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PRE-HOSPITAL SIMULATION MODEL FOR MEDICAL DISASTER MANAGEMENT

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ABSTRACT

Medical disaster management research aims at identifying methodologies and rules of best practice and evaluates performance and outcome indicators for medical disaster management. However, the conduct of experimental studies is either impossible or ethically inappropriate.

We generate realistic victim profiles for medical disaster simulations based on medical expertise. These profiles are used in a medical disaster model where victim entities evolve in parallel through a medical response model and a victim pathway model. The medical response model focuses on the pre-hospital phase which includes triage procedures, evacuation processes and medical processes. Medical decisions such as whether to evacuate or to treat the current victim are based on the RPM (respiratory rate, pulse rate, motor response) parameters of the victim. We present results for a simulated major road accident and show how the level of resource can influence outcome indicators.

1 INTRODUCTION

Until recently, reports of disaster responses primarily have been anecdotal and descriptive. There are currently no defined (validated) performance outcome measures as to what constitutes a "good" disaster response or not. Operational research in medical disaster management is limited by the fact that the conduct of prospective and randomized controlled studies under real world conditions is impossible or ethically inappropriate. Computer simulation has been used to overcome these methodological problems. For example, Escudero-Marin and Pidd (2011) use an agent based modeling system to simulate a hospital emergency department. Duguay and Chetouane (2007) describe a discrete event simulation study of another emergency department. Günal and Pidd (2010) present a literature review about discrete event simulation for performance modeling in health care. Su (2003) uses an object oriented simulation software to improve the emergency medical service of Taiwan. Brailsford and Hilton (2000) compare system dynamics and discrete event simulation to see which method should be applied in specific circumstances. Mes and Bruens (2012) develop a discrete-event simulation model for an integrated emergency post. They presented a generalized and flexible simulation model, which can be adapted to several emergency departments. McGuire (1998) dedicates a chapter to the application of simulation tools in health care. Tomasini and Van Wassenhove

(2009) discuss the evolution of supply chain management in disaster relief and the role of new players like the private sector. Van Wassenhove and Pedraza Martinez (2012) adapt supply chain best practices to humanitarian logistics.

In contrast to real world disaster exercises, computer simulations of medical disaster response allow the consecutive execution of a particular scenario with changes to the occurrences and timing of particular medical interventions or modifications to the utilization of human and material resources. This enables the evaluation of (medical) operational interventions in multiple plausible disaster situations and the development of a resource-efficient medical response without the costs and time constraints associated with full scale exercises.

The research presented in this paper is part of the SIMEDIS (Simulation for the assessment and optimization of medical disaster management in disaster scenarios for the Queen Astrid Military Hospital) project. The objective of SIMEDIS is the development of a stochastic discrete event simulation model which will be used to evaluate applicable methodologies and identify rules of best practice for medical disaster and military battlefield management in different large-scale event scenarios for the military hospital of the Belgian Defense. The four initial scenarios under investigation are an airplane crash and airport disaster, a CBRNE (Chemical, Biological, Radiological, Nuclear and Explosives) incident, mass gatherings and a hospital disaster.

A stochastic discrete event simulation model was constructed using Arena (a commercially available, SIMAN programming language-based simulation software). References for Arena include Altiok and Melamed (2007), Kelton et al. (2010) and Rossetti (2010). This simulation model is shown in figure 1 and consists of 3 interacting components: the medical response model (where the victim interacts with the environment and with the resources at the disposal of the disaster manager), the victim creation model and the victim pathway model (where the current clinical condition of every victim is monitored). The specificity of our simulation model is the fact that the victim entities will evolve through both the medical response model and the victim pathway model in parallel, while the interaction between both models is ensured through triggers. This paper focuses on the improvement of the medical response model presented in Van Utterbeeck et al. (2011). A pilot scenario depicting a major road traffic accident has been studied and has allowed the validation and verification of the simulation model and its outcome indicators (victim flow, morbidity, mortality).

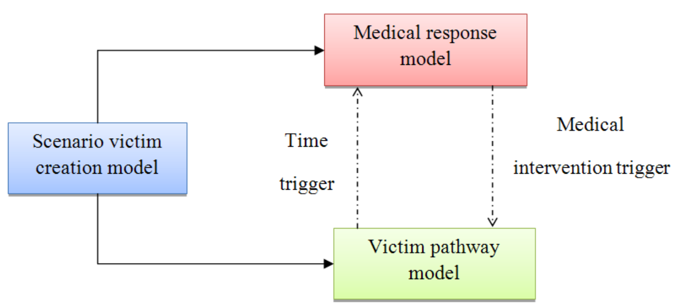

Figure 1: top-level view of the SIMEDIS simulation model

In this paper we propose an improved medical disaster model. In Van Utterbeeck et al. (2011), the medical response was limited to a single medical process on the disaster scene. We extended the model to a pre-hospital simulation model with 3 areas of interest. Concerning the victim pathway the limitation was that we could have only one medical intervention trigger per clinical condition and the implementation of the victim pathway was specific to the victim profile. We remove this limitation on the pathway definition and propose a logic to handle all the different pathways. We focus on improving the implementation of the two models and their interaction, and we show an implementation using the Arena software. In section 2 we present a way to manage multiple intervention triggers, a new implementation of the victim pathway model and new time factors for medical intervention. In section 3 we propose a more realistic medical response model. In Section 4 we describe the pilot model and discuss the results. Finally, in section 5 we conclude and discuss future work.

2 VICTIM PATHWAY

The victim creation model generates all the disaster victims needed in the simulation and maps these victims to victim profiles corresponding to the scenario. Each victim profile consists of general victim data, a set of possible clinical conditions (specifying primary survey, triage and diagnostic test data and injury severity scores) and a set of potential transitions in between.

The victim pathway model represents the clinical evolution of each victim in the disaster scenario and manages the transition of one clinical condition to another. These are triggered either by elapsed time or by medical treatment interventions (according to procedures, available equipment and supplies as well as skill levels of the on-site medical care providers).

2.1 Victim Profile

Victim profiles are created according to the hazard type and injury mechanism and their severity. The transition of one clinical condition to another clinical condition depends on time intervals (time interval of clinical deterioration if no treatment is provided, time interval to deliver the treatment and time interval of treatment procedures to be effective), treatment procedures and resources including the health care providers with their respective skill levels, medical equipment and supplies. The "no treatment" time interval and effect time interval of treatment are determined by medical experts. The treatment delivery time interval is based on experimental studies (see for examples: Cwinn et al. (1987)).

Figure 2 shows an example of a victim pathway with 24 clinical conditions (CC) and 41 transitions. CC0 is the clinical condition immediately after the impact of the disaster on the victim's health.

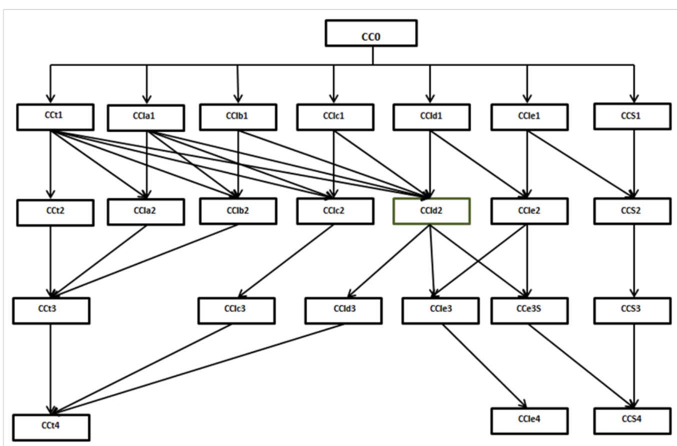

Figure 2: The different pathways of the clinical condition of a victim.

2.2 Implementation

In Van Utterbeeck et al. (2011), three possible transitions from one clinical condition to another were considered, within the victim pathway:

- only time trigger (TT);
- only one medical intervention trigger (MIT);
- one time trigger and one medical intervention trigger.

The first extension of the pathway model is the possibility to have several medical interventions per clinical condition. This modification is used to represent the incremental nature of treatment capabilities (i.e. partial treatment) and to avoid the situation where a medical intervention trigger is not performed because of the unavailability of one or more assets required for the intervention. Pathways with multiple medical intervention triggers allows medical experts to define several possible treatments in function of the available assets (with better treatment generally requiring more assets).

Each clinical condition is represented by a VBA class module. The transitions between the current clinical condition and the next one in the pathway are represented by a linked ordered list. The criterion for ordering the list is the number of medical interventions. The first item of the list is the medical intervention trigger with the highest number of interventions. A specific pathway is defined by all the clinical conditions and transitions and is implemented as a collection of instances of the class Clinical Condition.

The second extension is this “Effect Time”: for a medical intervention trigger we now define two time delays. The first one is for the delivery time of the intervention, during which medical assets are assigned to the victim. The second one is the effect time which is the time required for the intervention to have its effect on the clinical parameters of the victim. Medical assets are not seized by the victim during this time.

It is however possible that a medical intervention is initiated in the medical response model before the time trigger delay elapses or while the entity is being held until the next intervention. The entity is then sent to the “Being Treated” logic branch. The victim in question will be held there until the Medical Process logic sends the victim entity onward to the “Effect Time” logic. The victim is held during the effect time of the medical intervention and is sent to the entry station corresponding to the type of the new CC.

The third extension concerns the implementation of the victim pathway model. We implemented a new version in such way that it can handle all possible kinds of pathway with the same logic module. Each clinical condition can evolve by transitions, which are : time trigger and medical intervention triggers, only TT, only MITs and end CC. the duplicated victim enters the victim pathway model through a station (Victim Pathway IN), passes the clinical condition test. The time trigger module consists of a delay module where it will be held until the time trigger delay for this CC elapses. The value of the time trigger delay is stored in an attribute of the victim entity. The medical intervention trigger module consist of the “Being Treated” logic branch and “Effect Time” logic. When the delay elapses (time trigger or delivery and effect time), the victim entity enters the clinical adaptation module which updates the parameters to those corresponding to the next CC. The entity enters a second check module which evaluates if the new clinical condition is an end clinical condition or not. If it is not an end clinical condition, the victim entity returns to the first check else the victim enters the end clinical condition module. This logic is represented in Figure 3 below.

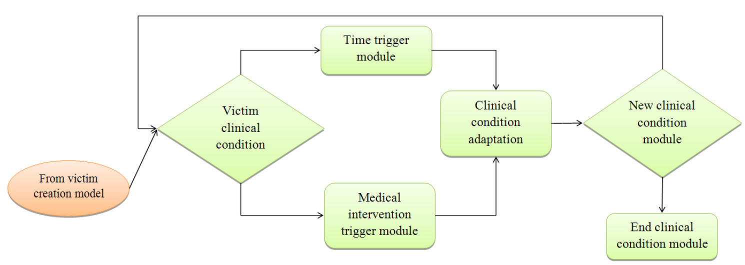

Figure 3: Clinical condition logic

3 MEDICAL RESPONSE MODEL

The medical response model represents the environment (areas of interest, time), the available human and material resources, a rule-set of medical/operational decisions and the localization of the victims as they are evacuated from one area to another. Typically, the three areas of interest are the disaster site, the forward medical post and the health care facilities of destination, these areas are depicted in the Figure 4. The non-urgent care area represents the family doctors.

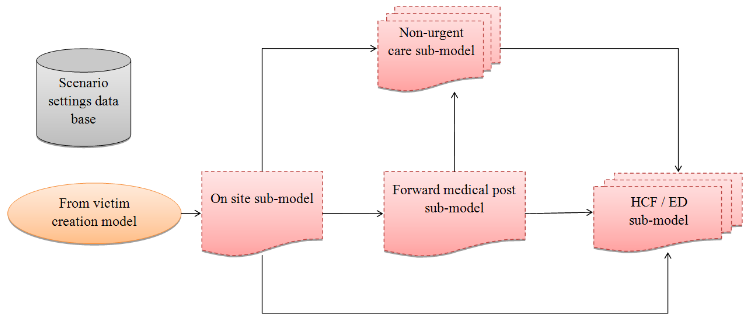

Figure 4: Medical response model

For each area of interest we can define three main processes, these processes and their interactions are illustrated in Figure 5. These processes, interactions and relations between areas of interest are function of the rescue policy. Two rescue policies have been implemented in our pre-hospital simulation model. In the "scoop & run" rescue policy, victims are directly evacuated to the health care facilities. In the "stay & play" victims are transferred to the forward medical post, where they are treated, stabilized or evacuated to health care facilities according to decision rules and availability of resources.

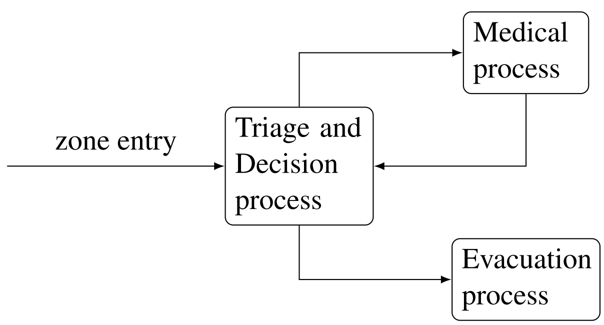

Figure 5: Area logic

In the following subsection we present the three areas of interest and detail which processes are involved as a function of the rescue policy chosen and the relation between the areas of interest.

3.1 Disaster Site

The on-site sub-model represents the disaster site, a part of the simulation model in which all the victims involved in the scenario are created in. The two rescue policies share a common initial process which consists of the primary triage. This process allows the separation of the urgent victims from the non urgent victims, the same rules are applied for both rescue policies. Victims are separated in function of their NATO triage category (defined in their profiles, NATO STANAG (1998)), T1, T4 and T2 victims are urgent and T3 victims are non urgent. The remaining processes and relation between the areas are specific to the rescue policy.

In the "scoop & run" policy, victim entities enter a second decision process called "disposition" after the primary triage. The process helps to decide whether to evacuate the victim to health care facilities or treat and/or stabilize the victim. The victims enter either the medical process or the evacuation process in function of the decision process. The evacuation to health care facilities depends on:

- the severity of the injuries, the associated survival probability and the deterioration rate or change of survival probability over time;
- the availability of ambulances or other transport vehicles;
- the transport time from the scene to health care facilities;
- the treatment capacity of the health care facilities.

In the “stay & play” policy, victims enter an evacuation process where all the urgent victims are evacuated to the forward medical post in function of their priority and the non-urgent victims are evacuated to the non-urgent care area. No medical process is modeled at the on-site sub-model as the victims are treated and/or stabilized at the forward medical post.

The aim of assigning priorities to victims when transferring them from the disaster scene or advanced medical post to health care facilities is to maximize the expected number of survivors. Priority is evaluated with the triage category and the RPM severity score. The injury severity is defined by the so-called RPM score which consist of respiratory rate, pulse rate and best motor response. The RPM score is the sum of coded values for respiratory rate, pulse rate and best motor response and takes integer values from 0 to 12 (Table1).

Table 1: RPM Score

Coded value	Respiratory rate (per minute)	Pulse rate (per minute)	Best motor response
0	0	0	None
1	1-9	1-40	Extends/flexes from pain
2	36+	41 - 60	Withdraws from pain
3	25 - 35	121+	Localizes pain
4	10-24	61 - 120	Obeys commands

Survival probability estimates were determined for each RPM value using a logistic regression on data obtained from a retrospective analysis of data from a trauma registry (Sacco et al. (2005)).

3.2 Forward Medical Post

Victims arrive at the Forward Medical Post (FMP) only if the “stay & play” policy of rescue is used as for the “scoop & run” the victims are directly evacuated to the health care facilities. The three processes and their interaction shown in the Figure 5 are used to model the FMP. First the victims enter the decision process, the rules used by this process are the same as the disposition described in the on-site area for the “scoop & run” policy. If the disposition process decides to evacuate the victim and this victim enters the evacuation process. If no means of transport are available the decision process checks the possibility of treating and/or stabilizing the victim, this victim enters the medical process. At the FMP the medical process is also composed of palliative care (if the severity of injury is too great to be treated or stabilized) and temporary mortuary. If no treatment and/or evacuation is possible the victim waits until resources are available.

3.3 Health Care Facilities

Actually the health care facilities model is limited to the arrival of the victims at the correct hospital, writing the log file, and updating the performance indicators (performance indicators are described in the subsection 4.2). A simple model of the emergency department will be implemented in the future using only the three processes presented and their interaction presented by the Figure 5. Victims will enter the decision process which will consist of the triage procedure, after this the victims will be routed according to the triage procedure either to medical processes (diagnostic test, treatment) or transferred to another department of the hospital.

4 MODEL AND RESULTS

4.1 Model

The model presented in this paper is the pilot model of the SIMEDIS project which simulates a major road traffic accident. The vehicles involved in this accident are a truck and a bus, the number of victims is 62 with the following distribution of the triage category:

- T1: 10
- T2: 15
- T3: 36
- T4: 1

We wanted to study the influence of several parameters on performance indicators. We vary the number of hospitals, Medical Mobile Teams (MMT), Advanced Life Support (ALS) ambulances, Basic Life Support (BLS) ambulances, distances and the speed of the vehicles. The time of alerting and sending medical mobile teams and ambulance is 5 minutes. If the “stay & play” policy is used, the victims are transferred from the disaster scene to the forward medical post with a travel time of 2 minutes with stretchers. The primary triage takes 30 seconds for urgent victims and 5 seconds for non-urgent victims. The distance column (in the tables 2, 3, 4 and 5) correspond to the high level of resource for the distance. The medium level is twice the distance for the high level ($distance_{Medium} = 2 * distance_{High}$) and the Low level is four times the distance of the high level ($distance_{Low} = 4 * distance_{High}$).

Table 2 presents the three levels of health care facility resources.

Table 2: Health care facility

		High				Medium				Low			
		Trauma	HTC			Trauma	HTC			Trauma	HTC		
ID	distance	Level	T1	T2	T3	Level	T1	T2	T3	Level	T1	T2	T3
1	0.3	1	5	7	18	2	3	6	15	4	1	2	9
2	2	3	2	2	9	3	2	2	9	3	1	2	9
3	4	3	2	3	14	1	5	7	18	2	2	2	10
4	7	3	2	2	9	3	2	2	9	3	1	2	9
5	9	3	2	3	9	4	1	2	9	1	4	7	17
6	10	2	3	4	14	2	3	4	14				
7	12	4	1	2	9	4	1	2	9				
8	12	2	3	6	16	2	3	6	16				
9	14	4	1	2	9								
10	15	2	3	6	15								
11	16	4	1	3	9								
12	19	4	1	3	8								

The Hospital Treatment Capacity (HTC) is the number of victims that the hospital can handle in one hour for each triage category. The HTC for each level of resource is presented in Table 2.

Each mobile medical team is composed of a doctor and a nurse. The first MMT assumes the role of medical director, the medical director ensures the logistic part for medical rescue teams. The second MMT does the primary triage on the scene and when the primary triage is finished they help in medical interventions at the FMP or on site (in function of the rescue policy). The third and following MMT ensure directly medical interventions at FMP or on-site. T1 victims need a doctor and a nurse to treat or stabilize them, T2 victims need one doctor or nurse depending on available manpower. Table 3 shows the availability of medical mobile teams as a function of the three level of resources. Tables 4 and 5 present

Table 3: MMT

			ID	Distance	Number
High	Medium	Low	1	0,3	1
			2	2	0/1/1
			3	4	1
			4	9	1
			5	10	1
			6	12	1
			7	15	1

the three levels of evacuation means available. T1 victims can only be evacuated by ALS ambulances, T2 victims are evacuated by BLS ambulances or ALS ambulances if there are no more T1 victims at the forward medical post and/or on site area. ALS and BLS ambulances can transport only one victim per journey.

Table 4: Ambulance BLS

			ID	Distance	Number
High	Medium	Low	1	1	2
			2	3	1
			3	5	1
			4	9	2
			5	11	2
			6	11	2
			7	12	1
			8	13	2
			9	14	1
			10	15	2
			11	16	1
			12	17	1
			13	17	1
			14	18	2
			15	19	1
			16	20	1

The last input parameter we studied is the velocity of rescue vehicle : MMT, ALS ambulances and BLS ambulances.We considered two values for the velocity : High = 60 km/h and Low = 30 km/h.

4.2 Outcome Indicators

In the previous section, input parameters have been described. In this section we present the outcome indicators used for this paper. We chose 4 outcome indicators which are: mortality, morbidity, time of clearance, and last arrival at the health care facilities.

Table 5: Ambulance ALS

			ID	Distance	Number
High	Medium	Low	1	1	1
			2	3	0
			3	4	1
			4	8	1
			5	10	0
			6	12	1
			7	14	0
			8	16	1
			9	18	0
			10	20	1

The first indicator is the mortality, which consists of two sub-indicators: the “immediate death” and the “pre-hospital death”. The immediate death corresponds to a victim who dies before being seen by any medical rescue team. The pre-hospital death is when a victim dies after the primary triage and before the arrival at the health care facilities.

The second indicator is the morbidity, which corresponds to a deterioration of the RPM score or Glasgow coma scale score between the primary triage and the arrival of the victims at HCF. This deterioration can lead to permanent injury or incapacity in the future life of the victims.

The third outcome indicator is the time of clearance defined as the time necessary for the number of victims at the disaster scene to reach 0. The number of victims decreases if the victim is evacuated or died. We split the time of clearance for each triage category, so we define the time of clearance for T1, T2 and T3.

The last outcome is the time needed by the last victim to arrive at the health care facilities. We split the time of arrival for the last victim for each triage category, so we define last T1, T2 and T3 arrival at health care facilities.

4.3 Results

For each possible couples of parameters, we ran 30 replications. The total number of couples is $2\times 3\times 3\times 3\times 2 = 108$. Therefore $30\times 108 = 3240$ replications where needed to obtain all the results presented below. Once all the results were available for each outcome indicators, we tested them with an ANOVA test or an Independent Samples Student test in function of each parameter in order to see their influences. Table 6 shows which input parameters have a significant influence on which outcome indicators.

Table 6: Results

	Death	Immediate Death	Time Clearance T1	Time Clearance T2	Last T1 HCF	Last T2 HCF
Rescue policy	X		X	X	X	
Hospitals	X		X	X	X	X
Ambulances	X	X		X	X	X
Distance						
Speed	X	X	X	X	X	X

We can see that the policy of rescue has a significant influence on the total number of dead, the time for the victims to be evacuated from the disaster site and to the hospital. The time to evacuate the victims

T1 and T2 from the disaster site is shorter in the “stay & play” policy of rescue. In this scenario, the victims are directly evacuated from the disaster site via the primary evacuation to a place near the site, the Forward Medical Post, where the victims are sorted, treated and prepared for evacuation. In the “scoop & run” policy there is no primary evacuation. The victims are evacuated from the disaster site directly to the hospital. However, the evacuation can sometimes be delayed if a treatment is needed or if the hospital capacities already are busy. On the contrary, the time for the last T1 to arrive at the hospital is shorter with the “scoop & run” policy of rescue, where the victims are directly evacuated to the hospital, than with the “stay & play” policy of rescue, where they first go to the Forward Medical Post for triage, treatment and preparation for evacuation. There is no influence of the policy of rescue in the immediate dead because the time for the ambulances to arrive on the disaster site is the same in the two policies. But, as said earlier, the policy of rescue has an influence on the total number of dead, which is lower in the “stay & play” policy. We can see in the Figure 6 that the median in the “stay & play” policy is lower. The quartile 1 and 3 are quite the same for the two policies, but the interquartile interval between quartile 3 and 4 is bigger in the “scoop & run” policy. It can be explained by the fact that the victims receive a treatment earlier in “stay & play” policy than in the “scoop & run” policy, giving the more critical victims more chance to stay alive.

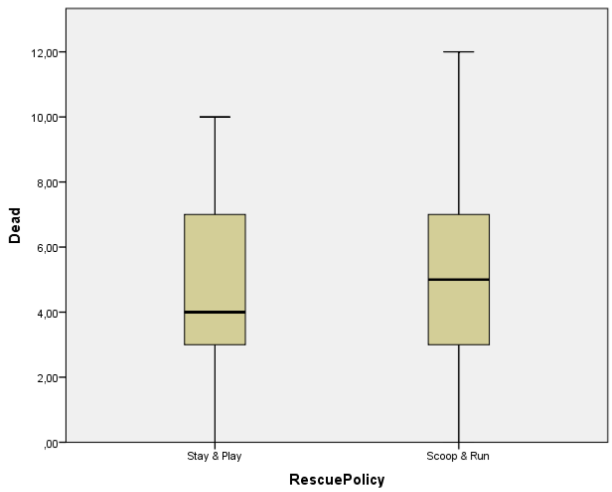

Figure 6: Death as function of rescue policy

There is an influence of the type of hospitals on nearly all the outputs: only the number of immediate dead is not influenced by it, which is normal because that output depends only on the medical staff on the site. All the other outputs are lower when the capacities of the hospitals are high: in this case, there are more places available to evacuate the victims, which results in a shorter time to evacuate all the victims and consequently in fewer dead.

The number of dead, immediate dead, the time to evacuate T1 and T2 from the site and to the hospital are significantly influenced by the number of ambulances in the two policies of rescue. There are fewer dead when there are more ambulances, which is normal: the more ambulances there are, the faster the victims are seen by medical staff. With the same logic, the victims are evacuated more quickly when there are more ambulances.

The speed influences significantly all the outputs. When the ambulances can go faster, they arrive earlier on the disaster site and the victims are seen faster. That results in less dead and immediate dead and the site is more rapidly evacuated.

5 CONCLUSIONS AND FUTURE WORK

We presented a simulation model of pre-hospital medical disaster response using realistic victims. The simulation model has been developed specifically to allow medical researchers to use it without changing the model in ARENA. Improvements have been made to the main components of our previous model (Van Utterbeeck et al. (2011)). The first one consists of the victim modeling and aims at representing more realistic victims and at defining pathways with multiple intervention triggers which enables the use of scarce resources for treatment. The victims profiles used in our model are highly realistic and their validity is ensured by experienced professionals in disaster medical management. The second one concerns the medical response model, where we define three main zones: disaster scene, forward medical post and hospital, which are the essential parts of the pre-hospital medical response system. The decision process based on the RPM (respiratory rate, pulse rate, motor response) score, the evolution of the survival probability over time and evacuation information (ambulance availability and travel time) allows choosing between treatment or evacuation of the victim. Threshold values used in the decision process have been validated by medical experts.

A pilot case study describing a major road traffic accident has been studied for verification and validation of the implemented medical response and victim pathway models and for performance and outcome measures evaluation. We presented the impact of several input parameters on four outcomes measures. This validation will also be useful to analyze the flexibility of our model and to improve the user interface for medical researchers. The medical response model will be extended to the emergency room processes. After the validation phase, future works will focus on continuing the development of the victim profiles database and four scenarios will be investigated: an aeronautical catastrophe, a CBRNE (Chemical, Biological, Radiological, Nuclear and Explosives) incident, mass gatherings and hospital catastrophes. The expected outcomes of the SIMEDIS project are evidence based recommendations and rules of best practices for optimal disaster management and medical battlefield management in different large-scale event scenarios, as well as evidence based recommendations for teaching, training and research in medical disaster management.

REFERENCES

Altiok, T., and B. Melamed. 2007. *Simulation Modeling and Analysis with Arena*. Academic press.

Brailsford, S. C., and N. A. Hilton. 2000. "A Comparison of Discrete Event Simulation and System Dynamics for Modeling Healthcare Systems". In *Proceedings of ORAHS*, 18–39. School of Management University of Southampton, UK.

Cwinn, A. A., P. T. Pons, E. E. Moore, J. A. Marx, B. Honigman, and N. Dinerman. 1987. "Prehospital Advanced Trauma Life Support for Critical Blunt Trauma Victims". *Annals of Emergency Medicine*:399–403.

Duguay, C., and F. Chetouane. 2007, April. "Modeling and Improving Emergency Department Systems using Discrete Event Simulation". *SIMULATION* 83 (4): 311–320.

Escudero-Marin, P., and M. Pidd. 2011. "Using ABMS to simulate emergency departments". In *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, 1239–1250. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Günal, M. M., and M. Pidd. 2010, March. "Discrete event simulation for performance modelling in health care: a review of the literature". *Journal of Simulation* 4 (1): 42–51.

Kelton, W. D., R. P. Sadowski, and D. A. Sadowski. 2010. *Simulation with Arena*. 5 ed. McGraw-Hill.

McGuire, F. 1998. "Simulation in healthcare". In *Handbook of Simulation : Principles, Methodology, Advances, Applications, and Practice*, edited by J. Banks, Chapter 17, 605–627. Wiley-Interscience.

Mes, M., and M. Bruens. 2012. "A generalized simulation model of an integrated emergency post". In *Proceedings of the 2012 Winter Simulation Conference*, edited by C. Laroque, J. Himmelspach,

R. Pasupathy, O. Rose, , and A. M. Uhrmacher, 872–882. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

NATO STANAG, 2879 1998. "Principles of Medical Policy in the Management of a Mass Casualty Situation".

Rossetti, M. D. 2010. *Simulation Modeling and Arena*. Wiley.

Sacco, W. J., D. M. Navin, K. E. Fiedler, R. L. Waddell II, W. B. Long, and R. F. Buckman Jr.. 2005. "Precise formulation and evidence-based application of ressource-constrained triage". *Acad. Emerg. Med.* 12 (8): 759–770.

Su, S. 2003, December. "Modeling an emergency medical services system using computer simulation". *International Journal of Medical Informatics* 72 (1-3): 57–72.

Tomasini, R. M., and L. N. Van Wassenhove. 2009. "From preparedness to partnerships: case study research on humanitarian logistics". *International Transactions in Operational Research* 16:549–559.

Van Utterbeeck, F., C. Ullrich, E. Dhondt, M. Debacker, J. L. Murray, and S. Van Campen. 2011. "Generating and Managing Realistic Victims for Medical Disaster Simulations". In *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, 2679–2689. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Van Wassenhove, L. N., and A. J. Pedraza Martinez. 2012. "Using OR to adapt supply chain managemman best practices to humatirian logistics". *International Transactions in Operational Research* 19:307–322.

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