

The Usage of Agent Based Modelling in Flood Evacuation during Dam Failure



F F Norkhairi, S Thiruchelvam, H Hasini, K N Mustapha, A Ghazali, R S Muda

Abstract: *With the advent of latest technology has enabled disaster management related efforts to be more efficient and effective. Agent based modelling has been utilized in crowd management context especially related to simulation of evacuation passage during the outbreak of any untoward incidents. In dam safety assessment, the number of loss of life during the flood indicates the severity of the catastrophe. Therefore, it is important for any dam owners to estimate the required warning time to ensure minimization of fatalities in the event of a disaster. The objective of the research is to estimate the loss of life at the downstream area of the Sultan Abu Bakar Dam when Probable Maximum Flood (PMF) scenario occurs. The adopted model is known as Life Safety Model (LSM), which is an agent-based model that uses the concept of dynamic interaction between the 2d-hydraulic and the receptor. A case study has been conducted focusing the population of Bertam Valley in Cameron Highlands, Pahang, West Malaysia. The outcome of this modelling has indicated that successful evacuation depends on the response rate of the victims towards the given warning prior to the disaster. It is shown that the response time might affect the fate of people during the evacuation. The application of Life Safety Model in this simulation proves its capability in estimating the loss of life as a planning measure to face the actual events.*

Keywords: Dam Failure, Disasters and Safety Model

I. INTRODUCTION

Flooding is one of the most common disaster faced by most countries. The definition of flood type depends on the source of event (coast, river) and the characteristics of the flood (depth, rise rate). The common categories of flood that we might encounter are flash flood, river flood and coastal flood. Dam break scenario is a state, which has the lowest probability of occurring, however it could cause catastrophic flooding to the downstream area of the dam.

Historical records have proven the impact of flooding due this phenomenon is devastating. The most recent dam break occurred in Laos in 2018 leaving behind at least 30 people dead and hundreds missing due to the collapsed hydroelectric dam [1, 2]. With the high number of loss of life during such event clearly indicates the level of severity of the flood. The evacuation process during flood situations may decrease the potential of loss of life which is coupled with a specific flood emergency plan to be implemented. With the improvement in 2-dimensional modelling in computer simulation, the use of agent based model to explore the behaviour and fate of the receptor is more prevalent [3]. One of the agent-based model that uses the concept of integration between 2-dimensional modelling and its agent is Life Safety Model (LSM) which is developed for dam break assessments and useful for evacuation and emergency plan. The emergency or disaster management plan is important to get better preparedness in terms of preparation, support and reconstruction when disaster occurs [4, 5]. In particular, the flood hazard map and 2-dimensional model is important to determine the depth and velocity of the flood and also to determine the impacted area by the flood plain.

This paper aims to investigate the potential of agent-based model in flood emergency management which could help to simulate the evacuation process to reduce the loss of life during flood events. Hence, this can help to improve the preparedness in managing the evacuation process and the improve decision-making during crucial moment.

II. OVERVIEW OF LIFE SAFETY MODEL

The Life Safety Model (LSM) is developed by BC Hydro in Canada which aims to carry out the dam break risk assessment and provides information on the evacuation and emergency plan [3, 6]. The LSM is an agent-based model which composed from a set of agents, the environment and their relationships that clearly define the boundary of inputs and outputs [7]. This model therefore allows the dynamic interaction between the receptors and the flood hazards, which later can determine the 'fate' of each receptor. Receptor in LSM is defined as the objects that can be affected by the hazards such people (a group or individual), vehicles and buildings. In order to build up a simulation, the LSM requires significant amount of data including:

- The 2-dimensional hydrodynamic model that represents the depth and the velocity of the flood;

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- The location of the buildings, number of people and vehicles;
- The details of road network and the other pathways.

The output of the LSM simulation includes the consequence analysis of fatalities, building damage and the dynamic computer-graphic visualisation. Figure 1 shows the architecture of the system in LSM. Two important input factor that must be included in the system is 2D hydrodynamic model and the 'virtual world'. The 2D hydrodynamic model is required to determine the depth and velocity of the flood and the 'virtual world' consist of the initial state of the receptor which includes building, people, road and vehicle.

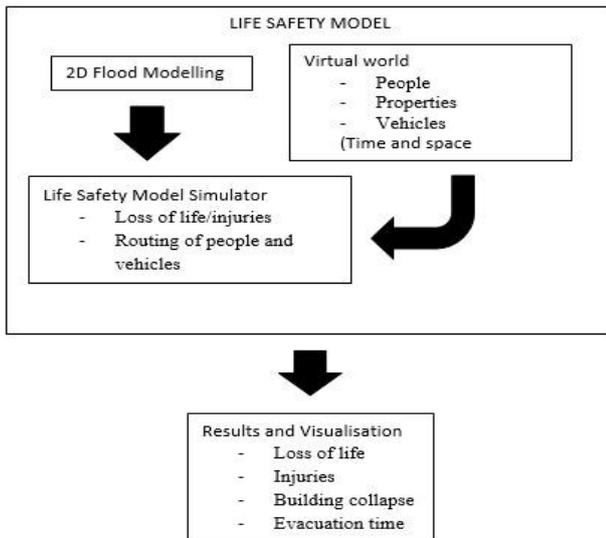


Fig. 1 The architecture of LSM [8]

The LSM used the event logic to determine the location of the person that might include their awareness at the time of warning, the decision to save their life, the effect of the flood to the victim and the survival of the person. Time prediction for the people to save their life during the mass evacuation and finally achieve the safe evacuation in the sufficient time is important in order to reduce the fatalities. The loss function of the receptors is define as the ability of the receptor to resists the flood wave [6]. The generic example of loss function used in LSM loss fuction is shown in Figure 2. Under people parameter several important information are captured, such as the ability of people to escape from flood risk can be either by driving, walking or releasing themselves to avoid drowning or decline in health. In evacuation modelling, the detailed description of road network is important to allow people and vehicles to be evacuated to the safe haven. From the previous research by Tagg (2016), the usage of local network is important in order to achieve a successful evacuation in that area [3].

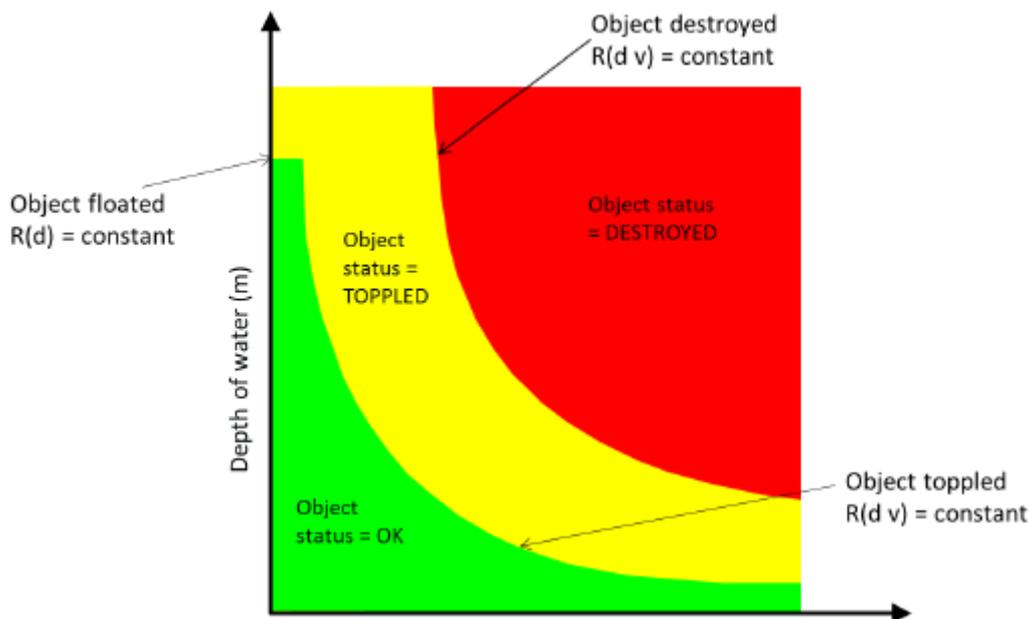


Fig. 2 Generic example of a loss function used in LSM [9]

The resistance R , depends on the object properties and the kind of state change. For example, a person's resistance to toppling depends on their factor such as height, weight and age. A typical building's resistance depends on the type of construction and on the failure mechanism, such as flexure or shear. The cumulative loss also reflects a reduction in

resistance that results from the exposure to the flood such as fatigue, human exhaustion or erosion of foundation.

LSM have been widely used especially in Canada, Italy, Malaysia and Australia.

One of the case studies that used the application of LSM is the dam risk assessment in Japan. A series of simulation were conducted to investigate the failure of the dam that caused by the decreasing strength of the construction associating with or without the warning issued. It is assumed that the warning is initiated 30 minutes after the breach. The result is summarised in Table 1 below.

Table. 1 Japan case study summary results [5]

	Warning issued	No warning
Low strength of construction		
Fatality rate	7%	74%
Buildings destroyed	29%	29%
High strength of construction		
Fatality rate	5%	76%
Buildings destroyed	33%	33%

The results indicate that issuance of warning could reduce the number of fatalities rate. The usage of warning siren can increase the awareness of the public thus reduce the number of fatalities during the flood event.

III. THE CASE STUDY

In Malaysia, the LSM study has been conducted in Cameron Highlands, which demonstrates the model

capabilities for the community in Bertam Valley, Cameron Highlands. The nearest hydropower structure in Bertam Valley is known as Sultan Abu Bakar Dam, which is located at Ringlet-Bertam Valley Road. The Ringlet reservoir is located at the upstream of the dam, which impounds 4.7 million m³ of water storage. Due to various reasons, the reservoir in Cameron Highlands is seriously threatened by the sedimentation. This area was chosen as a location for demonstration of model due to:

- The history in 2013 where the releasing of water from the dam cause loss of life.
- The population area which needs to be completely evacuated during extreme flood.
- There is reasonably good data on the locations of each of the existing buildings.

In this study, the Probable Maximum flood (PMF) has been chosen to complete the simulation. During the PMF failure, the time taken for the flood to increase to maximum flood level is 19 hours and the derived failure time is 0.77 hour. PMF inflow generally requires longer time to load up the dam so it provides longer lead time and evacuation time before the formation of breach. Under this scenario, the flood wave would travel along and within the Sg. Bertam main channel in high velocity especially in the upper reach. At 1km of the downstream area of the dam, the flood wave would hit after 0.25 hours of the dam break and the maximum flood depth could reach until 2.63m. Figure 3 shows the maximum flood depth in Bertam Valley for PMF scenario.

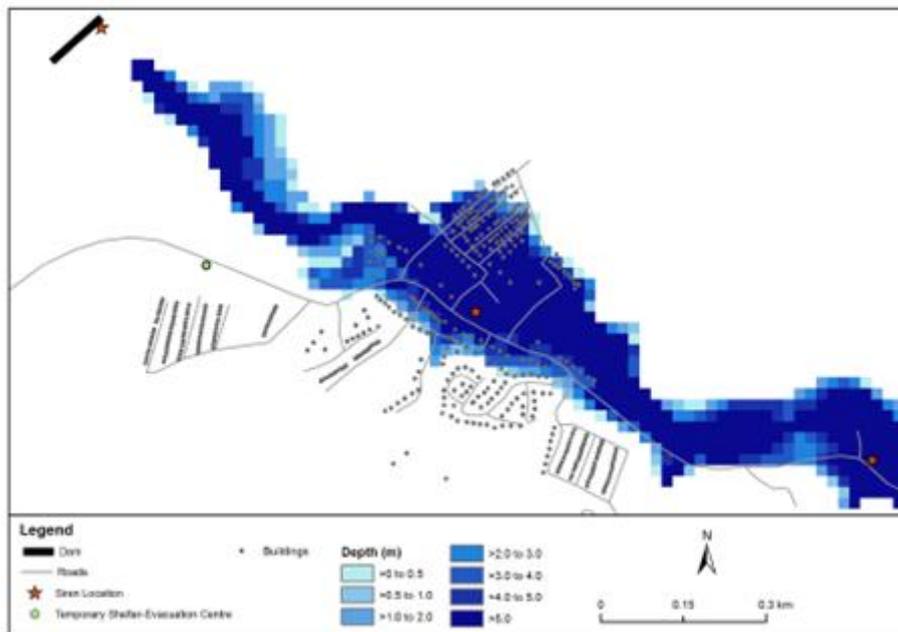


Fig. 3 Maximum flood depth in Bertam Valley for PMF

IV. MODEL SETUP

The model was setup for the application of the receptor and the intended scenario. The building and road data are set by using the Google Earth, Google Street map and GIS software. The location of the building and road were further revised during the site visits. A set of building location and

road networks data are shown in Figure 4. The population at risk for the village at the downstream was obtained from the Department of Statistics, Malaysia and being confirmed during the site visit.

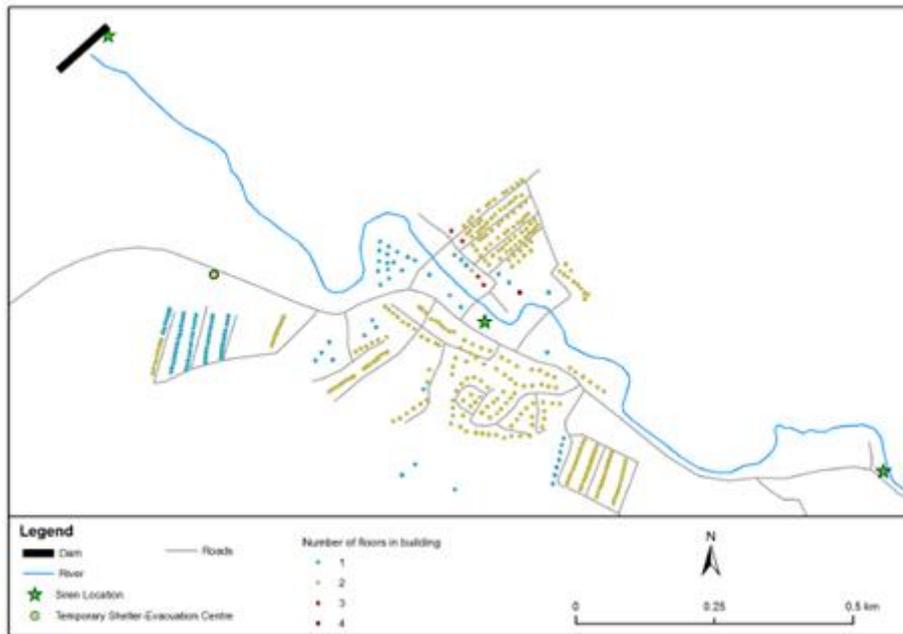


Fig. 4 Set of building and road networks in Bertam Valley

A series of simulations were carried out to investigate the scenario that may reduce the fatalities during the dam break incidents. It is assumed that the failure occur in the evening when people are at home. The scenarios that have been considered in LSM is dam failure during the PMF which is followed by the warning scenarios for:

- No warning issued
- Warning at the time of breach (with delay for 10min, 30min and 60 min for response rate)
- Warning issued 1 hour before breach (with delay for 10min, 30min and 60 min for response rate)

V. RESULTS AND DISCUSSION

The model was run for variety of conditions under the same scenario to evaluate the potential loss of life resulting from a dam failure in the PMF assuming no warning is issued. These conditions are:

- People trapped in the buildings - using estimates of building resistance at the lower, mid and higher range.

- People attempt to evacuate if it is perceived to be safe once they become aware of the flood - using estimates of a person resistance at the lower, mid and higher range.

Table 2 indicates the potential loss of life resulting from PMF dam failure with no warning issued. The causes of loss including drowning, exhaustion, drowned in building (may be due to higher flood wave compare to the building shelter) and building collapsed (this may be due to the potential of building collapsed with people inside). The low, mid and higher range in building columns indicate the resistance of the building towards the flood wave and the people’s resistance to toppling and drowning. Low resistance shows that the building is easily collapsed when the flood wave hits and people have low resistance to flood and easily toppled/drowning.

Table. 2 Potential loss of life resulting in PMF with no warning issued

Cause of loss	Trapped in buildings			Attempt evacuation		
	Low	Mid	High	Low	Mid	High
Drowning	0	0	0	213	332	346
Exhaustion	0	0	0	0	3	0
Drown in building	38	109	139	93	72	72
Building collapse	570	470	427	260	150	81
Total	608	579	566	566	547	499

Table 2 also shows the most likely baseline scenario where people trapped in buildings. The total fatalities rate slightly higher compared to the attempt to evacuate. Table 3

shows the summary of results where no warning is issued, warning is issued during breach with delay time and warning is issued 1 hour before breach with delay time.

Table. 3 Number of fatalities and the influence of warning time

	No warning	With Warning					
		0 hour			1 hour		
		Delay 10min	Delay 30min	Delay 60min	Delay 10min	Delay 30min	Delay 60min
No. of people	1800	1800	1800	1800	1800	1800	1800
PAR	348	348	348	348	348	348	348
Number of fatalities	147	72	104	109	0	0	222
% of fatality rate	42.2	21	30	31	0	0	63

Table 3 indicates two scenarios under PMF dam failure have been simulated. No warning is the baseline during the flood event. PAR represents Persons at Risk where people might have highly impact from the flood wave of the dam breach. For each of warning scenario, the model has been run with response delay times ranging from 10 minutes to 60 minutes to give an indication of how response of the population to warning can influence the effectiveness. Table 3 shows that response delay time have influence on the number of fatalities. This is attributed to the effect of interaction between people and flood wave.

During the scenario of initiating the warning siren one hour before the breach, the number of fatalities increased with delay time of 60 minutes. This high number of fatalities may be caused by the time flood wave arrived at the Bertam Valley, people just started to evacuate to the safe haven. This resulting in high number of fatalities as the flood wave is at the peak level. Therefore, it is best for evacuation to take place one hour before the dam breach but the delay time must not exceed 60 minutes in order to minimize the fatalities. The zero number of fatalities indicate that people were able to reach the safe haven in the given time between warning issued and dam breach.

VI. CONCLUSION

From the simulation conducted above, the result from the simulation can be used as a supporting document especially for the authorities to improve their emergency preparedness plan. In Malaysia, the exposure or implication of flood disaster due to the dam breach is rarely been under the spotlight. Therefore, with some simulation on the impact of the dam breach can increase the awareness of the authorities and the communities if the dam breach disaster happen in the future. Besides, the simulation conducted by Life Safety

Model can estimate the optimum time for people to save their life thus minimize the fatalities. The Life Safety Model is one of the models that have dynamic interaction between the receptors and the flood hazard. In terms of emergency planning, it is important for the planners to consider the worst-case scenario of the events.

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