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CONCEPT OF OPERATIONS FOR A REGIONAL TELEMEDICINE HUB TO IMPROVE MEDICAL EMERGENCY RESPONSE

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ABSTRACT

Telemedicine (TM) is a tool that permits medical services to be provided remotely. Applications of telemedicine to disaster response began in the mid-1980s for natural disasters such as earthquakes, tsunamis, and hurricanes and for "staged" disasters in experiments and exercises. These activities led to the concept of a regional telemedicine hub (TMH) with an extended network of clinical providers, which potentially could alleviate problems associated with surge capacity during disaster response. However, health-related benefits associated with this organizational model for disaster-related telemedicine remain to be quantitatively tested. In this paper, we describe a simulation study used to examine the operation of a regional telemedicine hub during the acute phases of hospital patient management in a hypothetical earthquake scenario. We explore the impact of using telemedicine to provide emergency specialty care to expand surge capacities at both local and regional levels.

1 INTRODUCTION

Natural and intentional disasters can unfold quickly and cause a variety of injuries to a large number of affected individuals, necessitating immediate and sustained medical care. While the timely extrication, stabilization, and transport of injured victims of mass casualty incidents is a cornerstone of emergency medical and trauma care, medical responses are often impeded by the overwhelming number of patients and the limited number of available medical personnel and resources, resulting in delayed treatment. Major disasters such as earthquakes or hurricanes may also damage infrastructure within the affected area, such as communications facilities and roads, further impeding the delivery of medical personnel and material resources from external sources, including neighboring communities, humanitarian organizations, and State and federal sources.

Telemedicine is a tool that permits medical services to be provided remotely. When equipped with the basic telecommunication devices that can be deployed by mobile units, responders on the scene of a disaster can quickly establish telemedicine linkages, potentially increasing both the speed and the capacity of medical responses when and where they are needed. Applications of telemedicine to disaster response began in the mid-1980s. Following the devastating 1985 Mexico City earthquake, NASA provided advanced satellite communication technology to support the international relief and rescue operations (Simmons, Hamilton et al. 2008). The U.S.-U.S.S.R. Space Bridge project provides a primary example of global telemedicine disaster assistance over time. After the 1988 Armenian earthquake telemedicine was employed to provide clinical consultation to several regional hospitals (Doarn, Lavrentyev et al. 2003; Simmons, Hamilton et al. 2008). Into the 2000's, telemedicine have been more widely used in various ways in response to disasters including earthquakes, tsunami and hurricanes

(Jamal, Gilani et al.; ABCRadioAustralia 2005; Sastrokusumo, Suksmono et al. 2005; Mack, Brantley et al. 2007; Meade and Lam 2007). In addition to response to real disasters, numerous telemedicine experiments, exercises and simulations of "staged" disasters have been carried out worldwide to evaluate the usefulness and performance of telemedicine systems (Lach and Vazquez; Paunksnis, Barzdziukas et al. 2005; Pieper and Meineke 2007).

Many in the emergency medicine and preparedness community believe that, based on the observed value of existing telemedicine capabilities for disaster management, more advanced telemedicine systems will greatly facilitate disaster response. However, support for this belief is mainly based on expert opinions, case studies, or anecdotal examples. Many questions arise as to how to most effectively apply and integrate telemedicine into a regional response framework. For example, what is the role of telemedicine in existing protocols and guidelines for disaster response? How can external doctors and other resources be mobilized in such an incident through the use of telemedicine? What are the appropriate infrastructure and information systems to support telemedicine interventions in the event of a major disaster?

To address these issues in a quantitative fashion, we examined whether the concept of a regional telemedicine hub (TMH) is the best organizational model to enable efficient, effective, and equitable delivery of medical services to a target population in the aftermath of a major medical disaster. The establishment of a telemedicine network with a regional hub has significant policy implications, such as the coordinated selection of communication platforms and information systems, the consolidated management of resources in a target area, and the facilitation of NIMS-compliant centralized command and control centers to direct the healthcare response for disasters. However, while a regional telemedicine hub with an extended network has the potential to alleviate multiple problems during disaster response, there is no consensus about how to quantify the health-related benefit associated with the proposed organization model (Garshnek, Logan et al. 1997). In this paper, we describe a comprehensive quantitative analysis that assesses the benefits of the telemedicine hub concept in emergency response to a hypothetical earthquake scenario.

2 MODELING APPROACH

We designed a comparative simulation study to examine one of the potential applications of regional telemedicine network to disaster response. The scenarios concentrate on the early phases of hospital patient management. We explore the impact of using telemedicine to provide emergency specialty care to patients at local hospitals on medical surge capacities at both local and regional levels. We aim to (1) provide a conceptual framework to incorporate telemedicine into emergency response; and (2) determine where it is appropriate to apply quantitative analysis to improve the effectiveness of disaster response activities, potentially measured through such factors as treatment capability and time to definitive treatment.

For the simulation study we examine two cases: a base case representing the current process of the acute phase of hospital-based medical response to mass casualties caused by an earthquake, and a second, alternative telemedicine case for which the response process allows and supports telemedicine interventions at the local level. Simulation environments were developed for both cases, which consist of (1) probabilistic models to generate earthquake injury profile; (2) queuing models to represent the delay of treatment when injured patients seek care at local Emergency Departments (ED), local specialty care, transportation from local hospitals to the Designated Receiving Center (DRC) and specialty care at the center; and (3) probabilistic mortality models to simulate potential patient deaths caused by severe injury and/or delay of treatment. These models were created using the ARENA© simulation package (Version 12.0).

The response processes for the two cases are illustrated in Fig. 1 and Fig. 2. Each simulation creates patient flow through the telemedicine system and calculates potential mortality associated with treatment delay along the resulting patient management paths. In both cases, patients with multiple types of injuries are generated via a probabilistic casualty generation model to induce the distributions of patient arrival, injury type, injury severity, etc. based on factors such as the scale of the disaster and local population distribution. Patients are sent to local hospitals for treatment, where emergency physicians examine the patients to identify their injury type and condition and perform general procedures where necessary. Most patients are discharged (released or hospitalized for further treatment) after local ED care and would not require a specialist care during the simulation time horizon. However, some patients with critical condition will require consultation or specialty care that may not be accessible at local treatment facilities. For this group of patients there are two possible pathways: if a specialist in the required area is present at the local hospital they will be called to assist with care;; otherwise if a specialist is unavailable (or too busy) at the local site, the emergency physician will have to transfer the patient to a regional DRC that provides specialty care.

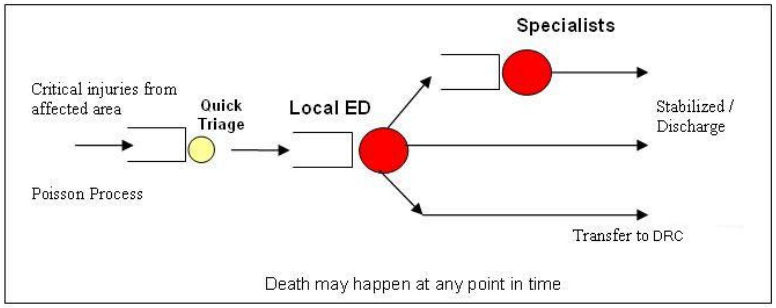

Figure 1: the Current Hospital-Based Medical Response Process (Base Case)

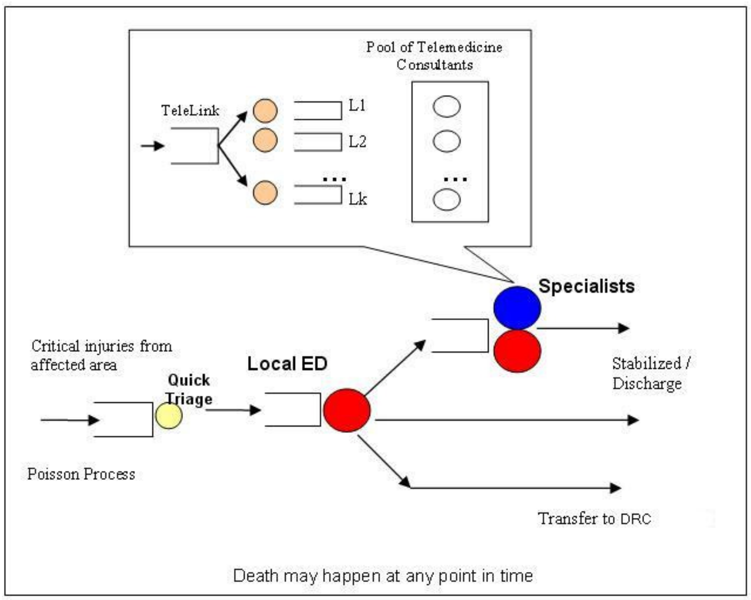

Figure 2: the Telemedicine-Enhanced Hospital-Based Medical Response

Queuing models are used to represent both patient waiting and treatment processes at local EDs, local specialty care if available, transportation to the DRC, and specialty care at the DRC. Due to surging demand and limited resources at both local hospitals and at the center, patients will endure waiting for ED care, specialty care and transportation at local sites, as well as specialty care at the DRC. Priority is given to patients in critical condition at local and DRC ED queues. Balking might happen at local ED queues, for example, if an incoming patient requires specialist consultation but finds the current queue length for ED beds exceeded a threshold value; a transfer decision may also be made to send the patient to the receiving center even when a specialist is available at the local facility. Based from medical literature, three time dependent patient survival curves are used throughout the process to determine the risk of death due to prolonged waiting(Sampalis, Denis et al. 1999; Garner, Lee et al. 2001; Sacco, Navin et al. 2005; Hupert, Hollingsworth et al. 2007).

To minimize lives lost, it is critical to increase local hospitals' capacity and reduce delay of treatment, which we hypothesized can be achieved through introducing telemedicine interventions to local hospitals during these decisive moments. In the telemedicine case, remote doctors in general specialty areas will be mobilized and connected to the local hospitals through the regional DRC. In addition to the current options, when a patient at the local ED requires specialist advice, the emergency physician could also choose to ask for telemedicine specialty care for the patient, thus avoiding transportation to the DRC before the patient is properly stabilized. In this case the receiving center is also considered as a control hub that facilitates and supports telemedicine calls between local healthcare facilities and remote specialists. However, since the number of simultaneous telemedicine sessions is constrained by available remote specialists as well as the center's technical capacity, it is possible for patients to have to wait for a telemedicine specialist or a telelink at local hospitals during times of peak demand.

3 DATA AND ASSUMPTIONS

The simulated disaster scenario is an earthquake that results in large numbers of casualties. The simulation focuses on the early phase of the disaster, specifically, the hospital-based medical response dealing with injuries that arrive within the first 48 hours following the disaster. Other disaster response efforts, such as search and rescue, and the recovery of infrastructure, are not explicitly represented in the simulation. Later phases of on-going medical support, such as follow-up care and rehabilitation, are also outside the immediate scope of this study. Data required for the comparative simulation study are collected and generated as follows:

(1) Earthquake Scale and Patient volume: Historic data suggests that the volume of casualties resulting from an earthquake may vary significantly depending upon the scale, time and location of onset of the disaster (Melnick, Nawathe et al. 2004). For simplicity, we adopt a ratio of affected population to generate the patient volume. We consider earthquakes ranging from a minor one with several hundred injuries to a medium scale and a major earthquake with thousands of injured patients.

(2) Simulation time horizon: The time horizon specified for the simulation study is selected to deal with injuries that arrive within the first 48 hours following the onset of the disaster, as suggested by past experience and literature. In the 1994 Northridge earthquake, most injuries were hospitalized during the first two days after it occurred (Peek-Asa, Kraus et al. 1998; Ganjouei et al. 2008).

(3) Impacted regions: When an earthquake hits the Bay Area, some of the casualties may be assigned and dispatched to a DRC which lies outside the multiple faults around the San Francisco/Oakland area and is therefore likely to be intact. The simulation considers a portion of the potentially impacted region, with a total population of ~540,000 over four local areas, with an average transportation time to the DRC of approximately 30 minutes. We also assume there are 4 local treatment facilities available for emergency medical services in the affected area.

(4) Injury types: Three injury types are explicitly considered in the simulation, i.e. trauma, burn, and "other", to represent the most commonly observed earthquake-related injuries and often require specialty care.

(5) Injury condition: Based on observations obtained in past mass casualty events (Peek-Asa, Kraus et al. 1998; Memarzadeh, Loghmani et al. 2004; Ganjouei et al. 2008), we estimate the percentage of severely injured patients to be 20~30%. In this study we occasionally use "critical condition" to indicate this group of patients, which is not to be confused with the medical term used in the field referring to patients with unstable vital signs. These patients plus selected "non-critical" patients are considered to require emergency specialist care for the purpose of the simulation.

(6) Hospital capacity: The local hospitals' capacities (as represented by the number of local ED beds in the simulation), as well as capacity for the DRC, are obtained based on state average levels (Melnick, Nawathe et al.). The numbers of specialists available at both local and regional levels are hypothetical and are estimated based on surveys obtained from the region. Table 1 displays information on local demographics and local hospitals' capacity that is used in the simulation:

(7) Specialty treatment: We estimate the treatment time of specialty care to be 40~60 minutes, which may implicitly include resuscitation, stabilization, triage, procedural supervision, and excludes continuing care such as ICU due to prescribed scope of the simulation.

Table 1: Basic Input Data to Simulation

	Population	Transport Time to Center (min)	Available ED Bed Capacity	# Local Ambulance Available	# Specialists Type 1 (Trauma)	# Specialists Type 2 (Burn)	# Specialists Type 3 (Other)
Local ED 1	145,000	25	6	12	1	0	0
Local ED 2	75,000	40	3	6	0	0	0
Local ED 3	220,000	25	8	16	2	0	1
Local ED 4	100,000	30	4	8	1	0	0
DRC	-	-	20	-	5	2	2
Remote	-	-	-	-	6	2	2

(8) Patient mortality: Patient mortality is possible at multiple points in the simulation, including: before ED care, after ED and before specialty care, and after specialty care. As shown in Figure 3, probability of survival of various types of patients is considered to be dictated by the delay of treatment (Hupert, Hollingsworth et al. 2007).

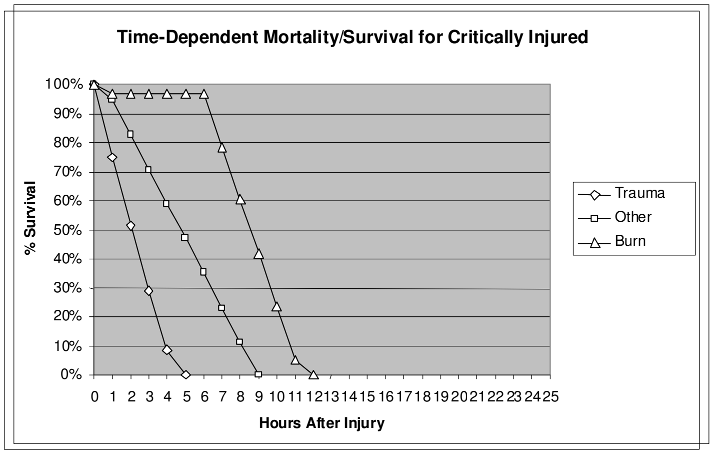

Figure 3: Time-dependent mortality curves for critically injured

(9) Telemedicine capacity: For the telemedicine case, the DRC's technical capacity in terms of supporting telemedicine calls is estimated to have five telelinks working simultaneously. Communication and telemedicine abilities are assumed to be available at local spoke sites.

4 RESULTS

100 simulation replications were conducted for each of the three disaster scenarios in both cases. We collected the following data and performance metrics from the simulation:

(1) Average number of injuries generated: volume (by type and condition).

(2) Average number of patients (by type and condition) that receive local ED care, receive local specialty care, are transferred to DRC, and receive DRC specialty care.

(3) Average patient mortality (by type and condition) before local ED (for ED bed), related to transportation (waiting for ambulance and en-route to DRC), and before DRC ED (waiting for ED bed for specialty care).

(4) Average patient waiting time (by type and condition) for bed at local ED, for local specialty care, for transportation to DRC, for DRC ED bed, DRC specialty care, etc.

4.1 Patient Arrivals

Patient arrival numbers for the three disaster scenarios (major, medium and minor scale) are summarized in Figure 4. We assume 0.5% casualty rate in the major scale earthquake, which yields on average 2700 injuries with 1970 non-critical and 730 critically injured patients. Similarly, there are 1080 casualties (774 non-critical and 306 critical) in the medium case and 540 casualties (381 non-critical and 159 critical).

4.2 Resource Utilization

Resource usage results are obtained from simulation and are summarized in Tables 2 and 3. For the medium and minor scale scenarios, the local EDs' bed usage rates are typically *lower* in the telemedicine case than in the base case (except for Local ED 2). ED beds are considered "occupied" only when patients are receiving ED or specialty care, or when they are waiting for specialists. In all three disaster scale scenarios, more patients are served and discharged at the local facilities in the telemedicine case than in the base case. The reduction in ED bed usage rates from telemedicine in the medium and minor scale scenarios therefore results from the reduction of patient waiting times for local specialty care. As more specialists are reachable locally in the telemedicine case, patients spend less time occupying ED beds waiting for the next available specialist. In other words, telemedicine helps reduce patients' ED "boarding" times and improve the efficiency of bed usage (as in more patients served with less total bed usage time).

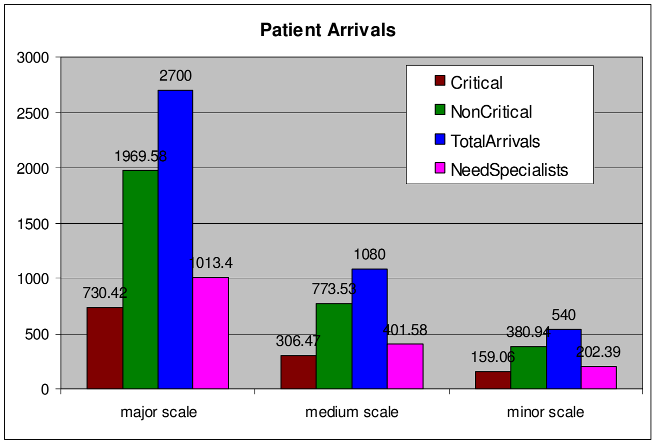

Figure 4: Average Patient Arrivals

The local and DRC specialists' "busy rates" are generally higher in the base case than in the TM case, which is expected since in the latter case there are also remote specialists to share their work load. Interestingly, the local specialists are busiest not in the major scale scenario that has the largest incoming demand for specialty care, but in the medium scale scenario. We believe the reason for these relatively low rates in the major scale earthquake scenario is due to the fact that local EDs are heavily overwhelmed, with ED queue lengths often exceeding the transfer threshold values. As a result succeeding specialty-care-seeking patients would "balk" the local ED queues and join the transportation queue instead, even when specialists are locally available and not occupied at the time. It will be important to validate this interesting simulated result against real-world observations, since it has major policy implications for casualty treatment versus triage.

Table 2: Average Usage Rates of Local Resource

		Local ED	ED beds	Specialists			Ambulances
				Type 1	Type 2	Type 3	
Major Scale	base case	1	94.55%	50.49%	-	-	13.85%
		2	49.76%	-	-	-	28.99%
		3	97.39%	47.18%	-	18.66%	16.92%
		4	90.51%	46.95%	-	-	15.89%
	telemed	1	90.25%	36.04%	-	-	11.14%
		2	96.70%	-	-	-	20.26%
		3	95.16%	37.31%	-	16.66%	12.69%
		4	90.77%	32.72%	-	-	13.55%
Medium Scale	base case	1	91.42%	79.78%	-	-	6.62%
		2	34.42%	-	-	-	20.70%
		3	79.31%	70.83%	-	13.59%	5.64%
		4	74.22%	63.80%	-	-	6.62%
	telemed	1	69.36%	55.99%	-	-	3.54%
		2	74.32%	-	-	-	6.44%
		3	76.34%	59.26%	-	17.24%	4.28%
		4	70.92%	48.56%	-	-	4.39%
Minor Scale	base case	1	47.13%	64.45%	-	-	2.43%
		2	20.10%	-	-	-	12.19%
		3	40.92%	50.76%	-	5.67%	2.39%
		4	40.74%	46.46%	-	-	3.03%
	telemed	1	34.09%	40.09%	-	-	1.88%
		2	35.54%	-	-	-	3.03%
		3	38.68%	40.77%	-	5.90%	2.06%
		4	34.87%	31.57%	-	-	2.29%

Table 3: Average Usage Rates of DRC and Remote Resource

		ED Beds	DRC Specialists			TeleLink	Remote Specialists		
			Type 1	Type 2	Type 3		Type 1	Type 2	Type 3
Major Scale	basecase	56.50%	52.37%	46.82%	52.03%	-	-	-	-
	telemed	29.98%	37.20%	29.03%	36.74%	48.73%	24.20%	19.29%	19.53%
Medium Scale	basecase	8.86%	21.63%	16.74%	16.08%	-	-	-	-
	telemed	0.69%	1.88%	1.06%	1.15%	67.38%	40.45%	18.41%	17.49%
Minor Scale	basecase	3.37%	7.12%	12.09%	3.58%	-	-	-	-
	telemed	0.00%	0.00%	0.00%	0.00%	29.02%	17.24%	12.38%	3.86%

4.3 Patient Waiting Times

The average waiting times for ED beds and specialists at local EDs and at the DRC are both shorter in the TM (telemedicine) cases than in the base cases, as shown in the Tables 4 and 5. The TM-enhanced process leads to significant reduction of patients' ED bed and specialist waiting times. In the major scaled scenarios, average waiting times are reduced by hours, and in the medium and minor scaled scenarios, average waiting times are reduced to minimal values.

Table 4: Average Waiting Times for ED Beds (hours): BaseCase vs. TM Case

	Local EDs				DRC			
Disaster Scale	BaseCase	Telemedicine	Reduction	% Reduction	BaseCase	Telemedicine	Reduction	% Reduction
Major	34.77	32.12	2.65	7.63%	6.22	0.39	5.83	93.69%
Medium	4.27	0.29	3.98	93.18%	0.00	0.00	-	-
Minor	0.14	0.01	0.12	91.09%	0.00	NA	-	-

Table 5: Critical Patients' Average Waiting Times for ED Beds (hours): BaseCase vs. TM Case

	Major scale			Medium scale			Minor scale		
	BaseCase	TM case	% Reduction	BaseCase	TM case	% Reduction	BaseCase	TM case	% Reduction
Local ED 1	1.4464	0.5212	63.97%	0.6733	0.0629	90.66%	0.0918	0.0052	94.34%
Local ED 2	NA	1.5386	NA	NA	0.2006	NA	NA	0.0297	NA
Local ED 3	0.5675	0.3132	44.81%	0.1907	0.0536	71.89%	0.0097	0.0018	81.44%
Local ED 4	1.1864	0.7033	40.72%	0.4112	0.1097	73.32%	0.0641	0.0123	80.81%
DRC	0.5357	0.0742	86.15%	0	0	0.00%	0	NA	-

4.4 Mortality

Finally, patient mortality outcomes from earthquake with three scales are illustrated in Figure 5. The results suggest that the performance of the telemedicine-enhanced medical response process is superior to that of the base process in all three disaster scenarios in terms of patient mortality. More specifically, even though a higher percentage of (and in absolute values, more) patient deaths happen at the local facilities in the telemedicine cases, significantly fewer occur while waiting for transportation/en-route to the DRC or at the DRC, indicating that the primary reasons of reduction of total deaths in the telemedicine cases are due to:

– Reduction of the number of patients transferred to avoid extra transportation time;
– Reduction of transportation-related waiting times; and
– Relieving of overall congestion at the DRC which leads to reduction of patient waiting time at the DRC.

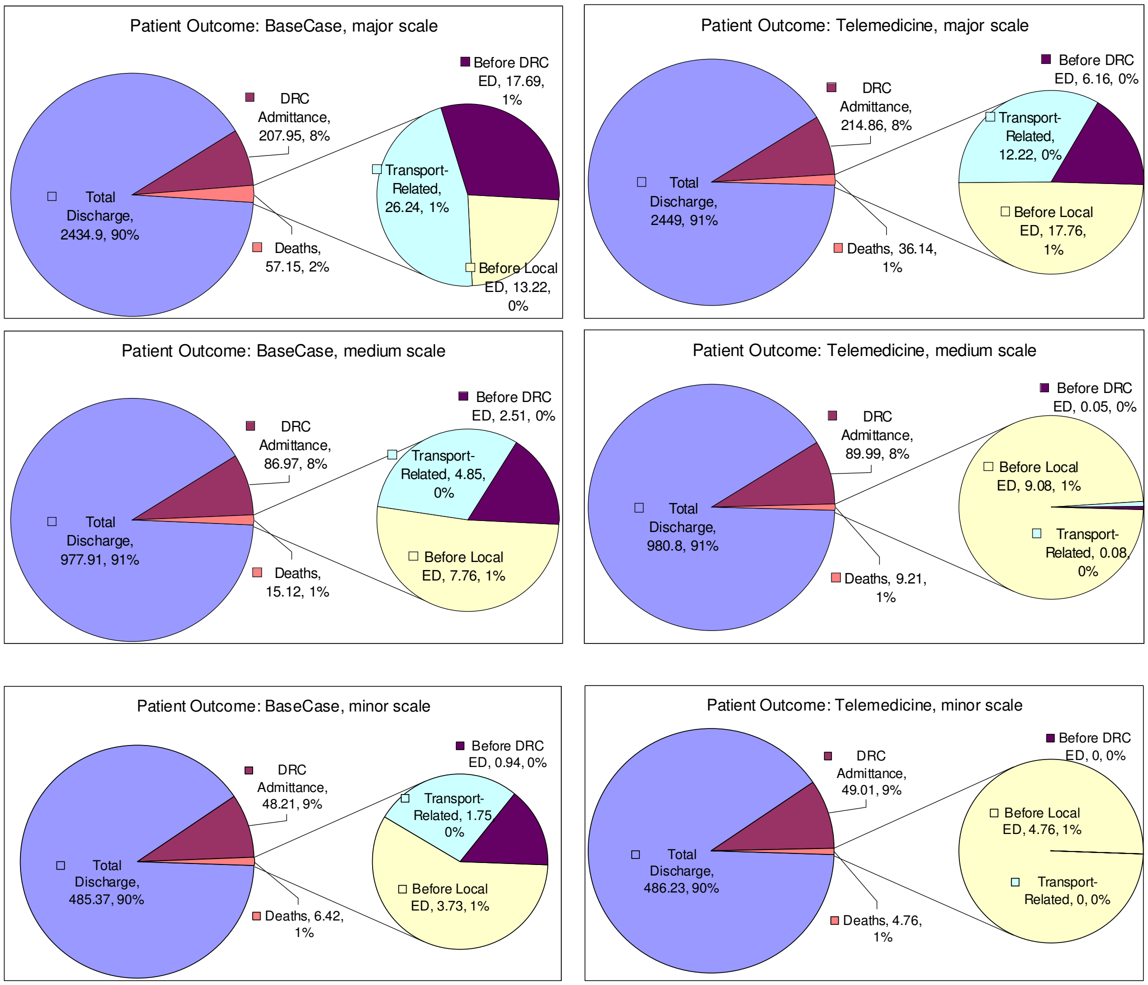

Figure5: Average Patient Mortality Outcome

5 CONCLUSIONS

The study presents quantitative results of simulation studies testing the concept of a telemedicine (TM) hub for post-disaster patient management. They suggest that TM-aided triage and treatment along the entire process of health system emergency response may improve the efficiency of resource utilization and care coordination in these settings. We believe the proposed TM Hub model provides a useful planning and training platform for regional disaster response preparations.

Our preliminary results suggest that a TM-enhanced strategy of preserving local management of disaster victims (i.e., not sending large number to DRC) may *improve health outcomes*. With essentially the same resources (i.e. local and DRC ED beds and doctors), health outcomes are typically better when telemedicine is used in disaster scenarios of various scales. More specifically, average patient waiting times at both local facilities and DRC are reduced, and total number of patient deaths is decreased. In all the scenarios we considered, we observe that application of telemedicine helps local EDs serve more patients locally while maintaining lower ED bed occupation rates by reducing patients' waiting (boarding) times, hence *utilizing resources more efficiently*. On the other hand, properly functioning TMHs will require rapid access to competent external specialists for optimal performance. In other words, benefits of telemedicine in heavy demand disaster scenarios require the rapid availability of *external* specialists, stressing the need to establish and maintain such resources for emergent uses.

The simulation models provide a basis for generalizable applications to the design and functioning of telemedicine systems for disaster response in general. However, there are a few limitations to this simulation study. First, the comparative study explores the requirements and process for incorporating telemedicine into the hospital-based medical response only. Incorporation of, and impacts of telemedicine activities on, command-and-control systems such as ICS as well as other disaster response systems such as EMS, are not examined. Next, a number of assumptions have been made as to patients' arrival patterns at the local facilities, injury types that may be presented, scales of patient's injury severity, as well as representation of various treating processes. Although the simulation is able to describe the medical response process (sequence of events and resource requirements) in general, advanced models will need to be constructed and incorporated to represent more complicated issues that arise in reality. Last but not the least, we need to understand that simulation is not an optimization tool. It may be used to evaluate the performances of alternatives (such as different queue length threshold values for transfer rules) in various scenarios. However, it is not able to directly provide a solution, or suggest a policy, that can be used to guide the operations and routing directions within the process.

We believe that existing telemedicine technology can be applied to current disaster response activities to enhance surge capacity of the healthcare system and the speed and effectiveness of medical response, to facilitate communications and improve resource and operations planning and to increase situational awareness within the command and control system and overall community. A working process of delivering emergency specialty care via telemedicine is proposed, and its performance and benefits quantitatively demonstrated through a comparative simulation study.

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