sourdough Fire Department personnel even stated that the agreements and cooperation "may be as good as it gets."

One of the biggest resource challenges for the volunteer fire department is money. Taxes and fees fund a portion of the department's service provision. The Federal Emergency Management Agency's Assistance to Firefighters Grants (FEMA AFG) can be used for recruitment, marketing and education, trucks, equipment, stations, and turn out gear. The department plans to use the funds to recruit and retain volunteers. Sourdough Fire Department also does a special fundraising event (pancake breakfast) and receives limited funds through donations.

One of the interviewees was the first firefighter hired at the Big Sky Fire Department, another rural fire department in Gallatin County. He noted that the Big Sky community population varies seasonally and generally had a very low interest in the viability of the fire department until it was needed. Taxes were low and did not equate to needed or expected service level. Throughout rural Gallatin County, these factors are compounded by the changing and increasing customer expectations and requirements for level of service. A significant percentage of the population moves to Gallatin County from more urban areas, bringing expectations for rural EMS like that of what they would get from a paid fire department, for example.

One goal or process improvement that Sourdough Fire would like to see is all fire districts running their own ambulance. Relating to the community and its needs was critically important and community education was at the top of the list. Having an unbiased, third party help identify needs and solutions was certainly of interest, as was gathering more information on processes and procedures from other rural areas with similar demographics.

3.4. Summary

The discussions with the local 911 Center and the Sourdough Fire Department brought to light several potential variables, components, constraints and outputs for a rural EMS systems model that is regional, coordinated, accountable, and sustainable. The subsequent section expands and discusses the topics in more detail and some of the highlights are noted below:

- Recruitment and retention of qualified volunteers;
- Meeting and maintaining training and certification levels;
- Managing and scheduling volunteers;
- Roadway network availability, condition, and accessibility;
- Topography;
- Geography and large coverage areas;
- Environmental conditions, particularly winter weather;
- Population growth and changes in community demographics;
- Increasing and changing customer service expectations and requirements;
- Jurisdiction-based dispatch;
- Interlocal and mutual aid agreements, coordinating operations and response;
- Maintenance of facilities, vehicles, equipment;
- Sharing resources;
- Desired level of service unique to a particular community;
- Lack of resources to meet demand.

Of interest to rural EMS service in general was the discussion of recruiting and training volunteers. A recurring discussion point was the nationwide trend for people who live in a rural fire district to not be the volunteers. Maintaining volunteer staffing levels can be challenging, and turnover may be high. This means that there is a constant cycle of recruiting and training volunteers. While this is a nationwide trend, it should be noted that the availability of college students for service in the Sourdough District is advantageous despite retention issues. Other rural areas without a resident college population may certainly be even more challenged in recruiting volunteers.

With respect to modeling, a number of issues were identified which were taken into later consideration. These included the potential for servicing rugged and remote terrain, environmental factors (e.g., winter weather conditions), experience levels of volunteers, road conditions, gaps in communication coverage and infrastructure constraints (e.g., bridge weight limits).

4. MODEL VARIBALES, COMPONENTS AND APPROACHES

4.1. Introduction

As the literature review indicated, the focus of EMS modeling efforts has primarily been on the optimization of coverage and/or response time. While each of these objectives are important, other factors which affect EMS, such as the approaches employed in providing service (public agency versus private business), available funding/resources, personnel and their training level, and other elements do not always receive consideration in modeling efforts. Collectively, the approaches employed in providing EMS may be a combination of both public (through fire departments) and private (through privately owned businesses). The cost components of an EMS system include the cost of readiness and the actual service delivery. Readiness may include on-call staffing for the service area. Service delivery includes staffing, durable and consumable equipment used for the response, provision of care on scene, and transportation to a treatment facility (43).

If these additional elements of EMS are neglected, a comprehensive understanding of the current and future performance and sustainability of systems cannot be obtained. Consequently, there remains a need to develop a comprehensive approach to modeling EMS systems that accounts for the different variables and constraints which impact them. To develop such approaches and address the sustainability and performance problems facing EMS in rural areas, a number of different data variables, elements and components are needed. These include, but are not limited to:

- Type of EMS Provider – public agency versus private business.
- Number of vehicles and EMTs available on a regular basis for each provider.
- Level of training of EMTs.
- Sources and mechanisms of funding for each provider.
- Dispatch protocols.
- Population demographics/call characteristics.

The following sections discuss the variables, constraints, and components which should be considered when developing future models of EMS service. The discussion of variables consists of a listing of general variable groups, as well as individual components within each group.

4.2. Variables

In reviewing past research related to EMS system modeling, information obtained through interviews with local public agencies, and during the course of considering modeling approaches to employ in the future, a number of variables were identified that should be considered. Some of these variables were included in the models discussed in the literature, while many were not. During past work, variables may have been excluded for a number of reasons, including computational limitations, data availability, a narrow research focus (e.g., optimization of coverage area or response time), and so forth. Regardless, it is clear that if a comprehensive approach is to be developed for modeling sustainable EMS systems in the future, the wide range of variables which influence such systems will need to be considered. The following paragraphs discuss the variables that should be incorporated in future modeling efforts.

Past call data – In modeling current and future EMS systems, an understanding of the past will serve as a useful input variable. Such information, when available over a period of time, provides a baseline indication of present trends/needs and may also guide future forecasting of expected call volumes (although this is influenced by demographic and overall health trends, systemic changes in the type of service provided, unanticipated events [plane crash, bus crash, etc.], etc.). Specific call data variables that are expected to be necessary for a future model include:

- Type of emergency – This information has a direct bearing on the type of response required and the corresponding costs associated with that response (i.e., paramedics, supplies, etc.).
- Computer Aided Dispatch (CAD) Protocols – In some cases, when a specific type of call is received (namely by a 911 dispatch center), a specific response is initiated based on an automated, preplanned approach programmed into CAD. This response has been developed and programmed based on the preferences and feedback of each agency in a service area. The 911 dispatch notifies the corresponding response agency, who in turn determines the response, equipment, etc. [Note: this is the approach employed in Gallatin County, Montana, where the researchers conducted agency interviews.] Conversely, in other locales, the dispatch (911 center, local department) which receives a call will determine the response employed. As a result, different types of calls or events will receive different responses in terms of resources deployed based on the locale, which should be accounted for in modeling efforts.
- Location – The location of a call response is an important variable for a number of reasons. First, it has a direct impact on response coverage and travel time. It also can have an impact on the outcome of the call itself. For example, if a response location is in an isolated area and requires a significant amount of time to reach and then return to a hospital, the 'golden hour' may come into play.
- The nature of the EMS delivery – Depending on whether EMS services are provided by a public agency or a private business, as well as its funding sources and operating strategies, different dispatching protocols may be employed when allocating resources for an event.
    - Funding and operations of entities – In understanding EMS delivery, it is important to understand how calls are handled. For example, dispatch may typically be made by jurisdiction as opposed to proximity. The result has direct consequences on modeling response, as well as the costs of providing service[6].
- Time of initial call – This variable is important for the location-specific reasons discussed in a previous point. It helps to determine when the specific call event commenced.
- Response time to scene – As discussed previously, this variable is important in establishing the overall time sequence for the call event.

[6] Aside from the general cost of service, there is the nature of agency funding which plays a role. While a response entity may be nearest to a call coming in from a neighboring jurisdiction, the taxpayers for that entity would not be receiving/benefitting from service and mutual aid agreements may or may not be in place.

- Time to hospital - As discussed previously, this variable is important in establishing the overall time sequence for the call event.
- Outcome – In addition to understanding the overall response times of the call event, it would be useful to understand the overall outcome of calls. It is not known what, if any, format such data might be recorded, but if it is available, it should be considered a useful secondary variable to include in future models. Of course, care must also be taken in using such a variable, as response time is not the only factor involved in the success or failure of an outcome.
- Actions taken – Although not as pertinent of information as the times associated with different portions of the call event, the actions taken in treating the patient throughout the call may also be of interest in future modeling efforts. However, such information should be considered a supplemental variable input when compared to the previously listed items.
- Prospective emergencies – In addition to past calls, there is also the potential for events that have not occurred previously to happen in the future. For example, an airplane or bus crash may not have occurred in a jurisdiction in the past, but there is always the potential for such an event to occur in the future. Such events, which are major in scope, have the potential to max out existing resources, having significant impacts on the provision of EMS. This variable would require the identification of such events and determine what its expected response and needs would be.

System priorities - A critical variable in modeling the current and future EMS system for a rural area are the priorities of that system. Namely, the priorities of EMS systems typically center on optimizing coverage area, response time, or some combination of the two. Each of these priority variables are discussed as follows:

- Coverage area – This variable would account for the priority given to maximizing the area covered by the entire EMS system/depots/fleet. For many agencies, maximizing the population area covered by EMS is a top priority, sometimes in combination with minimizing response times.
- The nature of the EMS entity – In some jurisdictions, all EMS response is provided by public agencies; in other jurisdictions, a private business may provide EMS service, or a public/private hybrid may be employed. Depending on the locale and agency agreements, a private EMS provider may respond to calls over a wide jurisdictional area, while public agencies may operate within a more restricted, limited area. Additionally, when EMS calls are received, many public agencies may also send responders (e.g., personnel with EMS/EMT training), even when a private EMS provider handles advanced treatment and transport. Consequently, decisions and protocol regarding the dispatching of such responders plays a role in understanding EMS response. Bear in mind that the approaches and operations employed will vary by jurisdiction.
- Response time – This variable would account for a minimization/optimization of response times. Often an agency seeks to minimize/optimize their response time to a call within a given standard. For example, in Montana, the most widely used ambulance response-time benchmark for urban areas is 8 minutes and 59 seconds (8:59), with a goal to meet it within 90 percent of the time (44). Response time goals will be influenced in part by the dispatching protocols of resources to calls (public versus private agency responders and jurisdictions). As an overall goal, entities may seek to minimize response

time, sometimes in conjunction with maximizing/optimizing coverage area. Note that in northern states, this priority may not be feasible year-round. An agency may want to minimize response time during any given season, but that optimization may vary depending on the time of year and more generally, current travel conditions (especially during winter).

- Combined priorities – In some cases, there may be a desire to maximize coverage area and minimize response time. In such cases, an approach to account for these dual priorities would be required.
- Mutual aid agreements – In addition to the protocols employed for calls, an important variable to consider in modeling EMS is mutual aid agreements. These are the agreements that exist between agencies where one agency will assist another in certain instances (i.e., major fires, crashes, etc.). Such agreements have a direct impact on an agency's ability to provide a significant level of response in their home jurisdiction, as resources will be tied up or maxed out elsewhere, with the corresponding potential to impact EMS in that area.

EMS System Data - When modeling an EMS system, general variables for specific components of that system are also necessary. These variables represent the actual physical components and aspects of EMS resources that are available for use. Specific EMS system variables that are expected to be necessary for a future model include:

- Providers – Depending on the geographic scope of the study area, future EMS models may be developed to include one or more providers. Consequently, information on each of these providers is necessary to incorporate in the modeling process. Critical variables pertaining to each provider include:
    - Type of entity – In order to model EMS service, the providers and their type must be explicitly accounted for. In some jurisdictions, public entities (i.e., fire departments) provide EMS service (response, treatment and transport). In other jurisdictions, public entities provide responders to handle initial treatment and provide general assistance, while private entities provide more comprehensive treatment (paramedics) and transport of the patient. Finally, in more urban jurisdictions, paramedics are likely to be on the staff of public agencies.
    - Equipment (i.e., ambulances) – One of the most critical variables for each provider is the actual equipment they operate – namely ambulances/vehicles. Note that for the purposes of the discussion in this document, air-based response (i.e., helicopters) has not been included, but it merits further treatment in areas for which that service is available or planned.
    - Location of assets – This variable accounts for two types of asset locations; stationary (depots) and mobile. Stationary ambulance depots are fixed locations from which an ambulance can be dispatched. These assets cover a base area and will not move when the coverage aspect of EMS service is considered. Mobile locations represent the position of an ambulance and other incident response vehicles in the field throughout the day to maximize coverage area. In each case, the location of these assets has a direct impact on the coverage area and response time of EMS services and must be considered in any modeling effort.
    - Coverage area – While this variable was cited previously in the context of an agency's priorities, it is also a geographic variable for any potential model.

Obviously, the geographic area and boundaries covered by any EMS system must be accounted for when modeling service. This data would account for that service area. It should account for instances where a private entity provides primary EMS response and transport, as well as any cases where local public agencies provide backup treatment and transport when private entity resources are maxed out.

    - Supplies – It is also necessary to account for the supplies used during the course of operating the EMS system. This should be done as the use of various supplies (and other incidentals, such as housekeeping materials/supplies) is an expense item and consequently, has an impact on the available budget and future budget needs.

- Personnel – The number of trained EMS staff available to respond to calls and perform general activities (e.g., non-emergency patient transport) has a direct bearing on the level of service which can be provided. The information pertaining to personnel has a number of attributes that are of interest for a modeling effort, including:
    - Type of staff – This personnel aspect is concerned with whether staff are paid employees, volunteers, or a combination of both. Aside from the direct budget implications that the type of staff has, it also has an impact on response availability. For example, paid staff are likely to be available to respond immediately to a call, whereas volunteers may need to travel to an ambulance depot from work or home before responding to a call. The consequences of this have a direct impact on response and travel times, as well as potentially the patient outcome. Finally, the entity that staff are a part of is also of concern, as this may have a direct impact on the level of training which staff has. For example, public agency responders whose department does not own/operate ambulances may only be trained as emergency medical technicians (EMTs) that provide basic treatment until paramedics from a private EMS service arrive. Such training levels have a direct impact on the level of treatment provided during calls, depending on the overall type of EMS system being employed (public versus private).
    - Availability/scheduling – This aspect of personnel is tied to the previous item in that some responders may be more readily available to answer calls compared to others. Consequently, a metric should be included in modeling efforts to account for the potential for a time lag between when a call is received and when personnel are available to respond. The more details pertaining to this personnel aspect, the better the model might be (i.e., three EMTs during day shift and two during night shift; on call/site versus at home/work, etc.). This will assist in the assignment and locating of personnel resources.
    - Level of Training – While not as crucial as the previous two variables, the level of staff training is another important consideration for future modeling efforts. It is important to understand and include, if applicable, the potential training levels that may respond to a call, as these could differ depending on the overall strategy for providing EMS in an area. For example, if a public entity provides responders (EMTs) but a private service provides paramedics and transport, different levels of overall personnel in terms of training may be available to respond to calls during different times of the day. Inclusion of such variables could potentially

allow for a projection of what future patient/call outcomes may result under different staffing scenarios.

Funding – This variable group is perhaps the most important in understanding how the present and future funds available for conducting EMS services can impact potential changes and optimizations. Incorporating this information will also help in identifying the impacts of changes made to service levels and coverage, as well as where costs may potentially be reduced and savings obtained through various changes made to the system. The information of interest for this variable group is as follows:

- Available budget – The current and future budget that is available for EMS service is a critical aspect to consider in any modeling scenario. It essentially dictates what can be done in terms of staffing, priorities and service levels. By incorporating budget information into future modeling efforts, it should be possible to simulate the impacts that higher or lower funding levels will have on the overall system. Of course, when employed in such a manner, available budget could also be considered a model constraint, but for the purposes of this discussion, it should be viewed as a variable.
- Funding sources – The source of funding is another important variable to consider in modeling. At present, funding for EMS services comes from different sources, primarily taxes and fees (e.g., remuneration by patients/insurance for services rendered). Depending on the source, the level of funding available to an agency may or may not be stable, having a direct impact on future service. For example, tax-based funding may fluctuate based on local economic conditions, making it difficult to plan for future services and expansion/improvements. Consequently, accounting not only for the available budget, but also the source and its stability should be made in future modeling.
- Alternative funding sources – This variable would incorporate information pertaining to funds raised by non-traditional sources such as fundraising events or grants. Such funding falls into the category of non-recurrent, making it a challenge to incorporate into a model, as its future timing and amount are not known. Consequently, such a variable should only be employed if an approach is identified which can incorporate it in an appropriate manner that accounts for its potentially fluctuating nature.

Network – Of critical performance in modeling an EMS system is the highway network that ambulances and emergency vehicles travel on. This variable group is important not only for establishing actual connectivity between call and treatment locations, but also for establishing the area covered and the response time required for EMS service. The following are network variables that should be employed in future EMS models:

- Roadway system – This variable would actually serve more in a simulation context than a numerical model. The use of this variable would allow for an understanding of the connectivity available in the overall system. It would also facilitate a factoring of travel time to and from potential call locations, as supported by the variable discussed next.
- Speed limit/travel time on links – This variable would also be employed in simulation as opposed to a numerical model. Travel time information is essential when examining the impacts on an EMS system that different call/patient types may have. Some patient emergencies are more urgent than others, requiring rapid response time to the call locations and then on to the hospital. Travel time will be affected by a number of factors,

including traffic, roadway design and seasonal variability, as discussed in the following points.

- Traffic – Depending on the time of day, traffic may be heavy or light. When heavy traffic is present, response times may suffer. Consequently, a more comprehensive modeling effort should employ traffic data, particularly if available in detail from throughout the day, in order to fully account for the impacts that may be encountered in responding to various calls.
- Roadway design – This variable can incorporate multiple pieces of information. At a minimum, it should include information regarding roadway surface type, as this may have a direct impact on the speeds which an ambulance may travel. Specifically, gravel and dirt roads are a less stable driving surface, requiring slower travel and potentially adding to response times. Additional information that could be considered includes more specific geometrics (curvature, grades, etc.), although this information may not be available in a format which can be readily employed in a modeling effort (i.e., GIS).
- Restrictions – In line with the previous element, roadway restrictions can limit the response routes available to different types of vehicles. For example, in cases where fire department personnel respond to EMS calls, large equipment aside from ambulances may be dispatched. Such equipment may be weight restricted on bridges, limiting the routes of travel available. These restrictions should be incorporated into modeling efforts if possible.
- Seasonal variability – This variable would incorporate the potential for weather to impact response times during certain times of year, specifically winter. During the winter, response times for calls are likely to be impacted either directly by an ongoing storm event, or indirectly by wet or icy roads that are present for much of the winter season due to vehicles needing to travel more slowly for safety. While difficult to quantify and incorporate due to the random nature of seasonal weather (which cannot be predicted months/years in advance), such a factor might be incorporated into modeling/simulation efforts through the use of a proxy, such as a penalty imposed during expected calls during a certain period of the year.

Note that the inclusion of travel time into the overall modeling effort is not recommending that faster speed be employed to and from a call by EMS crews. This has a direct impact on safety, as summarized by a number of sources (45,46,47,48,49). However, and particularly in rural areas, response time is a factor (arguably a critical factor), and travel time is a component of this. With challenges in locating incidents, as well as those due to weather and other road-related factors, travel time may be impacted solely by route selection. Consequently, future modeling efforts should take such information into account while balancing the understanding that the overall safety of EMS crews and the traveling public cannot be jeopardized by attempts to make faster responses than are warranted by a roadway and conditions.

Population – The final variable to consider in future modeling efforts is population demographics. This variable is very important, as it has a direct impact on the call volumes that can be expected in present and future modeling scenarios.

- General demographics – This variable has a direct impact on projecting the number of calls and their type which may be expected at present and in the future. An aging population can be reasonably expected to require more medical care and, consequently, produce more EMS calls. Such data should be relatively straightforward to acquire from recent census results.

- Historic trends – This variable would incorporate information related to the historic nature of emergencies serviced by past calls. While the past nature of responses is not a definitive indicator of future needs, it does provide a reasonable approach to understanding what trends may emerge in the future. It also provides a metric for evaluating the past performance of the system.

In summary, a number of different variable groups should be employed in future EMS service modeling. Generally stated, these groups are comprised of Past Calls (historic call data), System Priorities, EMS System Data (i.e., providers and assets), Funding, Network (highway attributes), and Population (demographics). Each of these variable groups contains several specific items that should be considered for use in any future modeling approach that is developed.

4.3. Constraints

In addition to the different variables discussed in the prior section, the modeling of EMS service should also take into account the various constraints which face the system. These constraints are different items that limit the ability to provide an optimal level of service or present other challenges to the system in general. The following categories discuss the various constraints that should be taken into consideration when modeling EMS service.

Provider – In some instances, particularly those where a private entity provides EMS service for a large area, there is a potential (although rare) for resources to be "maxed out", or completely allocated. In such cases, the availability of a fixed number of resources can be a constraint on the system, particularly if a serious, multiple injury event occurs (hazardous materials spill, plane crash, etc.). The limited number of units which can respond to events, even on a "normal" day, can be a severe constraint on the system. Additionally, a model should account for seasonal and/or time specific demands for personnel. In part, this relates to the management and allocation of resources for a given time. In many cases, resources are not positions where they are needed at a given time.

Funding – This is perhaps the greatest constraint facing EMS services today in the face of shrinking budgets, uncertain taxes and issues in the reimbursement of medical costs. Funding limitations impact the overall level of service (coverage, response time) which can be provided, the level of maintenance that can be performed to existing equipment, the types and features of new equipment purchases, the supplies which can be purchased to support existing service, and so forth. Additionally, EMS is only reimbursed by Medicare, Medicaid and private insurers for transport; the non-transporting first responder agencies do not reimbursement, despite the costs they incur in providing EMS services. Nor are the costs associated responses to address with patients with minor issues who are treated and released on scene covered. Accounting for these issues and the fluctuations in funding is essential to understanding the tradeoffs that may exist between different decisions and scenarios. Consequently, incorporation of different funding constraints and scenarios in future modeling efforts should be made.

Staffing – While the current level of staffing is a known variable, future levels are not known. This ties back in part to future funding levels, service priorities, workforce attrition, and so forth. However, for EMS providers that rely on a volunteer force, it is also a concern that less and less volunteers are stepping forward to serve, and those which presently are serving are an aging population. Consequently, a comprehensive modeling effort should take into account not only the current EMS workforce, but also employ a constraint on the model if future shortages of trained personnel are reasonably expected, particularly for agencies relying on volunteers. Perspective approaches should even account for the possibility that volunteer ambulance services might not exist for a specific area at a future date.

Additionally, current constraints may exist within the workforce, particularly at agencies where volunteers are primarily used, but also at agencies which employ paid staff. The availability of workforce is likely to vary at different times of day and even different times of year. The training of those staff is also likely to vary, with some personnel trained as EMTs, while others have more comprehensive paramedic training. As such, future models may consider including a constraint related to the availability of different staff to respond to calls.

Priorities – As changes occur in management, public policy, funding, and so forth, changes may occur in EMS service priorities. For example, funding constraints may lead to a change of priorities from response time to maximizing coverage area. In reality, future priorities may require matching patient needs with available resources, including those of EMS. Such changes to priorities are difficult to anticipate at the time of modeling, but might be taken into account through the consideration of different scenarios.

Traffic – This is also a critical constraint to an EMS service model in that it directly impacts the response time of different calls. Responses made during peak periods of the day may be prone to some delay, as a response vehicle must negotiate traffic en-route. Conversely, calls received at off-peak hours may see a faster response than the norm as no traffic is present. While it is difficult to account for traffic at a specific time throughout the day (this is highly detailed information that is not generally recorded on all routes), it may be reasonable to incorporate a constraint (as opposed to a variable) into future models which imposes a delay during different times of day when peak traffic volumes are known to exist. Additionally, such a delay penalty may vary by general location (e.g., quadrant of a city/town). Of course, in a rural environment, such delays are less likely to be present; as a result, the traffic patterns inherent to the specific areas being modeled should be taken into consideration on a case by case basis.

Weather – In some rural environments, namely those of northern states, weather can be a constraint on an EMS system, specifically during the winter. The rural roadway network includes many unpaved roads, which require slower travel during winter when snow and ice are present. Consequently, response times during winter months may be slower than those during the summer. This aspect of EMS should be accounted for in modeling efforts, particularly since it has a direct impact on the key metric of response time. In other words, while coverage area and response time might conceivably be optimized during the summer, such an optimized scenario is not likely to occur during the winter and must be accounted for as a constraint on the system. Once again, the impact of weather may be accounted for in a model through the imposition of a delay penalty. Note however, the development of such a penalty may prove to be complex, given the variability of future weather occurrence and severity.

In summary, while the constraints discussed in the previous paragraphs are somewhat general, they do represent items that have an impact on EMS service and which should be taken into consideration when modeling current and future services. Incorporating constraints into any future modeling effort will more accurately represent the true nature of the system in general, and should produce results which reflect the current and future performance of the system.

Caution is stressed here that not all of the constraints identified are in a quantified format which allows their inclusion into a model. Rather, some will require further study and/or the development of reasonable assumptions. The use of assumptions does impose some uncertainty on the results of any model. However, ignoring constraints to the EMS system entirely also presents the potential for skewed results to be produced. Consequently, those who develop future EMS models should weigh the pros and cons of any approach with respect to the constraints they are considering.

4.4. Components

Based on the different variables and constraints that should be incorporated or considered in modeling EMS service, it is possible to discuss a prospective modeling approach in more detail. The reader should note that the ultimate approach in selecting and developing models will depend on the goals of that effort, whether seeking to simply determine the optimal location of facilities or comprehensively evaluating the current and future performance of EMS service given a series of scenarios. The approach taken in the following sections reviews the different components that should be considered in modeling EMS service. The model components discussed in the following sections are presented in a standalone manner; in some cases, different components may be combined into one unified model depending on the modeling approaches identified by or needed for a specific agency or area. The intention of each individual model is to produce an output which provides answers to specific aspects of EMS service that may be of interest (i.e., financial optimization, coverage areas and response times, equipment needs, etc.). For the purposes of simplicity however, individual components are presented here and are presented in sequential order (e.g., the output of each could logically be employed in other models). Also, the specific types of models and their form have not been identified by this work; the identification of appropriate models, their variables, and their forms is a comprehensive effort and beyond the limited scope of this project.

Econometric Model – Without financial resources, an EMS service cannot operate. This is true even if a workforce is comprised entirely of volunteer staff since costs related to fuel, equipment maintenance, supplies and so forth are still incurred. Consequently, the first step in modeling an EMS service should account for different financial variables and constraints affecting that service. For this purpose, an Econometric model would be employed. Econometric models specify the statistical relationships between various economic quantities pertaining to a particular phenomenon being studied (50).

In the case of EMS modeling, whatever Econometric modeling approach is identified and employed would employ information about the funding that will be available (taxes, fees, grants, fundraisers, etc.) and identify how those resources might be allocated to optimize EMS service within each service area given a series of cost variables. The challenge is that different entities (e.g., fire agencies or districts) have separate funding streams which can only be used within their jurisdiction. In other words, the model employed in this initial component could not identify where a financial surplus might be obtained and transferred to another agency facing a shortfall. The eventual output of this model would be an economic allocation of resources for each jurisdiction and entity that would optimize the service they provide for a given funding amount. This information could then be employed in later portions of the overall modeling effort.

Call Volume Model – The call volume model would employ past call history to model future expected call volumes and types. Such information is necessary to better understand how available funding should be allocated, as well as what additional resources (equipment, personnel, etc.) may be needed in the future to meet given levels of service. While a recommendation of the type and form of such a model is beyond the scope of this work, the variables it would employ are generally understood. These would include the type of call (medical issue), the time received, its location, response times to scene, time to hospital, outcome, and general population demographics for the study area. Population demographics are especially important in modeling future call volumes, as this information plays a central role in the types of calls that can be expected, as well as their location (if demographic information is provided in detail specific to a geographic area). In addition, this model would require a mechanism to include information regarding events that have not occurred in the past but could occur in the future (e.g., bus crash). The output of this model would be future call volumes, the type of emergency, and, possibly, the general geographic area of each event. This information would then be employed in the following dispatch model.

Dispatch/Prioritization Model – This model would employ call volume data to determine, based on existing CAD-programmed procedures (if employed by agencies) or dispatch protocols, which agencies should be dispatched for particular calls. This model component should be the most straightforward to develop in one sense, as most agencies (i.e., 911 dispatch centers) have an established procedure that is employed for EMS calls received from different locations. This response would be fed into a second portion of the model, which would produce an allocation of individual resources for a particular response agency. For example, an EMS call in a rural fire district might trigger a response both from the fire agency and a local, privately-owned EMS provider. By modeling responses, the allocation of equipment and personnel resources can be tracked under different scenarios (i.e., funding levels, personnel assignment, etc.).

Input data for the model would include information generated by the Econometric and call volume models, dispatch protocols, and various data of agency resources (personnel, equipment, etc.). As a result of this model component, information can be developed regarding potential response approaches under different funding levels, personnel availability, and other aspects of interest.

Jurisdictional Model - In developing a realistic model of EMS service, there is a significant challenge in recognizing and accounting for the existence of different jurisdictions or service areas that are covered by different agencies, as well as the associated rules and deviations, including mutual aid agreements, that govern the operations of said entities. Ultimately, response entities are responsible to their constituents (e.g., taxpayers), funding source, contractual agreements (i.e., private business providers), and so forth. A failure to account for these aspects of EMS service will result in an inaccurate model. Additionally, there is a political aspect to EMS service and coverage that also needs to be accounted for. The political aspect incorporates the element of mutual aid; specifically, if assistance is being provided in another jurisdiction, who is paying for that assistance and what are the consequences to the jurisdiction of the entity that is providing aid elsewhere? If response is required in the base jurisdiction and response personnel are deployed elsewhere, how are the needs of the funding entity (i.e., taxpayers) being appropriately met, if at all? In other words, the service entity is being funded by the taxpayer in their jurisdiction, and they should receive priority. Consequently, the needs of various stakeholders must be balanced, and the approaches to balancing those needs incorporated into the model. Conversely, a situation might exist where all available resources (financial, equipment, staff, etc.) are pooled and allocated by one governing agency. This could result in an optimization of resources, but a perception on the part of some service recipients that they receive less for what they have invested (i.e., paid in taxes).

The jurisdictional model would address these different aspects and challenges of EMS service. Although the specific modeling approaches employed would require further investigation, there are prospective approaches that are applicable based on the information that would be available and incorporated into a model. One such modeling approach that may be applicable here is that of game theory. Game theory models strategic situations, or games, in which an entity's success in making choices depends not only on their choices, but also on the choices of others (51). Applications of game theory have been made in past work related to emergency management, which shares similarities to EMS modeling (52, 53, 54). In the context of EMS system modeling, the game would consist of a set of strategies (dispatching protocols, agency responses, mutual aid agreements, etc.) available to each agency/provider and the specification of payoffs (outcomes of EMS service/coverage) for each entity. The objective of such a modeling approach would be the identification of strategies (in combination between agencies) that would result in a equilibrium of service/coverage between agencies. In other words, given a prospective event, the model would identify the response that should be made to ensure that service recipients in one jurisdiction were not shortchanged coverage if their service provider was required to respond to an event in another jurisdiction.

Coverage and Response Model – This model component would take the information generated by the previous model and determine the coverage area and response times (and possibly routes) of various resources. While existing coverage would already be known from current agency practices, this model component would determine whether more optimal coverage was possible for a given set of resources (funding, equipment, personnel) and the available transportation network. For example, this model could be developed such that it would determine the location of ambulances positioned throughout the field over the course of a day based on observed and expected call types and volumes. Similarly, such a model could be developed to identify potential changes that could be made to existing dispatch protocols to optimize coverage (or response time). The output of this model component would be a determination of potential changes to coverage and routes that might be considered under different scenarios.

Personnel Allocation Model – This model would take the information generated by the economic, call volume, dispatch and coverage models to determine the optimal staffing levels for different service areas based on expected needs, available funding and given personnel and equipment resources. In essence, this model component would generate solutions to what human resources (including different training levels) should be available for given scenarios. By generating such information, agencies can better understand their future funding and personnel needs.

Equipment Allocation Model – Similar to the personnel model, this model component would examine what equipment needs are given economic, call volume and dispatching variables. Equipment resource allocation is an important consideration to understand in an EMS system as there may be more optimal locations where equipment may be stationed, especially given expectations of future service needs. For example, it is possible that a specific piece of equipment dispatched by an agency to EMS calls would be better housed at one fire station as opposed to another, given a particular level of calls observed in the past and those expected in the future[7]. Such optimized reallocation of equipment may not be readily apparent to service providers during the course of their day-to-day activities. The output of this model would therefore be an allocation of equipment resources based on the input variables ultimately selected as being of interest to an agency.

System Model - These different model components, while producing individual outputs, could conceivably be combined in a larger overall simulation of EMS service for an area. This approach is presented schematically in Figure 1. Using the input from various models, a system modeling procedure could produce an optimized output (after various iterations) which accounts for the various factors that affect EMS service in a given area. In addition, the compartmentalized nature of this approach would allow for different factors to be employed and changed on an individual basis yet still interact with others overall. In this manner, what-if analysis could be facilitated, allowing for a determination of the impacts that changes to one aspect of EMS services might have on the overall system. A Geographic Information Systems (GIS) component could also be incorporated into the overall simulation to produce results pertaining to different spatial aspects of EMS service (i.e., travel times, coverage areas, routings, etc.). Collectively, the individual models and the simulation would produce a number of outputs, which are discussed in the following section.

Note that while a simulation model is presented here, that does not mean that it is a necessary component in any future EMS modeling effort. Indeed, a number of different approaches may be indentified which tie the information generated by the various models discussed in the previous paragraphs into a systematic output which evaluates the EMS system as a whole. For example, Bayesian methods, which are used to make statements about an unknown quantity in a systematic way using what partial knowledge is available, could be employed for this purpose.

[7] It is important to note throughout this discussion that the caveat of "past performance does not indicate future results" applies here. While models are useful tools for developing estimates of future needs based on past observed data, they do not provide absolute answers. Changes in demographics, health care and other unmeasured or unobserved inputs can lead to significant changes in the actual environment at a future date.

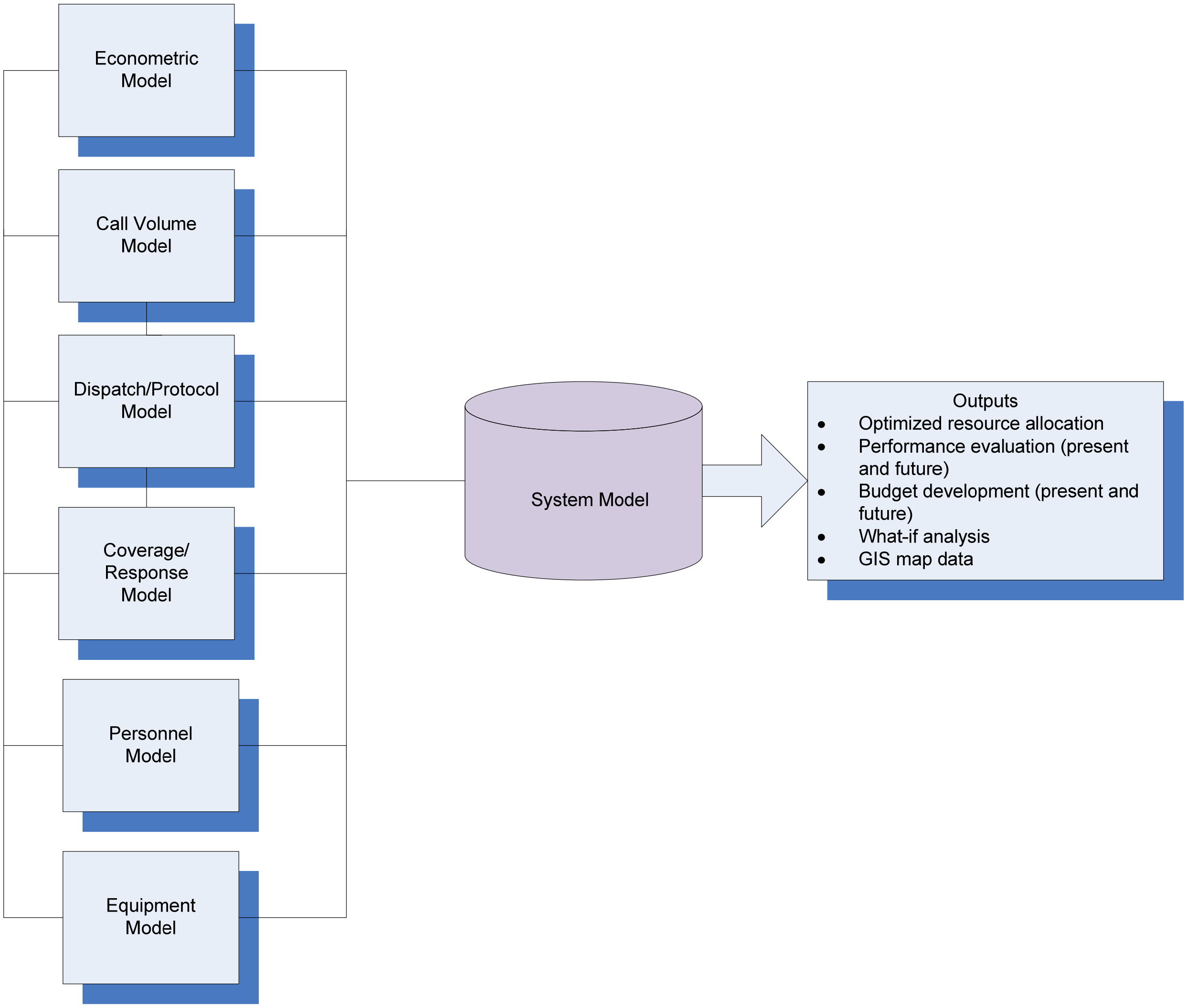

Figure 1: Schematic of the discussed modeling approach

4.5. Outputs

Depending on the variables and constraints selected, future EMS models may produce a number of different outputs. The outputs discussed in the following paragraphs are likely to vary depending on the modeling approach ultimately selected, but they represent a number of useful products that could be produced and employed by various decision-makers and managers. Ultimately, the outputs produced by any modeling effort will be the result of the input data (and its quality) available, the sophistication of the modeling approach employed, and the desires of the entity leading the effort itself.

At the most basic level, an output could consist of an optimized coverage or response time area given a set of input variables/parameters (i.e., available funding, expected call volumes and types, available personnel and equipment, etc.). A more complex model could provide outputs related not only to coverage area/response time, but also provide optimized solutions based on expected funding levels, the available workforce, and so forth.

The output of the model components and simulation would also produce estimates of future needs in terms of personnel, equipment and finances under given levels of service. This differs from the optimization outputs, as this type of information would be generated using status quo assumptions and data, where the system continues to operate in the same manner as it has previously, with no changes made. Such a simulation would be useful to decision makers in determining future budgets. If alternative scenarios with different data inputs are considered, the modeling approach would provide for "what-if" analysis for different funding levels, service goals, and so forth. In this latter manner, the modeling approach could be used to identify potential areas where savings could be accrued through various changes to the system. This approach could also be employed in developing present and future budgets.

The proposed modeling approach also holds the potential to produce information to aid in measuring current and future performance. In terms of current system performance, the model outputs could be compared to existing performance metrics for the same series of call responses. In theory, the output from the model would represent the optimized EMS system (assuming the models are developed in a manner which generates optimized results), which could be compared to what was actually observed in reality. Similarly, future system performance could be generated by running future call volume scenarios and comparing the performance of the system to the metrics presently employed by agencies.

Finally, in addition to producing the outputs previously described, the simulation portion of an overall modeling effort could also generate data for mapping in a Geographic Information System. GIS presents data with a spatial component in a visual (map-based) manner. In the context of an EMS modeling effort, several pieces of output data lend themselves to GIS mapping. First, there is the coverage area component of EMS, which would be useful to present on a map. There is also the allocation of resources (both existing and projected future), including equipment (stationary and mobile), and personnel. Past and expected future call locations (most likely generalized by block, section or other aggregation) can also be mapped out to assist in understanding how they correspond to the location of existing EMS assets. Finally, the overall performance of the EMS system could be presented in various ways, including constraints (e.g., vehicle weight restrictions), general response times (to a given area) and different routes that may be used. All of these map based products could be potentially useful in presenting information to both the public and government officials.

4.6. Conclusion

This chapter has presented a high-level overview and discussion of an overall approach that could be employed in future work to model EMS service. The discussion focused on different variables and constraints that could be incorporated into modeling efforts, assuming the availability of various pieces of data. These variables and constraints represent the critical pieces of information which affect the overall provision and performance of EMS service. Next, the general components of the modeling approach were discussed. These components included several individual, standalone models intended to produce outputs which provide answers to specific aspects of EMS service that may be of interest (i.e., financial optimization, coverage areas and response times, equipment needs, etc.). Individual component models identified during the course of this work covered the Econometric, call volume, dispatch/protocol, coverage/response, personnel, and equipment aspects of EMS service. Of course, additional models may be identified during the course of future research, depending on the needs of specific agencies.

The output of individual component EMS models can potentially be employed in an overall simulation, Bayesian, or other model of EMS service for an area. This could be used to produce an optimized output (after iterations) which accounts for various factors which affect EMS service in a given area. In addition, the compartmentalized nature of the overall modeling approach would allow for different factors to be employed and changed on an individual basis yet still interact with others overall. In this manner, what-if analysis could be facilitated, allowing for a determination of the impacts that changes to one aspect of EMS services might have on the overall system. Collectively, the individual models and the simulation would produce a number of outputs, including performance metrics, budget information, resource needs and allocations, and data to support GIS mapping, among other items.

5. CONCLUSIONS AND RECOMMENDATIONS

The project discussed in this report sought to develop a conceptual approach to modeling response systems for EMS in rural areas. To this end, a review of literature and limited discussion with practitioners was completed to identify variables, constraints and approaches to developing EMS service models. The following sections summarize the findings of the work, barriers to future implementation, and recommendations.

5.1. Summary of Findings

The literature review performed as part of this work found that the connection between economic and workforce consideration and the allocation of EMS resources has not been examined or developed. It was also evident that much of the work to date had focused on the urban context of the facility location and allocation problem, ignoring rural needs. Of course, part of this may be explained by the availability of urban data and the larger presence of EMS resources in such areas. In the context of the present project, the parameters employed in examining the location and allocation problem are generally similar between an urban and rural context. In a broad sense for each locale, the concern is to either minimize response time, maximize coverage area or both depending on the jurisdiction and its priorities. Solving such location and allocation problems requires varying data, depending on the approach, including information on available resources (i.e., ambulances, depots, etc.), the roadway network, call/response volumes by area, and in some cases, travel times on the roadway network. In general, such information is available for rural areas although travel times may not be available. Consequently, the problem becomes defining what is of interest to an agency/community: coverage, response time, a combination of both, or other?

In reviewing published literature, the RURALSIM modeling/simulation effort (14, 15) represented the closest approach to date at attempting to examine the complex issues of modeling rural EMS response systems. However, RURALSIM was developed during the 1980’s in a mainframe environment and was not transitioned to mainstream use, and no comparable program has been developed since. Aside from programs such as RURALSIM, much of the work conducted to date has focused on the problem of EMS vehicle/facility location. This work has employed generalized data inputs, namely number of vehicles, call demands (historical or probability-based), prospective facility/vehicle sites, and generalized response/travel times to optimize service coverage and identify facility locations. While these efforts have been worthwhile in progressing the state of the practice and accomplishing their objectives, they have not taken into account many other factors which have an impact on the EMS system (economic, personnel, etc.). The modeling approaches that were developed focused on a limited range of variables so that they did not require excessive calculations. Of course, as time has progressed, recent literature has indicated a shift toward more sophisticated approaches such as genetic algorithms and Bayesian networks which can adapt as new information becomes available (particularly through initial simulation iterations). Based on the review of literature, it became quite apparent that a more comprehensive approach to modeling rural EMS service needed to be developed, even if it was initially in conceptual form.

Interviews with rural EMS providers in Gallatin County, Montana supplied the critical “reality check” for a prospective rural EMS model. Practitioners identified and lent a practical perspective to potential model variables, components, and constraints. In speaking with local agencies, a number of factors that affect rural EMS were identified, including:

- Changing expectations and requirements for service;
- Increasing volume and diversity of EMS calls;
- Uncertain and changing funding sources and amount of available funds;
- Recruitment and retention of appropriately trained staff (volunteer, paid);
- Response to calls in rugged and remote areas;
- Collaboration between different jurisdictions and multiple agencies;
- Quality and accessibility of the transportation network;
- Diverse topography, climate and environmental conditions spread over a large geographic area.

Of interest to rural EMS service in general was the discussion of recruiting and training volunteers. A recurring discussion point was the nationwide trend for people who live in a rural fire district to not be the volunteers. Maintaining volunteer staffing levels can be challenging, and turnover may be high. This means that there is a constant cycle of recruiting and training volunteers.

With respect to modeling, a number of issues were identified which were taken into later consideration. These included the potential for servicing rugged and remote terrain, environmental factors (e.g., winter weather conditions), experience levels of volunteers, road conditions, gaps in communication coverage and infrastructure constraints (e.g., bridge weight limits).

In addressing the lack of a comprehensive approach to modeling rural EMS service, the researchers developed a conceptual framework. This approach can be considered high-level at this time and will require a more comprehensive future research effort to implement. The modeling discussion presented in this report focused on different variables and constraints that could be incorporated into modeling efforts, assuming the availability of various pieces of data. These variables and constraints represent the critical pieces of information which affect the overall provision and performance of EMS service. Model variables were generally grouped into a series of categories, including past call data, system priorities, EMS system data, funding, network and population. Each of these variable groups contains several specific items that directly impact the provision of EMS service and should be considered for use in any future modeling approach developed. Similarly, model constraints were categorized as provider, funding, staffing, priorities, traffic, and weather. These constraints represent items that have an impact on EMS service and should be taken into consideration when modeling current and future services.

Once the variable and constraint groups were developed, prospective model components were identified. These components included several individual, standalone models intended to produce outputs which provide answers to specific aspects of EMS service that may be of interest (i.e., financial optimization, coverage areas and response times, equipment needs, etc.). Individual component models identified during the course of this work covered the Econometric, call volume, dispatch/protocol, coverage/response, personnel, and equipment aspects of EMS service. Of course, additional models may be identified during the course of future research, depending on the needs of specific agencies. The specific model types/forms were not identified during the course of this work, as such efforts are time and budget intensive and require careful consideration and development.

The individual component model results would be employed in a unifying approach which models EMS service for an area. The approach employed in developing this unifying model could potentially include simulation, Bayesian, or other models. This could be used to produce an optimized output (after iterations) which accounts for various factors which affect EMS service in a given area. In addition, the compartmentalized nature of the overall modeling approach would allow for different factors to be employed and changed on an individual basis yet still interact with others overall. In this manner, what-if analysis could be facilitated, allowing for a determination of the impacts that changes to one aspect of EMS services might have on the overall system. Collectively, the individual models and the simulation would produce a number of outputs, including performance metrics, budget information, resource needs and allocations, and data to support GIS mapping, among other items.

5.2. Potential Barriers to Implementation

Based on the work presented in this report, a series of potential barriers have been identified which could present challenges to the eventual implementation of a modeling approach based on the conceptual framework developed. These include cost, data availability, agency goals/needs, and general reluctance of models. These are discussed in more detail in the following paragraphs.

The initial barrier to implementation of the modeling approach proposed in this report is cost. The cost barrier is actually twofold, consisting of the cost to develop a functional model and the cost for agencies to employ/run that model. From a development standpoint, the proposed modeling approach will require a good deal of effort to identify the appropriate modeling approaches to employ when examining the various data and constraints identified during the course of the work. From an agency standpoint, there is not only the cost of acquiring a model (either funding its development or purchasing any software developed/necessary to run it), but also the cost of collecting the necessary data to support the model, the time of the personnel to collect said data and use the model, and so forth.

The availability of data is another potential barrier to implementation, depending on the approach employed in developing models. In one respect, the data barrier can be minimized if an agency knows what data they have available and pursues development of their own, customized model. However, this is not likely to be practical for most agencies, and so, they will need to rely on generalized models that have been developed for use by multiple agencies. In such cases, data will need to be collected or reasonable assumptions employed in order to use a model. As a result, the lack of available data suitable to a particular model component(s) may present a barrier to implementation.

The agency goals/needs barrier refers to what the expectations of a modeling exercise are for an agency. In other words, a modeling approach may be developed and available for use by an agency, but it may not provide the answers of interest to them. Consequently, that approach would not be employed by an agency; indeed, no existing approach might be available to an agency depending on what is of interest to them.

Finally, general reluctance of models presents a barrier to implementation for agencies that may not have the requisite background in modeling or statistics. In essence, a model may appear to be a black box to agency personnel, producing outputs by an unknown and unseen series of equations. This barrier is significant, as an agency cannot be expected to use a model that it does not understand. Conversely, this barrier may be the most straightforward to address through the use of detailed user documentation and training which explains in detail what the model is doing and how it generates results.

5.3. Recommendations

The primary recommendation drawn from this work is that a follow-up phase to this project should be pursued to identify the proper modeling techniques to employ for each of the model components identified in this report. Each of these models is likely to take on a different type/form based on the input variables and constraints of interest. This work will require careful investigation of different modeling techniques and consideration of the desired model outputs, both at the component level as well as in a unified context. With respect to outputs, it would be advisable to sit down with potential stakeholders and learn in detail what types of outputs they would find useful for their purposes. It would also be advisable to determine at this time what type of approach will be employed in making the model available to users. In other words, will the model be incorporated into a stand-alone software package, will it be something run by the developers using data provided by stakeholders, or will another, unknown approach be employed. With this information, the actual development of models would begin.

Once the appropriate models are constructed, they should be tested and refined, preferably using data from a geographic area of limited size scope. This will allow for problems to be identified and corrected prior to more large-scale testing and implementation. Once the testing and refinement process is completed, it would then be feasible to employ a larger geographic area with more complex service delivery (e.g., a county) to demonstrate the use of the individual model components, as well as the unified modeling approach. This exercise could be employed to conduct what-if analysis, as well as demonstrate the different uses of output data from the model (e.g., GIS mapping).

Part of the rationale for a larger test of the model would be to aid in the development of training materials for future users. The statistical nature of the models in the proposed approach will present a daunting challenge to many intended users, making training a critical component when the time for implementation comes. A key recommendation of this work is that training be provided to users either through demonstration, detailed user manuals, or a combination of both of these aspects. In making the model as transparent as possible to users, a barrier to implementation can be eliminated and the model better applied by stakeholders.

Of course, the effort required to develop the approach set forth in this report is expensive. Consequently, a final recommendation of this report is to monitor the landscape for funding opportunities to support such research in the future. This will not only allow the project to proceed into its next phase, but may provide an opportunity for different agencies to leverage their funds together to produce a comprehensive and useful modeling product that meets the needs of a wide group of stakeholders.

6. APPENDIX I: AGENCY QUESTIONS

The following are a series of questions developed by the researchers prior to interviews with local fire agency and 911 dispatch center personnel interviews. The purpose of these questions was to lead discussions with different staff. As such, not all of the questions were posed to interviewees; rather, these questions cover areas of interest to this work and lead the researchers in obtaining various pieces of information.

Questions/topics of discussion for personnel

1. Name, title, length of time in position, other positions held within organization, responsibilities,
2. List facilities and assets (buildings, vehicles, equipment).
3. As an agency/organization, what is your coverage area? (Location, square miles, number of people)
4. What are the most common calls? What kind of records do you keep regarding the calls and for how long? What format is this data in?
5. How are vehicles/personnel dispatched?
6. What is the organization's annual budget and funding sources?
7. How many employees work for this organization? How many volunteers? What is the breakdown of responsibilities?
8. How are resources allocated and dispatched? (ambulances, fire trucks, volunteers, patrol cars) What systems and processes are in place to do this?
9. How is budgeting performed? How reliable are funding streams? How are shortfalls addressed? How is service impacted by budget shortfalls?
10. How are resources purchased? E.g., fire station, fire truck, ambulance, dispatch software, computers, firefighting equipment and gear. In other words, what is the process undertaken to determine when such assets need to be purchased and what is the process in identifying which specific item will be purchased. How do you select a certain brand/vehicle/etc.? (sole sourced, out for bids, etc.)
11. How are facilities sited, built, opened, operated, and maintained?
12. Is there a preference given to optimizing coverage area versus response time when planning new facilities and managing current assets?
13. How are decisions made regarding the above? (agency basis, interagency coordination, financial resource allocation and shortfall/surplus responses, physical resource allocation, personnel)
    a. From a modeling standpoint, are any decision rules applied in the above process?
14. What technologies do you currently employ and for what are they used? (CAD, information systems, GIS, software, etc.) How were they chosen?
15. How are human resources presently managed?
    a. How do you coordinate volunteers and / or schedule employees?
    b. How are new personnel hired?
    c. Are there different levels of employees/volunteers; if so, what are these staffing levels?
    d. What kind of training is required for employees/volunteers?
    e. Do they have different amounts of training (employee vs. volunteer)?

f. How accessible is training?

16. How much and to what level does your organization coordinate with other service providers and districts for response, facilities, asset acquisition/allocation, and resources? Are there interagency operations plans in place for communications, coverage/response, or fundraising?
17. What performance metrics do you use? (Are different metrics used depending on the call? Or different levels of performance? Car accident vs. forest fire vs. robbery)
18. What kinds of challenges do you face in relation to any of the above? (barriers to implementation) Money, physical resources, human resources, operations
19. How could any of the above processes/systems be improved? Is any form of optimization currently being employed? If not, why? (cost, complexity, other)

7. APPENDIX II: PRELIMINARY ANALYSIS OF EMS RESPONSE TIMES IN GALLATIN COUNTY

The WTI project team conducted a preliminary analysis of EMS reponse times in Gallatin County, Montana to investigate the associated challenges and viability of conducting such analyses. Summary statistics and maps were created and are presented here. However, no conclusions are drawn from this data beyond casual observations and recommendations for subsequent analysis.

7.1. Original Data Set

EMS "event" data was provided to the project team by Bruce Cunningham, the CAD System Administrator for the Gallatin County 911 Dispatch Center, for all of the 2009 and 2010 calendar years. Only events for which American Medical Response (AMR) of Bozeman or Three Forks Ambulance were dispatched were included, and non-emergency transport was not included in these datasets. The datasets were subsequently filtered to include only events for which the time fields shown in Table 2 were included:

Table 2: Original Time Fields Used in Analysis[8]

Data Field	Description
Alarm_Time	*the time the 911 call taker started processing the event. This is either the time the 911 call was spilled into CAD or first keystrokes on the event*
Time_Assigned	*the time for the first unit to be dispatched to event*
Time_Enroute	*the time first unit responding to event*
Time_ArriveAtScene	*the time first unit on scene*

In addition, XY coordinates (UTM) were provided in the data set and were converted to Latitude-Longitude to facilitate mapping. Although the data set included incident type information, that data was not used in subsequent analysis.

Note that fire departments within this coverage area respond to EMS calls within their respective districts. However, the time fields shown in Table 1 are for ambulances only.[9] As such, only response from the two ambulance providers is presented here.

It would be desirable in subsequent analysis (beyond the scope of this project) to investigate first responder and/or first EMS responder times, that includes EMS response provided by fire department personnel. Further discussion with the Gallatin County 911 Dispatch Center would be necessary to determine the availability of this data. Such analysis could potentially include comparison across fire departments and might include comparisons based on fire department type (paid, volunteer, mixed).

[8] Field descriptions provided by Bruce Cunningham via email, 7/28/2011
[9] Bruce Cunningham email, 10/5/2011

Additional data used in this analysis includes the locations from which ambulances are generally dispatched to incidents by AMR and Three Forks Ambulance. See Table 3.

Table 3: AMR and Three Forks Ambulance Station Locations

Provider	Ambulance Location
AMR[10]	2101 Industrial Drive, Bozeman
AMR[11]	522 W Main, Bozeman
Three Forks Ambulance[12]	13 E Date St, Three Forks
Three Forks Ambulance[13]	113 Main St, Willow Creek

7.2. Calculated Measures

The original data was used to calculate several derived measures of time associated with incident response as follows:

$$\begin{aligned} \mathit{Dispatch\_Time} &= \text{Time\_Assigned - Alarm\_Time} \\ \mathit{Start\_Time} &= \text{Time\_Enroute - Time\_Assigned} \\ \mathit{Drive\_Time} &= \text{Time\_ArrivedAtScene - Time\_Enroute} \\ \mathit{Response\_Time} &= \text{Time\_ArrivedAtScene - Alarm\_Time} \\ &= \text{Dispatch\_Time + Start\_Time + Drive\_Time} \end{aligned}$$

Dispatch_Time measures the time between the emergency call being answered and the dispatch for EMS. This time is viewed as largely a function of dispatch, although the time for the responder to answer might also be a factor.

Start_Time measures the time from assignment of a unit to the unit initiating travel to the incident. This time is viewed as a function of the responder's time to move from wherever they receive the dispatch message to their vehicle, including whatever preparation time may be needed.

Drive_Time measures the time it takes to drive to the incident.

Response_Time is the time it takes from the emergency call being received at the 911 dispatch center to the responder (ambulance) being at the scene of the incident, and is the sum of

[10] Phone Interview with Art McKiernan, AMR Operations Manager in Bozeman, 10/7/2011
[11] Phone Interview with Art McKiernan, AMR Operations Manager in Bozeman, 10/7/2011
[12] http://threeforksfire.tripod.com/threeforksfire/contact.html
[13] http://threeforksfire.tripod.com/threeforksfire/contact.html

Dispatch_Time, *Start_Time* and *Drive_Time.* Thus, these times are considered the components of *Response_Time*.

In order to reduce *Response_Time,* the time it takes for medical service to arrive at an incident to provide EMS treatment and possibly transport, each or all the component times might be considered for reduction. Thus, it is a worthwhile exercise to analyze the times and, if possible, determine contributing factors that might be addressed to provide improvement. For instance, *Dispatch_Time* might be impacted by dispatch center staffing, technology and process. Thus, increasing staffing, improving technology and/or changing procedures at the dispatch center might be examined to determine if improvement is feasible. *Start_Time* might be reduced by positioning responders closer to response vehicles, particularly in the case of volunteer departments in which responders may need to travel from their home or workplace to the emergency vehicle. *Drive_Time* could be reduced by allocating more resources, including the possibility of new stations and emergency vehicles. Or, mechanisms for positioning responders and vehicles dynamically, based on anticipated demand and known coverage gaps, might be considered.

Of course such changes, particularly building new stations or purchasing new vehicles, would require significant, additional funding, and that funding may not be available. Such recommendations are considered beyond the scope of this preliminary analysis, and would require significant subsequent analysis, research, optimization and discussion prior to recommendation.

7.3. Summary Statistics and Maps

Summary statistics were computed on the incident event data using Microsoft Excel and the R statistical package, which was also used to produce boxplots. Microsoft MapPoint was used to produce rudimentary maps of incident locations. MapPoint was also used to create "Drive Time Zones", as estimates of drive time for response. These drive time zones should be interpreted as little more than rough estimates since they present estimated, normal drive times for normal traffic as opposed to emergency response travel time, which likely would be faster. Further, underlying street network data for rural areas is typically incomplete, includes inaccuracies and may not reflect conditions representative of the time in which the incidents analyzed occurred. With these qualifications, drive time zones are presented as rough estimates and as frames of reference. More advanced GIS tools and timely street network data, ideally from city, county or state government sources should be considered in subsequent analysis.

The Gallatin County 911 Dispatch Center does not provide service to all of Gallatin County. The West Yellowstone Emergency 911 Center responds to 911 calls in the southern portion of the County.[14] Only incidents handled by the Gallatin County 911 Dispatch Center are included in this analysis. Thus, the area of interest is primarily North Gallatin County. 0 to 4, 4 to 8, 8 to 12 and 12 to 16-mile drive time zones around the two Bozeman ambulance stations and the stations in Three Forks and Willow Creek help to demonstrate the expanse of Northern Gallatin County. See Figure 2. The 12 to 16-mile drive time zones for Three Forks Ambulance do not overlap those for Bozeman's AMR. Further, there are large areas in the county both to the north and the south that are not within these drive time zones either. Figure 3 further illustrates the station locations and drive time zones along the I-90 corridor, which crosses the county.

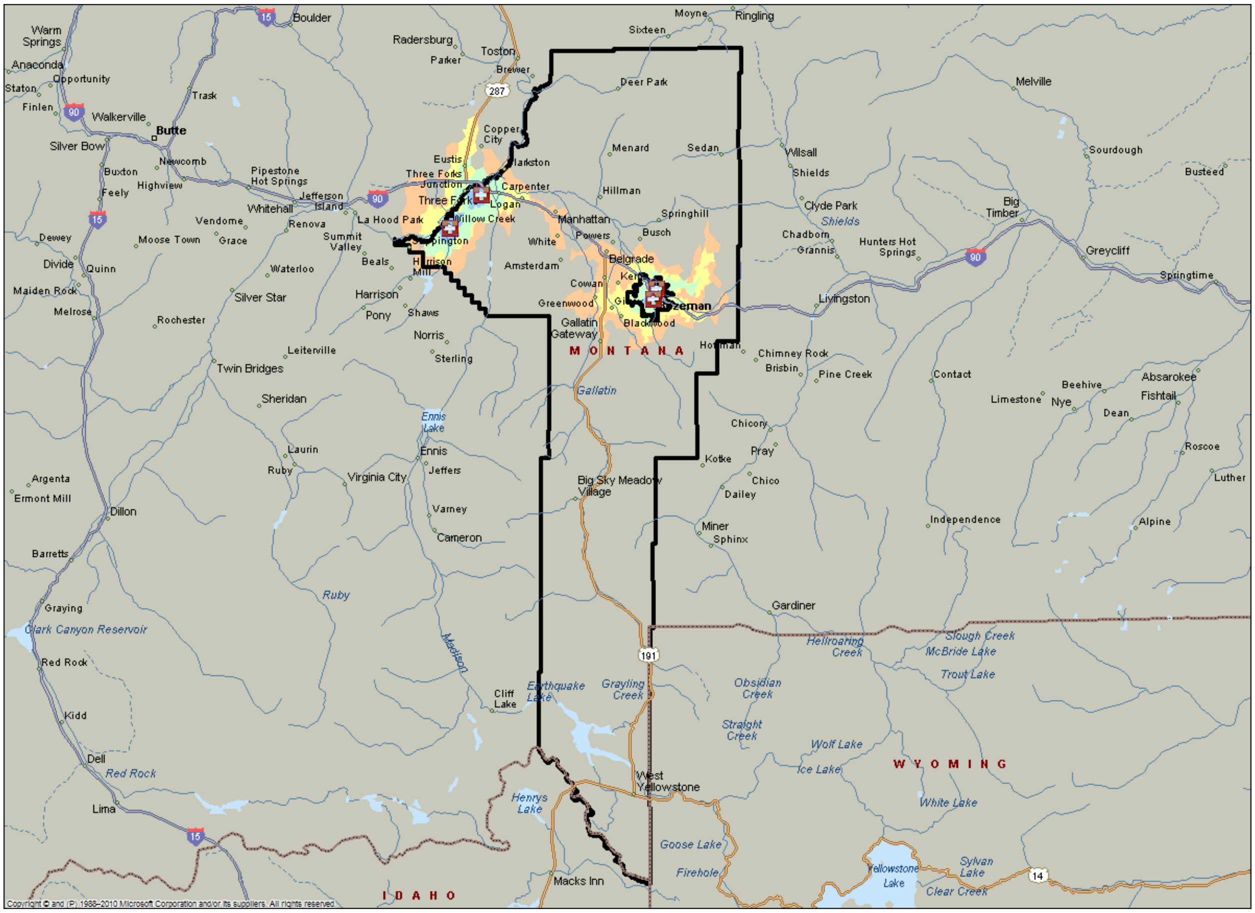

Figure 2: Station Locations and Drive Time Zones Relative to Gallatin County

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

[14] http://www.townofwestyellowstone.com/sublevel.cfm?template=police

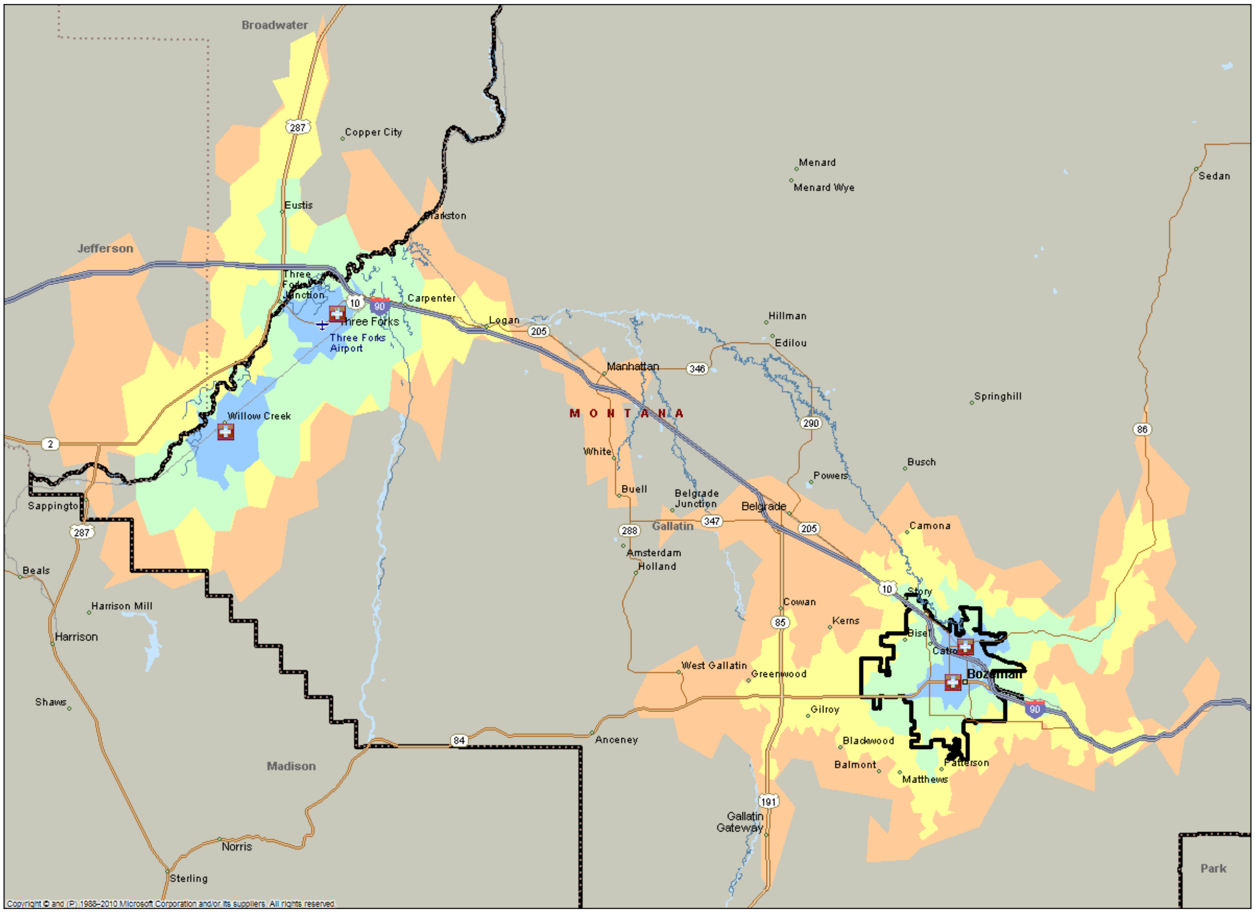

Figure 3: Station Locations and Drive Time Zones – Three Forks and Bozeman

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

Figure 4 and Figure 5 show the drive time zones relative to the Bozeman city limits. AMR has a response time requirement for the City of Bozeman to arrive on the scene of an incident within eight minutes 90% of the time. [15] The 0 to 4 and 4 to 8 minute drive time zones shown generally cover Bozeman although there are some areas where an 8 to 12 minute drive time is indicated.

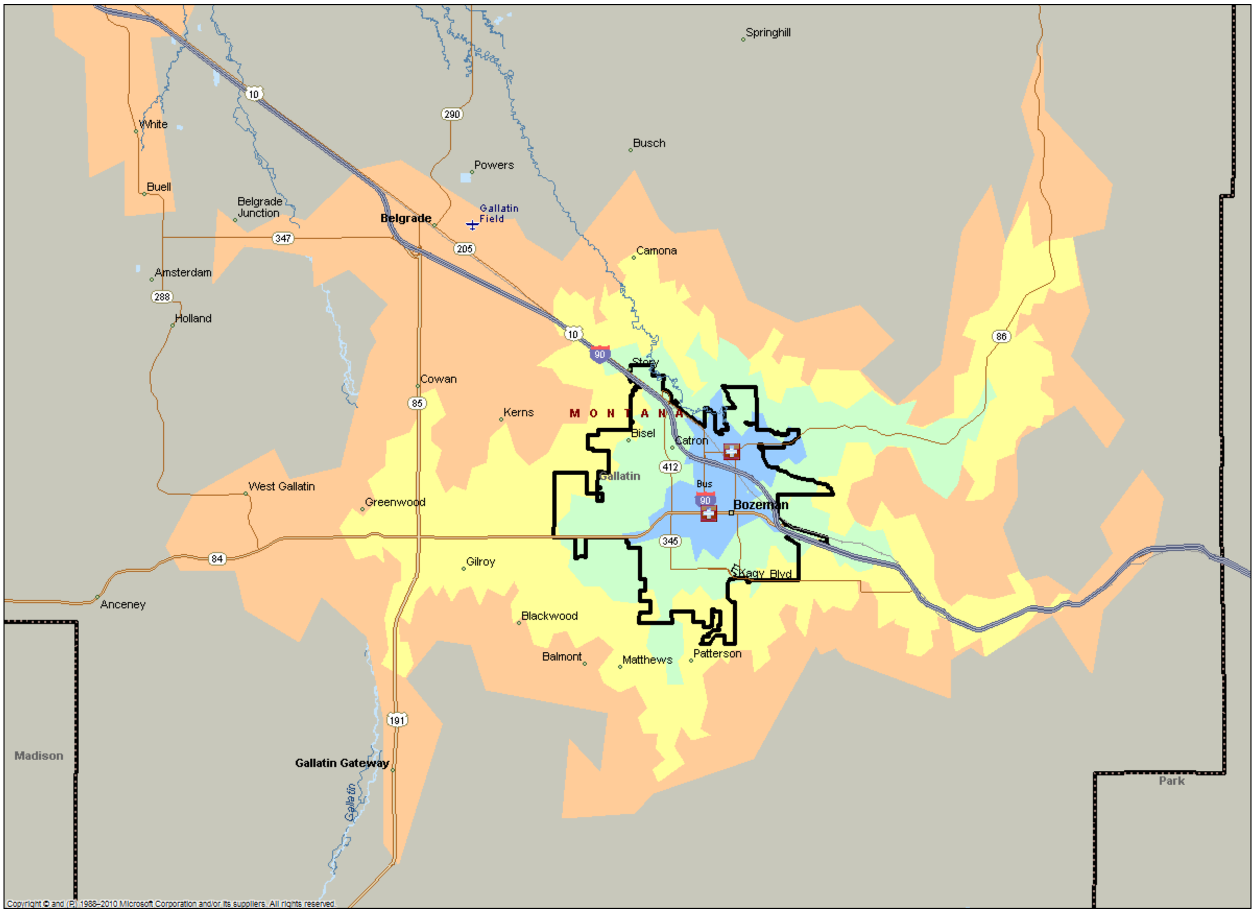

Figure 4: Station Locations and Drive Time Zones – Bozeman and Surrounding Area

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

[15] Phone Interview with Art McKiernan, AMR Operations Manager in Bozeman, 10/7/2011

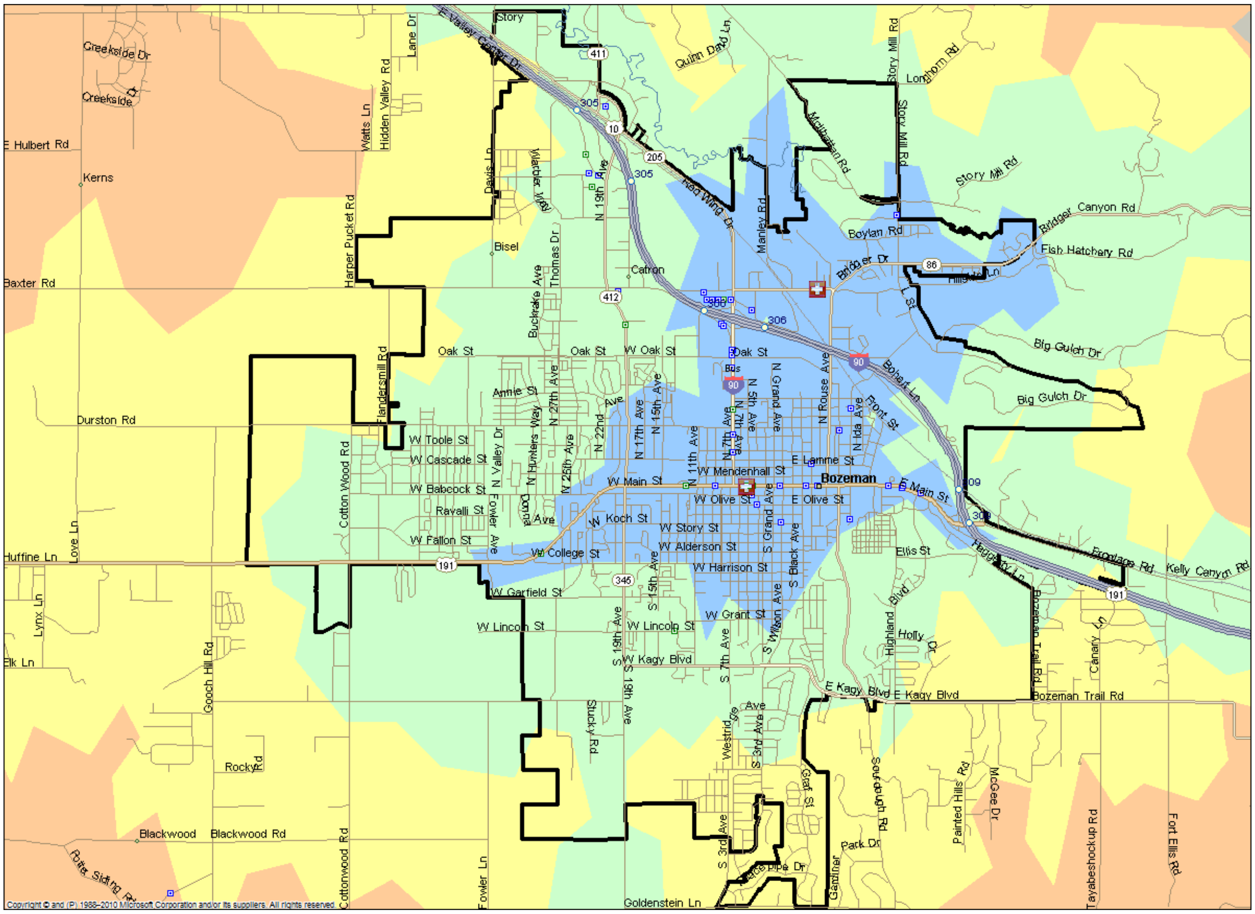

Figure 5: Station Locations and Drive Time Zones – Bozeman

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

The drive time zones for Three Forks Ambulance are shown in Figure 6 and Figure 7. I-90 and US 287 are covered entirely by these drive time zones in the western portion of Gallatin County. Note that because of their location in the extreme western portion of the county, drive time zones for these ambulance sites overlap into Jefferson and Broadwater counties.

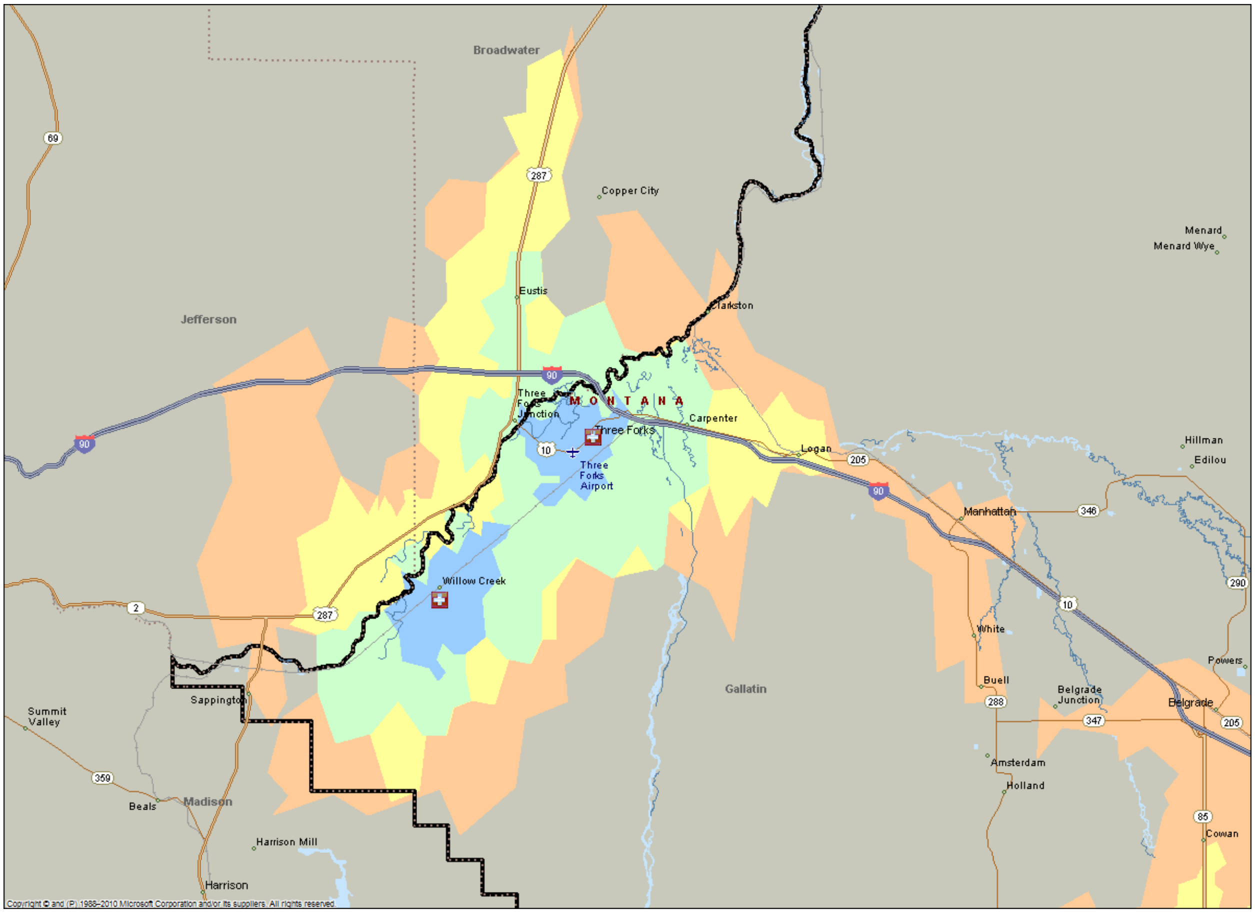

Figure 6: Station Locations and Drive Time Zones – Three Forks, Willow Creek and Surrounding Area

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

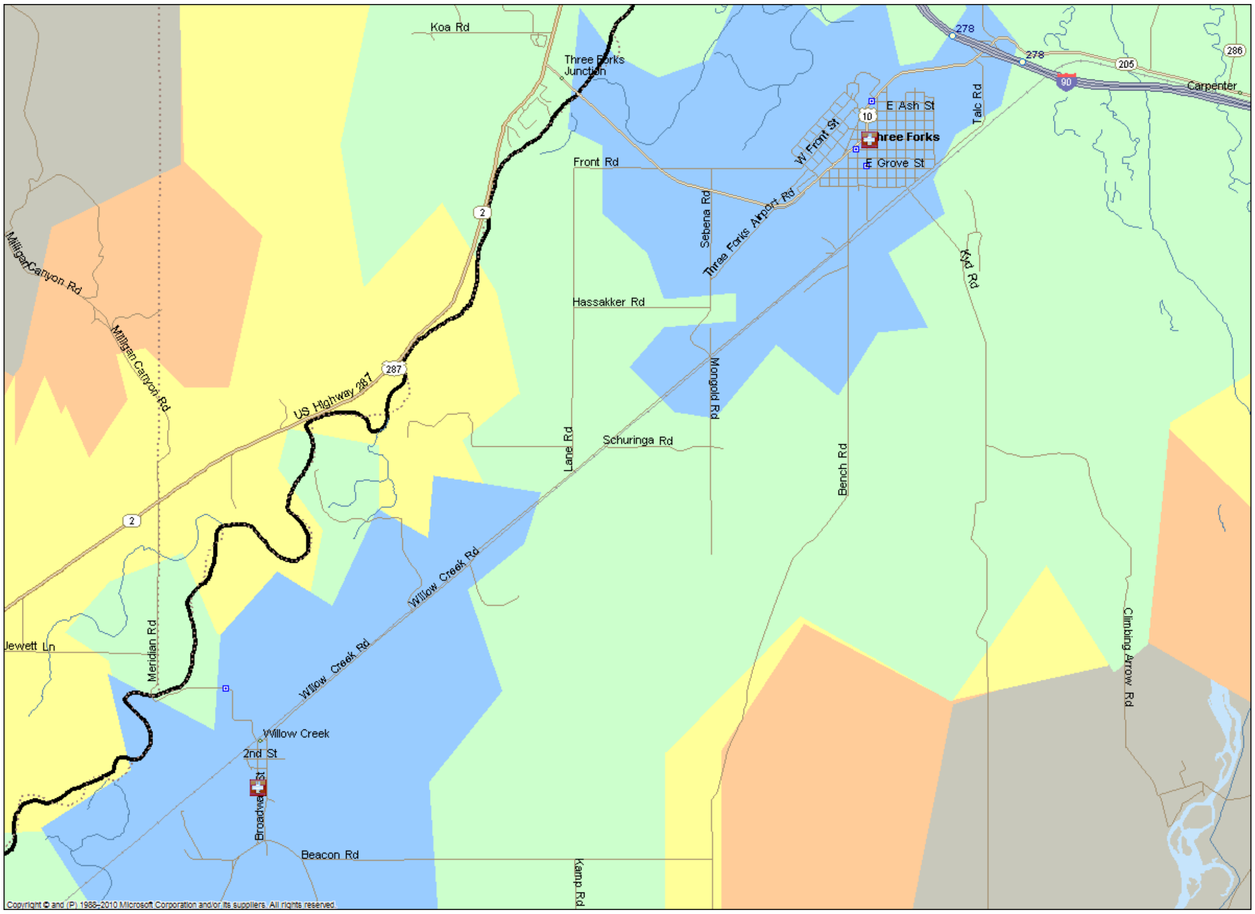

Figure 7: Station Locations and Drive Time Zones – Three Forks and Willow Creek

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

Figure 8 shows locations of all events for which there were responses by AMR in 2009-2010. The concentration around Bozeman is expected since that is the primary service area. There are some responses in the Three Forks area. Three Forks Ambulance may request to have AMR meet them if a paramedic is needed for an incident.[16] This explains some of the longer drive times for AMR, although there are some drive times of less than 16 minutes for AMR shown in the Three Forks area. We have no explanation for these less than expected drive times at this time. There are incidents with excessive (32 minutes or greater) drive times shown, and these generally correspond to remote areas of the county. Drive times of 16 to 32 minutes appear common in the area between Logan and Manhattan.

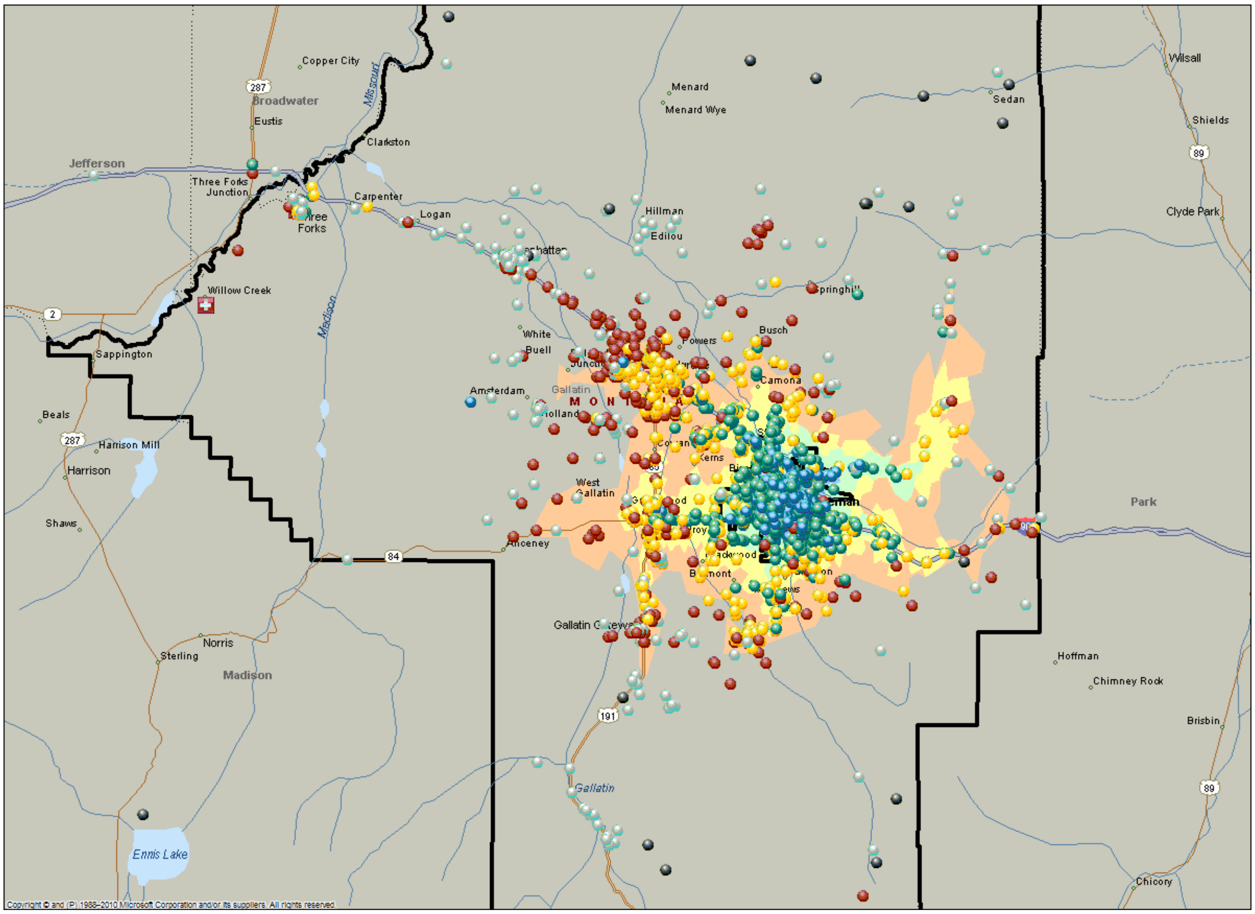

Figure 8: Actual 2009-2010 Incident Drive Times for AMR Relative to Drive Time Zones

- 32+ minutes
- 16 to 32 minutes
- 12 to 16 minutes
- 8 to 12 minutes
- 4 to 8 minutes
- 0 to 4 minutes

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

[16] Bruce Cunningham email, 9/30/2011

Figure 9 shows further detail for AMR responses in the Bozeman area. Actual drive times roughly correspond to the drive time zone estimates with a few notable exceptions. In particular, many incidents in the Belgrade area northwest of Bozeman on I-90 are shown with response times of less than 12 minutes. Incidents in the Belgrade area are shown in greater detail in Figure 10.

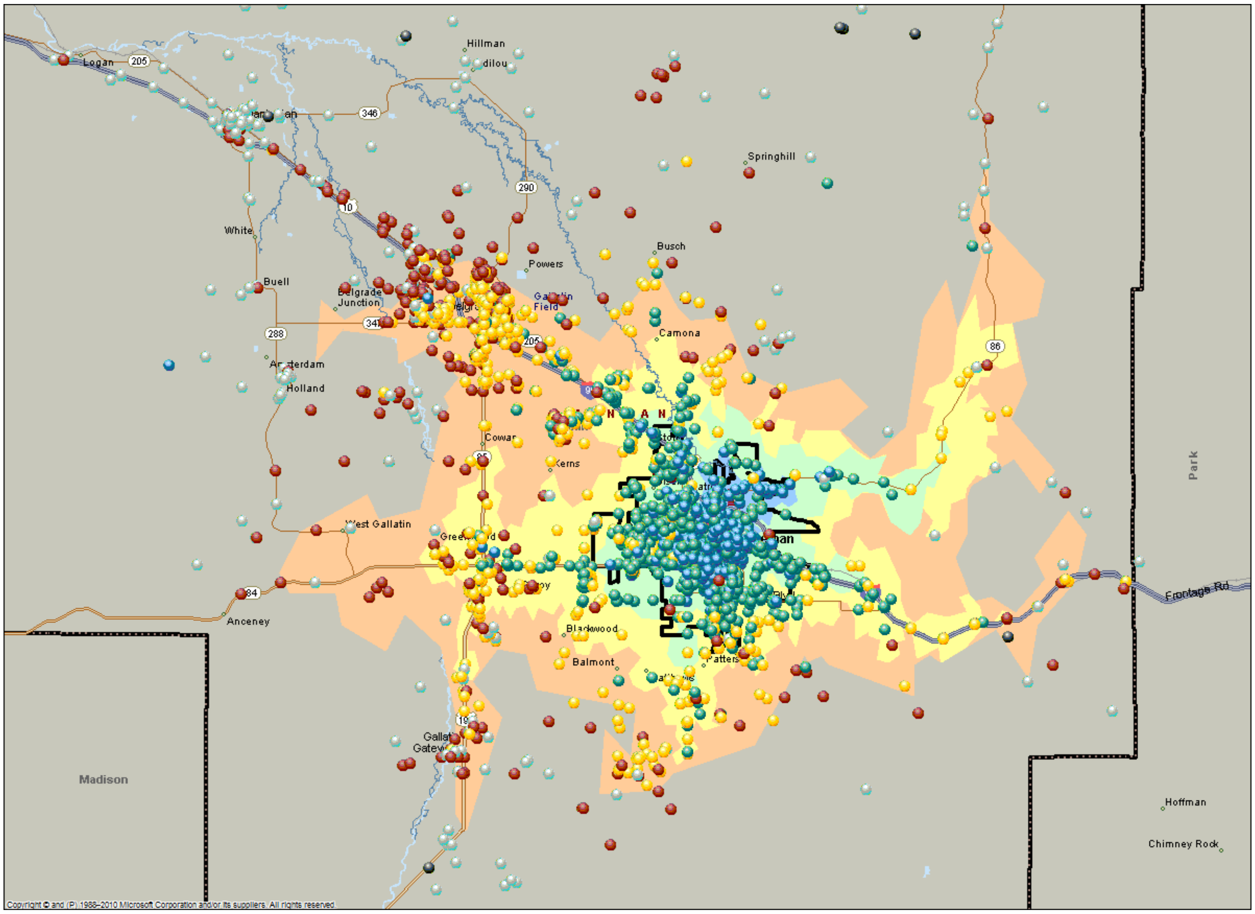

Figure 9: Actual 2009-2010 Incident Drive Times for AMR Relative to Drive Time Zones – Bozeman and Surrounding Area

32+ minutes
16 to 32 minutes
12 to 16 minutes
8 to 12 minutes
4 to 8 minutes
0 to 4 minutes

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

Figure 10 also shows some incidents for which there is a 4 to 8 minute drive time. These might be explained by an arrangement AMR has with the Central Valley Fire Department (CVFD), which provides fire service to Belgrade and other surrounding areas. AMR has a fee-based agreement with CVFD that if AMR is overloaded, an ambulance operated by CVFD may be called for a response.[17] It is assumed but unverified that this ambulance would only be used in the event that AMR is overloaded. AMR has a similar arrangement with the Bozeman Fire Department, except AMR purchased the ambulance for the Bozeman Fire Department and presumably does not pay a fee for incidents in which that ambulance is used. The 8 to 12 minute responses in the Belgrade area might be explained by proximity to I-90 and the Frontage Road, both of which could be used by AMR for rapid response from Bozeman.

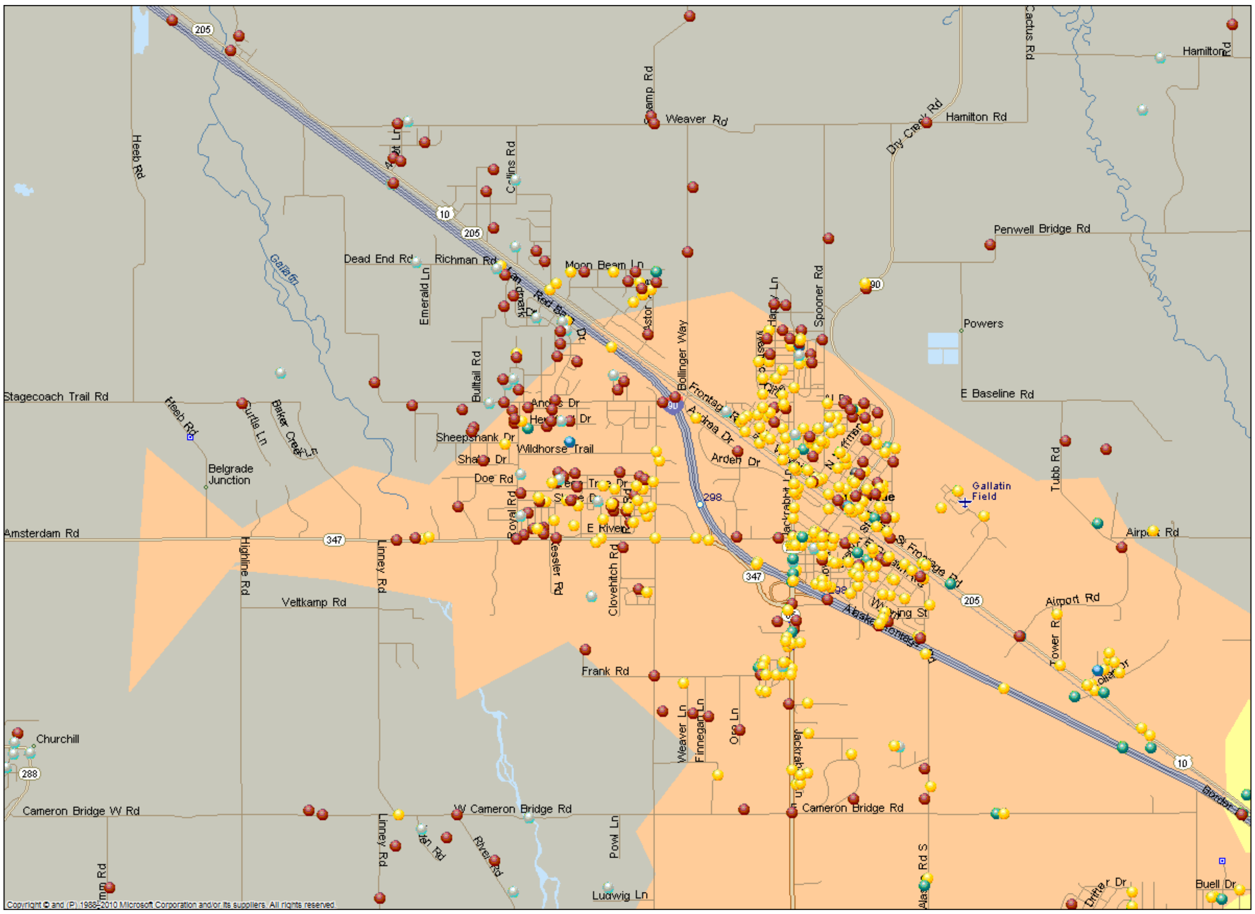

Figure 10: Actual 2009-2010 Incident Drive Times for AMR Relative to Drive Time Zones – Belgrade

[17] Phone Interview with Art McKiernan, AMR Operations Manager in Bozeman, 10/7/2011

Drive times to incidents within the Bozeman City limits are generally less than eight minutes, as would be expected based on the drive time zone estimates and the requirement by the City of Bozeman for AMR to arrive on the scene of an incident within eight minutes 90% of the time.[18] See Figure 11. Do note that drive times, not response times are shown here, so there isn't sufficient information in Figure 11 to judge conformance with this requirement. However, there are some incidents visible for which the drive time exceeded 8 minutes. Thus, response time would also exceed 8 minutes for these incidents. The cause of these excessive drive times is unknown. Perhaps they correspond to low priority incidents or occurred at times in which ambulances were not immediately available.

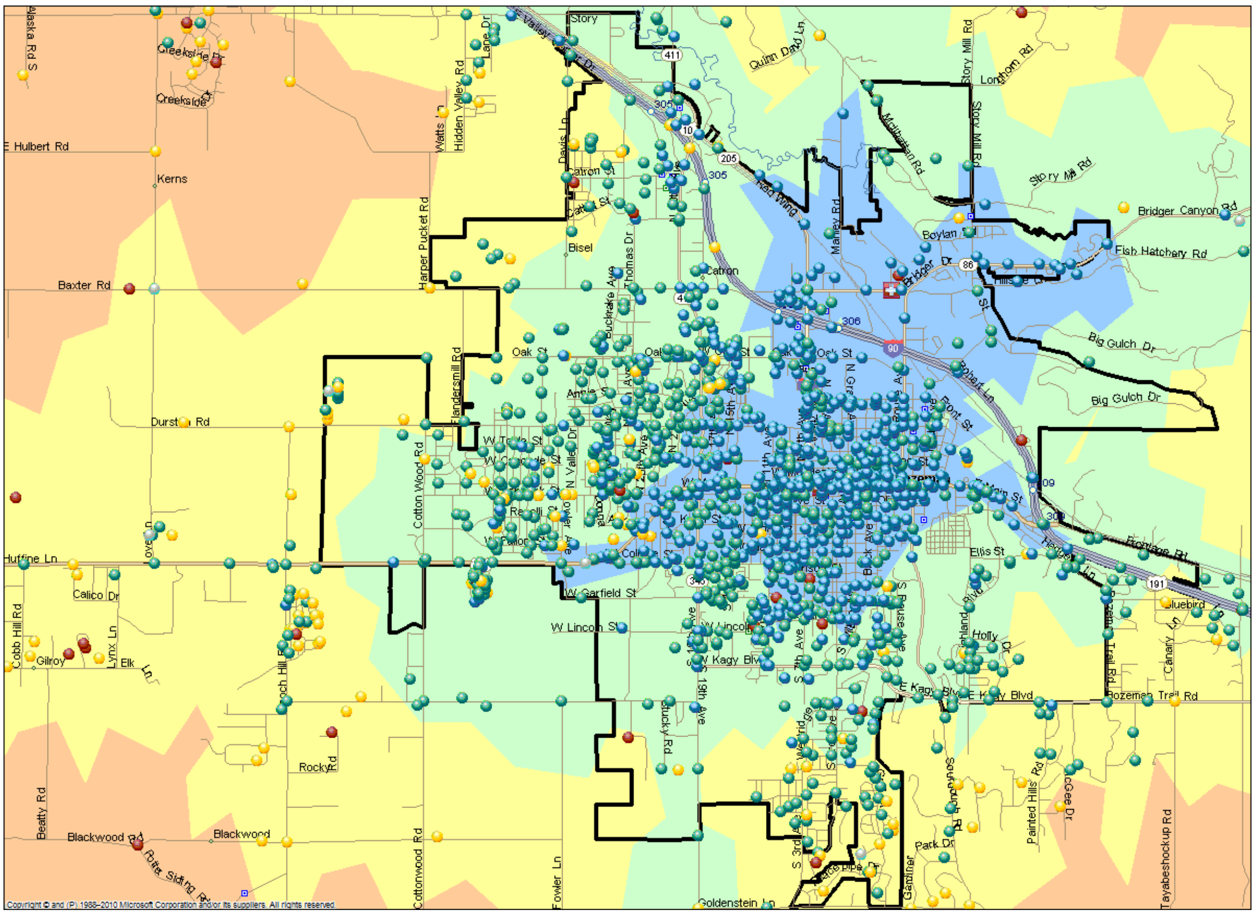

Figure 11: Actual 2009-2010 Incident Drive Times for AMR Relative to Drive Time Zones– Bozeman City Limits

[18] Phone Interview with Art McKiernan, AMR Operations Manager in Bozeman, 10/7/2011

Three Forks Ambulance incident drive times are shown in Figure 12 and Figure 13. Note that most of the longer drive times (16 minutes and above) correspond to a remote area along the Missouri River to the Northeast of Three Forks. Also note that service was provided to several locations in Jefferson and Broadwater counties. It is unknown if there are service agreements between Three Forks Ambulance and those counties, but relative proximity of these incidents to Three Forks and Willow Creek is apparent in this sparsely populated area.

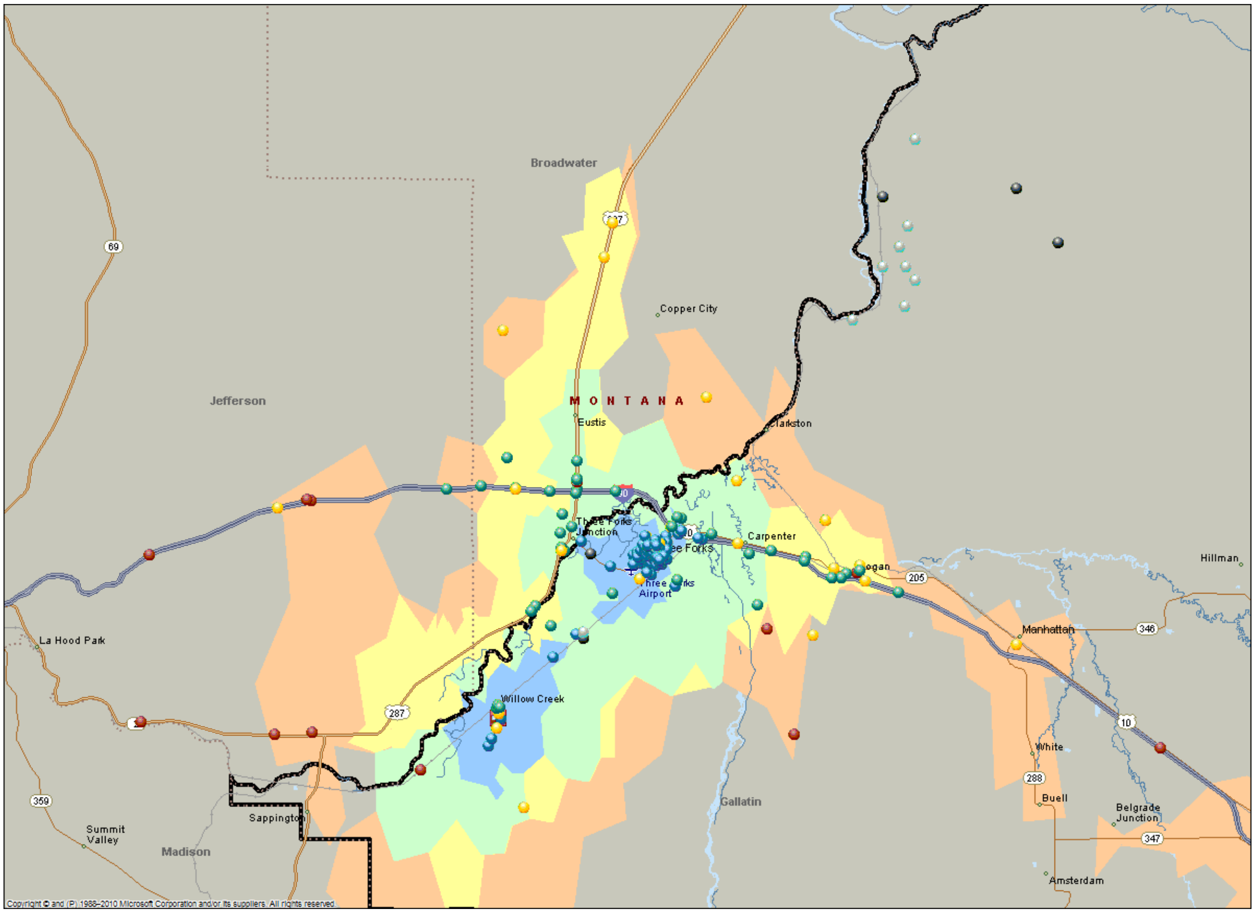

Figure 12: Actual 2009-2010 Incident Drive Times for Three Forks Ambulance Relative to Drive Time Zones– Three Forks, Willow Creek and Surrounding Area

32+ minutes
16 to 32 minutes
12 to 16 minutes
8 to 12 minutes
4 to 8 minutes
0 to 4 minutes

0 to 4 minutes
4 to 8 minutes
8 to 12 minutes
12 to 16 minutes
Gallatin County
Bozeman City Limits

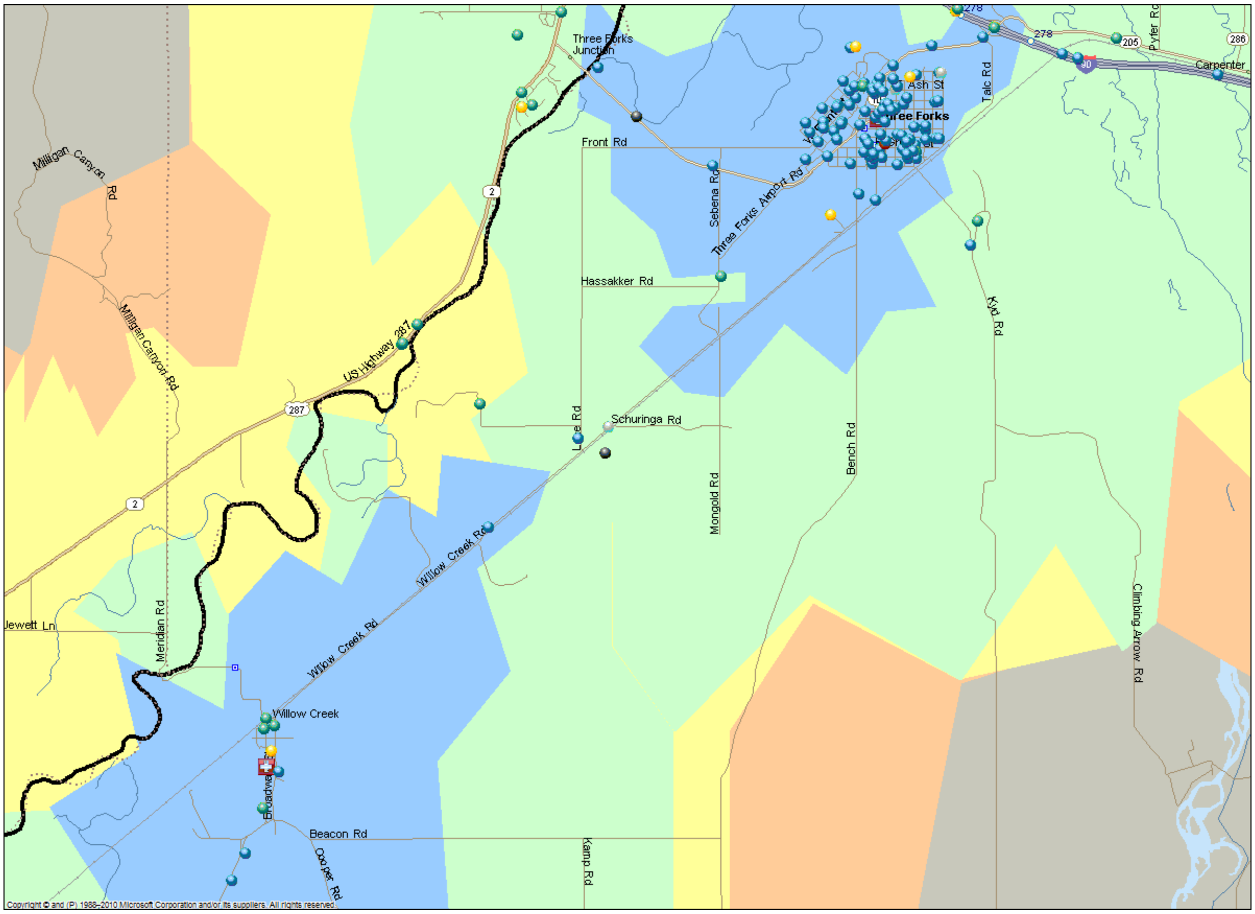

Figure 13: Actual 2009-2010 Incident Drive Times for Three Forks Ambulance Relative to Drive Time Zones– Three Forks and Willow Creek

- 32+ minutes
- 16 to 32 minutes
- 12 to 16 minutes
- 8 to 12 minutes
- 4 to 8 minutes
- 0 to 4 minutes

- 0 to 4 minutes
- 4 to 8 minutes
- 8 to 12 minutes
- 12 to 16 minutes
- Gallatin County
- Bozeman City Limits

Summary statistics for a total of 6067 EMS incidents in 2009-2010 for AMR and Three Forks Ambulance combined are shown in Table 4 for dispatch time, start time, drive time and response time. The average and standard deviation appear to be influenced heavily by extreme values. Each time measure has a large number of associated outliers, as can be seen in the boxplots in Figure 14. Figure 15 shows boxplots for this data set with the outliers removed.

Table 4: Summary Statistics for 2009-2010 EMS Incidents, AMR and Three Forks Ambulance Combined (times in minutes)

	Dispatch Time	Start Time	Drive Time	Response Time
AVG	1.33	2.56	7.34	11.23
STDEV	2.89	2.26	6.39	7.60
MIN	0.05	0.02	0.00	1.32
Q1	0.65	1.73	3.27	6.58
MEDIAN	0.97	2.13	5.37	8.98
Q3	1.37	2.62	10.03	13.92
MAX	72.38	85.10	138.50	146.13
				COUNT = 6067

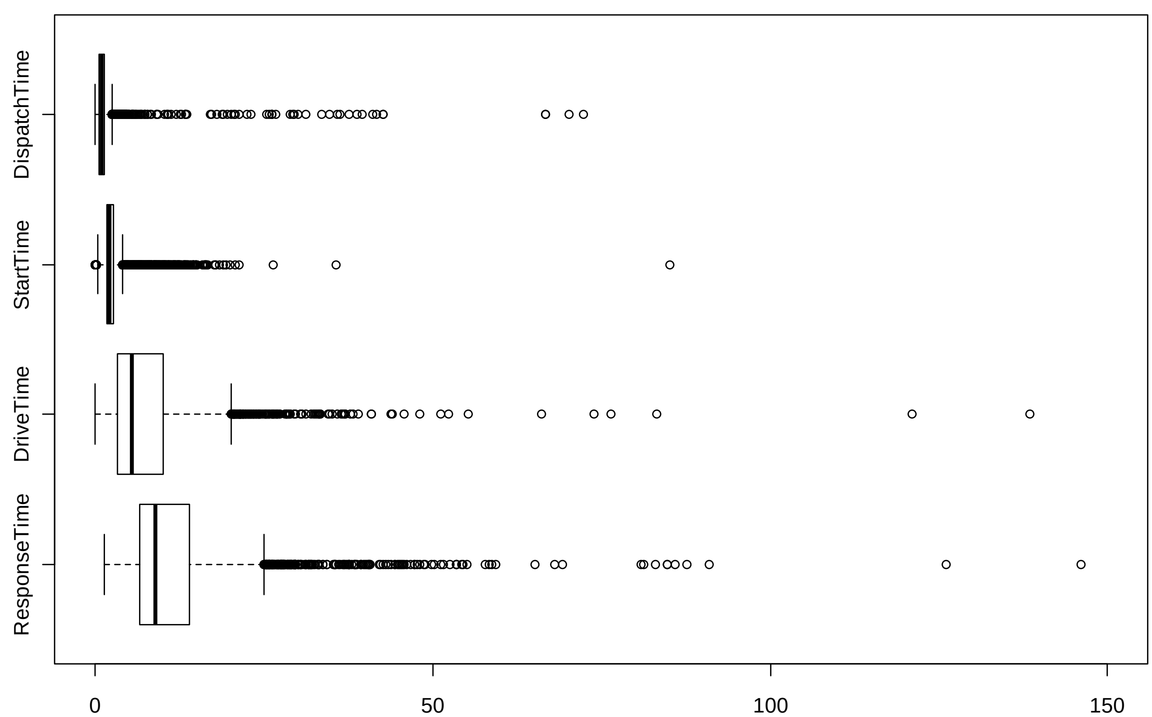

Figure 14: Boxplot 2009-2010 EMS Incidents, AMR and Three Forks Ambulance Combined (times in minutes)

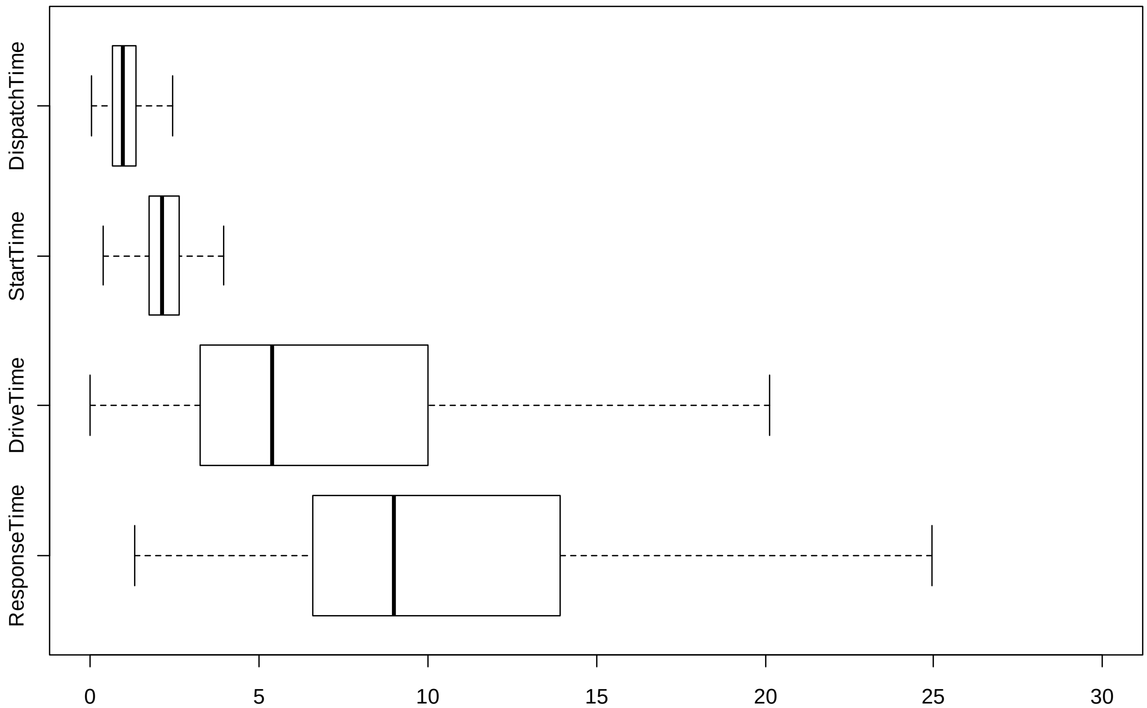

Figure 15: Boxplot 2009-2010 EMS Incidents, AMR and Three Forks Ambulance Combined, Outliers (>1.5 IQR) Removed (times in minutes)

There were 5788 incidents in the 2009-2010 data set for which AMR provided response. Extreme values have heavy influence on the averages and standard deviations, and outliers can be seen in the boxplots in Figure 16. With outliers removed, dispatch times are generally less than 3 minutes, start times are generally less than 4 minutes, drive times are generally less than 21 minutes, and overall response time is generally less than 24 minutes. See Figure 17. Median values show a dispatch time of less than 1.37 minutes, a start time of less than 2.1 minutes, a drive time of less than 5.5 minutes and an overall response time of less than 9 minutes.

Table 5: Summary Statistics for 2009-2010 EMS Incidents, AMR (times in minutes)

	Dispatch Time	Start Time	Drive Time	Response Time
AVG	1.33	2.20	7.37	10.90
STDEV	2.95	1.01	6.11	7.17
MIN	0.05	0.02	0.02	1.32
Q1	0.65	1.72	3.33	6.48
MEDIAN	0.97	2.10	5.42	8.93
Q3	1.37	2.53	10.13	13.52
MAX	72.38	35.65	120.98	126.10
				COUNT = 5788

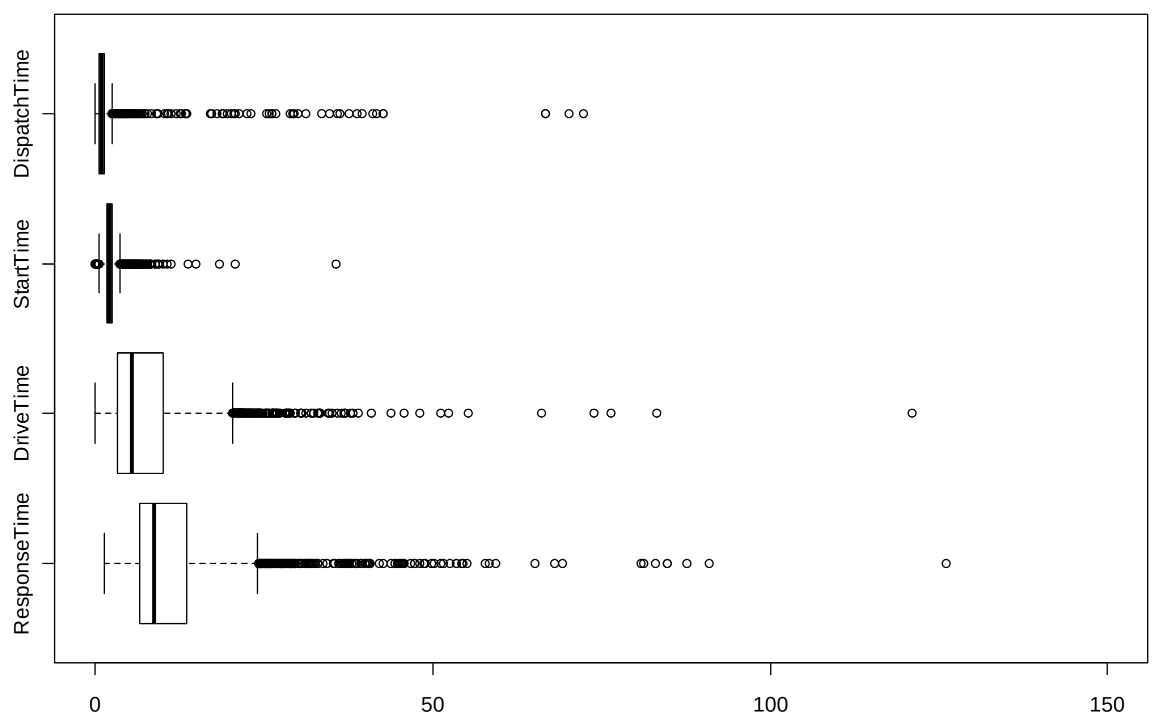

Figure 16: Boxplot 2009-2010 EMS Incidents, AMR (times in minutes)

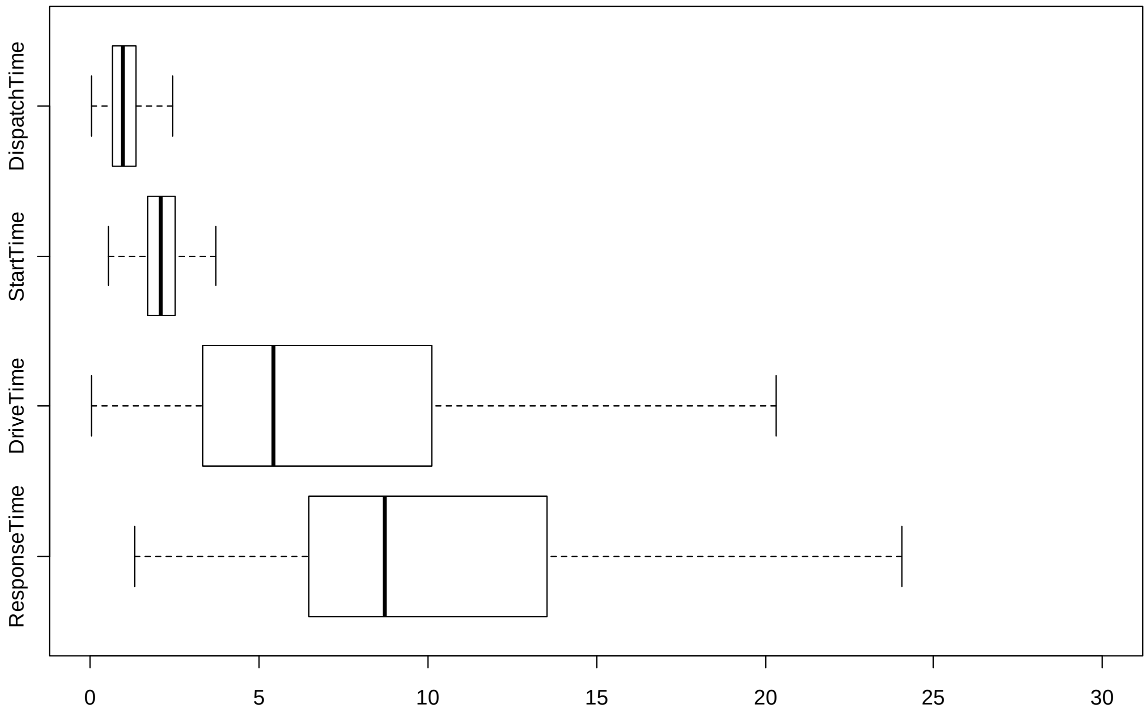

Figure 17: Boxplot 2009-2010 EMS Incidents, AMR, Outliers (>1.5 IQR) Removed (times in minutes)

There were 279 incidents in the 2009-2010 data set for which Three Forks Ambulance provided response. As with AMR, extreme values have a heavy influence on the averages and standard deviations. Outliers can be seen in the boxplots in Figure 18. With outliers removed, dispatch times are generally less than 3 minutes, start times are generally less than 18 minutes, drive times are generally less than 17 minutes, and overall response time is generally less than 31 minutes. See Figure 19. Median values show a dispatch time of less than 1 minute, a start time of approximately 9 minutes, a drive time of less than 4.5 minutes and an overall response time of over 15.6 minutes. In comparison to the AMR data, the Three Forks Ambulance start times are greater by a relatively large amount, while dispatch times are comparable and drive times are generally lesser. The start times are somewhat suprising and the cause of the difference is unknown. It may be attributable to the volunteer status of Three Forks Ambulance, assuming that personnel must travel to meet the ambulance at the ambulance station. If this is not the case, then there is no obvious explanation. Further investigation is merited, but is outside the scope of this project.

Table 6: Summary Statistics for 2009-2010 EMS Incidents, Three Forks Ambulance (times in minutes)

	Dispatch Time	Start Time	Drive Time	Response Time
AVG	1.27	9.92	6.78	17.97
STDEV	1.30	5.77	10.61	11.94
MIN	0.05	0.02	0.00	5.45
Q1	0.63	7.20	1.53	12.10
MEDIAN	0.95	9.03	4.47	15.62
Q3	1.47	11.84	7.99	19.73
MAX	13.40	85.10	138.50	146.13
				COUNT = 279

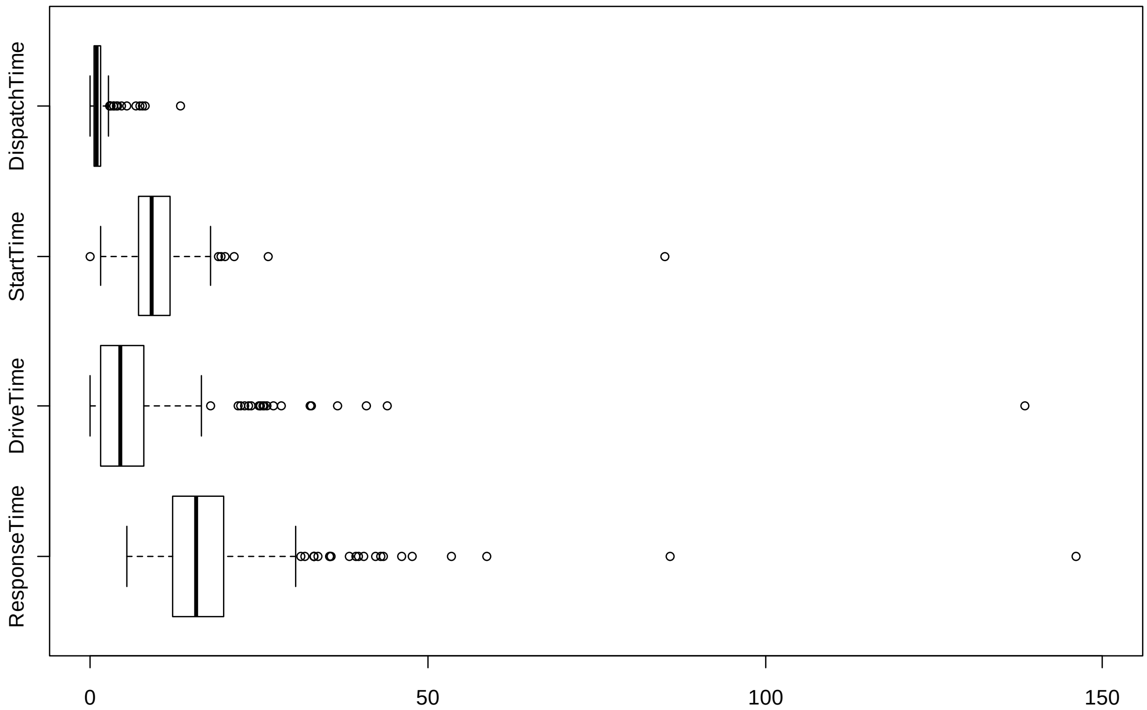

Figure 18: Boxplot 2009-2010 EMS Incidents, Three Forks Ambulance (times in minutes)

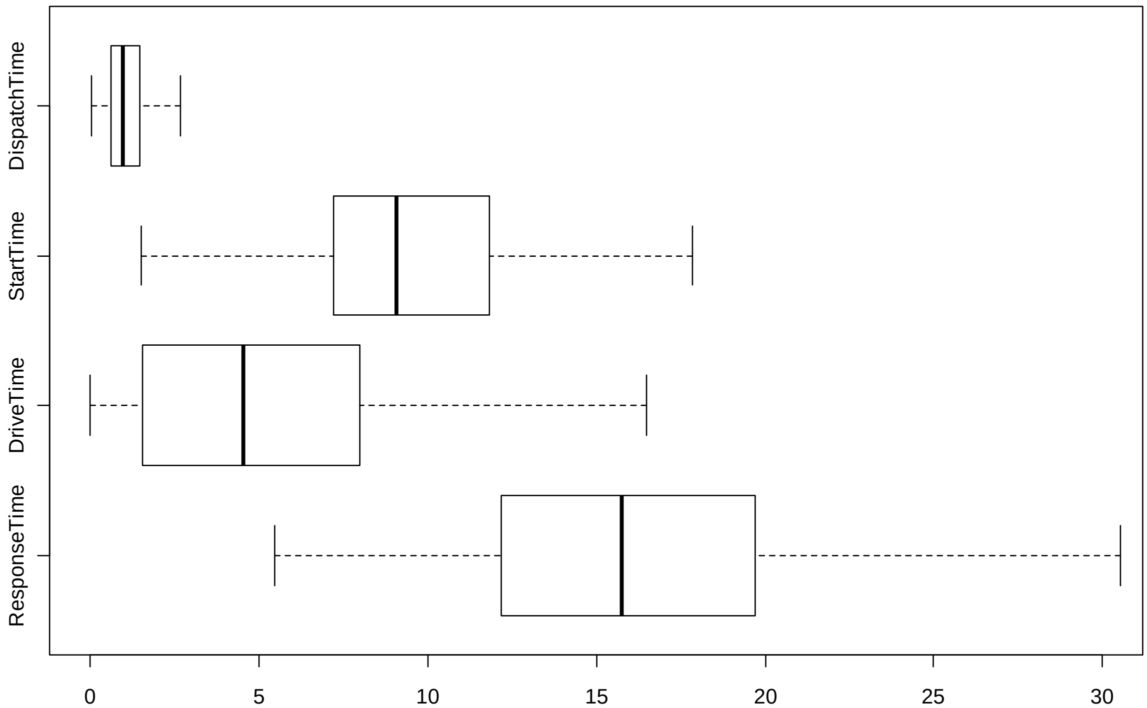

Figure 19: Boxplot 2009-2010 EMS Incidents, Three Forks Ambulance, Outliers (>1.5 IQR) Removed (times in minutes)

7.4. Conclusions

No solid conclusions should be drawn from this preliminary analysis regarding specific problems and solutions associated with provision of EMS service in Gallatin County. First responder data in addition to the ambulance-only dataset examined may more accurately represent response times in regard to timely provision of care. As stated earlier, it is unknown if the corresponding data for fire department first responders is available. The data could also be further broken down by time of day, day of week and time (month) of year to determine if service varies over different time frames. Incident types could be taken into account, although it is unclear if the incident information is conducive to grouping. Statistical significance tests could be used to formally signify differences between data sets and groupings. A utilization analysis could also be performed, to assess overall utilization of resources and identify individual times during which resources were all or nearly all utilized.

Obviously the amount and quality of analysis that can be peformed is dependent on the data recorded and available, and the quality of that data. If response times such as those used in this prelimary analysis are not available for a given area, then additional data collection efforts may be necessary to investigate dispatch times and start times. Drive time analysis can be conducted using drive time zones for existing facility locations. New facility locations could be proposed based on drive time zones and coverage gaps in drive times from existing facilities. Such analysis should be paired with incident locations, if available. Advanced optimization techniques such as those discussed earlier in this report could be used to address related facility location-allocation problems to determine where to "optimally" place existing or prospective new resources.

8. REFERENCES

1 Committee on the Future of Emergency Care in the United States Health System – Institute of Medicine. (2006). Emergency medical services: At the crossroads. Washington, DC: National Academies Press.

2 Pantridge, J. F., and J.S. Geddes, J. S. (1967). A mobile intensive care unit in the management of myocardial infarction. Lancet, 2, 271–273.

3 National Academy of Sciences. Accidental death and disability: The neglected disease of modern society. (1966) Washington, DC, National Academy of Sciences, National Research Council.

4 National Registry of Emergency Medical Technicians. *Longitudinal Emergency Medical Technician Attributes and Demographics Survey (LEADS) Data*. 2003. Accessed November 28, 2005. Available at: http://www.nremt.org/about/lead_survey.asp

Putnam, R.D. *Bowling Alone: The Collapse and Revival of American Community*. New York: Simon and Schuster, 2001.

5 Putnam, R.D. *Bowling Alone: The Collapse and Revival of American Community*. New York: Simon and Schuster, 2001.

6 Delbridge, T.R., B. Bailey, J.L. Chew, A.K. Conn, J.J. Krakeel, D. Manz,and D.R. Miller. *EMS Agenda for the Future*. Washington DC, National Highway Traffic Safety Administration, 1996.

7 McGinnis, K. *Rural and Frontier Emergency Medical Services: Agenda for the Future*. Washington, DC: National Rural Health Association, 2004.

8 Fitzsimmons, James. "A Methodology for Emergency Ambulance Deployment". *Management Science*. Vol. 19, No 6, pp. 627-636, 1973.

9 Larson, Richard. "Urban Emergency Service Systems: An Iterative Procedure for Approximating Performance Characteristics". *Department of Housing and Urban Development*, Report R1493-HUD, January, 1974.

10 Brotcorne, Luce, Gilbert Laporte and Frederic Semet. "Ambulance Location and Relocation Models". *European Journal of Operational Research*. Vol. 147, pp. 451-463, 2003.

11 Aly, Adel and John White. "Probabilistic Formulation of the Emergency Service Problem". *Journal of the Operational Research Society*. Vol. 29, No. 12, pp 1167-1179, 1978.

12 Daskin, Mark and Edmund Stern. "A Hierarchical Objective Ser Covering Model for Emergency Medical Service Vehicle Deployment". *Transportation Science*, Vol. 15, No. 2, pp. 137-152, 1981.

13 Daskin, Mark. "A Maximum Expected Covering Location Model: Formulation, Properties and Heuristic Solution". *Transportation Science*, Vol. 17, No. 1, pp. 48-70, 1983.

14 Wolfe, Harvey and Larry Shuman. "Rural Emergency Medical Services Project Study Final Report". *National Highway Traffic Safety Administration*, 1988.

15 Ames, James, Maximillian Etschmaier, Larry Shuman and Harvey Wolfe. “Simulation of a Rural EMS System”. *Proceedings: Annual Symposium on Computer Applications in Medical Care*. pp. 139–143, 1979.

16 Goldberg, Terry, Robert Dietrich, Jen Ming Chen, Mousa Mitwasi, Terry Valenzuela and Elizabeth Criss. “A Simulation Model for Evaluating a Set of Emergency Vehicle Base Locations: Development, Validation and Usage”. *Socio-Economic Planning Sciences*. Vol. 24, No 2, pp. 125-141, 1990.

17 Revelle, Charles and Stephanie Snyder. “Integrated Fire and Ambulance Siting: A Deterministic Model”. *Socio-Economic Planning Science*. Vol. 29, No. 4, pp 261-271, 1995.

18 Branas, Charles, Ellen MacKenzie and Charles Revelle. “A Trauma Resource Allocation Model for Ambulances and Hospitals”. *Health Systems Research*. Vol. 35, No 2, pp. 489-507, 2000.

19 Branas, Charles and Charles Revelle. “An Iterative Switching Heuristic to Locate Hospitals and Helicopters”. *Socio-Economic Planning Sciences*. Vol. 31, No 1, pp. 11-30, 2001.

20 Tavakoli, Asad and Constance Lightner. “Implementing a Mathematical Model for Locating EMS Vehicles in Fayetteville, NC”. *Computers & Operations Research*. Vol. 31, pp 1549-1563, 2004.

21 Church, R., J. Current, and J Storbeck. “A Bicriterion Maximal Covering Location Formulation Which Considers the Satisfaction of Uncovered Demand”. *Decision Science.* Vol. 22, pp 38-52, 1991.

22 Yang, Saini, Masoud Hamedi and Ali Hafhana. “An Integrated Approach for the EMS Location and Assignment Problem”. *Proceedings: Transportation Research Board 83rd Annual Meeting*. January, 2004.

23 Restrepo, Mateo, Shane Handerson and Huseyin Topaloglu. “Erlang Loss Models for the Static Deployment of Ambulances”. *Health Care Management Science.* Volume 12, pp. 67-79, 2007.

24 Erdemir, Elif, Rajan Batta, Seth Spielman, Peter Rogerson, Alan Blatt and Marie Flanigan. “Optimization of Aeromedical Base Locations in New Mexico Using a Model that Considers Crash Nodes and Paths”. *Accident Analysis and Prevention*. Vol. 40, No 3, pp. 1105-1114, 2008.

25 Zhao, Yan-Chao, Li-Qun Shan and Bin Zhou. “A PDE Model for Location in Emergency Response Systems”. *Proceedings: 2010 International Conference on Computer Application and System Modeling*. 2010.

26 Lightner, Constance and Jonathan Graham. “A Heuristic Approach for Locating EMS Facilities and Vehicles”. *Unpublished document.*

27 Moore, George and Charles Revelle. “The Hierarchical Service Location Problem”. *Management Science*. Vol. 28. No. 7, pp 775-780, 1982.

28 Batta, Rajan and Narasimha Mannur. “Covering-Location Models for Emergency Situations That Require Multiple Response Units”. *Management Science*. Vol. 36, No. 1, January 1990.

29 Wears, Robert and Charles Winton. "Simulation Modeling of Prehospital Trauma Care". *Proceedings of the 1993 Winter Simulation Conference*. 1993.

30 Acid, Silvia, Luis de Campos, Susana Rodriguez, Jose Rodriguez and Jose Salcedo. "Using Bayesian Networks to Model Emergency Medical Services". *Proceedings of the Second International Symposium on Medical Data Analysis.* 2001.

31 Carley, Kathleen, Douglas Fridsma, Elizabeth Casman, Alex Yahja, Neal Altman, Li-Chiou Chen, Boris Kaminky and Damian Nave. "BioWar: Scalable Agent-Based Model of Bioattacks". *IEEE Transactions on Systems, Man and Cybernetics – Part A*. Vol. 36, No. 2, pp. 252-264, 2006.

32 Zhao, Yan-Chao, Li_Qun Shan and Bin Zhou. "A PDE Model for Location in Emergency Response Systems". *Proceedings: 2010 International Conference on Computer Application and System Modeling*. 2010.

33 Huang, Yongxi, Yueyue Fan and Ruey Long Cheu. "A PDE Model for Location in Emergency Response Systems". *Proceedings: Transportation Research Board 86th Annual Meeting*. January, 2007.

34 Wu, Engnan, Larry Shuman, Bopaya Bidanda, Matthew Keppey, Ken Sochats and Carey Balaban. "Embedding GIS in Disaster Simulation". *2007 Environmental Systems Research Institute International User Conference Proceedings*. San Diego, 2007.

35 Erdemir, Elif, Rajan Batta, Seth Spielman, Peter Rogerson, Alan Blatt and Marie Flanigan. "Location Coverage Models with Demand Originating from Nodes and Paths: Application to Cellular Network Design". *European Journal of Operational Research*. Vol. 190, No. 3, January pp. 610-632, 2008.

36 Census and Economic Information Center. *Montana Facts*. Montana Department of Commerce, various dates. Accessed April 13, 2011. Available at: http://ceic.mt.gov/MTFacts.asp

37 Gallatin County. *About Gallatin County*. Gallatin County, Montana, Undated. Accessed April 13, 2011. Available at:

http://www.gallatin.mt.gov/Public_Documents/GallatinCoMT_WebDocs/about

38 Gallatin County Sherriff. *Search and Rescue*. Gallatin County, Montana, Undated. Accessed April 13, 2011. Available at:

http://www.gallatin.mt.gov/Public_Documents/gallatincomt_sheriff/SpecialDuties/SAR

39 Bozeman Deaconess Hospital. *Bozeman Deaconess Health Services*. Bozeman Deaconess Hospital, Undated. Accessed June 6, 2011. Available at:

http://www.bozemandeaconess.org/faq.php?categoryID=2#42

40 Gallatin National Forest. *Fire – Gallatin National Forest Fire Management*. U.S. Department of Agriculture – Forest Service, Undated. Accessed June 6, 2011. Available at:

http://www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c4/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gjAwhwtDDw9_AI8zPyhQoY6BdkOyoCAGixyPg!/?ss=110111&navtype=BROWSEBYSUBJE

CT&cid=stelprdb5136499&navid=091000000000000&pnavid=null&position=Not%20Yet%20Determined.Html&ttype=detail&pname=Gallatin%20National%20Forest-%20Home

41 Town of West Yellowstone. *Police Department*. Town of West Yellowstone, 2004. Accessed June 6, 2011. Available at:

http://www.townofwestyellowstone.com/sublevel.cfm?template=police

42 Sourdough Fire Department. *Organization – Staffing - Leadership*. Sourdough Fire Department, Undated. Accessed April 15, 2011. Available at:

http://www.sourdoughfire.org/index.php?pageId=49

43 Lerner, E.B., G. Nichol, D.W. Spaite, H.G. Garrison, and R.F. Maio. A Comprehensive Framework for Determining the Cost of an Emergency Medical Services System. *Annals of Emergency Medicine*, Vol. 49, No. 3, pp. 304-313, 2007.

44 Department of Public Health and Human Services and Board of Medical Examiners. *Performance Audit (07P-11)*. Legislative Audit Division, Montana Legislature, Helena, Montana, 2008.

45 Sanddal, T., N. Sanddal, N. Ward, and L. Stanley. Ambulance Crash Characteristics in the U.S. Defined by the Popular Press: A Retrospective Analysis. *Emergency Medicine International*, Vol. 2010, Article ID 525979, 7 pages, 2010.

46 Sanddal, N., S. Albert, J. Hansen and D. Kupas. Contributing Factors and Issues Associated with Rural Ambulance Crashes: Literature Review and Annotated Bibliography," *Prehospital Emergency Care*, Vol. 12, No. 2, pp. 257–267, 2008.

47 Eckstein M. Primum Non Nocere—First Do No Harm: An Imperative for Emergency Medical Services. *Prehospital Emergency Care*, Vol. 8, No. 4, pp. 444–446, 2004.

48 National Association of EMS Physicians and the National Association of State EMS Directors. Use of Warning Lights and Siren in Emergency Medical Vehicle Response and Patient Transport. *Prehospital Disaster Medicine*, Vol. 9, No. 2, pp. 133-136, 1994.

49 Ray, A. and D. Kupas. Comparison of Crashes Involving Ambulances with Those of Similar-Sized Vehicles. *Prehospital Emergency Care*, Vol. 9, No. 4, pp. 412-415, 2005.

50 Washington, S., M. Karlaftis and F. Mannering. S*tatistical and Econometric Methods for Transportation Data Analysis*. Chapman & Hall: Boca Raton, 2003.

51 Myerson, R. B. *Game Theory: Analysis of Conflict*. Harvard University Press, 1991.

52 Ranganathan N., U. Gupta, R. Shetty and A. Murugavel. An Automated Decision Support System Based on Game Theoretic Optimization for Emergency Management in Urban Environments. *Journal of Homeland Security and Emergency Management*, Vol. 4, No. 2, 2007.

53 Yi-Ming Chen, Wu Dachrahn, and Wu Cheng-Kuang. A Game Theory Approach For An Emergency Management Security Advisory System. *Conference Proceedings*: *IEEE International Conference on Intelligence and Security Informatics, 2008.* June 17-20, 2008, pp.116-121.

54 Deo, Serang and Itai Gurvich. Centralized vs. Decentralized Ambulance Diversion: A Network Perspective. *Management Science*. 2011 (In Press).