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GENERATING AND MANAGING REALISTIC VICTIMS FOR MEDICAL DISASTER SIMULATIONS

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ABSTRACT

We propose a methodology to generate realistic victim profiles for medical disaster simulations based on victims from the VictimBase library. We apply these profiles in a medical disaster model where victim entities evolve in parallel through a medical response model and a victim pathway model. These models interact in correspondence with the time triggers and intervention triggers from VictimBase. We show how such a model can be used to assess the impact of asset availability and implemented victim prioritisation rule on the clinical condition of the victims.

1 INTRODUCTION

Medical disaster management is a young medical discipline which requires a solid scientific foundation. However, it is obviously impossible and/or ethically inappropriate to identify the experimental and control groups essential for the hypothesis testing which is required to conduct scientific randomized controlled clinical trials. 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.

An improved methodology is clearly needed to judge and evaluate the effectiveness and adequacy of health and relief services provided during disaster medical response. Computer simulation has already been widely applied in health care studies. For example, Brenner et al. (2010) develop a simulation model based on process and flow data to model 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. McGuire (1998) dedicates a chapter to the application of simulation tools in health care.

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 aeronautical catastrophe, a CBRNE (Chemical, Biological, Radiological, Nuclear and Explosives) incident, mass gatherings and hospital catastrophes. The simulation model for these scenarios will be based on three principal components: the victim pathway model, the medical response model and a set of outcome performance measures. This paper focuses on the development of a realistic victim pathway model and its interaction with a generic medical response model.

The remainder of the paper is organized as follows. In Section 2 we introduce the VictimBase project. We will use VictimBase victims to define the victim profiles used in our simulation model, including all parameters as well as the evolution of their clinical conditions. In Section 3, we propose the victim profile used in our simulation model. In Section 4, we detail the implementation of the victim pathway model and its interaction with the medical response model. In Section 5, we propose the results of a small test case. Finally, in Section 6 and 7 we conclude and discuss future work.

2 VICTIMBASE

VictimBase is an on-line tool designed to support the medical community in creating dynamic victims for use in disaster medicine exercises. The tool is specifically focused on creating a database of disaster victims to be used in medical disaster management exercises and research, however; the individual victims can also be used for small incident simulation and training.

VictimBase was developed following an iterative user-centered design process. Representatives from across the international medical community were engaged at various stages of development to provide input into the definition of the user requirements of the system. As such, VictimBase will facilitate the use of victims across a number of different platforms.

Each victim includes three primary components:

- General victim data;
- A set of clinical conditions which each include: Primary Survey, Triage and Diagnostic Test data;
- A set of transitions, which are time trigger based or intervention trigger based.

The general victim data provides an overview of the victim as well as the victim parameters that do not change over time or as the result of a clinical intervention (e.g., name, gender, anthropometric data, injury or illness and medical history). A clinical condition (CC) refers to a specific victim state. A complete victim includes multiple CCs. Each CC consists of Primary Survey data, Triage data and Diagnostic Test data. Figure 1 illustrates the structure of a victim created using VictimBase.

When creating a victim, the author will first define the Primary Survey, Triage and Diagnostic Test parameters for the Initial CC. The Initial CC (CC0) describes the victim immediately after the incident happens. Once the data for CC0 has been inputted, the author will enter additional CCs to represent the no treatment pathway. The no treatment pathway represents the consecutive clinical states the victim will pass through if no treatment is administered. The second pathway defined is the optimal treatment pathway, which represents the best possible outcome for the victim if all resources needed (i.e., disaster or medical care providers, equipment and medications) were available. Following the definition of the no treatment and optimal treatment pathways, additional CCs and alternate pathways can be created. The number of

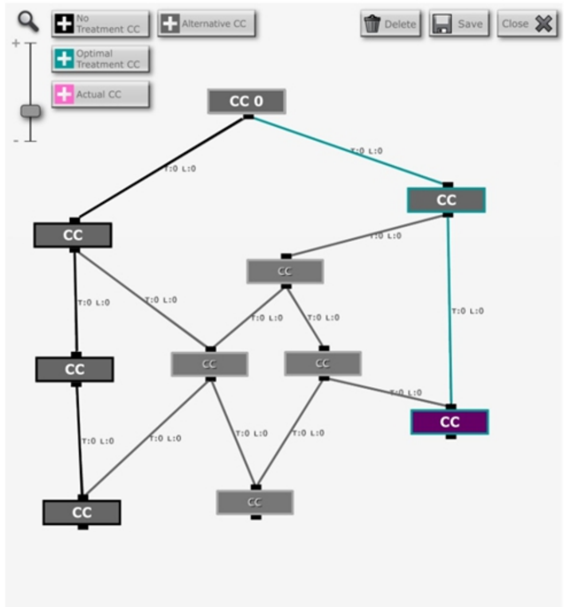

Figure 1: VictimBase victim structure.

CCs between the Initial CC and an End CC is defined by the author based on the victims injuries, time and administered interventions.

Validity of the VictimBase content is managed by the account system. Medical professionals are granted authorship by the European Master in Disaster Management Academy, the founder of the VictimBase project. Institutes and organizations who want to use VictimBase content must acquire a user account from the Academy. Each author must indicate the use permission of individual victims or groups of victims and in which medium(s) the victims can be used, for example in education, exercises and/or research.

All victims are accessible through the on-line VictimBase Library. Both users and authors can filter this library to search for victims with specific parameters. Selected victims can be grouped and labeled for future use. Furthermore, authors and users can elect to share their groups with other users who are designing similar exercises. Individual victims and groups of victims can be exported in a number of different formats. The possible export formats for each victim are automatically identified by VictimBase based on the victims pathway design.

3 VICTIM PROFILES

The victim pathway model used in SIMEDIS will be based on victim profiles. Each victim profile is generated using a victim from the VictimBase library. Although VictimBase allows CCs with multiple intervention triggers, we will only use profiles with maximum one intervention trigger per CC. As such, each victim's current medical status is uniquely identified by his clinical condition and there are two possibilities to evolve towards a different clinical condition: either the time interval defined by the time trigger elapses or the victim receives the medical attention defined by the medical intervention trigger before said time trigger elapses. The application of a medical intervention trigger requires the presence of specific assets. We consider three types of assets: qualified personnel (each individual has an associated skills matrix which specifies the interventions that he can undertake), medical material and consumables. The list of assets required for a medical intervention trigger is predefined in the model.

We will use two example victim profiles to illustrate the working of the model and to obtain the results presented in Section 5. The pathways of these two profiles have the same shape and are shown in Figure 2. Each victim starts with the initial clinical condition tag CC0. Time triggers (t_i) or medical intervention triggers (T_i) can change the clinical condition. An end clinical condition is a stationary status of the victim, which will not evolve by the passing of time and/or the application of a medical intervention. In Figure 2, there are three possible end clinical conditions: CC3 (reached when no timely medical interventions are applied), CC5 (reached when a single medical intervention was applied) and CC6 (reached after two timely medical interventions). The remaining clinical conditions represent transient states, which will evolve by either the passing of time or the timely application of a medical intervention. For the sake of this example, we accept that CC3 is the “worst” end CC and CC6 the “best” end CC.

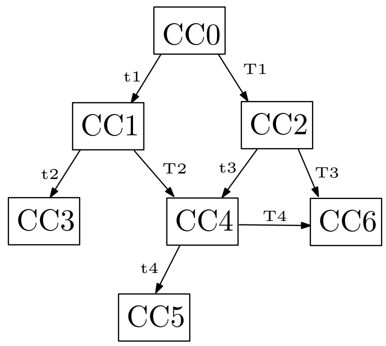

Figure 2: Example victim pathway.

Table 1 regroups the time trigger parameters for both victim profiles. Table 2 details the required assets for the various medical intervention triggers. Table 3 gives the average time required for the different medical interventions.

Table 1: Time trigger values.

Profile ID	t1 (min)	t2 (min)	t3 (min)	t4 (min)
1	40	75	125	300
2	50	100	200	350

Table 2: Assets required for the medical interventions.

Profile ID	Intervention	Skill 1	Skill 2	Skill 3	Material 1	Material 2	Consumable 1
1	T1	1	0	0	1	0	1
1	T2	0	1	0	0	1	1
1	T3	0	0	1	1	0	1
1	T4	1	1	0	0	1	1
2	T1	0	1	0	0	1	0
2	T2	1	0	0	1	0	1
2	T3	0	0	1	1	0	0
2	T4	1	1	0	0	1	1

4 MEDICAL DISASTER MODEL

4.1 Introduction

A disaster scenario is composed of incidents associated to a point in space and time, expressed in terms of categories, material damage and victims, on which the disaster manager has no control. The decision making process of the disaster manager is expressed in terms of material and human resources made

Table 3: Average medical intervention durations.

Pathway ID	T1 (min)	T2 (min)	T3 (min)	T4 (min)
1	10	10	5	6
2	8	8	4	3

available and their assignment to tasks in space and time. The consequences of these decisions are assessed and this gives rise to rules of best practice.

Our medical disaster model contains two major components: a medical response model (where the victim interacts with the environment and with the resources at the disposition of the disaster manager) and a 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 (Figure 3). In this section we focus on the implementation of these two models and their interaction, and we show an implementation using the Arena software. References for Arena include Altiok and Melamed (2007), Kelton et al. (2010) and Rossetti (2010).

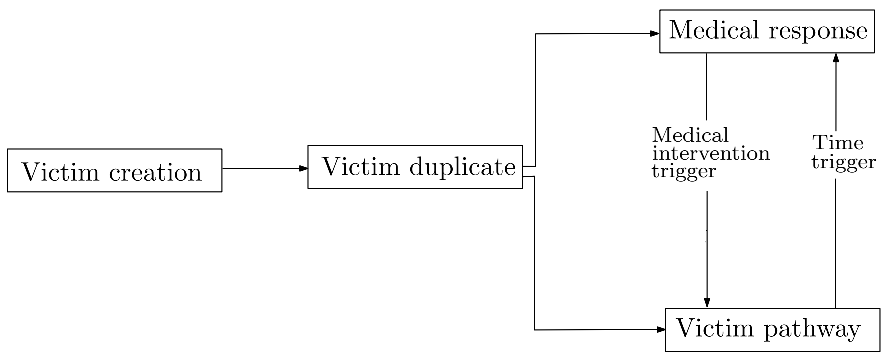

Figure 3: Disaster model.

The *victim creation* module creates all the victims of the scenario (in most disaster scenarios all the victims will exist at the simulation start, immediately after the disaster event which marks the start of the scenario). For every victim we define the specific victim profile which corresponds with the nature of his injuries in an attribute. The number of victims generated and the mapping of the victims to victim profiles is of course scenario-specific.

The *victim duplicate* module creates a copy of the victim entity. Subsequently, both copies are assigned an attribute “Entity ID” which contains the SIMAN identifier of the corresponding duplicate. This attribute is crucial for the communication between the medical response model and the victim pathway model.

The *medical response* model describes the environment (victims, places, time related factors, . . .), the resources at the disposition of the disaster manager (medical personnel, equipment, means of transportation, . . .) as well as the operational procedures and decision making models used (triage procedure, assignment of victims to hospitals logic, ambulance dispatch logic, . . .).

The *victim pathway* model contains the victim profiles and all the information found in the corresponding VictimBase victim descriptions. This includes for example the required parameters for triage procedures and diagnosis and all information concerning the clinical conditions. The final victim pathway model will be a modular library containing a large number of victims which can be used to generate the required random victims for the scenario under consideration. The two victim profiles used as an example throughout this paper have been described in Section 3.

4.2 Medical Response Model

The medical response model represents the intervention of the rescue teams (firemen, medical staff, civil guards, ...) in order to rescue, treat and evacuate victims. A typical simple medical response model contains three zones (the disaster site, the advanced medical post and the hospital) and the evacuation procedures from one site to another. Depending on the scenario and the procedure followed by the disaster manager, medical interventions can take place in each of the zones or during the evacuation process. Medical interventions follow the medical process logic defined below (see Figure 4).

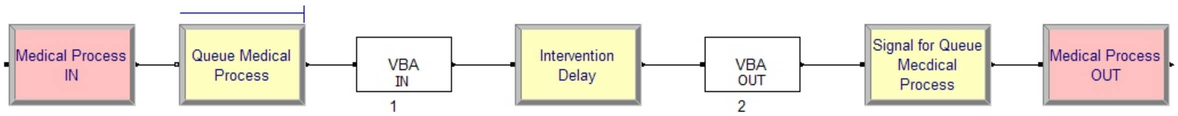

Figure 4: Medical process logic.

The victims enter the medical process through the entry station (Medical Process IN), which is immediately followed by the medical process queue (linked with a hold until signal ARENA module). Queuing discipline is based on a priority attribute, whose exact value has been set depending on the clinical parameters of the victim and the applied triage logic. Subsequently a signal is sent which releases all the victim entities in the medical process queue. The victims (in order of priority) now enter the VBA IN module where we check both the presence of the required assets in the zone as well as their current availability, as shown in the pseudo-code of Algorithm 1 below. If the required assets are present but currently being used for the treatment of another victim, the victim is sent back to the medical process queue through the Medical Process IN station. Note that seized consumables lead to the permanent reduction of the number of that asset present in the zone, while other assets are only temporarily unavailable. To move the duplicate entities in the parallel model using VBA after a trigger, we use the method "EntitySendToStation". The tricky part of this relocation is remembering to cancel the next planned calendar event of the duplicate using the method "CalendarCancelEntity".

Algorithm 1 Medical process VBA IN

Check if medical intervention is required
if No medical intervention trigger defined for current CC **then**
    Send entity to station OUT
    EXIT
end if
Check asset presence in zone
if At least one asset not present **then**
    Send entity to station OUT
    EXIT
end if
Check current availability of assets
if At least one asset currently not available **then**
    Send entity to station IN
    EXIT
end if
Seize assets
Locate the duplicate entity in the victim pathway model
Send the duplicate entity to the "Being treated" station

The victim entity is then delayed for a random time period (drawn from a distribution linked to the medical intervention) before entering the VBA OUT module, where the pseudo-code of Algorithm 2 below is executed. The parameters corresponding with the next CC are read by the VBA module from an excel-sheet which contains all the victim pathway data. Finally, now that the assets have been freed and before the victim leaves the medical process, a signal is sent to the medical process queue in order to release any victims awaiting treatment there.

Algorithm 2 Medical process VBA OUT

```
Release non-consumable assets
if Next CC is an end CC then
    Update medical intervention trigger parameters to end CC
else
    Update medical intervention trigger parameters to next CC
end if
Update clinical parameters to next CC
Locate the duplicate entity in the victim pathway model
if Next CC is an end CC then
    Update time trigger parameters of the duplicate to end CC
else
    Update time trigger parameters of the duplicate to next CC
end if
Send the duplicate entity to the entry station of next CC
```

4.3 Victim Pathway Model

The victim pathway model is illustrated in Figure 5 below, which shows the generic logic associated with a clinical condition. The victim entity enters through an entry station and if this is an end clinical condition then it is immediately disposed of. In all other cases, the victim is sent to a delay module where it will be held until the time trigger delay for this CC elapses. It is however possible that a medical intervention is initiated in the medical intervention model before the time trigger delay elapses. In this case the Medical process VBA IN logic will remove the victim from the delay module and sent it to the "Being treated" station (Figure 6). The victim in question will be held there until the Medical Process VBA OUT logic sends the victim entity onwards to the next CC. If no timely medical intervention is initiated, then the victim triggers a VBA module where the pseudo-code of Algorithm 3 below is executed. The parameters corresponding with the next CC are again read by the VBA module from an excel-sheet which contains all the victim pathway data. Finally, a route module sends the victim entity to the entry station of the new CC.

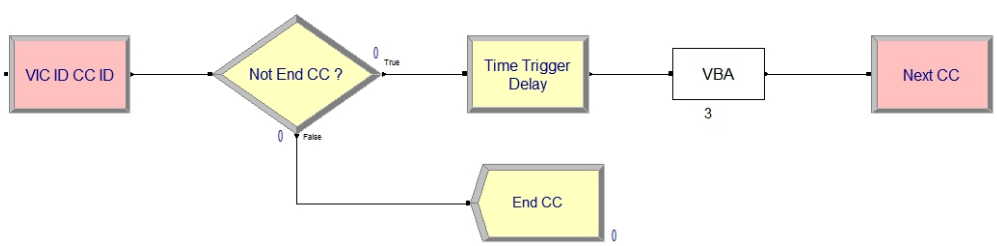

Figure 5: Clinical condition logic.

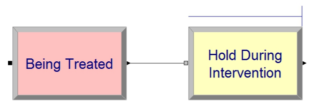

Figure 6: Being treated logic.

Algorithm 3 Clinical condition VBA

if Next CC is an end CC **then**
  Update time trigger parameters to end CC
else
  Update time trigger parameters to next CC
end if
Locate the duplicate entity in the medical response model
if Next CC is an end CC **then**
  Update medical intervention trigger parameters of the duplicate to end CC
else
  Update medical intervention trigger parameters of the duplicate to next CC
end if
Update clinical parameters of the duplicate to next CC

5 RESULTS

The test case results presented in this section serve as proof of concept for the medical disaster model presented in Section 4. We use the two example victim profiles from Section 3 and a simplified medical response model with a single medical process (at the disaster site zone). We consider 8 scenarios: 2 different settings for the assignment of the priority in the medical process queue combined with 4 different settings for the assets present in the zone. In each scenario we generate 20 victims (10 of each profile ID) and we note the number of victims in each end CC for each scenario. Priority rule 1 assigns a higher priority to victim ID1 than to victim ID2, and within each victim ID the highest priority to the CC with the lowest index (i.e., victim ID1 CC0 has the highest priority and victim ID2 CC6 has the lowest priority). Priority rule 2 is identical but assigns the highest priority to victim ID2. The 4 settings for the assets are shown in Table 4 below.

Table 4: Assets present in the zone.

	Skill 1	Skill 2	Skill 3	Material 1	Material 2	Consumable
Assets 1	2	2	2	2	2	20
Assets 2	2	2	2	2	2	10
Assets 3	1	1	1	1	1	20
Assets 4	1	1	1	1	1	10

Table 5 shows the results obtained using priority rule 1 for the 4 different assets settings. We remind that CC6 is the “best” end CC. When we have the highest number of assets (assets 1), all victims end in CC6. When the number of consumables is reduced (assets 2), then the victims with profile ID1 end in CC5 instead. Indeed, despite their higher priority, victims with profile ID1 require more consumables for their treatment than ID2. When the available skills and materials are reduced but the setting for consumables is high (assets 3), we obtain a mix of CC5 and CC6. Finally, if the number of consumables is low as well (assets 4), nearly 50 percent of the victims end in the undesirable CC3.

Table 6 shows the results obtained using priority rule 2 for the 4 different assets settings. When we have the highest number of assets (assets 1), we obtain the same results as with priority rule 1. As soon

Table 5: Results with priority rule 1.

	ID1 CC3	ID1 CC5	ID1 CC6	ID2 CC3	ID2 CC5	ID3 CC6
Assets 1	0	0	10	0	0	10
Assets 2	0	10	0	0	0	10
Assets 3	0	5	5	0	5	5
Assets 4	4	2	4	5	0	5

as the assets are reduced, there are significant changes: the results for victims with profile ID2 are greatly improved when the number of skills and materials are low (assets 3 and 4), while the outcome for victims with profile ID1 is clearly worse than with priority rule 1. It is clear that the number of consumables plays an important role for ID1 victims, which is reflected by the fact that the results obtained with assets 3 are better than with assets 2.

These results clearly show the influence of both the priority rule and the available assets on the end CC of the victims. It is interesting to note that optimal priority rule selection and asset availability are not necessarily independent: imagine for example that CC3 corresponds for both victim IDs with the death of the victim, and that the objective for priority rule selection is simply the minimization of the number of victims with this end CC. Under these assumptions, there is indifference between the two priority rules for assets 1, priority rule 1 is optimal for assets 2 and 3 but priority rule 2 is optimal for assets 4.

Table 6: Results with priority rule 2.

	ID1 CC3	ID1 CC5	ID1 CC6	ID2 CC3	ID2 CC5	ID3 CC6
Assets 1	0	0	10	0	0	10
Assets 2	3	4	3	0	0	10
Assets 3	2	2	6	0	0	10
Assets 4	5	5	0	0	1	9

6 CONCLUSIONS

We propose a victim profile for medical disaster simulations based on victims from the VictimBase library. These victims are highly realistic and their validity is assured by the VictimBase account system: only medical professionals who are granted authorship by the European Master in Disaster Management Academy can create these victims. This victim profile is applied in a medical disaster model where victim entities evolve in parallel through a medical response model and a victim pathway model. We show the implementation in Arena of the interaction between a medical process in the medical disaster model and a victim profile in the victim pathway model. These interactions correspond with the time triggers and intervention triggers from VictimBase. We provide a simple example that shows how such a model can be used to assess the impact of asset availability and the decision rule used to prioritize the victim being treated on the clinical condition of the victims.

7 FUTURE WORK

In future work a more complex and realistic medical response model will be developed. The victim pathway model will be expanded into a library containing a large number of victim profiles. These components will then be used to investigate several scenarios: a pilot case study describing a major road traffic accident will be studied for verification and validation of the implemented medical response and victim pathway models and for performance and outcome measures evaluation. Afterwards, the four scenarios described in the introduction will be developed. 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.

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