Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

EMSSIM: EMERGENCY MEDICAL SERVICE SIMULATOR WITH GEOGRAPHIC AND MEDICAL DETAILS

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ABSTRACT

This paper introduces EMSSim that is an agent-based simulation of emergency medical services during disasters. We developed EMSSim to encompass the disaster victims' pass-ways from their rescues to their definitive care. This modeling scope resulted that our model delivers the detailed geographical and medical modeling which are often modeled separately. This is an effort to fill the gap between the pre-hospital delivery and the in-hospital care over the disaster period. We specified the model with a variant of the dynamic DEVS formalism so that the complex models could be better understood and utilized by others. Also, we suggest a modeling approach to create a profile with mathematical modeling on the victims' survival rates, which would enable our models to simulate the effectiveness of the treatments by the responders. Finally, we provide a case study of virtual experiments that analyzes the sensitivity of rescue performances by varying the disaster response resources.

1 INTRODUCTION

In the chaos of disasters, the disaster victims and the responders are often on their own with little systematic support. Such situations dictate the victims and the responders to follow their instincts as well as drilled routines, and we hope that the combination of such behavior mechanisms would result in less casualties and damages to our society. Prior to the disasters, we prepare ourselves and our society to mitigate the challenge by establishing rules of behavior as well as pre-deploying necessary logistical supports. Having said that, our question is how to measure the quality of our preparedness against unseen disasters. The evaluation can be qualitatively made by subject-matter experts, and these experts' opinions matter most in the real world because they know the fields and the events of the past. Also, the historic data provide us the scenarios to prepare for the conventional disasters. However, what if we have to prepare ourselves against unconventional disasters that have never been observed in the real world? Preparing for such unseen disasters requires guidance beyond the expert opinions and the historic data because the events are yet unchartered. One way to mitigate this difficulty is artificially generating the potential disasters that we expect, and we model and simulate our preparedness with the virtual disasters to measure the performance. This approach of modeling and simulation (M&S) has been widely used in various fields, such as civil violence, disasters, military, economics, etc.

The disaster management field is not new to the M&S approach; rather, it is one field that frequently utilizes the approach (Dynes and Tierney 1994; O'Reilly et al. 2004). However, many simulation models in the field are dedicated models to simulating the disaster from one perspective. For instance, previous models, i.e., fire spread models, flooding models, bombing models (Hernández Encinas et al. 2007; Liu et al. 2008), included the geospatial characteristics of events, and the models would have in-depth representations of how the spatial distributions of resources and damages would evolve over time. These models lean toward the regional modeling; and the physical and the spatial modeling of disasters. While the models have big picture and regional hypothetical situations, the models frequently do not have the details of modeling on a specific response operation. For example, flooding models, fire models, and bombing models are keen to anticipate the effect of the disasters in terms of the number of casualties, but those models may not provide the storyline of how the casualties are rescued, delivered, and stabilized with details of medical operations. On the contrary, the models with medical backgrounds decide their scopes to the area of in-hospital activities, i.e., the operations in the emergency room (Paige et al. 2014; Saunders, Makens, and Leblanc 1989). Frequently, these models deliver the patients as an abstract process, and the victims were being modeled as an object to be processed. This is understandable because there are protocols for handling patients in the emergency room, and modelers assume that the personnel in the emergency room follow the protocols. These medical simulators could be either very specific: to the level of surgical operations on patients; or very location-oriented: to the scope of the emergency room or the hospital operation rooms.

This paper is an effort to fill the gap between the pre-hospital delivery and the in-hospital care over the course of a disaster response. Authors who are experts in the disaster and the emergency medicine have been noticed the communication problems between the personnel in the pre-hospital stage and the hospital, and their experience reveals that the pre-hospital care, the triage, and the transportation decision have the utmost impact toward the victims' remaining care, and this would not be solved by only optimizing either rescue and transportation; or hospital care. In spite of their conjecture, the logs of pre-hospital and hospital care are separately maintained: one by the fire department and related services and the other by the hospital administration; so, it is difficult to generate convincing arguments from the separated and incomplete log data on rarely or unseen disasters. Therefore, we were motivated to build a simulation model that encompasses the whole operation of the emergency medical service, or EMS, in disaster scenarios, from the rescue of the victims at disaster scenes to the definitive treatment for the victims in hospitals.

Our model starts from the casualty at the disaster scene, and the model simulates the rescue operation, the triage process, the transportation of victims, the emergency room cares, and the potential diversion and transfer of victims. This simulation scenario includes the geospatial elements of the transportation and the deployments of key resources, such as ambulances and hospitals, as well as the in-hospital care elements, i.e., the number of operation rooms, the number of emergency room doctors, the number of X-Ray machines, etc. Moreover, the protocols and the practices in the transportation and the hospital care are modeled and implemented, such as the field triage rules, the disaster response team operation procedures, the operation priorities in the emergency rooms, the transportation priorities, etc. This model enables investigating the overall procedure of the emergency medical services in the disasters, and this type of overarching model with the details of geographic modeling as well as medical background knowledge is new to our knowledge. Our virtual experiments test the number of casualties reduced by enhancing the emergency medical resources in diverse aspects, and this could be the start of the cost-benefit analyses to prepare for future disasters.

2 MODELED SCENARIO

Our model includes various entities and environmental aspects in the disasters with a focus on the emergency medical service. This section enumerates which features are included, how and why as well.

2.1 Modeled Components in Emergency Medical Service

The presented simulation model aims at generating the disaster victim care from the rescue to the definitive care. This simulation scope requires including the field entities and the in-hospital resources at the same time. The modeled field entities are listed in the below.

- **Victims** are the individuals who require medical care at the disaster scene. The victims have their vital sign as well as implicit survival rate curve which is modeled, but they are not visible to the interacting entities in the simulation. The behavior of the victims is described in Section 3.2.
- **Ambulances** are the entities that transport the victims to the hospital where the victims receive the definite care that terminates their status as victims. The modeled ambulances are categorized into three different types which are the ambulance with the first-level rescue expert licensed by the government, the second-level rescuer, and the para-medical transporter that has no medical expertise. These different levels of ambulances have different abilities in treating and triaging victims.
- **DMATs, or disaster medical assistance teams,** are the entities responding to the disaster scene with the speed equivalent to the ambulances. The DMATs consist of emergency room (ER) doctors and nurses who are able to correctly triage victims and provide basic medical assistance to them.
- **Field EMS, or field emergency medical service,** is a truck and assigned personnel that corresponds to the scene with a much slower speed because of the resources on board. Despite its slow response, once deployed, the field EMS becomes the center of the triage and the treatment on the scene with much higher throughput compared to the DMAT.
- **Hospitals** are the ultimate emergency medical resource where victims receive triage, treatment, X-Ray/CT scan, and operation if needed. The victims receive the definitive treatment that terminates the victim's pass-way from the scene.
- **Emergency Management Agency** is the only entity that does not present on the geographical environment in the simulation, but this is the center that controls and communicates with the ambulances, the DMATs, and the field EMSs. However, given the volume of communication in the disasters, the agent is not capable of providing the step-by-step instruction to the controlled responders. For example, the ambulances become autonomous entities that determine which victim to transport and where.

The followings is a list of in-hospital care resources. These are resources deployed to each hospital, and the resource amounts are different by the hospital size and its disaster preparedness level, which is assessed and designated by the Korean government. By law, the level of disaster preparedness dictates the amount of resources to be maintained by hospitals.

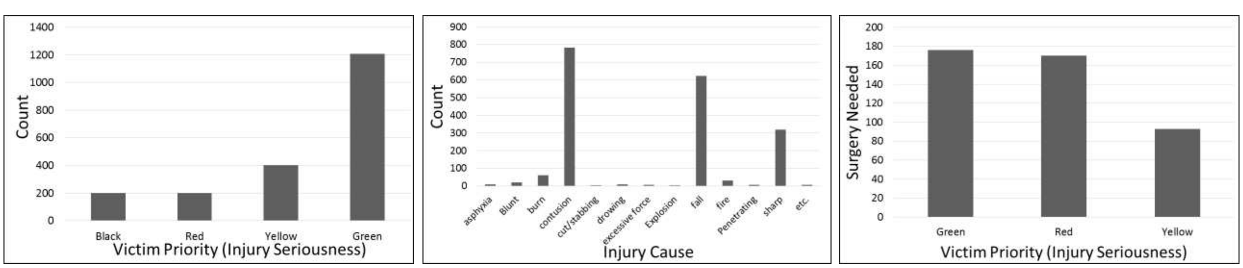
- **Beds** are the fundamental resources limiting the number of patients to be admitted to a hospital. Beds basically refer to monitored beds that victims with serious injuries can use.

- **ER doctors, or emergency room (ER) doctors,** are the resources to splint and suture the critical wounds. They provide care to the victims prior to the surgical operations if needed. If the victims do not require operations, the victims are treated definitely by the ER doctors.
- **X-Rays** are the resources to identify and assess the critical injury. For this objective, there are various resources, such as ultra-sonar scanner, CT, etc., used in the emergency room, but our subject-matter experts acknowledge that the X-Rays are the bottleneck of the ER operation because monitored beds have ultra-sonar scanners, and CT is not so frequently used compared to X-Rays in disasters.
- **Operation rooms** are the ultimate resources to stabilize the victims who need surgery. Hospitals have the limited number of operation rooms, and the numbers are differentiated by their levels and sizes.

2.2 Modeled Environment and Abstracted Disaster

The environment of the simulation mainly originates from the traffic aspect (i.e., road network) of the simulated region. This paper experiments a disaster in the GangNam region of Seoul, where the road network is dense and complex. We hypothesized the scenario of a mass casualty incident, or MCI, in one of the shopping mall in the region. Our road network environment includes both main avenue and lanes that ambulances can use. The road network consists of road segments and junctions, and the average speed of the road segments is collected from a traffic information service, which is Naver Map, through its Open API. Our traffic information is collected by assuming that the disaster occurred at 5:00pm on Friday, which is the busiest hour and in the busiest district of Korea (Bae et al. 2014).

Our disaster scenario starts from an event of MCI in any cases that include large-scale fire, gas leak, or building collapse. Our simulator is able to change the configuration of hypothetical victim profiles by the types of disasters. This approach enables us to abstract the cause and the progress of disasters, and we build more detailed models on the EMS perspective. The victim profile that we used is created by the subject-matter experts among the authors. This dataset has 2013 individual victim types specifying the cause of the injury, the implicit survival rate curve, the requirement of surgery, the usual number of X-Rays to be taken, the number of sutures needed, and the triage difficulty. Figure 1 shows the descriptive statistics of the victims. Each victim has the evaluation on the injury seriousness that falls into four categories: Black, Red, Yellow, and Green. This follows the triage method named Simple Triage And Rapid Treatment (START) (Kahn et al. 2009). Black means that the victim is dead or about to, and Red means that the victim will die unless he or she receives medical care immediately. Yellow and Green mean that the victim will be alive without immediate care. Our victim profile holds predetermined and true designation of this triage result, but our simulated responders will triage victims with errors.



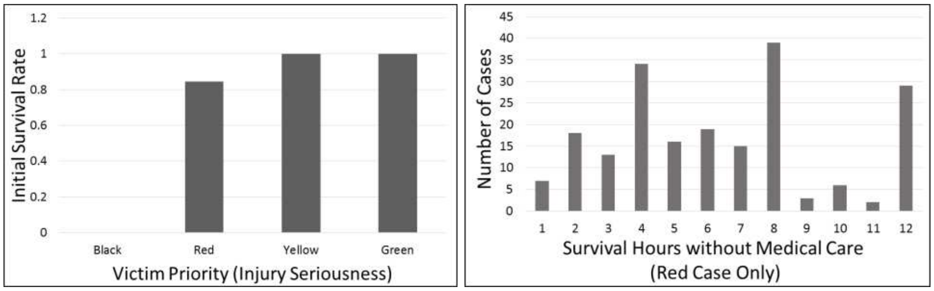


Figure 1: Descriptive statistics of the utilized victim profiles.

3 MODEL DESCRIPTION

This section describes the simulation models designed and implemented to represent the entities of interest in Section 2. We utilize the LDEF formalism (Bae, Lee, and Moon 2012) and its corresponding simulation environment to develop this model, and the LDEF formalism is a variant of the dynamic structured DEVS formalism (Zeigler, Praehofer, and Kim 2000). We used the formalism 1) to clearly represent the structure and the behavior of our simulation model and 2) to incrementally compose and develop the simulation models through the coupling structure of the formalism.

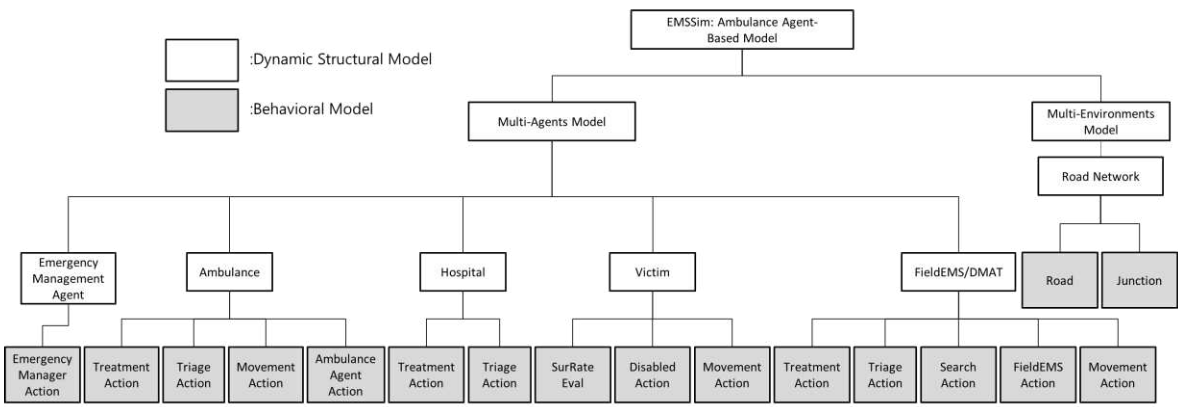


Figure 2: Hierarchical structure of EMSSim.

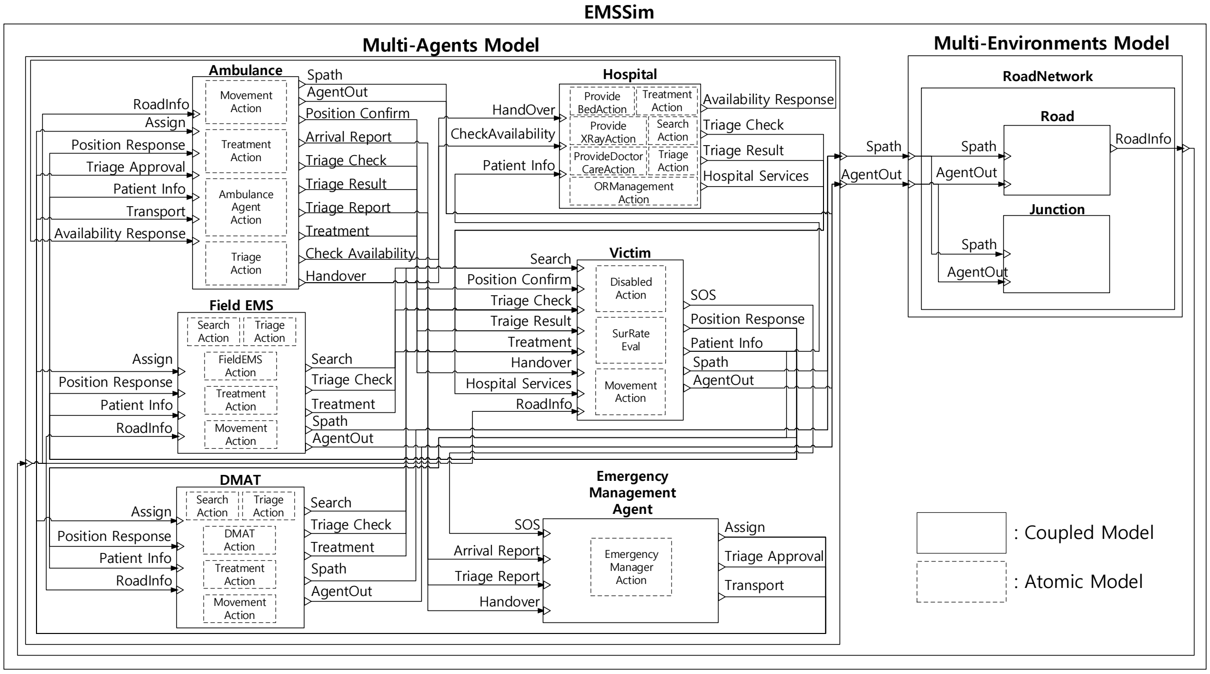


Figure 3: Coupling structure of EMSSim. This diagram follows the notation of the DEVS coupled model.formalism.

3.1 Model Composition and Structure

Our simulation model is hierarchically composed as illustrated in Figure 2. The EMSSim is the outmost coupled model that consists of the multi-agents model and the multi-environment model. The multi-agents model includes the responders (i.e., emergency management agency, ambulances, field EMS, DMAT, and hospitals) as well as the victims. Each responder exhibits different behaviors, so the associated model reflects such diversities through the different compositions by different responder types. For example, Field EMS and DMAT are responsible for identifying victims, so they have the search action while the ambulances do not have such action. Additionally, a hospital cannot move to the scene, so it does not have the movement action. On the other hand, the medical actions, such as triage and treatment, are common behaviors performed by all of these medical responders, so they are composed in every responder model. This common behavior model is developed as a single model, and the model is composed for each responders with different model parameters. The victim has the survival rate evaluation behavior that calculates the survival curve of the agent, and the behavior determines when the victim will die. Figure 3 is the composition structure to enable the hierarchy. We used the DEVS diagram notations (Song and Kim 2010) to show a more transparent view on the model designs.

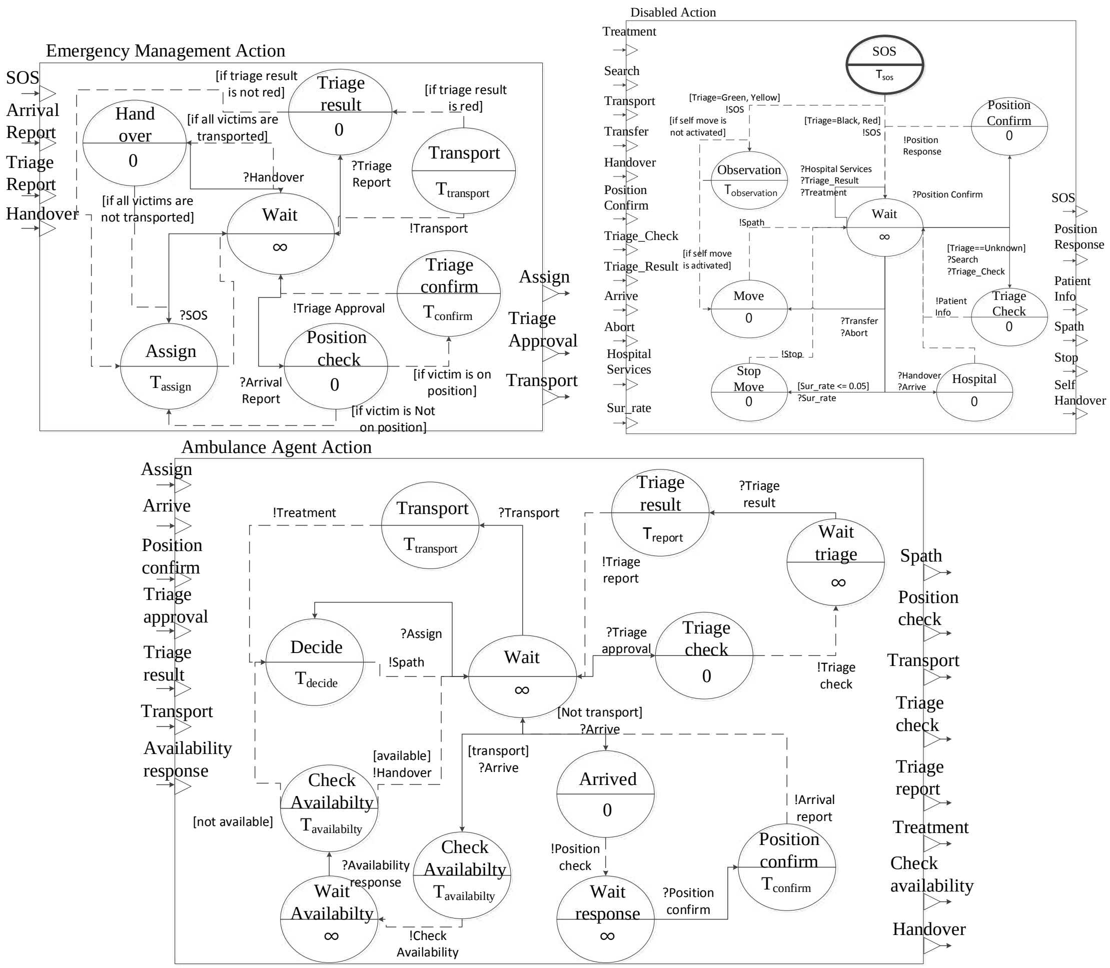


Figure 4: State transition diagram of three action models: emergency management action, disabled action, and ambulance agent action. The diagrams follow the notation of the DEVS atomic model formalism.

3.2 Model Behavior and Process

The models simulate interactions using messages through the dynamic coupling structures, and the fundamental driver of the simulation progress is the atomic model, which corresponds to the leaf node of the model hierarchy. According to the DEVS formalism, the atomic model is a state-transition model with internal state transitions and time-advancements. We represent three atomic models in the model hierarchy, such as the emergency management agency's emergency management action, the victim's disabled action, and the ambulance's ambulance agent action. These models are selected because their interactions are tightly linked with each other, and they are the key models from the disaster scene to the hospital ER. These three state machines are inter-linked through messages, and their message inputs and time advances trigger the state changes as well as specified outputs by the visited states. These outputs become the inputs of the coupled models, and this becomes the simulation progress. Because it is difficult to regenerate the progress and the interaction between the models, we provided our design on the sequential message exchanges in Figure 5.

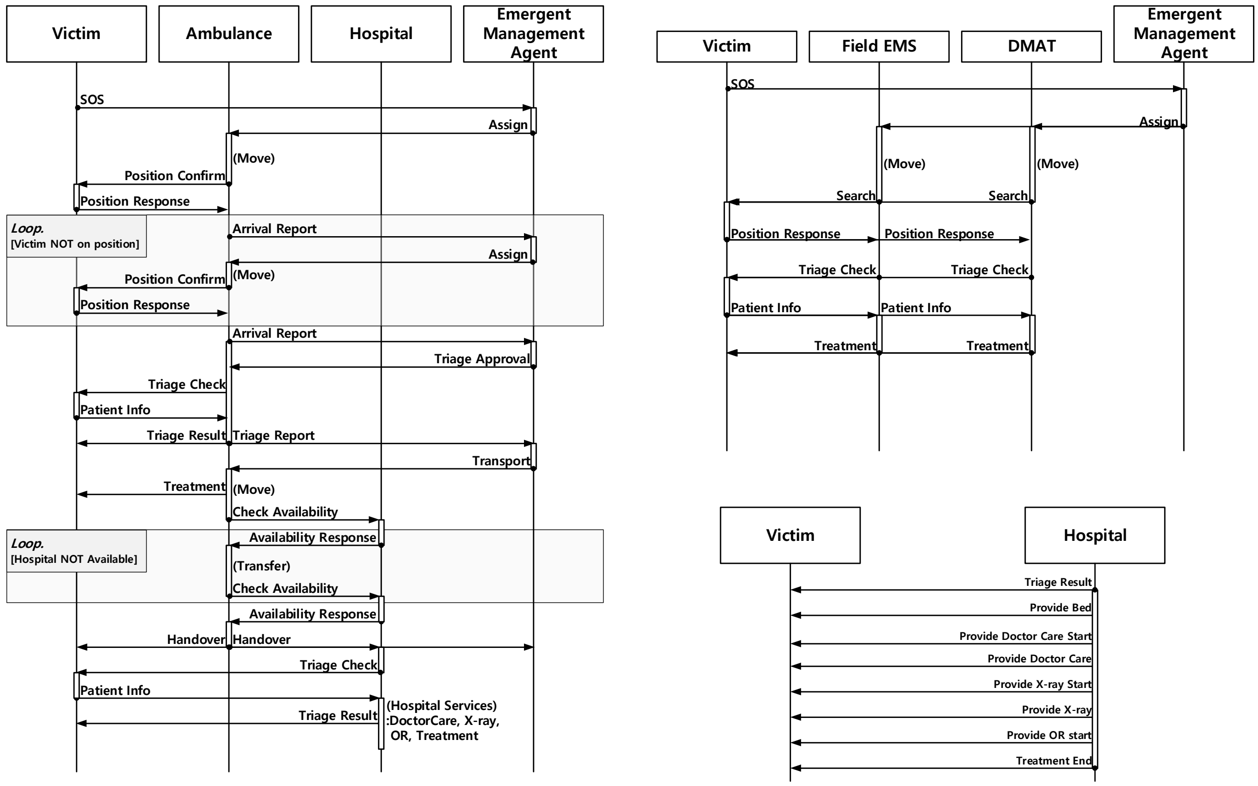


Figure 5: Sequential event exchanges over the course of the simulation. (Left) The first phase of the simulation rescues the victims from the scene through the interactions between victims, ambulances, and emergency management agency. At the final stage of the transportation, the hospital interacts with the ambulances and the victims. (Right Top) In the middle of the rescues, the field EMS and the DMAT provide the search, the triage, and the treatment to the victims, and they also deliver information to the emergency management agency. (Right Bottom) When the victim is delivered to the hospital, the victim becomes a passive receiver of the hospital care.

Besides the interactions of simulated entities, a key feature of our simulation is the survival rate of the individual victims. The idea of generating and utilizing victim profiles was introduced to the field in the past work. However, the previous models did not provide the mathematical formulation of the individualized survival curve, which we introduce here. Our victims' deaths are caused by mainly four factors: hemorrhage shock (hours to die without any treatment); asphyxia (minutes or an hour to die without any treatment); a mixed cause of hemorrhage shock and asphyxia; and a mixed cause of hemorrhage shock and traumatic brain injury. We differentiated the curve shape by the cause of death, and the method is calibrating the logistic function to show the part of the curve. The logistic curve can represent the quick death by the asphyxia, the sudden death by the traumatic brain injury, and the continual and constant decrement by the hemorrhage. Figure 6 represents the shape of the logistic function and the correspondence of the used parts. By utilizing this originating function of the survival rate, each victim profile has calibration of the curve shape by setting its own logistic function calibration parameter; see Formula (1).

$$\text{SurvivalRate}(t) = \frac{L}{1 + \exp(k(x - x_0))} + y_0 \qquad (1)$$

The calibration of the survival rate curves for 2013 victims was provided by the subject-matter experts who used their experience in the emergency medicine, the background study of animal experiments on hemorrhage shock experiments, and their knowledge on past ER records in the real world.

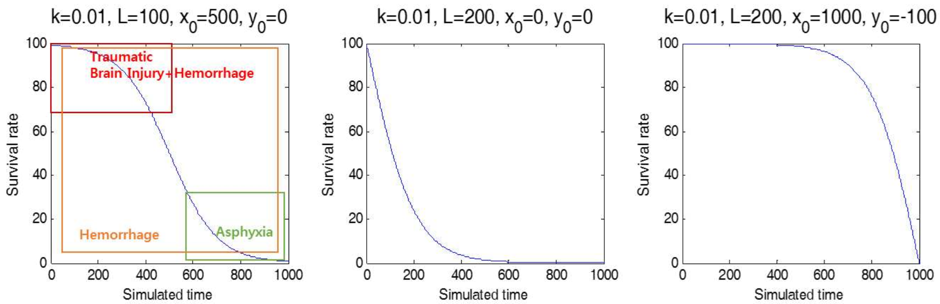


Figure 6: Original function of the survival rate curves. A part of the logistic curve shape is used to represent the survival rate change by an injury type. Additionally, individual victims have their own shape parameters, which are k, L, x_0, and y_0, to calibrate the individualized curve.

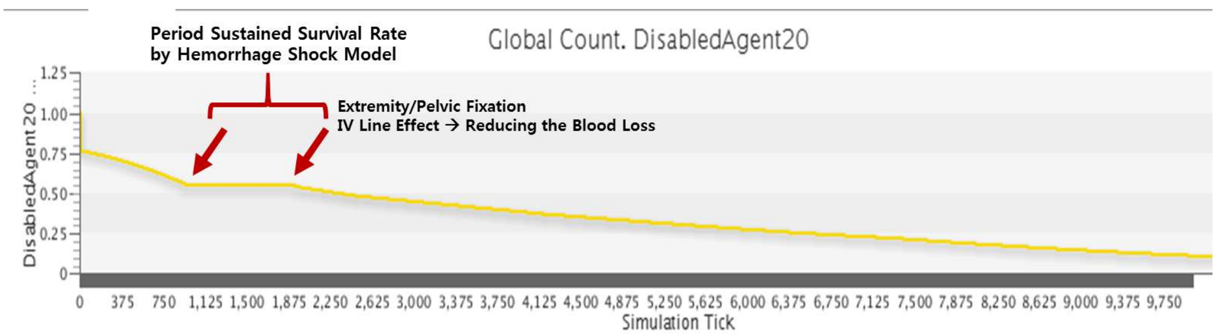


Figure 7: Screen-capture of the survival rate plotting part of EMSSim. We manually annotated the time-step when the field intervention by the responder is made and when the effect of the intervention wears off.

The modeled responders can perform three different interventions: the pelvic fixation, the extremity (limb) fixation, and the IV line establishment. These interventions effect the shape of the survival rate over time. Specifically, these interventions limit the blood loss from the victim, and they buy time to transport the victim to the hospital where they can receive the definitive treatment. The victim profile specifies the expected blood loss for each individual, and these interventions at the simulated time are hypothesized to prevent the further blood loss up to a certain amount of time. This elongated time is determined by the technical specification of the IV (blood or saline) and the expected remaining blood loss from the extremity and the pelvic at the intervention time.

Table 1: EMSSim Model Parameters. SME means the subject-matter experts.
(9 ambulance settings X 3 DMAT settings X 3 Prob. of Triage settings = 81 cells for 30 replications)

Model	Parameter	Value	Implication
Multi-Agents Model	Num. of ambulances	Experimented (10, 15, and 20 AMBs. Refer to the ambulance type setting)	The number of ambulances in the simulation
	Num. of hospitals	Real world	The number of hospitals in the simulation

	Num. of field EMS	Real world	The number of Field EMS in the simulation
	Num. of DMAT	Experimented (1, 2, 3 teams)	The number of DMAT in the simulation
	Num. of victims	Experimented (10 blacks, 20 reds, 30 yellows, 20 greens)	The number of victims with black, red, yellow, and green triage
Multi-Env. Model	Target region	Experimented (Fixed, Gangnam, Seoul)	The region of interests in the simulation
	Disaster scene	Experimented (Fixed, COEX mall, Seoul, 67 meter rad.)	The center coordinate of the disaster a source point and a radius of disaster scene in the target region
Victim Agent	Current position	Experimented (Random)	The initial coordinate of the victim in the simulation
	Used victim profile	Experimented (Random)	The index of the victim profile used to generate the simulated victim from 2013 victim profile cases
Ambul-ance Agent	Current position	Real world	The initial coordinate of the ambulance in the simulation
	Ambulance type	Experimented (# of ALS, # of BLS) (6, 4), (8, 2), (9,1) (9, 6), (11, 4), (14, 1) (12,8), (15,5), (18,2)	The type of ambulances. Category: Advanced Life Support (ALS), Basic Life Support (BLS)
	Prob. of treatment success	Survey from SME (Fixed)	The probability of the success on the interventions by the ambulance type
	Prob. of triage test	Experimented (40%, 50%, 60% on Red triage by BLS)	The probability of the success on the interventions by the ambulance type and the victim case
FieldEMS and DMAT	Current position	Real world	The initial coordinate of the field EMS and the DMAT in the simulation
	Search radius	Survey from SME (67 meters)	The radius of search, treatment and triage
Hospital Agent	Position	Real world	The coordinate of hospitals
	Num. of beds		The number of beds in the hospital
	Num. of ER doctors		The number of ER doctors in the hospital
	Num. of X-rays		The number of X-Rays in the hospital
	Num. of OR-rooms		The number of operation rooms in the hospital

We understand that further details required to fully understand and replicate the simulation introduced in this paper. However, given the space and the objective of this article, we limit our explanations on the victim profile and the model to this point.

3.3 Model Parameters

Table 1 provides the list of the simulation parameters and our parameter settings for the virtual experiment design of this paper. We only varied some of the listed parameters, and there are further parameters that we can use to vary and perform sensitivity analyses. Additionally, some parameters are collected from the real world, and they are not going to be changed unless the experiment hypothesizes that such changes are enabled in the reality. We marked such real world collectible values from the hypothesized values.

4 RESULTS

4.1 Overview of Simulation Results

Figure 8 illustrates the simulation progress over time. Initially, the victims are distributed across the disaster scene. After the simulation starts, the disaster responders including field EMS, DMAT, and ambulances, converge to the disaster site. The field EMS and the DMAT provide search, triage, and treatment services at the scene; and the ambulances are the transporters for the prioritized victims by the triage results. These behaviors follow the model description in Section 3. Once the victims are admitted to the hospital one by one, the hospital operates to deliver emergency medical care, shown in Figure 9. One special case is the hospital transfer of victims, and this transfer occurs when there is no further operation rooms in the admitted hospital.

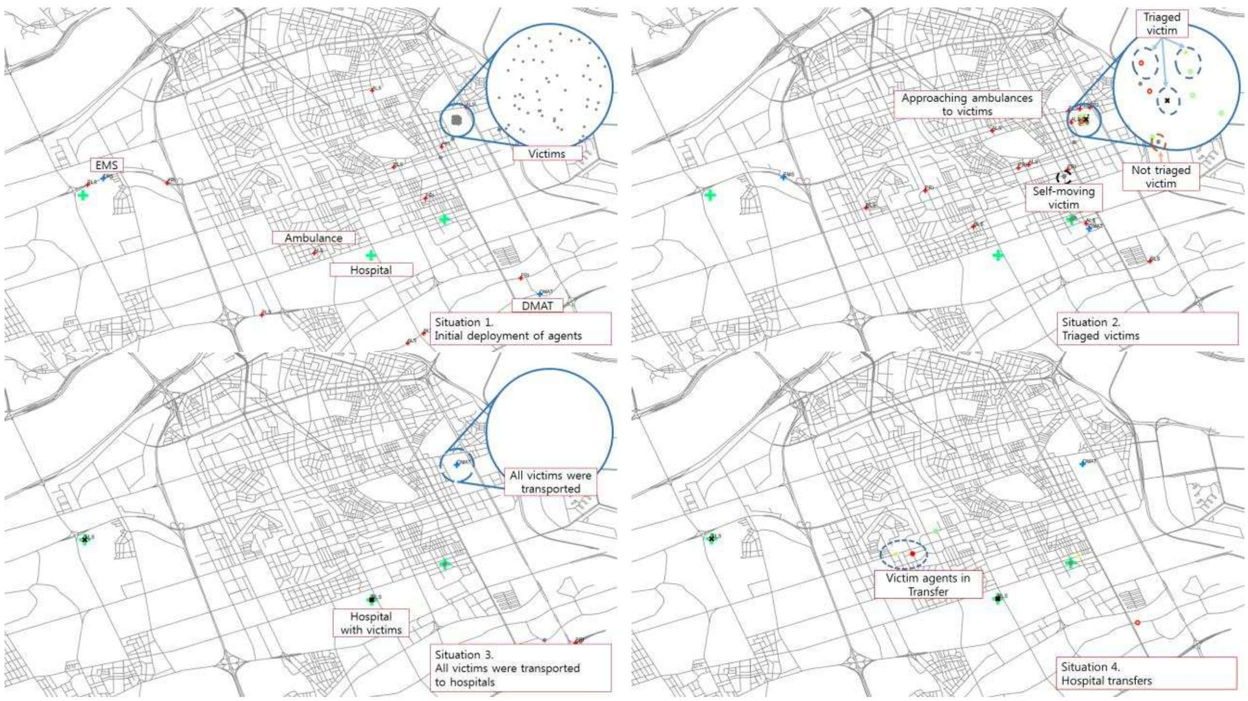


Figure 8: Screen-capture of the GIS display in EMSSim. Disaster responders and victims are displayed on the GIS of EMSSim interfaces. As simulation progresses, the triage, the transport, and the transfer occur.

4.2 Statistical Analyses of Simulation Results

We performed the statistical analyses on the virtual experiments with the EMSSim. Table 2 is the meta-modeling result to summarize our findings from the experiments. We were not able to reduce the number of casualties by only changing the experimented parameters, but there was a significant improvement on the rescue time that is being measured from the MCI incident occurring (0 timestep) to the definitive care of victims. More importantly, the victims with the red triage are those who need to be transported immediately, and there was a significant reduction in the rescue time of the red victims when there was a higher ratio of ALS per BLS. This quantitatively verifies the necessity on the improvements of rescue personnel because their triage ability does impact on the red rescue time. Still, this simulation experiment is preliminary, and more virtual experiments would be called upon.

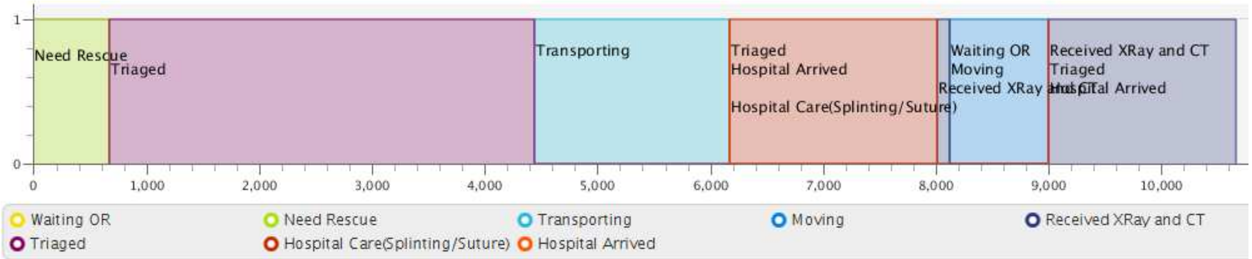


Figure 9: Screen-capture of the simulated hospital care process chart in EMSSim. The x-axis shows the simulated time, and the chart shows the pass-way of this particular patient. This patient was triaged at 675 timestep, but triaged as yellow by mistake. Hence, the victim waited for transport by 4437 timestep. After the arrival on the hospital, the splinting, the suture, and the X-Ray were applied to the victim by 8120 timestep. However, there was no available operation room in the hospital, so the victim was transferred by 8997 timestep.

Table 2: Linear regression meta-modeling of the virtual experiment results from EMSSim.

Variables	Standardized coefficients of performance measures (**bold figures**: p-value under 0.05)						
	Dead Victims	Diversions	Transfer cases	Rescue time (all patients)	Rescue time (red patients)	Avg. time of waiting triage	Avg. time of waiting transport
Number of AMBs	-0.041	0.108	-0.117	**-0.941**	**-0.448**	**-0.894**	**-0.822**
AMB Ratio (ALS/BLS)	0.047	**0.390**	0.032	**-0.047**	**-0.232**	**0.056**	-0.055
Number of DMATs	0.041	-0.054	0.105	0.023	**0.150**	**-0.062**	0.066
Triage accuracy of BLS AMB	0.017	0.036	-0.006	0.022	-0.025	0.013	0.027
Adj. R^2	-0.009	0.170	0.025	0.884	0.275	0.810	0.674

5 CONCLUSION

This simulation is an effort to present the overall victim pass-way from the disaster scene to the moment of the definitive care, and currently these pass-ways are broken into the pre-hospital transport and the in-hospital care. While we introduce the EMSSim, we are continuously working on the experimentation and the validation of the model, which will give more credibility to the EMSSim.

REFERENCES

Bae, J. W., G. H. Lee, and I.-C. Moon. 2012. "Formal Specification Supporting Incremental and Flexible Agent-Based Modeling." In Proceedings of the 2012 Winter Simulation Conference, edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhmacher, 1–12. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Bae, J. W., S. H. Lee, J. H Hong, and I. -C. Moon. 2014. "Simulation-Based Analyses on Massive Evacuation from Metropolis during Bombardment." SIMULATION: Transactions of The Society for Modeling and Simulation International 90 (11): 1244–1267.

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

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

Kahn, C. A, C. H Schultz, K. T. Miller, and C. L Anderson. 2009. "Does START Triage Work? An Outcomes Assessment after a Disaster." Annals of Emergency Medicine 54 (3) (September): 424–30

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 (1): 58–67.

O'Reilly, G. P., D. J. Houck, E. Kim, T. B. Morawski, D. D. Picklesimer, and H. Uzunalioglu. 2004. "Infrastructure Simulations of Disaster Scenarios." In Telecommunications Network Strategy and Planning Symposium. NETWORKS 2004, 11th International, 205–210. Vienna, Austria: IEEE. doi:10.1109/NETWKS.2004.1341842.

Paige, J. T, D. D Garbee, V. Kozmenko, Q. Yu, L. Kozmenko, T. Yang, L. Bonanno, and W. Swartz. 2014. "Getting a Head Start: High-Fidelity, Simulation-Based Operating Room Team Training of Interprofessional Students." Journal of the American College of Surgeons 218 (1) (January): 140–9.

Saunders, C. E, P. K Makens, and L. J. Leblanc. 1989. "Modeling Emergency Department Operations Using Advanced Computer Simulation Systems." Annals of Emergency Medicine 18 (2) (February): 134–140.

Song, H. S. and T. G. Kim. 2010. "DEVS Diagram Revised: A Structured Approach for DEVS Modeling." In Proc. European Simulation Conference, Hasselt, Belgium.

Zeigler, B. P., H. P., and T. G. Kim. 2000. Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems. 2nd Edition. New York: Academic Press.

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