Chapter 22
Modeling and Simulation of a French Extended White Plan: A Hospital Evacuation Before a Forecasted Flood

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Abstract As high level emergencies can have serious consequences on hospital activities, an emergency management plan to face a crisis situation must be specified and assessed. Even though more and more research is devoted to this area, most studies are based on academic assumptions and the proposed improvement methods are difficult to be applied in the real world. This paper addresses the French Extended White Plan i.e. a hospital evacuation plan facing a flood based on a real life scenario. First, a global model is built, using linear programming to roughly estimate the resources needed for an evacuation and to get a lower bound of the evacuation time. Second, a detail model is proposed in two steps, using the software, ARIS and SIMIO. In the first step, a frame model, which considers the processes of the vested interest actors and the information flow among them, is established to get the sequence of events based on activities from the ARIS diagrams. In the second step, a simulation model, which integrates the information transmission and the different activities, is proposed based on the frame model in the SIMIO programme. The correctness of the detail model has been checked, using the linear model results and the rationality of the simulation model is verified by various experiments. Through experiments, the best way to assign the resource has been found and two organizational improvements have been proposed. With such improvements, 1 h and 18 min is saved in evacuating all the patients and the improvement rate is as high as 26.2%. Thus, our work can provide some guidelines for managers who work in hospitals to improve their evacuation management plan.

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22.1 Introduction

Hydrological disasters, triggered by flood or wet mass movement (mudslides), bring about heavy loss of life and property damage. For instance, in March 2011, Japan's tsunami and earthquake, accounted for the biggest amount of money distributed for disasters in Japan ($210 billion), as well as the most casualties (15,500 deaths with 7,300 still counted as missing). After Japan, the costliest disaster was the flood from December 2010 to January 2011, in Australia, which caused a $7.3 billion loss [1]. In the Asian continent in 2010, hydrological disasters were responsible for 92.9% of disaster victims, the highest number since the 1980s. Extensive floods and landslides, following heavy monsoonal rains in Southern China affected 134 million people. Floods and flash floods in Pakistan brought about another 20.4 million victims. Hydrological disasters are among the most serious disasters worldwide [2]. Moreover, the impact of those catastrophic floods in Pakistan in July 2010 showed how disaster-risk and poverty are closely interlinked [2]. An effective way to tackle the serious hydrological disaster consequences is to establish a prudent and comprehensive emergency management plan.

The emergency management plan is made up of four phases: mitigation, preparedness, response, and recovery [3]. Mitigation efforts are intended to keep dangers from escalating into disasters and to reduce the impact of disasters, thus reducing loss of life and damage to property if a disaster happens. Preparedness means that we take measures beforehand, to reduce the impact of disasters on human beings. The response phase seeks to minimize the consequence of a disaster. The aim of the recovery phase is how to restore the affected area to its normal state. To minimize human suffering and deaths is the most important criteria in the emergency logistic management amongst the numerous objectives, such as minimizing the economical cost and reducing the impact to the environment [4]. Realizing the importance of the emergency management plan, many countries have made different emergency management plans, based on the situations in their own countries. The French White Plan (Plan Blanc) is the emergency plan for the sudden increase of activity in a hospital. Moreover, as this activity could affect several hospitals, it is called An Extended White Plan. Its aim is to organize the rescue resources to cope with the concentrated number of casualties.

Our work is devoted to studying the part of the French Extended White Plan dedicated to a hospital evacuation. A hospital evacuation occurs when a threat is posed to the hospital itself or when the patients in one hospital must be transported to other hospitals, in the case of an emergency. Our research focus is the hospital evacuation in which the patients have to be moved to other hospitals before a forecasted flood. As far as we know, there are very few investigations of the French Extended White Plan. Our objective is to improve the whole evacuation system from two aspects: optimize the resource dimensioning and minimize the needed evacuation time.

Our paper has made the following scientific contributions:

– The model and the simulation we have done are based on a real scenario. Therefore the model is well suited to the hospital's practices and the improvement methods that we propose can be applied on the ground easily.
– All the cooperation among different departments during the evacuation is taken into consideration, which is often ignored by other pieces of research.
– The quantitative approach we used guarantees the reliability of our result and the feasibility of the whole process.
– Our attention is focused on the hospital evacuation, the research of which is limited, but could inspire other applications.

The remainder of this paper is organized as follows. Section 22.2, briefly, reviews the related literature. Section 22.3 describes the evacuation problem from the context of the vested interest actors and activities. A global model and a detailed model have been formulated separately in Sects. 22.4 and 22.5. In Sect. 22.6, several experiments have been done to analyze the evacuation process and to identify where improvements could be made. The conclusion and perspectives can be found in Sect. 22.7.

22.2 Literature Review

This part is a brief review of the related papers in terms of the research content and the approach. Optimization model and computer simulation seem to be the two most popular research approaches to study evacuation problems. As early as 1982, Sheffi et al. [5] used computer simulation to build a network emergency evacuation model based on a simulator capable of estimating traffic patterns and evacuation time on road networks surrounding nuclear power plants. Filippoupolitis [6] presented a distributed decision support system which consisted of a number of decision nodes helping evacuees to find the best available outlet in a disaster. A multi-agent simulation platform for building evacuation was developed to evaluate the proposed system in various emergency scenarios. Su et al. [7] built a discrete-event computer simulation model for assessing evacuation programs and provided a comprehensive idea of evacuation plans for hospital buildings in the event of a possible bomb threat. Wu et al. [8] proposed a dynamic discrete disaster decision simulation system, which combined the ARENA simulation model with a geographic information system and an SQL Server database to simulate evacuation process and resource deployment. Russo and Vitetta [9] implemented a formulation of the general evacuation problem in the standard simulation context of a 'what if' approach with the consideration of the transportation system in ordinary conditions.

The researchers studying the evacuation model with optimization tools always combine the evacuation problem with the 'facility location problem' or 'relief distribution problem'. All location-evacuation models built for large-scale emergency situations seek to minimize total evacuation time. Kongsomsaksakul et al. [10]

proposed a bi-level program based on the Stackelberg game to find the optimal shelter locations for flood evacuation planning. The upper level problem is a location model which solves the shelter location. The lower level problem is a combined distribution and assignment model that deals with the evacuee route choices. Sherali et al. [11] established a location-allocation model in the event of hurricanes. This model selects the candidate shelters among a given set of admissible alternatives and prescribes an evacuation plan which minimizes the total congestion-related evacuation time. As the evacuees can be regarded as a vehicle or a commodity, it is understandable that some researchers study the relief distribution and the evacuation together using the vehicle routing. This methodology simplifies the model and the solution, but it is not practical in the real world. Different evacuees have different situations and disruptions are likely to happen to patients during an evacuation trip. Adding a probability of disruption parameter may be a solution. Odamar [12] described a hierarchical cluster and route procedure for coordinating vehicle routing in large-scale post-disaster distribution and evacuation activities. He used a multi-level clustering algorithm that groups demand nodes into smaller clusters at each planning level, enabling the optimal solution of cluster routing problems. Wei [13] proposed a mixed integer multi-commodity network flow model that co-ordinates logistics support and evacuation activities while maintaining equilibrium among service rates of medical facilities. Both wounded people and commodities are categorized into a priority hierarchy, where different types of vehicles are utilized to serve priority transportation needs. The model is based on a network flow formulation. Song et al. [14] formulated a location-routing model with uncertain demands. This model identifies the optimal serving areas and transit vehicle routings to move evacuees from the affected zone to safe destinations.

To sum up, from a view of the content, it can be found that even though the papers studying emergency evacuation are abundant, the papers focusing on hospital evacuation are few. From a view of the approach, the optimization model and the computer simulation are the more suitable in this field. However, none of the research on hospital evacuation was based on a real scenario, which led to two problems: one is to ignore the detail, and the other is to fail to respect the hospital's rules and its laws. These two problems make the existing plans and the improvement methods difficult to put into practice. These gaps have been our main drive: to study the Extended White Plan and to use the computer simulation and the optimization model together based on a real scenario.

22.3   Problem Description

The flood situation we intend to study here is that of a dam, located in Commune Cernon (Jura, France), which, if damaged could rapidly generate a disaster. The dam is about 103 m tall and 36,000 m long. Its water volume is about 600 million m^3. The speed of the flood is estimated at 20 km/h and the height of the water is between 1 and 8 m. The Hospital Saint-Joseph/Saint-Luc is located in the

passage of the potential flood, which, in the event of a breach, would arrive in 5 or 6 h in Lyon and in 8 or 9 h at the Hospital Saint-Joseph/Saint-Luc. Water in the hospital would rise to between 6 and 9 m. The whole situation would last approximately 24 h and its overall impact is difficult to estimate. The flood would affect buildings, infrastructure, electrical and telecommunication networks as well as water networks. Therefore, the evacuation of all the patients in the Hospital Saint-Joseph/Saint-Luc, to other unaffected hospitals is necessary. The patients can be classified into non-autonomous patients, who must be transported with ambulances, and autonomous patients who can be evacuated with public transportation. This latter group will not be considered here. According to the requirement of the Hospital Saint-Joseph/Saint-Luc, the benchmark evacuation time is 5 h (with 6 nurses, 2 coordinators, 12 ambulance teams and 10 stretchers) and the number of non-autonomous patients evacuated is estimated to be 120.

22.3.1 The Vested Interest Actors

The hospital Saint-Joseph/Saint-Luc is located beside the river Rhone. This hospital has 1,207 employees and a capacity of 344 beds. In 2011, the number of people who are treated in the emergency department was 35,767. During the holiday, at night, or on Saturday and Sunday, 19 physicians are on duty. These hospital employees take care of autonomous and non-autonomous patients.

Hospices Civils de Lyon (HCL) is a network of hospitals providing expertise in all disciplines – both medical and surgical. The whole annual budget of HCL is 1.5 billion Euros. It has 23,000 professionals and a capacity of more than 5,400 beds. SAMU is a health care coordinator in France standing for 'Service d'Aide Médicale Urgente'. SAMU controls the response vehicles and ambulances from SMUR (Service Mobile d'Urgence et Reanimation) which is a 'mobile intensive care unit' (MICU). The tasks of SAMU are as follows: to evaluate the patient's needs according to the calls; to find the best care solution for the patient's requirements; to dispatch the most appropriate mobile care resource (MICU, Ambulance . . .) to move the patient to hospital . . . In this project, SAMU decides the destination of evacuated patients and the assignment of medical vehicles.

22.3.2 The Activities

The emergency committee is the leader of the evacuation and will control the whole situation. The non-autonomous patient evacuation can be divided into three main processes: preparing the patients, using stretchers to move the patients in the Hospital Saint-Joseph/Saint-Luc, and assigning the ambulances to transport the patients from Hospital Saint-Joseph/Saint Luc to Hospices Civils de Lyon. Every process consists of several activities. The patient preparation includes the

preparation of: the list of the patients to be evacuated, the list of places to which the patients will be moved, the medication that the patients will need during the evacuation and the clinical history of each patient. Ambulance utilization is similar to stretcher utilization respectively both outside and inside the hospital. These two equipment utilization processes involve the demand of the ambulance/stretcher, the assignment of the ambulance/stretcher and the transportation of the patient needing the ambulance/stretcher.

22.4   Global Model

In this part, an optimization model is proposed firstly to model the evacuation globally, mainly for resource dimensioning reasons and also in order to measure the patient evacuation time.

22.4.1   Optimization Model

As linear programming technique is an exact method, we adopted this optimization technique to find our resource dimensioning. A linear programme has been built according to the three aforementioned processes.

The data of this model is:

– T: the number of periods t (in hours)
– M: the number of activities
– Nbpat: the number of non-autonomous patients to evacuate
– Dur (j): the duration of the activity j (by minutes)
– Suc (j): the set of successors of the activity j
– Cap (j,t): the capacity of the resource associated to the activity j (by minutes)

The variables are:

– X (j,t): the number of patients who benefit from the activity j during period t
– S (j,t): the number of patients who wait for the next activity during period t

Model:

$$Min \sum_{t=1}^{T} X\,(M,t)\,.t \tag{22.1}$$

Subject to

$$S\,(j,t-1)+X\,(j,t)-S\,(j,t) \geq X\,(k,t) \quad \forall k \in Suc\,(j) \quad \forall j=1,\ldots,M-1$$
$$\forall t = 1,\ldots,T \tag{22.2}$$

$$X(j,t).Dur(j) \leq Cap(j,t) \quad \forall j = 1,\ldots,M \quad \forall t = 1,\ldots,T \qquad (22.3)$$

$$\sum_{t=1}^{T} X(M,t) = Nbpat \qquad (22.4)$$

The objective function endeavors to minimize the sum of two series where each term of same rank in both series is multiplied. To be minimized, the series X(M,t) has to be ranked in decreasing order as the series t is in increasing order. So activities are realized at the earliest. We try to use this dynamic model to find the suitable resource dimensioning. The constraint (22.2) controls the patient flow. Constraint (22.3) respects the resource capabilities. Constraint (22.4) defines the number of patients to be evacuated. Using the software Cplex, we got the needed resources are: 6 nurses, 12 ambulance teams, 10 stretchers and 2 coordinators. This result indicates that, according to the policies of the hospital, it will cost at least 5 h to evacuate 120 non-autonomous patients.

22.4.2   Problem Complexity

Even though the three main processes can be modeled via our linear programming, several problem complexities lie in our study and make our linear programming not perfect enough to properly reflect the real world. First, since the evacuation situations are plagued with uncertainties [15], it is better to use stochastic data, which can reflect the situation better. With the stochastic data, however, the solution of the optimization model is difficult to find. Second, the optimization model is an analytical method which can only represent the as-is system in an aggregated way and lot of details are omitted. Third, the optimization model cannot achieve the organization improvement objective effectively in practice. So, it is necessary to find another suitable approach. The results calculated by the linear program, however, can be used to check the result obtained by the next approach i.e. to define a lower bound.

22.5   Detailed Model

Judging from our literature review, the most suitable way to solve problems related to real-world complex systems is a computer simulation approach [16]. First, a computer simulation can capture the stochastic data by a user-friendly interface [17]. Second, unanticipated problems and the sequential or parallel events can be easily exposed by simulation. Third, the combination of 3-D technology makes simulation powerful at presenting detailed information, hence helping people to find the weak points [18]. Fourth, simulation can act as a 'what if' tool and will be useful to support training exercises, performance and impact evaluation [19].
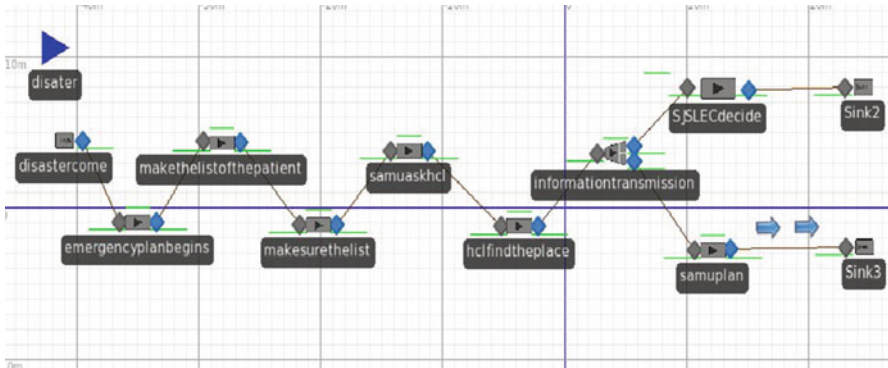
Fig. 22.1 The process of sending the information in SIMIO

According to our objective and the way proposed by Bradley et al. [20] to choose a Business process re-engineering (BPR) software, we decided to adopt two software tools in our detail model. At the beginning, we used ARIS to build a frame model which can detail the evacuation activities because ARIS is a powerful communication tool. However, the simulation ability is a weakness in ARIS. SIMIO is impressing in the previous model, with its simulation ability. So it is adopted to implement the later simulation work. ARIS, as one of successful products of IDS Scheer, is widely used for the purpose of business process design and management. It is powerful in process modeling and provides reliable information flowcharts. ARIS was chosen to build a frame model which clearly shows the co-operation and information sharing among the different hospital departments. Our frame model [21] is made up of 17 processes and 108 activities. Once the frame model is finished, we intend to use SIMIO to implement the simulation. SIMIO is designed to support the object modeling paradigm and supports both discrete and continuous systems, along with large scale applications based on agent-based modeling. These advantages help us to build a simulation model based on the frame model and display logically and graphically the characteristic of discrete events in our model. The strong 3-D simulation effect is useful tool for presenting the result to the practitioners in the hospital.

Our simulation model consists of two levels. Level One is to show the information communication among the vested interest actors. Level Two is to simulate the evacuation activities. Different trigger events are used here to synchronize these two levels. Figure 22.1 presents Level One. At the beginning of Level One, six different activities will happen in chronological sequence. After these six activities, two activities take place in parallel. A model entity is used to represent the disaster. Among the six chronological sequence activities, five servers are used to represent the first five activities separately. The first one is triggering Emergency Management Plan and assembling the Saint-Joseph/Saint-Luc Emergency Committee (SJSLEC). The second one is the process of making the list of the patients to be evacuated. The third one is assessing the needs of those patients and passing it to a SAMU. The 4th

one is that the SAMU requires the HCL to find available beds for the patients to be evacuated. The 5th one is the process of making a list of the available places in HCL. The 6th activity shows the information process from HCL to SAMU and Saint-Joseph/Saint-Luc. After the information process has been completed, the SAMU will direct the ambulances and the SJSLEC will plan the utilization of the available beds in HCL.

22.6 System Improvement

After the correctness of the detail model was checked, several experiments were launched and from these two proposals for improvements were made.

22.6.1 Experiments

In order to evaluate the performance of the as-is system and find a way to improve the existing evacuation process, a good design of the experiment is necessary. The common and normal steps for the experiments are the following [22, 23]: define the goal of the project, identify and classify the experiment variables and choose an experiment design. Because our goal is clear enough, we begin with the second step. A cause-effect diagram can be applied to look for the two kinds of experiment variables, the dependent variable and the independent variable. The dependent variables are the total evacuation time and the time used to evacuate the first patient. The independent experiment variables are the number of nurses, coordinators, ambulance teams and stretchers. For the third step, a factorial design experiment has been retained. This experiment allows studying the effect of each independent variable on the dependent variables, as well as the effects of interactions between the independent variables and the dependent variables.

Four experiments have been conducted. Every combination of the experiments ran 20 times and the confidence level has been set to 95%. After calculation, it is found that the effect of every independent variable is similar. However, the effects of interactions between the independent variables and the dependent variables are significantly different. According to the benchmark evacuation time, the minimal and reasonable resources that we must assign are 6 nurses, 2 coordinators 12 ambulance teams and 10 stretchers. These correspond to the linear model result.

22.6.2 The Improvement Scenarios

After the experiments, two improvement methods have been proposed. As the material resource and the human resource are limited, we have modified the way

to use the resource, and thus a first modification was proposed. It was found that the time to evacuate the first patient appeared too long, and, therefore, we have sought to solve the problem and proposed the second change.

To further enhance the organization, a change is needed to the practice of stretcher use. In the basic model, the worker who pushes the stretcher will transport the patient to the car park and wait for the ambulance until it comes and then he will go back to the care unit with the stretcher. In the improved model, the worker will move the stretcher from the care unit to the car park, and then go back to the care unit to continue the transportation of patients, using a free stretcher from the car park. As a consequence, the number of stretchers must be increased. The patient will wait in the car park and be cared for by an employee until he can be transferred to the ambulance. When the patient is on the ambulance, the stretcher is released and is left in the car park, for further use.

From the result of the simulation we can find that the time to evacuate the first patient is too long. If we assign 6 nurses, 2 coordinators, 12 ambulances and 10 stretchers, the time used to evacuate the first patient will be more than 1.4 h. Our experiment found that not a lot of time can be saved even if more resources are available. After the analysis, we found that the main reason is that the information preparation tasks consume a lot of time. To be exact, it takes too much time to make two lists, the patient list and the available place list. In the as-is model, humans make the patient list and the placement list. In fact, an appropriate information system can do this task better and faster than a human. So the second way to improve the system is to add an information system. The information system can create the patient list and the placement list automatically and quickly. The Regional Health Agency in France is beginning to build a web site where each private or public hospital must specify the number of their available beds twice a day. In the as-is system, it would take about 10 min to assemble the patient list and 15 min to build the placement list. With the web information system, it takes just 1 min to create the patient list and just 5 min to produce the placement list. To evacuate 120 patients, the original system takes 4.94807 h, our first modification can reduce the time to 4.68333 h and the second modification further reduces the time to 3.98220 h. When these two improvements are combined, an overall improvement of 1.29622 h will have been achieved, with it taking only 3.65185 h to evacuate 120 patients.

22.7   The Conclusion and the Future

This is one of the first papers studying the French Extended White Plan and a prudent and comprehensive detail model has been made based on a real scenario in the context where the hospital suffers from a threatening flood and all the patients must be evacuated. In order to evaluate the needed resources and to ensure the correctness of the evacuation model, we first used a global linear model and second a detailed simulation model. The best way to assign the resources and improvements based on new IT information has been proposed. The results of the experiments

confirm the idea behind our suggested modifications: that the evacuation time could be largely reduced. One of the limitations of our research is the reliability and availability of the data we obtained. All the data we obtained is solely based on the experience of the people in the hospital. The possibility of an interruption was not taken into account during the evacuation such as transportation congestion, for example. In that case, helicopters should be used. In such a case, fuzzy theory will probably be adopted to get more valuable data and build an extended simulation model. This work was sponsored by the Rhone-Alps Region.

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