Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

CHARACTERIZING EMERGENCY RESPONSES IN LOCALITIES WITH DIFFERENT SOCIAL INFRASTRUCTURES USING EMSSIM

Taesik Lee
Kyohong Shin
Hyun-Rok Lee
Hyun Jin Lee
Inkyung Sung
Junseok Lee
Il-Chul Moon

Department of Industrial & Systems Engineering
KAIST
291 Daehak-ro, Yuseong-gu
Daejeon, 34141, KOREA

Jangwon Bae

Department of BigData Intelligence Research
Electronics and Telecommunications Research Institute (ETRI)
218 Gajeong-ro, Yuseong-gu
Daejeon, 34129, KOREA

ABSTRACT

A well-functioning Emergency Medical Service (EMS) system is a fundamental requirement for saving lives in a Mass Casualty Incident (MCI). While the benefit of strengthening an EMS system is obvious, it is not so evident which components in an EMS system will most contribute to its performance. Using the Emergency Medical Service Simulation model (EMSSim), we test a hypothesis that the social infrastructure and geographic characteristics are key factors in determining the best strategy for the improvement of the EMS system of a particular region. Specifically, we investigate an MCI scenario in three regions – metropolitan, urban, and rural environments, and analyze the factors that will effectively enhance the EMS system in each of these regions.

1 INTRODUCTION

The standard framework of disaster management involves the fours phases of emergency management: prevention/mitigation, preparedness, response, and recovery (Petak 1985, Cova 1999). Prevention efforts focus on eliminating or reducing the chance of an incident occurring. As we cannot entirely prevent all future disaster incidents, mitigation is necessary to take actions that will minimize the consequence of unavoidable incidents. Preparedness refers to plans or procedures designed to guide response efforts when a disaster incident occurs. Along with the plans and procedures, preparedness efforts involves the training of emergency response personnel and general public to ensure those plans will be reliably followed in the disaster situation. When a disaster incident strikes, emergency response then puts the preparedness plan

978-1-5090-4486-3/16/$31.00 ©2016 IEEE

into action. These actions are taken within the time frame of minutes and hours from the moment of a disaster incident. Recovery is the effort to help the affected community return to its normal situation.

Minimizing the loss of lives from a disaster incident is the first and foremost goal in all phases of disaster response, but it is particularly relevant to the response phase. The effectiveness of emergency response hinges upon timely and correct decision making and flawless execution, which in turn depends on the level of preparedness. To achieve a high level of preparedness, there are two fundamental questions that we must be able to answer. First, given that the real world environment always poses resource constraints, we need to know the ranges of threats that we should prepare for and how much preparation will be enough. Second, we need to ensure that we are capable of responding as planned under a strenuous disaster environment.

Modeling and simulation offers an effective means to address both of those questions (Dynes and Tierney 1994, Levi et al. 1998, Takeuchi, Kakumoto, and Goto 2003, Encinas et al. 2007, Liu et al. 2008, Bae et al. 2014). To answer the first question, we need an accurate risk assessment capability. Simulation allows for a virtual space to test out a wide range of disaster scenarios and conduct experiments to assess the risks associated with them. The second question requires effective education and training. As some emergency response organizations put it, we need to "train to respond, and respond as trained." Simulation has been widely recognized as an effective and economical platform to offer training and educational experiences for emergency response personnel and the general public.

We focus on the emergency medical service aspect of disaster response. An EMS system is responsible for managing medical resources to provide necessary medical interventions quickly and effectively to casualties from a disaster incident. An EMS system can be largely divided into a prehospital phase and a hospital phase. In the prehospital phase, the focus is to quickly get to the disaster site to provide first-aid and to transport patients to nearby Emergency Departments (EDs) as soon as possible. In the hospital phase, the main role of EDs is to resuscitate, stabilize and care for the patients to prepare them to receive surgery or other types of definitive care. Effective response from an EMS system is a critical requirement for saving lives of victims from a disaster.

This paper presents a case study that compares the EMS system's response capabilities of different locales by using the EMSSim. EMSSim is an abbreviation for Emergency Medical Service Simulator, and it was developed by authors to represent detailed EMS system operations (Moon et al. 2015). EMSSim will be briefly reviewed in section 2. Using EMSSim, we modeled three locales of varying degrees of urbanization in Korea. The three regions have different characteristics in terms of their social infrastructures and geographic locations, which presumably affect the requirements and performance of the EMS system.

The remainder of this paper is organized as follows: in section 2, a brief review of the key features of EMSSim is presented. Then in section 3 we describe the experimental settings for the three regions. Results are analyzed in section 4 to compare distinctive characteristics of EMS responses in each of the three regions. Finally, a summary of the work and its conclusion is provided in section 5.

2 EMSSIM

2.1 Structure and model elements

EMSSim is an agent-based model to simulate EMS responses to a Mass Casualty Incident(MCI) situation (Moon et al. 2015). EMSSim is developed by Large-scale, Dynamic, Extensible, and Flexible (LDEF) formalism and its simulation environment (Bae and Moon 2016). LDEF is based on the dynamically-structured Discrete Event System Specification (DEVS) formalism (Zeigler, Praehofer, and Kim 2000).

At its highest level, EMSSim consists of the Multi-Environment Model and the Multi-Agents Model. The Multi-Environment Model describes the environment for agent-based simulation space. Specifically, it defines a road network in the region where we simulate an MCI. EMSSim intends to encompass both the prehospital and hospital phases of the EMS operation. To do so, it includes several entities modeled as agents relevant in both phases, as shown in Table 1.

Table 1: Type of agents in EMSSim.

Agent type	Description
Victim	casualties requiring emergency medical care
Ambulances	vehicles to transport the victims to nearby hospitals; has three EMT skill level
DMAT	disaster medical assistance team; DMAT consists of EMS physicians and nurses
Field EMS	mobile ED unit with care personnel and equipment
Hospital	includes emergency department and operating rooms of different specialties
EMA	emergency management agency who is in charge of managing response operation

These agents behave in the simulation as defined by relevant behavioral models, and interact with other agents and the environment as the behavioral models are executed. Coupling relations among the agents and environment are shown in Figure 1. Also shown in the figure is which behavioral models are used to define each agent's behavior in the model. For example, *Ambulance* agent contains <Movement Action>, <Treatment Action>, <Ambulance Agent Action>, and <Triage Action>. Each behavioral model takes a form of the DEVS atomic model formalism and expresses state transitions related to the execution of the action. For more details on the model construction, we refer the readers to Moon et al. (2015).

2.2 Synthetic casualties: Korean VictimBase

In addition to the operational aspects of EMS system, a key requirement for a high-fidelity MCI simulation which is as close to a real world situation as possible is the profile of casualties to be simulated in the model. The simplest way of constructing casualty populations for a simulation experiment would be by using triage categories (Jenkins et al. 2008) – e.g., expectant(black), immediate(red), delayed(yellow), and minor(green); This is a typical practice in most EMS simulation models. Yet, a higher level of detail for a victim's clinical condition is necessary to create a richer and more realistic simulation experiment. For example, a patient with a risk of hemorrhage shock vs asphyxia would present different challenges and responses from EMS responders.

EMSSim uses synthetic casualty population data that has been constructed by EMS physicians. From this synthetic casualty population, which we refer to as Korean VictimBase (Bae et al. 2016), we can draw patient samples for a simulation experiment that fit the characteristics of a specific scenario under study. Korean VictimBase has a patient profile for 2013 patients. A key component in a patient profile is the pattern of patient survivability deterioration, which is estimated by a relevant decease model. A decease model refers to a monotonically decreasing function that depicts a gradual reduction in a patient's survival probability. Korean VictimBase assigns a patient with one of the following decease models: hemorrhagic shock, asphyxia, traumatic brain injury, and their composites. The decease model essentially defines the rate of decrease in a patient's survival probability when no intervention is provided. Korean VictimBase also defines detailed clinical information that is relevant to the pre-hospital and hospital phase of EMS provision. Input fields and example entry values for a patient profile are shown below in Table 2:

Table 2: Patient profile in Korean VictimBase.

Field	Example	Field	Example
Age	23	Gender	Male
Decease model	Hemorrhagic shock	Time to death w/o care	4hr
Symptom 1	Right chest pain	Symptom 2	Dyspnea
Diagnosis 1	Traumatic lung injury	Diagnosis 2	Rib fracture
True triage code	Red	Likelihood for mistriage	Low
Injury mechanism	Contusion	ED procedure required	3 splint, 2 suture
X-ray required	9 shots	Surgery required	Thoracic CVT Surgery

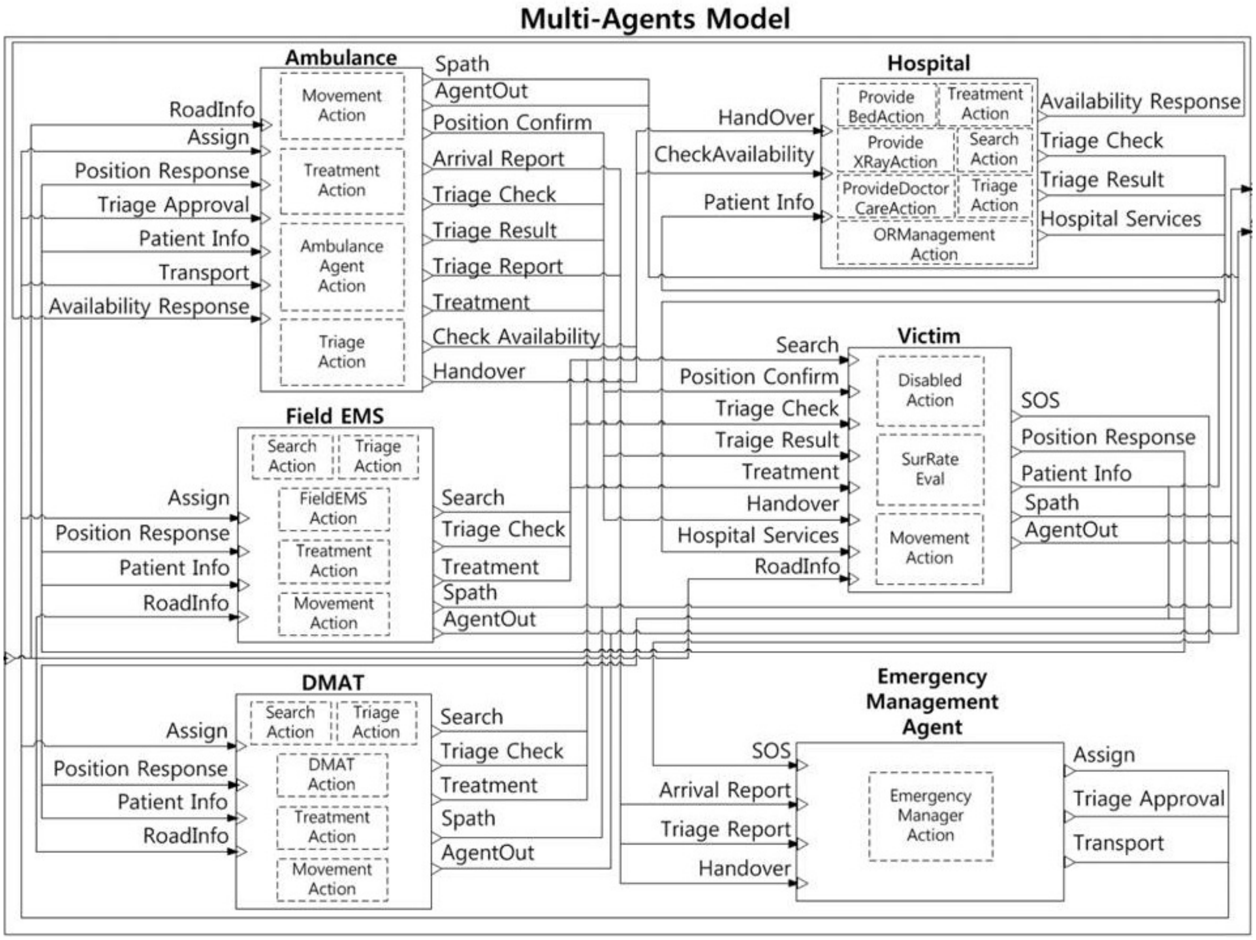

Figure 1: Relations among agents and environment (adapted from Moon et al. 2015).

With this profile information, the simulation model can replicate the complications and complexity of real-world MCI responses. For example, depending on the first responder's skill level, patients may be mistriaged and there would be a consequence. If overtriaged, a mistriaged patient would take up resources from patients with higher severity. If undertriaged, there would be delay in providing time-sensitive care to the patient. Another example of real-world complexity is that it is typical that one hospital cannot conduct an emergency surgery of the same specialty for more than three patients simultaneously. Thus, if multiple patients who require the same type of surgery are sent to one hospital, only some of those patients would receive surgery even when there is a sufficient number of operating rooms. Still another example is that depending on the decease model, the time frame and rate of reduction in the patient's chance of survival is going to be different.

3 EXPERIMENT

We use the EMSSim to investigate the effectiveness of the EMS system in three regions in Korea. The three regions represent different levels of urbanization and EMS resources. In the experiments, we assess the relationships between various EMS resource factors and the EMS system's performance indicators. In particular, we examine how those relationships differ across the three locales.

3.1 Disaster scenario

The three locales tested in the experiments are chosen to represent different levels of urbanization – a large convention center in the Gangnam ditrict in Seoul, a sports stadium in a suburban area in Cheonan-city, and an outskirt resort in Gyeongju-city. Urbanization seems to have an implication in the effectiveness of EMS response in the region as it is associated with many factors related to social infrastructures including EMS resources. To name a few such factors, the three regions have significantly different sizes, population densities, road networks, traffic congestion, number of higher-tier EDs, available ambulances, etc. Characteristics of the three regions are summarized in Table 3.

Table 3: EMS resources in the three locales.

	Gangnam-district	Cheonan-city	Gyeongju-city
Urbanization	Metropolitan	Small-sized, urban	Urban-rural mix
Area [km^2]	39	636	1,324
Emergency care provider†	4 Level-2 EMC 1 Level-3 ED	1 Level-1 EMC 2 Level-2 EMC 2 Level-3 ED	1 Level-2 EMC 3 Local EMS provider
Ambulances	20	16	12
119-operated	10 (9 stations)	7 (4 stations)	8 (8 stations)
Hospital-operated	10	9	4

† Emergency care providers in Korea are structured in a four-layer hierarchy: Level-1 EMC (Emergency Medical Center), Level-2 EMC, and Level-3 ED, and local EMS providers. Local EMS providers do not operate a fully-functional ED, and have minimum care capability to cover under-represented areas.

As shown in Table 3, the Gangnam-district has the highest accessibility to an EMS system, with 4 Level-2 EMCs and 20 ambulances serving the area. (Note that there exists significant disparities in health care services between Seoul - the capitol city of Korea - and other cities in Korea. The four EMC's in Gangnam-district are designated as Level-2, but it is due to the administrative constraint and does not represent their care capability which is very highly regarded.) Gyeongju city, on the other hand, is supported by only 1 EMC and no other fully-functional EDs. It also has a fewer number of ambulances while the geographic area to cover is largest among the three tested locales.

For the Gangnam-district, we choose a large convention center in the downtown area as an MCI site and assume there are 80 casualties – 10 black, 20 red, 30 yellow, and 20 green. For Cheonan city, a sports stadium located in the suburban area is used as an MCI site, and we also assume 80 casualties with 10 black, 20 red, 30 yellow, and 20 green. In the case of Gyeongju city, due to the limited number of EMS providers, we assume a half-scale MCI with 40 casualties and the same severity distribution – 5 black, 10 red, 15 yellow, 10 green. We use a youth hostel complex in an outskirt of the city as an MCI site.

In all three scenarios, we assume an MCI occurs at 5pm on a Friday. In many cities in Korea, Friday evening typically entails a very heavy traffic congestion, which makes it a very challenging environment for an EMS system.

3.2 Experimental setting

As a main performance measure, we define a preventable death ratio, R as follows:

$$R(\%) = (1 - \frac{\sum_{i=0}^{N} P_f^i}{\sum_{i=0}^{N} P_o^i}) \times 100 \tag{1}$$

where P_o^i is the initial survival probability of patient i, while P_f^i is the survival probability of patient i at the moment of care provision. The fraction in the parenthesis is the ratio of the expected number of surviving patients as a result of EMS provision to the expected number of survivors if EMS is immediately provided.

Subtracting this ratio from 1 then gives the ratio that represents the expected number of deaths that could have been saved if EMS were provided immediately.

For control variables in the experiments, we use three variables related to the pre-hospital phase and four variables for the hospital phase. The three pre-hospital phase variables are 1) number of ambulances dispatched, 2) ratio of level-1 and level-2 Emergency Medical Technicians(EMTs), and 3) number of DMATs dispatched. The number of ambulances is varied at three levels: current level, 150% and 50% of the current level. For the ratio of level-1 and level-2 EMTs, we use 4:6, 6:4 and 8:2 in the experiments. EMTs carry out three functions in the simulation (triage, first-aid, hospital selection), and we assume level-1 EMTs have a higher probability of success for all three functions when compared to level-2 EMTs. A DMAT is a medical assistance team dispatched to a disaster site, and it consists of doctors and nurses. They perform triage at a massive scale and provide treatments to stabilize a patient's condition. We use two levels in the experiments for DMATs: number of DMATs = 1 or 2.

The hospital phase variables are 1) ED capacity, 2) number of X-ray rooms, 3) number of EMS physicians, 4) number of operating rooms (ORs). A reference value for ED capacity is estimated by EMS experts based on disaster management protocols (surge capacity), and it is estimated to be 250% of the nominal number of beds in an ED. Accordingly, we use 200% and 300% as the low and high-levels for the experiments. We set three levels for the number of X-ray rooms and EMS physicians: 50%, 100%, 150% of the current number in an ED. The number of ORs are set at three levels as well: 2, 3, and 4.

With the seven variables, full factorial experiments require 1458 settings, each of which involves simulation replication. Instead, we adopt a fractional factorial design by using the L18 orthogonal array (Taguchi 1986) as shown in Table 4. For the 18 settings, we run simulation experiments with 15 replications under each setting.

Table 4: L18 orthogonal array used in the experiments.

	Pre-hospital phase factors			Hospital phase factors			
Experiment Set	EMT level-1:level-2	No. of Ambulances†	No. of DMATs	ED capacity	No. of X-ray rooms†	No. of EMS physicians†	No. of ORs
1	4:6	50 %	1	200 %	50 %	50 %	2
2	4:6	100 %	1	250 %	100 %	100 %	3
3	4:6	150 %	1	300 %	150 %	150 %	4
4	6:4	50 %	1	200 %	100 %	100 %	4
5	6:4	100 %	1	250 %	150 %	150 %	2
6	6:4	150 %	1	300 %	50 %	50 %	3
7	8:2	50 %	1	250 %	50 %	150 %	3
8	8:2	100 %	1	300 %	100 %	50 %	4
9	8:2	150 %	1	200 %	150 %	100 %	2
10	4:6	50 %	2	300 %	150 %	100 %	3
11	4:6	100 %	2	200 %	50 %	150 %	4
12	4:6	150 %	2	250 %	100 %	50 %	2
13	6:4	50 %	2	250 %	150 %	50 %	4
14	6:4	100 %	2	300 %	50 %	100 %	2
15	6:4	150 %	2	200 %	100 %	150 %	3
16	8:2	50 %	2	300 %	100 %	150 %	2
17	8:2	100 %	2	200 %	150 %	50 %	3
18	8:2	150 %	2	250 %	50 %	100 %	4

† Level for these factors is defined as % of the current number of each resource in the respective EMS system.

4 RESULTS

We first test the effects of each of the seven control variables on the preventable death ratio *R*. For this, we conduct a t-test across the factor levels of each variable. Table 5 and 6 shows the t-test results for the three locales.

Table 5: t-test results for preventable death ratio *R* across pre-hospital factor levels. (shown in bold are results with a p-value less than the experiment-wise significance level 0.05).

	No. of ambulances			EMT level-1:level-2			No. of DMATs		
Gangnam		100%	150%		6:4	8:2		2	-
(Metropolitan)	50%	1.452	-0.427	4:6	-0.398	-1.933	1	-0.483	-
	100%	-	-1.882	6:4	-	-1.713	-	-	-
Cheonan		100%	150%		6:4	8:2		2	-
(Urban)	50%	-0.381	-1.179	4:6	-1.235	**-2.491**	1	-0.128	-
	100%	-	-1.323	6:4	-	-1.187	-	-	-
Gyeongju		100%	150%		6:4	8:2		2	-
(Urban-rural)	50%	**-6.106**	**-6.874**	4:6	-0.276	-2.006	1	0.005	-
	100%	-	-0.733	6:4	-	-1.946	-	-	-

We see from Table 5 that for the Gangnam district, enhancing the pre-hospital phase factors does not significantly reduce the preventable death ratio. This suggests that in the Gangnam district, pre-hospital EMS resources are already sufficient. On the other hand, the results for Cheonan city and Gyeongju city show that some of the pre-hospital phase factors do have influences in the preventable death ratio. For Cheonan city, it is the EMT skill levels and, for Gyeongju, it is the number of ambulances as well as EMT skill levels that make a difference in the preventable death ratio. Especially for Gyeongju city, the result indicates that the amount (number of ambulances) and quality (EMT level) of the pre-hospital phase's resources are inappropriate; thus, securing more of those resources seems to be a high-priority task to improve its performance. The hospital-phase factors show more or less similar effects on the preventable death ratio in all three areas. Specifically, an increase in the number of ORs plays a significant role to reduce *R* in Gangnam, Cheonan, and Gyeongju. The number of EMS physicians can also improve the preventable death ratio in Gangnam and Gyeongju. Overall, the experimental results clearly show that an area-specific improvement strategy is required to augment the performance of an EMS system.

While preventable death ratio is clearly an ultimate outcome performance indicator, it is beneficial to understand in more detail how each of the control variables contributes to the preventable death ratio. To that end, we measure the intermediate performance indicators from the simulation results that are correlated with the preventable death ratio. Specifically, we conduct Pearson correlation tests between preventable death ratios and various intermediate performance indicators measured from simulation experiments. From the test, five statistics that have the highest correlation coefficient have been identified. Table 7 shows the top five intermediate performance indicators identified for the three region. In all three cases, the number of patients who died in ED before surgery is most highly correlated with the preventable death ratio. In Cheonan's case, it is noteworthy that the number of transfer patients is identified as a intermediate indicator. Recall from Table 3 that Cheonan city has 1 Level-1 EMC and 2 Level-2 EMCs, all of which are high-capability EDs, but it also has two Level-3 EDs. Those Level-3 EDs are not capable of providing specialty surgeries, and thus if such patients are sent to the Level-3 EDs, then they need to be transferred to one of the higher-tier EDs. Such transfers seem to be responsible to some degree for an inflated preventable death ratio. In Gyeongju, four of the five indicators are from the pre-hospital phase. This suggests that the pre-hospital phase of EMS system operation is a potential concern for the city of Gyeongju, as pointed out in Table 3. Note that except for "ED arrival time for Red patients", a smaller value in each indicator corresponds to a smaller preventable death ratio.

Table 6: t-test results for preventable death ratio R across hospital factor levels. (shown in bold are results with a p-value less than the experiment-wise significance level 0.05).

	ED capacity			No. of X-ray			No. of EMS physicians		
		250%	300%		100%	150%		100%	150%
Gangnam (Metropolitan)	200%	-0.271	-0.329	50%	-1.756	-1.782	50%	**-2.548**	**-3.687**
	250%	-	-0.053	100%	-	0.034	100%	-	-1.063
	No. of ORs								
		3	4						
	2	**-8.796**	**-13.499**						
	3	-	**-4.780**						
	ED capacity			No. of X-ray			No. of EMS physicians		
		250%	300%		100%	150%		100%	150%
Cheonan (Urban)	200%	0.502	0.583	50%	-1.407	-0.874	50%	-0.812	-0.963
	250%	-	0.056	100%	-	0.631	100%	-	-0.127
	No. of ORs								
		3	4						
	2	**-10.578**	**-15.096**						
	3	-	**-4.297**						
	ED capacity			No. of X-ray			No. of EMS physicians		
		250%	300%		100%	150%		100%	150%
Gyeongju (Urban-rural)	200%	1.753	0.982	50%	-0.064	-0.027	50%	**-2.305**	**-2.993**
	250%	-	-0.737	100%	-	0.038	100%	-	-0.862
	No. of ORs								
		3	4						
	2	**-9.276**	**-15.432**						
	3	-	**-6.513**						

Now that the top five intermediate performance indicators have been identified, we conduct a linear regression analysis to understand how each of the control factors affects these intermediate performance indicators. Table 8, 9, and 10 show the results from the linear regression model for the three regions respectively. Interpreting other factors' effects on the intermediate performance indicators requires an investigation into the operational details and the geospatial specifics in the region. For example, it is not straightfoward to see how increasing the number of ambulances in Gangnam area would result in an *increase* in the surgery sojourn time. This is due to the fact that transporting patients to an ED faster only increases the waiting time for surgery, given that ORs are the bottleneck resources in the entire process. Another example is that increasing ED capacity *increases* TSTR (Treatment sojourn time for Red patients) in Gangnam's case. This can be explained as follows: When ED capacity increases, an ED admits a higher number of patients. If the ED does not increase the ED staff, then there will be a shortage of personnel, leading to delays in providing treatment procedures. Also in Gangnam, it shows that increasing EMT Level-1 increases the time of arrival at an ED for Red patients. This is due to the location of EDs in the region. In the Gangnam scenario, the ED that is closest to the MCI site is not a higher-tier ED, and therefore has a limited surgery capability. Thus, it is the right decision to send a Red patient to a higher-tier ED, which is located farther away from the site. Level-1 EMTs are more skilled and more likely to make correct decisions for triage and hospital selection. Therefore as more EMTs are of level-1, more Red patients will be sent to a higher-tier ED the first time, thus the apparent statistics for ED arrival time for Red patients will increase.

Table 7: Intermediate performance indicators for the three locales.

	Phase	Indicator description (accronym)	Coefficient
Gangnam (Metro-politan)	hospital	No. of patients who died in ED before surgery (NDEDBS)	0.807
	hospital	Surgery sojourn time (SST)	0.451
	hospital	Treatment(splint, suture) sojourn time at ED (TST)	0.307
	hospital	Treatment sojourn time for Red patients (TSTR)	0.294
	pre-hospital	ED arrival time for Red patients (EDARR)	-0.268
Cheonan (Urban)	hospital	NDEDBS	0.766
	hospital	SST	0.330
	hospital	No. of transfer (XFR)	0.255
	pre-hospital	No. of Red patients admitted at highest-tier ED (NRADM)	0.196
	hospital	TSTR	0.179
Gyeongju (Urban-rural)	hospital	NDEDBS	0.668
	pre-hospital	Triage waiting time for Red patients (TWTR)	0.269
	pre-hospital	No. of patients who died before transport to ED (NDBTR)	0.254
	pre-hospital	Triage waiting time for all patients (TWT)	0.252
	pre-hospital	Time to transport all Red patients (TTR)	0.242

Table 8: Standardized coefficients from linear regression models for the intermediate performance indicators: Gangnam district (bold for p-value < 0.05).

Factor	NDEDBS	SST	TST	TSTR	EDARR
Pre-hospital phase					
No. ambulances	0.086	**0.132**	**0.196**	**-0.091**	-0.063
EMT Lv-1:Lv-2	**-0.113**	0.036	-0.057	**-0.115**	**0.283**
No. DMATs	-0.003	-0.041	0.028	0.016	-0.006
Hospital phase					
ED capacity	-0.043	**-0.162**	**-0.272**	**0.187**	-0.001
No. X-ray	-0.061	**0.088**	0.006	0.018	-0.003
No. EMS physicians	**-0.188**	**0.158**	**-0.649**	**-0.668**	-0.017
No. ORs	**-0.612**	**-0.729**	**-0.111**	-0.005	0.062
Adjusted R^2	0.421	0.601	0.538	0.490	0.064

Increasing the number of ORs always reduces the intermediate performance indicators, which means it will reduce the preventable death ratio. For example, the NDEDBS (Number of patients who died in ED before surgery), which is very strongly correlated with preventable death ratio, can be significantly reduced by increasing number of ORs in all three regions. It is intuitive that increasing availability of ORs will reduce the waiting time for surgeries, thereby reducing the number of patients who die before receiving surgery. Other than the addition of ORs, improvement strategies differ by each region. For the Gangnam district, increasing the number of EMS physicians will be an effective strategy as it significantly reduces the indicators. For Cheonan city, improving EMT Level is a key factor in reducing the number of transfer patients. Sizing up EDs (capacity, X-ray, EMS physicians) should be considered with great caution as it may increase the chance of admitting patients to EDs that should not admit the patients, which could potentially increase the number of transfers. In Gyeongju city, increasing the number of ambulances has a strong positive impact in all pre-hospital phase indicators. It clearly shows that securing more ambulances to increase coverage is an improvement strategy of the highest priority.

Table 9: Standardized coefficients from linear regression models for the intermediate performance indicators: Cheonan city (bold for p-value < 0.05).

Factor	NDEDBS	SST	XFR	NRADM	TSTR
Pre-hospital phase					
No. ambulances	**0.108**	**0.223**	0.022	**0.138**	**-0.142**
EMT Lv-1:Lv-2	-0.029	0.013	**-0.224**	0.063	0.002
No. DMATs	0.059	**-0.167**	0.021	**-0.136**	**0.178**
Hospital phase					
ED capacity	**0.100**	**-0.238**	**0.280**	-0.099	**0.474**
No. X-ray	-0.018	**0.130**	**0.137**	0.065	0.005
No. EMS physicians	0.033	**0.257**	**0.204**	**0.111**	**-0.445**
No. ORs	**-0.642**	**-0.653**	**-0.323**	**-0.277**	-0.028
Adjusted R^2	0.424	0.634	0.275	0.121	0.461

Table 10: Standardized coefficients from linear regression models for the intermediate performance indicators: Gyeongju city (bold for p-value < 0.05).

Factor	NDEDBS	TWTR	NDBTR	TWT	TTR
Pre-hospital phase					
No. ambulances	0.005	**-0.829**	**-0.368**	**-0.828**	**-0.894**
EMT Lv-1:Lv-2	-0.015	**0.074**	**-0.121**	**0.070**	**-0.043**
No. DMATs	0.023	-0.042	-0.026	-0.017	-0.016
Hospital phase					
ED capacity	0.021	-0.001	-0.054	0.024	**-0.037**
No. X-ray	-0.025	-0.003	-0.013	0.005	-0.018
No. EMS physicians	-0.011	-0.005	**-0.103**	0.030	-0.020
No. ORs	**-0.563**	0.025	-0.018	0.023	-0.014
Adjusted R^2	0.312	0.692	0.156	0.689	0.802

5 CONCLUSION

EMSSim is an agent-based simulation model developed to simulate EMS responses, particularly for MCI situations. It is developed by LDEF formalism, which is based on the dynamic structured DEVS, and it offers flexibility and expandability in constructing an EMS system with operational details. EMSSim uses Korean VictimBase, a synthetic casualty population database, so that the simulation model can express complications and complexities from real-world MCI responses.

Using EMSSim, we examine the effectiveness of an EMS system's response in three locales in Korea. The three regions represent different levels of urbanization – metropolitan, urban, and urban-rural mix, all of which have tangibly different effects on the effectiveness of EMS responses and its improvement strategies. Our simulation experiments show that in the metropolitan region, where EDs are closeby and where the of ambulances are sufficient, enhancing hospital resources is going to be an effective improvement strategy. Specifically, securing more ORs and increasing the number of EMS physicians should be considered. In the urban region tested in this study, reducing transfer patients by transporting patients to an ED with the right care capability is an important factor. One way to achieve that is to improve the skill levels of EMTs dispatched to the site. In the urban-rural region, ambulances have to cover a large distance, and thus increasing the number of available ambulances will be an effective strategy to improve the overall performance.

Improving the performance of an EMS system is a critical requirement to minimize casualties from a disaster incident. Strategies for improvement for a specific region requires a detailed understanding of the current status and a careful assessment of candidate strategies' effectiveness in that region. Simulation is a logical choice for the task. A simulation model for such purpose should capture rich details in both operational and clinical aspects along with realistic geospatial information. We demonstrate in this paper that EMSSim is an effective tool to achieve the goal.

ACKNOWLEDGMENTS

This research was supported by a grant 'research and development of modeling and simulating the rescues, the transfer, and the treatment of disaster victims' [nema-md-2013-36] from the man-made disaster prevention research center, national emergency management agency of korea.

REFERENCES

Bae, J. W., S. Lee, J. H. Hong, and I.-C. Moon. 2014. "Simulation-Based Analyses of an Evacuation from a Metropolis During a Bombardment". *Simulation* 90 (11): 1244–1267.

Bae, J. W., and I.-C. Moon. 2016. "LDEF Formalism for Agent-Based Model Development". *IEEE Transactions on System, Man, and Cybernetics: Systems* 46 (6): 793–808.

Bae, J. W., K. Shin, H.-R. Lee, H. J. Lee, T. Lee, J.-H. Kim, W.-C. Cha, G. W. Kim, and I.-C. Moon. 2016. "Evaluation of Disaster Response System using Agent-Based Model with Geospatial and Medical Details". *IEEE Transactions on System, Man, and Cybernetics: Systems*. To appear.

Cova, T. J. 1999. "GIS in Emergency Management". *Geographical Information Systems* 2:845–858.

Dynes, R. R., and K. J. Tierney. 1994. *Disasters, Collective Behavior, and Social Organization*. University of Delaware Press Newark, DE.

Encinas, L. H., S. H. White, A. M. del Rey, and G. R. Sanchez. 2007. "Modelling Forest Fire Spread Using Hexagonal Cellular Automata". *Applied Mathematical Modelling* 31 (6): 1213–1227.

Jenkins, J. L., M. L. McCarthy, L. M. Sauer, G. B. Green, S. Stuart, T. L. Thomas, E. B. Hsu et al. 2008. "Mass-Casualty Triage: Time for an Evidence-Based Approach". *Prehospital and Disaster Medicine* 23 (1): 3–8.

Levi, L., D. Bregman, H. Geva, and M. Revach. 1998. "Hospital Disaster Management Simulation System". *Prehospital and Disaster Medicine* 13 (1): 22–27.

Liu, Y., G.-L. Chang, Y. Liu, and X. Lai. 2008. "Corridor-Based Emergency Evacuation System for Washington, DC: System Development and Case Study". *Transportation Research Record: Journal of the Transportation Research Board* 2041:58–67.

Moon, I.-C., J. W. Bae, J. Lee, D. Kim, H. Lee, T. Lee, W.-C. Cha, J.-H. Kim, and G. W. Kim. 2015. "EMSSIM: Emergency Medical Service Simulator with Geographic and Medical Details". In *Proceedings of the 2015 Winter Simulation Conference*, edited by L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, 1272–1284. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Petak, W. J. 1985. "Emergency Management: A Challenge for Public Administration". *Public Administration Review* 45:3–7.

Taguchi, G. 1986. *Introduction to Quality Engineering: Designing Quality into Products and Processes*. Asian Productivity Organization.

Takeuchi, I., S. Kakumoto, and Y. Goto. 2003. "Towards an Integrated Earthquake Disaster Simulation System". In *First International Workshop on Synthetic Simulation and Robotics to Mitigate Earthquake Disaster*. Citeseer.

Zeigler, B. P., H. Praehofer, and T. G. Kim. 2000. *Theory of Modeling and Simulation*. Academic press.

AUTHOR BIOGRAPHIES

TAESIK LEE is an associate professor of Industrial & Systems Engineering Department at KAIST, Korea. His research interests include system design, modeling and simulation. For the past few years, he has been working on designing various aspects of healthcare delivery systems. His email address is taesik.lee@kaist.edu.

KYOHONG SHIN is a Ph.D. candidate in Industrial & Systems Engineering at KAIST, Republic of Korea. His current research interest focuses on modeling and simulation of emergency medical service system. His email address is hong906@kaist.ac.kr.

HYUN-ROK LEE is a Ph.D. candidate in Industrial & Systems Engineering Department at KAIST. His research interests include modeling and simulation. His email address is hyunrok@kaist.ac.kr.

HYUN JIN LEE is a Ph.D. candidate in Industrial & Systems Engineering Department at KAIST. His research interests include modeling and simulation. His email address is uhyh9002@kaist.ac.kr.

INKYUNG SUNG is a Ph.D candidate in Industrial and Systems Engineering Department at KAIST. His research interest is on modeling and simulation and its application to healthcare delivery system, EMS systems in particular. His email address is inkyung@kaist.ac.kr.

JANG WON BAE is a senior researcher at Electronics and Telecommunications Research Institute (ETRI) in Korea. His email address is jwbae@etri.re.kr.

JUNSEOK LEE is a Master in Industrial & Systems Engineering Department at KAIST. His research interest focuses on modeling and simulation. His email address is agil82@kaist.ac.kr.

IL-CHUL MOON is an assistant professor of Industrial & Systems Engineering Department at KAIST, Korea. His research interest is modeling and simulation of complex socio-economic systems in our societies. His email address is icmoon@kaist.ac.kr.