Accuracy of Computer Simulation to Predict Patient Flow during Mass-Casualty Incidents

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Abbreviations:
SIM = computer simulation
UAH = University of Alberta Hospital
VLE = virtual, live exercise

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Abstract

Introduction: Although most hospitals have an emergency department disaster plan, most never have been implemented in a true disaster or been tested objectively. Computer simulation may be a useful tool to predict emergency department patient flow during a disaster.

Purpose: The aim of this study was to compare the accuracy of a computer simulation in predicting emergency department patient flow during a mass-casualty incident with that of a real-time, virtual, live exercise.

Methods: History, physical examination findings, and laboratory results for 136 simulated patients were extracted from the **disastermed.ca** patient database as used as input into a computer simulation designed to represent the emergency department at the University of Alberta Hospital. The computer simulation was developed using a commercially available simulation software platform (2005, SimProcess, CACI Products, San Diego CA). Patient flow parameters were compared to a previous virtual, live exercise using the same data set.

Results: Although results between the computer simulation and the live exercise appear similar, they differ statistically with respect to many patient benchmarks. There was a marked difference between the triage codes assigned during the live exercise and those from the patient database; however, this alone did not account for the differences between the patient groups. It is likely that novel approaches to patient care developed by the live exercise group, which are difficult to model by computer software, contributed to differences between the groups. Computer simulation was useful, however, in predicting how small changes to emergency department structure, such as adding staff or patient care areas, can influence patient flow.

Conclusions: Computer simulation is helpful in defining the effects of changes to a hospital disaster plan. However, it cannot fully replace participant exercises. Rather, computer simulation and live exercises are complementary, and both may be useful for disaster plan evaluation.

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Introduction

Computer simulations of patient flow potentially may be useful to model emergency department flow. These simulations may be useful, particularly for modeling disaster situations, as few hospitals ever experience true disasters. Predicting patient flow is paramount for designing a disaster plan. Nonetheless, studies validating the use of computer simulations in predicting emergency department flow during disasters are lacking.

This study was designed to assess the accuracy of a computer simulation in predicting a hospital's emergency department flow by comparing it to a previously performed virtual, live exercise (VLE) using the same simulated disaster victims.

CTAS Code		Scenario V1	Scenario V2	Scenario V3	Scenario V4	VLE
1	Arrival to triage	0	0	0	0	4
	Arrival to room assignment	47	49	13	6	
	Arrival to MD	65	65	14	10	6
	Arrival to admission	0	485	314	313	57
	Arrival to discharge	112	112	81	71	
2	Arrival to triage	0	0	0	0	10
	Arrival to room assignment	0	0	52	30	
	Arrival to MD	16	17	49	49	15
	Arrival to admission	226	368	258	212	74
	Arrival to discharge	204	195	146	97	42
3	Arrival to triage	0	0	0	0	9
	Arrival to room assignment	18	28	10	0	
	Arrival to MD	77	75	13	19	15
	Arrival to admission	130	317	184	169	66
	Arrival to discharge	106	121	72	93	55
4	Arrival to triage	0	0	0	0	12
	Arrival to room assignment	0	0	27	0	
	Arrival to MD	134	0	30	105	26
	Arrival to admission	0	0	0	0	53
	Arrival to discharge	75	106	86	101	62
5	Arrival to triage					9
	Arrival to room assignment					
	Arrival to MD	261				25
	Arrival to admission					48
	Arrival to discharge		111	79	77	29

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Table 1—Comparison to four "V" scenarios time stamps in minutes (VLE = virtual, live exercise)

Methods

Setting

The University of Alberta Hospital (UAH) is a large, academic, tertiary care hospital located in Edmonton, Alberta Canada. The UAH manages approximately 70,000 acute care visits per year. The Edmonton community has a population of approximately one million people and is managed by a single health authority. There are eight acute care hospitals in the Capital Health Region. All hospitals, with the exception of three, are urban teaching hospitals staffed by full-time emergency physicians whose responsibilities include medical student and resident education.

Although the UAH has a detailed, written disaster plan, the plan has never been invoked during a disaster. However, it has been reviewed in several tabletop exercises and a VLE. The principal author of this paper developed the plan and has managed its administration for the past eight years. Physicians and residents are given instruction in the hospital emergency incident command system (HEICS) and the UAH plan on a recurring basis. Furthermore, the disaster plan and an online tutorial are available at all times. During a disaster, the hospital will continue to triage using the five-level Canadian Triage and Acuity Scale.[1]

Model

One hundred thirty-six simulated disaster patients were obtained from the **disastermed.ca** patient database. The sample size (n = 136) was deemed adequate to stress a large, tertiary care hospital.[2] The database provided a set of simulated patients representing a multiple-casualty vehicle collision.

The computer simulation was developed using SimProcess (2005, CACI Products, San Diego, CA) on a 1.8 Mhz Athlon 64 computer (Advanced Micro Devices, Sunnyvale, CA) under the SUSE Linux 9.2 operating system (2005, Novell, Provo, UT). SimProcess is a commercially available process simulation software package capable of combining process mapping with discrete event simulation. SimProcess models are constructed using a graphical, user interface similar to flowcharting.

The computer simulation was designed to represent, as accurately as possible, the emergency department at the UAH. The design of the simulation is sufficiently complex and cannot be represented on paper easily (for an interactive representation of the model, visit: **http://www.disastermed.ca/sim/index.html**). The number and location of beds and the patient flow were designed to mimic the usual operations of the department. Using a set of randomly generated patients, the model was accurate when compared to average data collected as part of an emergency department flow study at the UAH.[3]

The computer model initially ran for a simulated 1,000-hour period, as a warm-up, to allow the patient flow to reach equilibrium. During this time, patients were created at random representing a typical pattern at the UAH. After the initialization phase, random patient generation was stopped and the simulated patients from the **disastermed.ca** database began to arrive. During the initial phases of study design, it was decided that the usual baseline patient flow would be stopped during the simulation. Although this may not be representative of an actual disaster, as it is presumed that

CTAS Code		Scenario V1	Scenario V2	Scenario V3	Scenario V4	VLE
All	Triaged	86	86	98	127	132
	Assigned to bed	97	94	136	136	NA
	Seen by MD	31	24	95	121	132
	Admitted	3	8	18	21	62
	Discharged home	18	32	78	72	51
1	Triaged	12	12	12	12	9
	Assigned to bed	8	7	12	12	NA
	Seen by MD	6	6	12	12	9
	Admitted	0	1	2	1	8
	Discharged home	2	2	3	3	0
2	Triaged	1	1	13	42	23
	Assigned to bed	51	51	51	51	NA
	Seen by MD	8	5	10	43	23
	Admitted	1	2	4	7	9
	Discharged home	2	3	5	17	3
3	Triaged	51	51	51	51	40
	Assigned to bed	32	31	51	51	NA
	Seen by MD	15	13	51	52	40
	Admitted	2	5	12	13	20
	Discharged home	13	20	48	46	15
4	Triaged	21	21	21	21	29
	Assigned to bed	5	4	21	21	NA
	Seen by MD	1	0	21	14	29
	Admitted	0	0	0	0	15
	Discharged home	1	6	20	5	13
5	Triaged	1	1	1	1	31
	Assigned to bed	1	1	1	1	NA
	Seen by MD	1	0	1	0	31
	Admitted	0	0	0	0	20
	Discharged home	0	1	2	1	20

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Table 2—Comparison to four "V" scenarios time stamps in number of patients (VLE = virtual, live simulation)

non-disaster-related patients would continue to present to some extent, it was felt for several reasons that stopping usual flow during the simulations would be preferable. The first reason was to allow for a better comparison of the computer simulation (SIM) to the VLE—by eliminating independent variables such as non-disaster patient flow, the differences between the SIM and VLE could be defined more readily. Second, it is difficult to fully predict what will happen specifically to non-disaster patient flow during an actual disaster, thus any attempt to simulate non-disaster flow would be a gross approximation. The third reason was because one of the major goals of the study was to provide an international benchmark for evaluation of disaster plans, therefore, eliminating the non-disaster patient flow simplifies comparison of disaster plans between different hospitals.

Results from the SIM were compared to those obtained from a prior VLE. The VLE was performed at the University of Alberta computer training facility over a four-hour period. The exercise was conducted by a team of emergency physicians, emergency medicine residents, nurses, and registration clerks, and was designed to represent the hospital personnel that would be available during a mass-casualty incident. To prepare for the exercise, all participants were trained using two Web-based tutorials. Three liaison officers represented administrative, consultant, and support staff throughout the hospital and community.[4] Each patient was triaged by the triage physician and the triage nurse. The patient identification number and triage code were entered into a training version of the hospital's patient tracking software (HASS/iSOFT). The treating physician assessed the patient, reviewed the history and physical examination findings, and completed the chart documentation. To simulate the time required to see and assess the patient in real-life, a delay time was provided on the history sheet representing the minimum time the physician could spend with the patient. The physician was not permitted to perform any other tasks until the time had elapsed. "STAT" investigations (portable chest x-ray and arterial blood gas) could be viewed 10 minutes after they were ordered. Other radiographic and laboratory studies could be viewed 30 minutes after they were ordered. The patient remained in the department for the minimum time as specified on the worksheet. At the conclusion of the exercise, markers of patient flow were obtained from the patient tracking software.

Data Collection

In each simulation, the following parameters were measured for each triage category:

```
SIMPROCESS Standard Report for UAH_ED_6.0
Simulation Initiated at Sun Sep 17 17:44:51 2006
Simulation Concluded at Sun Sep 17 17:45:13 2006
Simulation Run Duration 00:00:22.309

Model Start Date/Time : 01/01/2006 00:00:00:000:000:000
Model End Date/Time : 02/11/2006 20:00:00:000:000:000
Actual Start Date/Time : 02/11/2006 16:00:00:000:000:000
Actual End Date/Time : 02/11/2006 20:00:00:000:000:000
Actual Run Duration : 04:00:00:000:000:000


Entity : Total Count - Observation Based : Replication 1

                Total Remaining Total
Entity Names Generated In System Processed
CTAS_2 56 59 1
CTAS_4 33 34 10
CTAS_5 3 3 2
CTAS_3 71 78 10
CTAS_1 14 13 2

Time Stamps : Replication 1

Stamp Keys Average Std. Dev. Minimum Maximum #Observed
1_ARR To CTAS1_ADM 11.923 0.000 11.923 11.923 1
1_ARR To CTAS1_DIS 3.544 0.000 3.544 3.544 1
1_ARR To CTAS1_MD 1.494 0.887 0.171 2.667 8
1_ARR To CTAS1_ROO 0.512 0.605 0.095 1.654 12
1_ARR To CTAS1_TRI 0.045 0.059 0.002 0.233 14
2_ARR To CTAS2_ADM 0.000 0.000 0.000 0.000 0
2_ARR To CTAS2_DIS 4.127 0.000 4.127 4.127 1
2_ARR To CTAS2_MD 0.000 0.000 0.000 0.000 0
2_ARR To CTAS2_ROO 0.975 0.284 0.707 1.408 4
2_ARR To CTAS2_TRI 0.630 0.244 0.045 0.922 56
3_ARR To CTAS3_ADM 8.373 0.720 7.457 9.217 3
3_ARR To CTAS3_DIS 4.935 0.596 4.120 6.123 7
3_ARR To CTAS3_MD 0.751 0.117 0.633 0.868 2
3_ARR To CTAS3_ROO 0.000 0.000 0.000 0.000 0
3_ARR To CTAS3_TRI 2.905 1.190 0.056 3.678 7
4_ARR To CTAS4_ADM 7.200 0.044 7.156 7.245 2
4_ARR To CTAS4_DIS 3.828 0.715 2.755 4.824 8
4_ARR To CTAS4_MD 0.785 0.000 0.785 0.785 1
4_ARR To CTAS4_ROO 0.000 0.000 0.000 0.000 0
4_ARR To CTAS4_TRI 0.000 0.000 0.000 0.000 1
5_ARR To CTAS5_ADM 11.616 0.000 11.616 11.616 1
5_ARR To CTAS5_DIS 4.101 0.000 4.101 4.101 1
5_ARR To CTAS5_MD 1.350 0.000 1.350 1.350 1
5_ARR To CTAS5_ROO 0.000 0.000 0.000 0.000 0
5_ARR To CTAS5_TRI 0.000 0.000 0.000 0.000 0
```

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Figure 1—Sample data file for simulation results

1. Time from arrival to triage;
2. Time from arrival to room assignment;
3. Time from arrival to physician assessment;
4. Time from arrival to admission; and
5. Time from arrival to discharge.

In addition, the number of patients to reach each of the following care milestones was recorded for each triage category:

1. Triage;
2. Room assignment;
3. Physician assessment;
4. Admission; and
5. Discharge

Data were analyzed using **OpenOffice.org** (2005, Sun Microsystems, San Diego, CA) and the "R" statistics package (2005, The R Foundation, Vienna, Austria) for Linux (2005, Novell, Provo, UT). All statistics were reported as means or population proportions with 95% confidence intervals. Comparison between proportions were evaluated using Fisher's Exact Test. Comparisons between samples were considered significant at a $p < 0.05$ level.

Results

Four modified SIM scenarios were developed following the VLE. These scenarios were based on the original SIM model, but included the creative solutions that the participants in the VLE had developed to facilitate patient flow. The participants developed three major creative solutions to increase flow: (1) the participants had all emergency inpatients admitted immediately; (2) the participants called for additional physician staff; and (3) the participants provided additional emergency department beds. Results of the computer simulation for the four scenarios were compared to the VLE results by timestamps (Table 1) and in the number of patients to reach the care milestone (Table 2).

Scenario V1—The base computer simulation using the baseline assumptions of minimal laboratory workup and no delay to admission following emergency physician disposition.
Scenario V2—As V1 above, with all emergency inpatients immediately admitted.
Scenario V3—As V2 above, with additional physician staff (14 physicians total).
Scenario V4—As V3 above, however, with the addition of additional beds. Participants added 23 beds by rearranging the emergency department layout. Scenario V4 represented the sum of the three creative solutions employed by the VLE staff and thought to most closely represent the VLE.

Following each SIM scenario, a detailed simulation report was generated from which a variety of data points were extracted. Each simulation result report is approximately 50 pages in length and provides detailed tracking of patient flow (Figure 1).

The data from 100 runs of each SIM scenario were averaged and means and standard deviations were calculated. Mean transit times for the various timestamps were calculated and organized by triage code (CTAS-1 to CTAS-5).

Differences between the SIM and VLE could not be attributed solely to differences in triage code assignments. The data from scenario V4 were re-analyzed with the triage codes of the VLE corrected to those of the original patient data set (Table 3). In this way, individual patients had the same triage code in both the SIM and VLE, and thus, would be assigned to the same CTAS group in both data sets.

As the V4 scenario, corrected for triage, was felt to most closely replicate the VLE scenario, the two were compared by average time for each milestone. Although comparison of data from the computer simulation and virtual live exercise showed a statistically significant difference between predicted transit times for all time stamps for all triage codes (confidence intervals do not cross zero) many of the differences were small (Table 4).

A comparison between the number of patients to reach each milestone is presented in Table 5: significant disagreement between the results of the SIM and VLE was repre-

CTAS Code		SIM	VLE	VLE (corrected)
1	Arrival to triage	0	4	5
	Arrival to MD	10	6	7
	Arrival to admission	131	57	57
	Arrival to discharge home	71		68
2	Arrival to triage	0	10	10
	Arrival to MD	49	15	17
	Arrival to admission	212	74	72
	Arrival to discharge home	97	42	64
3	Arrival to triage	0	9	9
	Arrival to MD	19	15	23
	Arrival to admission	169	66	49
	Arrival to discharge home	93	55	49
4	Arrival to triage	0	12	13
	Arrival to MD	105	26	23
	Arrival to admission	0	53	19
	Arrival to discharge home	101	62	51
5	Arrival to triage		9	
	Arrival to MD		25	
	Arrival to admission		29	
	Arrival to discharge home	77	448	

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Table 3—Comparison of a computer simulation to a virtual, live exercise (VLE) with VLE corrected for triage codes timestamps (in minutes)

CTAS Code		SIM	VLE	(corrected) difference
1	Arrival to triage	0	5	5 ± -0.1
	Arrival to MD	10	7	3 ± -0.1
	Arrival to admission	131	57	74 ± -2.3
	Arrival to discharge home	71	68	3 ± -0.1
2	Arrival to triage	0	10	10 ± -0
	Arrival to MD	49	17	32 ± -0
	Arrival to admission	212	72	140 ± -0.3
	Arrival to discharge home	97	64	33 ± -0.3
3	Arrival to triage	0	9	9 ± -0
	Arrival to MD	19	23	4 ± -0.1
	Arrival to admission	169	49	120 ± -0.4
	Arrival to discharge home	101	51	50 ± -0.6
4	Arrival to triage	0	13	13 ± -0.1
	Arrival to MD	105	23	82 ± -0.2
	Arrival to admission	0	19	19 ± -3.5
	Arrival to discharge home	101	51	50 ± -0.6
5	Arrival to triage			NA
	Arrival to MD			NA
	Arrival to admission			NA
	Arrival to discharge home	77		

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Table 4—Difference between timestamps comparing a computer simulation (SIM) vs. a virtual, live exercise (VLE) corrected for triage codes: (in minutes)

CTAS Code		SIM	VLE (corrected)	*p*-value
1	Arrival to triage	12	11	1.00
	Arrival to MD	12	11	1.00
	Arrival to admission	1	8	0.01
	Arrival to discharge home	3	1	0.59
2	Arrival to triage	51	51	1.00
	Arrival to MD	42	51	<0.01
	Arrival to admission	7	25	0.17
	Arrival to discharge home	17	12	0.38
3	Arrival to triage	51	46	0.06
	Arrival to MD	51	46	0.06
	Arrival to admission	13	22	0.09
	Arrival to discharge home	46	25	<0.01
4	Arrival to triage	21	19	0.49
	Arrival to MD	14	19	0.13
	Arrival to admission	0	5	<0.05
	Arrival to discharge home	5	12	0.06
5	Arrival to triage	0	0	NA
	Arrival to MD	0	0	NA
	Arrival to admission	0	0	NA
	Arrival to discharge home	1	0	NA

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Table 5—Difference between number of patients to reach milestones in a computer simulation (SIM) vs. a virtual, live exercise (VLE) corrected for triage codes (in minutes)

sented by *p*-values <0.05, while larger *p*-values favor agreement. In total, eight of 16 available time markers were statistically different, while the other eight were not.

Discussion

The construction of computer simulations of emergency departments is becoming much more commonplace. However, the use of these simulations to model disaster scenarios still is in its infancy.

Although there are a number of commercially available emergency department computer simulations, for a number of reasons, it was felt that it was more prudent to construct the model using generic modeling. First, the goal was to design a study that was independent of any particular software vendor. The study was not sponsored by any agencies. Second, it was important to demonstrate that the use of computer modeling does not require sophisticated commercial software, untoward expense, time, or sophistication. The CACI software simulation software appears to be well designed; it is well within the capabilities of users with intermediate to advanced computer knowledge to use the software to create a simulation model.

After the construction of the initial model, the obvious advantage of computerized simulations is the ability to make small changes in the simulation to evaluate the effect of the intervention on patient flow. Although for this exercise, four scenarios were demonstrated (based on the VLE participant performance), there are a limitless number of scenarios that could be developed. The computer simulation parameters more closely parallel the VLE (V1-V4), and the calculated parameters more closely resemble the VLE. This suggests that computer simulation can play a role in evaluating how small changes in department structure, such as adding physician staff or increasing patient care areas, can change emergency department patient flow.

Comparison of data from the computer simulation with those of the VLE was problematic, as there was a large discrepancy between the triage codes in the patient database and those given to the simulated patients during the VLE, making it difficult to make direct comparisons between groups when patients were sorted. In particular, during the VLE, patients were much more likely to have been assigned the lower acuity scores of CTAS-4 and CTAS-5.

Modeling of patient numbers to reach a milestone showed some promise. For many of the milestones, the SIM and VLE agreed within statistical error. Even when there was disagreement, the magnitude of the disagreement often was small.

There are several possibilities why it was not possible to find a statistical correlation between the results of the SIM and the VLE regarding patient times to reach milestones. Only one VLE was conducted. Therefore, there was only a single estimate of patient flow. However, it is likely that if the VLE were repeated several times, the results would vary widely. Alternatively, it may be that the computer model is too simplistic, and is unable to account for all aspects of human behavior. This may be thought of as a motivation to develop more complex computer simulation models, or conversely, an acceptance that not all human behaviors can be predicted by a computer model.

Limitations

Several important limitations are present in the study. As all computer simulations are based on simplification of a complex human system, it is impossible to adequately model all aspects of human behavior. In addition, since computer simulations are based on mathematical rules, they are, by definition, much more rigid and incapable of finding creative solutions. Furthermore, it is difficult to comprehend to what degree a simulation must reflect reality in order to provide useful information. For instance, although the study showed statistical differences between the results of the simulation and the live exercise in regards to patient times to reach particular milestones, it may be reasonable to assume that the differences are, in some cases, of a magnitude to be clinically unimportant. For example, the difference in average predicted transit times between the SIM and VLE often were only a few minutes. Similarly, when comparing the number of patients reaching particular milestones, the simulation and VLE often agreed within a few patients. When planning for a disaster, it remains up to the individual to decide if these differences are important.

The choice to base the comparison of the simulation to the VLE on a dataset that did not include non-disaster patients also may have biased the study. Although this serves to reduce the extraneous variables, it may reduce the reproducibility of the results in real-life. In fact, many of the participants in the VLE commented that the lack of non-disaster patients made the scenario seem unrealistic. In response to this concern, non-disaster patients have been added to the most recent update of the **disastermed.ca** database, and can be used during future simulation or exercises.

Conclusions

It appears that both SIMS and VLEs are beneficial for modeling of disaster plan implementation, each providing different, but equally vital, information. In particular, the VLE appears to be useful to expose the creative solutions that participants are able to utilize during disaster situations. These creative solutions then may be used as a model to create various scenarios for computer simulation. Computer simulation is useful to predict how a given change in the disaster plan, such as adding more physicians or increasing patient care areas, will change patient flow. However, at this time, it appears that the present technology of computer simulation is unable to completely replace live exercises in the prediction of patient transit and flow.

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