A CIVILIAN EVACUATION MODEL UNDER A DEGRADED ENVIRONMENT

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ABSTRACT

This paper presents an analytical framework based on Discrete Event Simulation for evacuation of the civilian population under a degraded environment such as post natural disasters. When a person is injured in a disaster, they receive immediate care from the local medical team to be stabilized and transported to a larger facility, where a higher level of care is available. The patient is further evaluated and treated at this higher level, possibly undergoing surgery. The model's primary objective is to provide the initial care necessary to stabilize and triage the patient for transport out of the disaster environment and to a comprehensive medical facility.

The mobility, logistics, and resources required to support such a system are complex and often subject to random events from an operational standpoint. This research proposes a new approach, focusing on using simulation methodology to determine a feasible level of parameters that must be incorporated into the corresponding simulated system. The method is currently under development and implemented in an ExtendSim [3] environment using discrete-event simulation blocks. We intend to report additional results as the modeling phase is completed and the test results are available.

Keywords: *Natural Disaster, Simulation, Logistics, Medical Evacuation, Modeling*

INTRODUCTION

Climate change directly or indirectly has been a cause of the increase in numbers and severity of natural disasters across the world. These events, particularly when they occur in a populated area, affect a large number of people, causing massive injuries and fatalities. Therefore, providing rapid medical treatment and transportation of patients to medical facilities are two of the main priorities after a natural disaster.

Hurricanes, earthquakes, pandemic outbreaks or some other type of external emergency may cause medical facilities to become inoperable or function under reduced capacity, which may overwhelm the existing (remaining) resources. To meet new patients' demands and continue to care for existing patients, a healthcare facility may have to evacuate some or all of its occupants. Depending on the type of facility, less critical patients can be discharged early to decrease the number of patients that require coordinated evacuation efforts, but those that need continued care will have to be transferred to another facility.

A common measure of capability has been the number of available "beds." However, the number of beds is not as vital as the ability to move patients since, in most large-scale disasters, it is the final inpatient facility that provides definitive care. Moreover, in the primary or secondary stages of patient care, it is essential to do so quickly and as is prudent to handoff (transport) the patient to the next level of care. Thus, the number of beds in degraded locations would not truly reflect capability.

The evacuation of patients during or after a major natural disaster is a complicated task since civilians who require help after a natural disaster may range from infants to the elderly with a gamut of unrelated illnesses.

In this paper, we are focused on a modeling movement of large numbers of patients who must be treated and evacuated. We are proposing to develop a simulation model to capture these complex systems of processes.

MODELING REQUIREMENTS FOR HUMANITARIAN SUPPORT

The post-disaster operation, as with any complex system, requires adequate planning. The more it is known about the medical requirements, the better the operators can prepare and respond. This involves forecasting casualty rates, injury types, and injury severity.

A population has members with a wide range of ages, preexisting medical conditions, diversity of fitness and overall health. Natural disasters do not discriminate in their impact on the population, and therefore immediately post-disaster, the "normal" care is needed and may become more acute. In addition to regular care, medical staff also needs to deal with physical and psychological trauma. Lifesaving but straightforward medication may become inaccessible, putting additional stress on the affected population and the medical team. This was amply illustrated in the 2004 Asian Tsunami, where there was a shortage of insulin. Post-Hurricane Katrina in New Orleans, 56 percent of evacuees residing in shelters had chronic diseases requiring medication (see Figure 1).

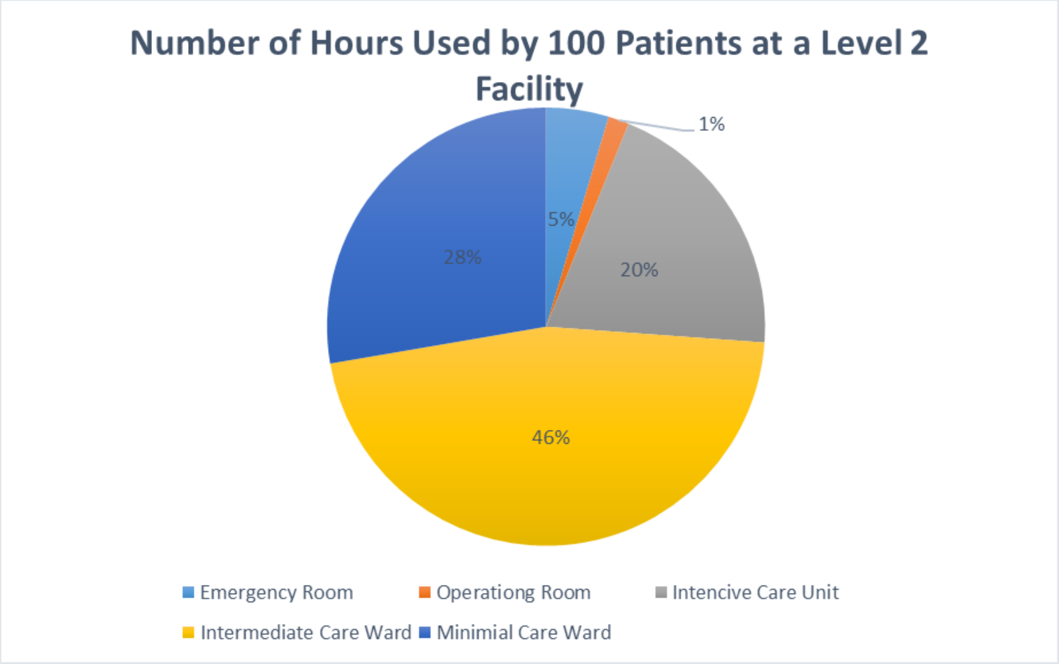


Figure 1: Medical Needs

More often than not, humanitarian disasters occur with little or no warning and are characterized by possible high casualty rates. This is true even for foreseeable events such as hurricanes, as they tend to have unpredictable patterns and intensity, as was evident recently in Hurricane Harvey that made landfall in parts of Texas and Louisiana in August 2017, causing catastrophic flooding and many deaths.

As discussed above, a large number of casualties could overwhelm potentially already degraded medical systems. In addition, outside assistance may be hours or days away, putting additional stress on the system. Therefore, to help understand the capability needs for medical assistance in humanitarian disasters, planners need to know the medical treatment requirements, such as the type of disaster resulting in the distribution of injuries and the arrival time of medical support (see Figure 2).

Injuries from natural disasters such as earthquakes, hurricanes, and tsunamis lead to different types of injury patterns and with unclear injury distribution. For example, experience has shown there is relatively less demand for surgery in natural disasters than in other types of care such as lacerations and infected wounds, respiratory infections, gastrointestinal illnesses, complications from unattended chronic conditions, and non-disaster-related injuries. However, several studies of the 2004 Asian tsunami and Hurricane Katrina noted the common frequent occurrence of gastrointestinal ailments, respiratory infections, skin infections and rashes, and infected wounds.

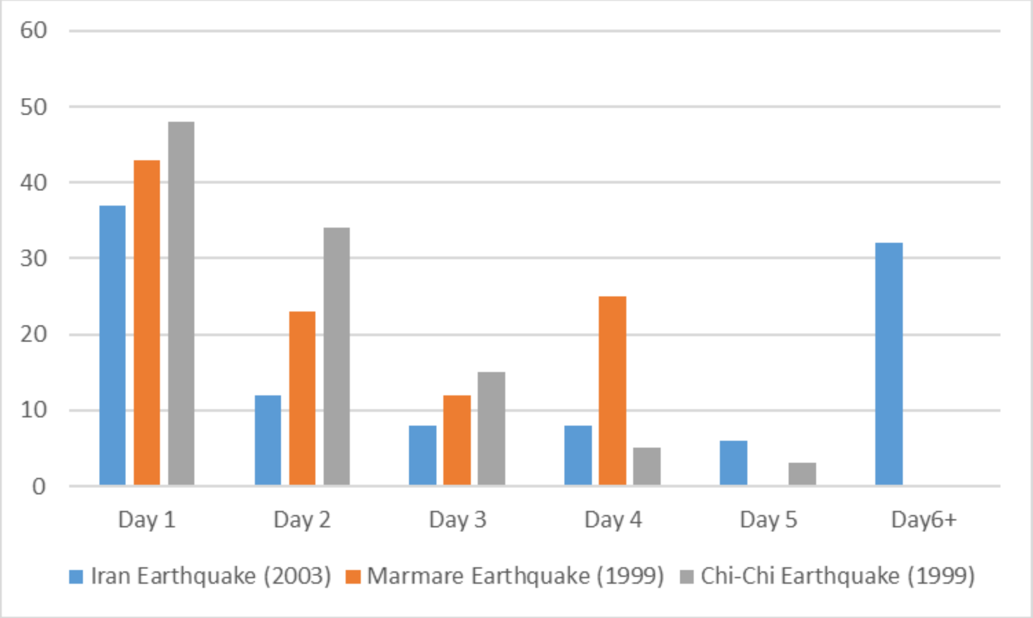


Figure 2: Distribution of Injured Arrival ([1] and [2])

THE PRINCIPLES OF THE MODEL

The goals of every medical facility and evacuation during or post-natural disaster, where local capabilities are diminished, are stabilization, triage and treatment, and if possible, evacuation of patients to a higher level of care. Therefore, the degree and quality of each activity level may be the key to success. For example, evacuation of patients would require resources such as ambulances, buses or even flatbed trucks, or more sophisticated vehicles such as helicopters and fixed-wing aircraft.

There are many ways to measure success in post-disaster scenarios, but one good measure could be the number of patients per day that can be transported. This rate would incorporate the number of air and ground vehicles assigned and the trip time and capacity. The number of beds is still an important metric, but a better measure would be the number of patients treated locally (at the disaster site). The latter measure would allow us to compute the number of people per day (or other measures of time) who either do not need evacuating or have been stabilized sufficiently to be transported.

SIMULATION MODEL

We propose an input-output flow model, simulating the total number of patients who need some degree of care. The number of patients and the type of care are the model's first inputs. These patients may be treated at local existing medical facilities (with possible additional support from the military or FEMA), where we can simulate various degrees of degradation. Some of these patients are released after receiving care, thereby leaving the system with no further treatment. Others may need to be stabilized and then released (again leaving the system), and the third group may need to be stabilized and then transported to the next level of care (e.g., going from a clinic to a close-by medical center that still has some capacity). Finally, patients may be transported outside the disaster zone (possibly out of the country during international humanitarian efforts). This process incorporates the rate at which patients arrive for treatment and provides the rate of those processed to the next level based on the types and severity of the injury. For our discussion, we categorize local clinics and degraded local hospitals as level 3 and 4 (depending on the level of degradation), a large hospital with more capacity than level 3, field hospitals set up by the military or FEMA as level 2 and large complex hospitals as level 1 (See Figure 3 for a notional flow model).

In the figure, the flow of patients begins with the population in need of treatment, including individuals with preexisting conditions and those who have sustained injury or illness due to the natural disaster. Different scenarios will produce casualties at different rates and yield various injuries and illnesses. This will significantly affect the patient flow rate achieved with a given set of resources.

Patients move to the first local facilities available with the assumption that after a natural disaster, there may be only level 3 or 4 facilities operating. Although it is not shown in the figure, patients may move to that level directly if superior level facilities exist. At the initial level, patients go through triage (depicted by an orange small flowchart within the larger process box), where depending on the capability of the facility, each patient is stabilized and then either released or offered additional treatment. Finally, a group of patients that require further treatment is transported to the next-level facility.

The input to each facility can be considered as a Discrete-Event flow model where the flow rate is the number of patients that can be "processed" within a given time. Thus, each processing cell has its holding capacity (number of patients it can triage), treatment capacity (e.g., number of beds), and flow rate (measured by the number of patients it can treat and release back to the population or advance to the next level in an hour or day).

The flow of patients from one level of care to the next level depends on the transportation system's capacity, including the number of vehicles, actual load capacity of each vehicle, and speed and distance from one node to the subsequent node.

Although the flow in the figure is illustrated as a sequential process with just a few facilities, actual operations may be more complex, involving multiple locations and multiple paths of flow. For example, there may be numerous support services and thus numerous points of entry into the medical system, with each point potentially having a different rate of arrival and care. Furthermore, the flow of patients may not be as sequential as the figure implies as patients could also be evacuated out of the disaster zone into a level 1 care directly (Figure 4, below, illustrates the user interface layer of the model; also see [4] and [5]).

CONCLUDING REMARKS AND NEXT STEP

This paper presented the basic elements of developing a robust simulation model for patient flow in a post-natural disaster environment.

We are still in the process of assessing our results and expect to be able to offer recommendations at the next conference.

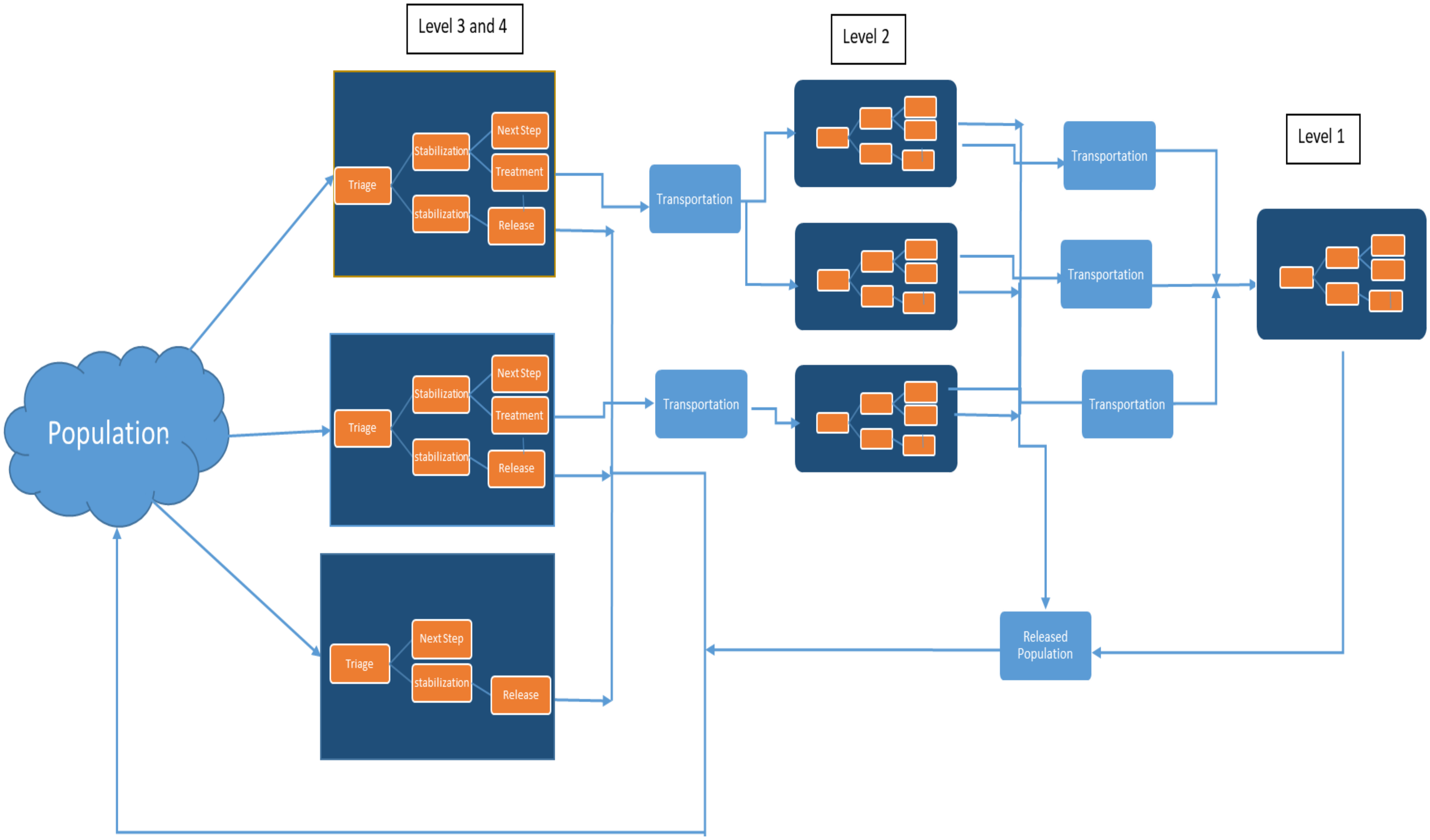
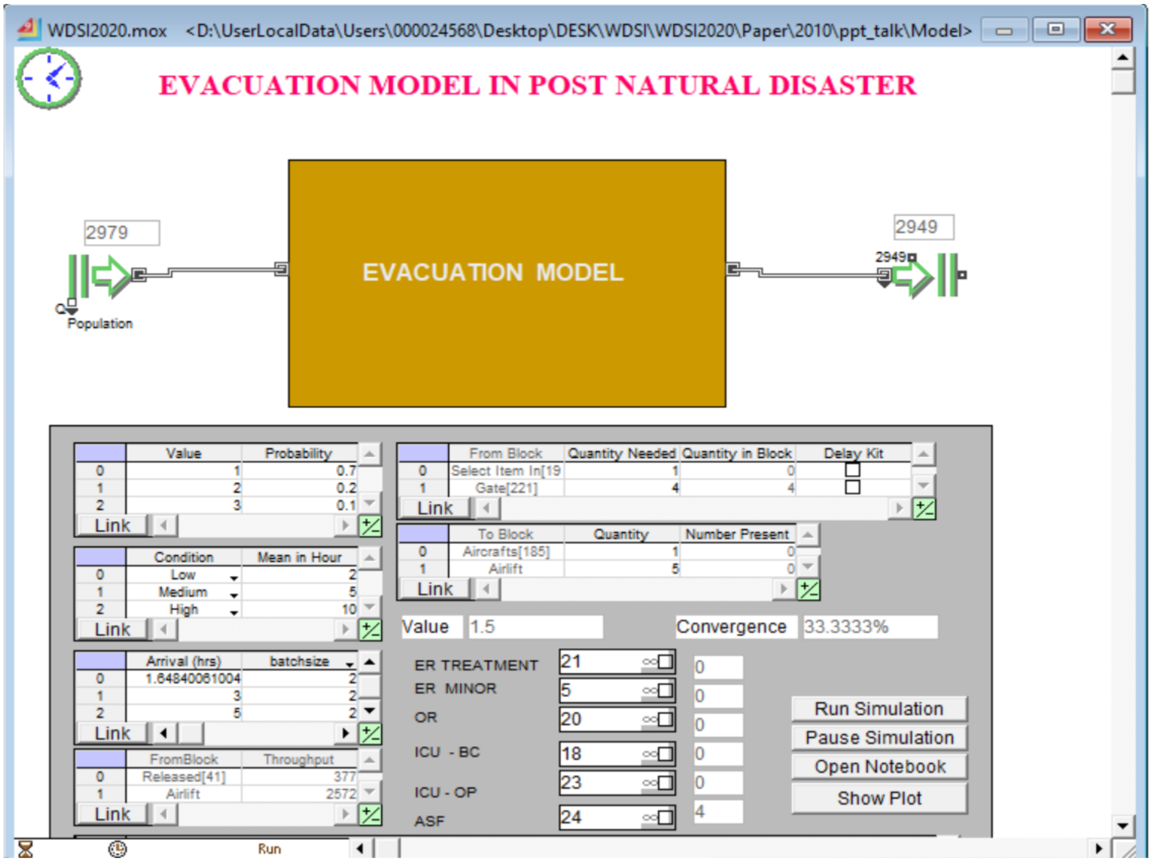


Figure 3: Notional Input / Output Model



	Value	Probability
0	1	0.7
1	2	0.2
2	3	0.1

	Condition	Mean in Hour
0	Low	2
1	Medium	5
2	High	10

	Arrival (hrs)	batchsize
0	1.64840061004	2
1	3	2
2	5	2

	FromBlock	Throughput
0	Released[41]	377
1	Airlift	2572

	From Block	Quantity Needed	Quantity in Block	Delay Kit
0	Select Item In[19	1	0	☐
1	Gate[221]	4	4	☐

	To Block	Quantity	Number Present
0	Aircrafts[185]	1	0
1	Airlift	5	0

Value 1.5
Convergence 33.3333%

ER TREATMENT	21	0
ER MINOR	5	0
OR	20	0
ICU - BC	18	0
ICU - OP	23	0
ASF	24	4

Figure 4: User Interface layer of the Simulation Model

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