A Review of Recent Studies on Flood Evacuation Planning

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Abstract: Flooding is viewed by many as a natural phenomenon, which is necessary for biodiversity. However, with the anthropogenic activities brought about by changes in land-use and climate, floods are observed to be more frequent and severe. In order to avert the negative impacts of flood, preparedness measure such as evacuation is increasingly necessary. This review is conducted to identify recent advances on evacuation research in the view of behavioral science, risk analysis and transportation modeling. The elements of the evacuation process such as decisions, warning, withdrawal, shelter and reentry with relevance to transportation planning constitutes the framework and emphasis of this review. Future uptakes for research include travel behavior that covers decision to evacuate and reentry, and in-depth consideration of the flood hazard, its associated risk and shelter information to evacuation transportation demand modeling.

Keywords: Flood, Evacuation Planning, Transportation Modeling

1. INTRODUCTION

1.1 Background

Floods, considered as a part of natural ecosystems with perceived benefits are becoming more frequent and severe, causing widespread damage to many countries and societies at large. Its impact is increasingly devastating with increasing urbanization (Campion *et al.*, 2013). This is especially obvious in developing countries where population, economic activities and housing are rising in near flood-prone areas. For instance, in 2011 several flood events in Asia such as in Philippines and Thailand, claimed significant number of lives and damage to properties (Guha-Sapir *et al.,* 2012). Considering that flood is part of the natural process, the communities should invest in strengthening preparedness measures to avert the foreseen impacts of flood disaster. Evacuation is one of the effective preparedness measures to minimize damage and losses as a result of flooding (Na *et al*., 2012).

Evacuation is a vital part of disaster management (Cova and Johnson, 2003) that is described as moving people at risk to safety (Na *et al.*, 2012). It is a procedure most often used in cases where the community or infrastructure is potentially hit by hazard such as flood (Stepanov and Smith, 2009). Evacuation can be categorized into small or large scale; and immediate (no-notice) or pre-warned (short-notice) (EMA, 2005; Hsu and Peeta, 2012; Bish and Sherali, 2013), which is further classified as mandatory, recommended, and voluntary (Urbina and Wolshon, 2003; Stepanov and Smith, 2009; Taylor and Freeman, 2010).

1.2 Evacuation Process

Evacuation usually follows a process that includes detection, warning, preparation to evacuate, movement through a network, arrival to the shelter and verification (Stepanov and Smith, 2009). Obviously, transportation has a major role in evacuation. Careful and rigorous planning is deemed important to effectively implement this process. Effective evacuation depends on several factors such as warning time, response time, information and instructions dissemination procedure, evacuation routes, traffic flow conditions, dynamic traffic control measures, and others (Pel *et al.,* 2012) to mention a few.

Understanding the evacuation process and models are fundamental to evacuation planning. This serves as a basis for the implementation of evacuation plan (Taylor and Freeman, 2010). For example, Australia's evacuation process model which is similar to Stepanov and Smith (2009) includes hazard impact, decision, warning, withdrawal, shelter and reentry. Australia's model explicitly indicates evacuation logistics such as assembly area, evacuation center, one-stop shop and temporary accommodation (EMA, 2005) which are categorized as ultimate and proximate destinations in most studies (e.g. Stepanov and Smith, 2009). Taylor and Freeman (2010) labeled this policy as 'stay or go' which considers a voluntary type of emergency evacuation as most households does not prefer otherwise.

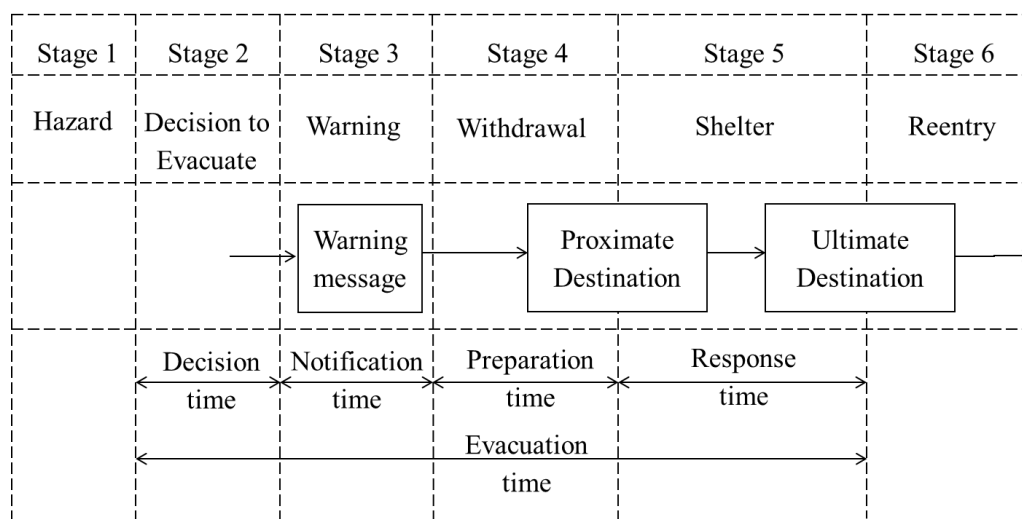| Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Hazard	Decision to Evacuate	Warning	Withdrawal	Shelter	Reentry
		Warning message	Proximate Destination	Ultimate Destination	
	Decision time	Notification time	Preparation time	Response time	
			Evacuation time		

Figure 1. Evacuation process model

Figure 1 illustrates an integrated model from EMA (2005) and Stepanov and Smith (2009) that captures the essential aspects of both models. This model emphasizes some essential logistical considerations in evacuation planning such as time and destinations. In addition, this process model indicates complex decision-making made by both authorities and individuals/households at risk.

This paper reviews recent advances on flood evacuation planning and modeling research based on the framework of the integrated evacuation process model mentioned in Figure 1. After which, key areas for further research are suggested.

2. EVACUATION PLANNING AND MODELING

Disaster conditions are most often times chaotic, communication is rather difficult and command structures can break down as a result of logistical or communications failure and

hard to control and predict human behavior during the emergency (Lumbroso, *et al.,* 2008). With this, preemptive planning is needed to address the threat of impending hazards. Evacuation planning is important to reduce loss of lives and damage to property from all possible hazards and emergency events (Jafari, 2005). Its goal is to define optimal evacuation policies for the individuals/households from areas under risk and uncertainty (Stepanov and Smith, 2009).

Evacuation planning is one of the important aspects of today's growing initiative on Local Flood Early Warning System (LFEWS) in the Philippines (GIZ, 2012) and similar projects implemented in Bangladesh, India, Nepal, Myanmar and Vietnam (ECHO, 2012), as well as Emergency Operations Plans (EOPs) in France (Piatyszek and Katagiannis, 2012). Benefits of having an evacuation plan could be seen for instance in the case of Philippines, the timely issuance of warning resulted to efficient execution of bringing people to evacuation centers; in other words, it enhanced the community's response capability during flood events (GIZ, 2012).

Moreover, evacuation planning employs proactive approach for solutions to evacuation problem by modeling the process of hazard occurrence through many kinds of simulation techniques and develops recommendations for improvement of evacuation procedures, redesigning and creating additional shelter areas, evacuation training, etc. (Jafari, 2005). Modeling of the evacuation process is particularly important to authorities, planners and evacuation managers for efficient movement of evacuees to safety. Particularly, modeling can help identify bottlenecks in the transportation system prior to the disaster event; determine the impact of road closures due to flooding, and understand the impact of phased evacuation on traffic loading, among others. Furthermore, being able to model alternative evacuation scenarios can lead to the establishment of suitable evacuation policies, strategies, and contingency plans and can help facilitate communication and information transfer (Lumbroso, *et al.,* 2008).

Evacuation planning models vary due to their applicable geographical scales, affected population density or size, and time span (Xie *et al.*, 2010). The goal and content of an evacuation plan also depend on the period of implementation, nature and probability of a disaster, and the degree of uncertainty prediction faced by the evacuation planner (Lebel *et al.*, 2011). A short-term evacuation plan, which serves as an emergent response to an identified impending hazard, may be developed with less uncertainty. Nevertheless, all actions in the plan must be made according to the available resources and infrastructure, and to be executed in least time possible (Piatyszek and Katagiannis, 2012).

To prepare an evacuation plan in case of future disaster, a long-term plan is needed. In this case, it is critical to incorporate unpredictable event characteristics, environmental and societal factors into the plan (Lumbroso *et al.*, 2011). Also, some strategic decision-making in system upgrading and resource allocation needs to be made (Xie *et al.*, 2010). An effective plan includes a well-defined account of the roles, responsibilities and communication of the stakeholders (Piatyszek and Katagiannis, 2012). Moreover, other technical aspects such as accessibility of roads, evacuation, and representation of the flood hazard as well as impacts of floods on critical infrastructure could be considered (Lumbroso *et al.*, 2011). During evacuation, there is urgency in moving people to safer places, of which the demand is overwhelming compared to the capacity of existing transportation networks (Hsu and Peeta, 2012). Thus, careful consideration and integration of the above mentioned factors affecting steps in evacuation planning and modeling is necessary.

Evacuation planning involves several decisions made by many people involved in the execution process that include several stakeholders. The process involves complex behaviors that should be considered in planning. Due to the complexity of the underlying processes and

many factors that determines these processes, evacuation modeling is important for planning (Pel *et al.,* 2012). Such models could be used to understanding the conditions of the network, the effect of traffic and control policies, predicting departure and arrival patterns, travel times, average speeds, queue lengths, traffic flow rates, and among others.

2.1 Hazard

Murray-Tuite and Wholshon (2013) underscores that for future evacuation modeling, specific disaster type should be considered. This is due to characteristics of the hazard type and its impacts. Some of the hazard-related criteria that could be considered in evacuation planning are frequency of evacuation, severity, existing vulnerable conditions, complexities on the nature and detection of flood (Taylor and Freeman, 2010). Additionally, hazard attributes such as intensity, spatiotemporal pattern (frequency), impact on the roadway network, and predictability (Hsu and Peeta, 2012) could also be considered.

The question is "Why Flooding?". There are several reasons why flooding can be a disaster type that can be considered. Flood is considered as a common hazard that affects a defined area. Predictive tools and warning system are in place for flood disaster (Taylor and Freeman, 2010). However, in spite of the advancement on early warning systems for flood, flood events continues to affect and kill significant number of people and cause massive damage to properties e.g. flooding in the Philippines and Thailand in 2011 (Guha-Sapir *et al.,* 2012). Evacuation planning and modeling studies that specifically considered flood hazard are still limited in number to date. Although there are some evacuation modeling studies that considers short-notice evacuation which are included in the later on Section 2.3 and 2.4. To mention some, are the studies conducted by Sherali *et al.* (1991), Simonovic and Ahmad (2005), Huibregtse *et al*. (2010), as well as Pel *et al*. (2010).

Sherali et al. (1991) investigated the optimal shelter locations by prescribing diversion strategy to minimize the total evacuation time of vehicles for designated origins under hurricane/flood disasters. Furthermore, a model of approximating optimal evacuation instructions that incorporates departure time, destination and route instruction was the focus of Huibregtse *et al*. (2010) where flood scenarios considered the source and direction of flood hazard was done. On the other hand, simulation of compliance to flood evacuation orders considering several flood related variables inundation of routes, flood condition, flood warning and evacuation orders was the central theme of Simonovic and Ahmad (2005). Likewise, Pel *et al*. (2010) in his study on compliance behavior and travel information assumes the recent setting of evacuation plan in preparation for possible flood evacuation.

Recent findings in research shows that households are motivated to evacuate by visual cues, flood forecasts, and risk level of their homes; all represent direct threats posed by flood hazard (Siebeneck and Cova, 2012). Against this is the background of existing transportation models, still lacking the integration of the dynamic nature of the hazard although Pel *et al.* (2010) indicated that EVAQ simulation-based model is capable of capturing the dynamic nature of the hazard more has to be done in conducting numerical examples that emphasizes the hazard. Thus, the nature of the flood should be considered for future evacuation planning and modeling. The great deal of the evacuation routing modeling is discussed in Section 2.4.

2.2 Decisions in the Evacuation Process

Decisions made in the evacuation process are complex and dependent on who decides. Practically, decisions could be done by the authorities and individuals/households. The former serves as one of the focus of this review. The decisions that the authorities face are rather

more complex as they need to consider all the stages of evacuation prior to issuance of warning. Their decisions primarily constitutes from hazard detection to reentry, where assessment of risk, assessment of information, identification of assembly area, shelter-in-place, mode of transport, route, and evacuation centers among others should be included (EMA, 2005; Stepanov and Smith, 2010).

Considering the complexity of decision-making that authorities face, future research could focus on the multi-criteria approaches that could be used to facilitate efficiency and effectiveness for evacuation planning. Tools that are proven to facilitate efficient and reliable way of decision-making such as analytical hierarchy process (AHP) could be used. Its application in the area of disaster management is limited to incident process assessment (Chen, *et al.,* 2012), effectiveness of preparedness measure (Manca, 2011), evaluation (Chen *et al.,* 2009), risk assessment on flood and landslide (Sinha and Singh, 2008; Wu, 2009; Mondal, 2011; Pourghasemi *et al.,* 2012; Kayastha and Smedt, 2013), industrial safety (Chang and Chiu-Lan, 2009; Jiangqing, 2011; Mohammadfam, 2013;), assessing vulnerability (Nouri, *et al.*, 2011; Orencio and Fujii, 2013), and critical facilities (Samadi, 2012).

On the other hand, the decision of the individual/household plays an important role in the overall evacuation planning and modeling. Knowing how many people decide to evacuate, stay in the area or go somewhere else, is a basic foundation for proper allocation of people to temporary shelters, available resources such as food and water (Lindell *et al.*, 2011). Consequently, planners could estimate the evacuation travel demand, vehicle allocation and traffic assignment in order to reach identified shelters at the least time possible (Pel *et al.*, 2010; Hsu and Peeta, 2012). One should understand that this can be overridden by the government once the hazard endangers the lives of their people.

2.3 Warning

The evacuation operation starts upon issuance of an evacuation notice (referred to as warning in this paper). The issuance of warning involves the definition of the evacuation areas, the sequential order in which areas are evacuated (if staged evacuation is considered), and the preparation and provision of shelters. The operation further includes traffic routing and management strategies, aid to people who need special care (such as the elderly, injured, disabled, etc.), organizing evacuation fleets, and related emergency services (Hsu and Peeta, 2012). These process steps require different decisions both from the individuals/households and the authorities.

Once the authorities involved have assessed the hazard, the issuance of warning is the next component of the evacuation process. Warning could be divided into a general warning and a specific warning (EMA, 2005). There are several considerations in the issuance of warning such as source of information, the information that detail out the characteristic of the hazard, vulnerability, and risk, the communication channels, receiver of the information and feedback (EMA, 2005; Dash and Gladwin, 2007). It is suggested that warning should be more specific and clear in order to capture a compliant response from the individual/household. Additionally, warning messages should be thoughtfully prepared and designed along the lines of behavioral actions by large numbers of people in order to be effective (Kievik *et al.*, 2011).

Another aspect of warning is the lead-time. Flooding typically has a lead-time of 1-3 full days (Hsu and Peeta, 2012). This lead-time allows both the evacuees and emergency management agencies to be better prepared for the evacuation operations. An evacuation commonly results to an increase in traffic demand on a specified time frame which typically results to congestion (Bish and Sherali, 2013). Thus, issuance of the warning while providing lead time is very important for evacuation process. In addition, warnings, particularly those

issued by authorities, and relatively long lead times were also factors for an effective implementation of emergency measures (Kreibich *et al*., 2011).

2.4 Withdrawal

The withdrawal stage in the evacuation planning process includes the movement of people from the area at risk to the shelters identified. An efficient evacuation operation at this stage involves management of both the demand and supply sides. The demand side of evacuation considers the evacuation travel demand, of which complex behavioral decision making is involved. The supply-side management includes the deployment of information guidance and capacity expansion approaches, such as contraflow lanes (Ubina and Wolshon, 2003; Cova and Johnson, 2003), lane-based and crossing elimination at intersections to optimize evacuation flows for the desired objectives (Xie *et al.*, 2010; Xie and Turnquist, 2011), where traffic flow modeling and route assignment serve as the basis for network optimization (Hsu and Peeta, 2012). The supply-side of evacuation operations consists of the components that physically provide capacity to evacuate the affected population from the threatened areas: transportation system, evacuation plan, and operational strategy.

Murray-Tuite and Wolshon (2013) gave a comprehensive review on previous studies on the demand and supply aspect of evacuation modeling as well as strategies used in the modeling process. Most existing evacuation management approaches address the problem considering the supply-side only. However, evacuation operations model could be ineffective if it does not carefully capture the processes associated with the demand–supply interactions (Hsu and Peeta, 2012).

The following sections discuss the elements of evacuation modeling at this stage of withdrawal. The first section looks at the complex travel behavior involved in assessing the demand side. While the second section considers the supply side that include network traffic assignment in routing as well as the mode of moving people.

2.4.1 Travel Behavior in Evacuation Modeling

Each individual/household in areas at risk may recognize the evacuation situations differently based on his/her behavioral attitudes and past experience (Scolobig *et al*., 2012). The decision of evacuees is crucial for the estimation of travel demand in evacuation. One of the most comprehensive flood evacuation models which considered a broad range of behavioral factors is that of Simonovic and Ahmad (2005) where they tested a system dynamic approach capturing human behavior during flood emergency evacuation. In the analysis of demand, the model has taken into account social, internal, initial and psychological factors as well as policy variables. Moreover, Murray-Tuite and Wolshon (2013) provides a summary of broad range of behavioral factors that affects the likelihood of evacuation decision. However, the utilization of this information has not been fully maximized and/or integrated in evacuation route modeling. Also, only a handful studies have considered broad range of factors specific to the type of disaster (e.g. Pel *et al*., 2010; Hsu and Peeta, 2012).

2.4.2 Evacuation Route and Network Modeling

Recent studies on evacuation routing have heavily used optimization-based models, simulation-based models or both. One advantage of simulation-based models is its ability to capture behavior characteristics of evacuees and traffic flow dynamics. On the other hand, optimization-based models are capable of identifying optimal planning solutions in a

systematic, self-driven manner (Xie, *et al.*, 2010). Combination of these two could solve the inherent disadvantages of using only one type of model.

Considering that withdrawal stage is described as the movement of evacuees to the shelters, most evacuation modeling studies were carried out in this boundary: evacuation routing and evacuation network. Murray-Tuite and Wolshon (2013) detailed the studies related to evacuation modeling in the context of all disaster types especially on hurricane, a well-studied area on evacuation research. With the objective of identifying research and application efforts in evacuation modeling that could be applied for flood, a review is presented in this section and the evacuation route and/or network models are summarized in Table 1.

Stepanov and Smith (2009) proposed an integrated optimization and simulation-based evacuation model to examine the optimal routing policies for evacuation planning. A multi-objective optimization-based model was set up to solve the problem, further evaluated with the integer programming model that utilizes state-dependent decaying service rate M/G/c/c queueing models to capture time delays functions on road links. Evacuation planning policy was compared to the shortest path policy, shows better results than shortest path. Thus, the combination of the optimization and simulation methods allows decision makers to deal with massive regional evacuation, particularly address congestion while capturing stochastic nature of evacuees' departure process.

Table 1. Recent studies on flood evacuation route and network modeling

Hazard/s	Method	Optimized variable	Author/s
Not specified	Multi-objective route optimization and M/G/c/c	Minimize travel time, traffic delays, travel distance	Stepanov and Smith (2009)
Flood	Single objectives optimization and EVAQ	Maximize number of evacuees; minimize arrival time	Huibregtse *et al.* (2010)
Not specified	Route optimization and CPLEX	Minimizing travel time; optimize evacuation routes	Sayyady and Eksioglu (2010)
Not specified	Route optimization	Shortest independent paths, maximize flow	Campos *et al.* (2012)
Not specified	Network flow optimization and Evacuation Scheduling Algorithm (ESA)	Shortest path, maximize no of evacuees	Lim *et al.* (2012)
Not specified	Bi-objective route optimization	Minimize maximum time, minimize cost	Na *et al.* (2012)
Not specified	Route optimization	Maximize flow	Bish and Sherali (2013)

Huibregtse *et al.* (2010) used optimization method to evaluate optimal evacuation instructions using the factors of departure time, destination and route for evacuation by cars. Sets of instructions were tested and results of performance were noted. Although the analysis of network occupancy during the evacuations as a result of instruction sets was assessed, no clear patterns can be seen in instructions leading to the network occupancy. This study confirms that optimization methods could be used to create evacuation instructions instead of applying instructions setup by straightforward rules.

Sayyady and Eksioglu (2010) proposed a methodology using mixed-integer linear programming for designing evacuation plans for transit-dependent citizens. The goal of the

method is to find the optimal evacuation routes, with minimum time of movement and casualties. A traffic simulation package is used to integrate the traffic flow dynamics into the model in generating solutions. A tabu search algorithm was also designed to reduce the running time of the simulation. The model is useful for evacuation planning and also for implementation during evacuation operations.

Campos *et al.* (2012) designed and analyzed evacuation routes using a heuristic algorithm to define two independent paths from the disaster area to each shelter identified. The travelling time and capacity of the transportation network are considered as the parameters for analysis. Independent paths are identified in order to allow continuous traffic flow and reduce potential accidents.

Lim *et al.* (2012) proposed an optimization model of capacity constrained network flow for finding evacuation paths, flows and schedules while maximizing total evacuees. In the study, a time-expanded network considering the static network over the planning horizon for every time interval was constructed due to dynamic nature of the optimization problem. Then the result of the optimization model was evaluated and assessed using Evacuation Scheduling Algorithm (ESA) that utilizes Dijkstra's algorithm in finding the evacuation paths. A greedy algorithm was used to evaluate the maximum flow of each path and schedule to execute the flow for each time interval. Numerical examples were performed to validate results while showing the advantage of ESA in terms of computation time of about less than a second.

Na *et al.* (2012) proposed a bi-objective model to optimize route assignment with consideration of secondary evacuation. Using an approximation algorithm to solve the model, it is set up to simultaneously minimize travel time and minimize the secondary evacuation expected costs. A set of constraints specified for the optimization include travel time, ensured that all people are evacuated, capacity of temporary and fixed shelters as well as the capacity of buses. A numerical exercise was done to validate the algorithm and test the significance of the models.

Bish and Sherali (2013) proposed a modeling framework by using demand-based approaches of aggregate-level staging and routing. The stages are analyzed in the case of congestion and without congestion in order to assess the performance of the model. The modeling framework proposed offers strategic flexibility which uses lexicographic objective function to a hierarchy of evacuation-based goals. Study shows the effectiveness of using demand-based strategies as compared to using the static simultaneous evacuation process.

Other evacuation models used in other kinds of hazards could be tested for transferability in the case of flood. For instance methodologies involved in evacuation decisions such as demand generation, route choice are reviewed and discussed by Hsu and Peeta (2012). Readers are directed to these papers for further details on methodologies that capture the behavioral complexities in evacuation planning. Hsu and Peeta (2012) argued that real-time routing in evacuation entails the explicit consideration of the demand–supply interactions. Hence, there is a need for an integrated framework that incorporates behavioral aspects into the evacuation process. Moreover, knowing the limitation of simulation-based models, previous studies should be tested to consider a real time data in order to understand the errors related to the modeling exercises.

2.5 Shelter

Lindell and Prater (2007) categorized evacuation shelters as an important aspect of evacuation planning. Its allocation is considered inevitable (Lim *et al.*, 2012). For example, the success of evacuation effort done by the Thai government during the flood in Thailand in 2011 is attributed on the sufficient number of evacuation estimated at around 2,600 evacuation centers

nationwide (World Bank, 2012). Shelters can be often times categorized as either ultimate or proximate destinations which have been the basis of recent studies on evacuation modeling (e.g. Lindell, and Prater, 2007; Stepanov and Smith, 2009). A particular reason for this movement from one shelter to another is because of depletion of resources to address basic needs. However, this depends on how the shelters are used by the evacuees. For example, shelters can be assembly area, evacuation center, shelter-in-place, one-stop-shop or temporary accommodation (EMA, 2005). These shelters can be an ultimate or proximate depending on the evacuees. If the shelter serves as an intermediate destination then it is considered proximate. But if it is considered as an accommodation before returning back home, then it is ultimate destination.

In previous modeling studies, it is assumed that most public evacuation shelters provide enough space to host the evacuees and are located in areas where there is adequate ingress routes to deliver humanitarian aid, medical assistance, etc. (Campos *et al*., 2012), (e.g. sports complex, institutional buildings such as in schools and universities, medical facilities) as they are designed to hold large number of people (Stepanov and Smith, 2009). Previous and recent studies accounted shelters in the view of destination choice (e.g. Sayyady and Eksioglu, 2010; Campos *et al*., 2012; Lim *et al.*, 2012; Bish and Sherali, 2013). However, when considering the impact of evacuation planning to the movement of people, the capacity and resources of identified shelters should also be considered. Also, understanding the behavior of the people on their choices of destination is important so as to better forecast the travel demand during future events of disaster. Sudden changes in evacuation plan might for example be vital by the much larger number of evacuees that show up than planned for. When these likelihoods are not properly accounted for, last-minute changes in the evacuation plan might lead to chaos such as overcrowded networks (Ng and Waller, 2010).

Table 2. Recent studies on evacuation modeling with emphasis on shelter

Hazard/s	Consideration on Shelter	Author/s
Not specified	Shelters were considered as destinations and shelter capacity was considered as a constraint	Stepanov and Smith (2009)
Flood	-	Huibregtse *et al.* (2010)
Flood	-	Pel *et al.* (2010)
Not specified	Shelters were considered as destinations	Sayyady and Eksioglu (2010)
Not specified	Shelters were considered as destinations	Campos *et al.*(2012)
Not specified	Shelters were considered as destination	Lim *et al.* (2012)
Not specified	Capacity of temporary shelter and fixed shelter were considered as constraints	Na *et al.* (2012)
Not specified	Shelters were considered as destinations	Bish and Sherali (2013)

It should be understood that shelter has their characteristics such as parking space and building capacity that can affect congestion and secondary evacuation once their reach their limitations. Table 2 above summarizes the studies which considered the characteristics of the shelters and how they have treated its characteristics in view of evacuation planning. Majority of the studies indicate shelters as destination choices (Sayyady and Eksioglu, 2010; Campos *et al.*, 2012; Lim *et al*., 2012; Na, *et al*., 2012; Bish and Sherali, 2013) and the rest did not consider shelter in their modeling exercise (Huibregtse *et al.*, 2010; Pel *et al.*, 2010). For instance, Na *et al.* (2012) in his study considered the capacity of the temporary and fixed shelters as constraints in investigating the optimal route assignment. While Stepanov and Smith (2009) analyzed egress route assignment algorithms and considered shelter as destination and shelter capacity as a constraint. To date, there is still a need to incorporate shelter characteristics in dynamic models.

In many evacuation plans, there is an underlying assumption that all evacuees will go to specific designated shelter locations, but this may ignore some obvious points of egress from the network. If other egress points are recognized, the pattern of network configurations implemented maybe quite different (Xie and Turnquist, 2011). Studies should particularly investigate the effect of the capacity of shelter on congestion as reality indicates that evacuation results to congestion in the destination. Also, the effect of limited parking spaces of evacuation areas should also be studied as the parking spaces are normally limited in terms of area.

With these considerations, future evacuation modeling studies could address the following questions: Can the shortest path as an approach in determining paths from areas at risk to the shelter create congestion in the network? Are the evacuees free from hazard impact and threats when travelling on shortest paths? Could a shelter located at a longer distance from the area at risk result to a less congested network during the withdrawal stage? What is more important in selecting evacuation shelter? How does the capacity of shelter affect the evacuation time? Could consideration of the capacity of shelters result to a necessary secondary evacuation?

2.6 Reentry Process and Travel Behavior

The reentry process describes the events when the evacuees move back to their homes after a disaster event. It has been acknowledged in research that considering the reentry, not only evacuation should be considered in evacuation planning. Ignoring the 2-way nature (evacuation and reentry) of the evacuation process fails to capture what is really happening during these periods of events (Siebeneck, 2010). The importance of reentry is a vital part of the evacuation process especially on the practical perspective. Hence, events during the reentry should also be considered in evacuation planning. And this, before implemented in practice needs to be proven in research. This component is already well accounted in the context of countries like Australia (EMA, 2005).

Previous research specific on flood demonstrates that previous flood experiences significantly shape individual perception about risk, making the decision to adjust to flood, and purchasing flood insurance. Individual experiences and characteristics have also been found to influence precautionary behavior in response to floods. Terpstra *et al.* (2009) examined how emotions, trust, and perceived risk influenced flood preparedness intentions by citizens, and concluded that negative feelings (e.g., perceived dread, powerless, damage, and anger) and positive feelings (e.g., trust in flood relief, care, and relief/sensation) influenced flood preparedness and behavioral intentions. However, these findings of understanding risk perception are related to decisions made for evacuation compliance.

In determining the demand during the reentry process, understanding the reentry decision of individual/household is important. In doing so, identifying the factors that determine the decision is necessary. Results on modeling the reentry compliance using series of binary logistic regression models was done by Siebeneck (2010). In the study, the effects of factors grouped into individual characteristics and event-specific characteristics were considered in relation to estimating the models. A model considered the household characteristics, socio-economic characteristics and household structure. Another model considered the socio-demographic characteristics of individuals/households. Results of the models suggest that factors influencing reentry compliance differ from those that influence evacuation compliance.

It could be argued that the socio-demographic characteristics of household that include income, number of members in the household, presence of children specially those less than 6

years of age may have significant effects on the decisions of individual/household on reentry. In the case of income, a household with damaged properties having the capacity of fully repairing their homes would decide to return later after completion of repairs. While individual household with lower income would decide to return at once due to limited capacity in further staying somewhere else. In addition, a household with small children/aged people would also decide to return later, because they want to make sure that everything is safe and ready when compared to households with no small children. Moreover, significance of factors such as readiness of the area that could include safety and health hazard-free indicators could be studied. Moreover, factors such as location of work of the household head in relation to the place of evacuation, and location of school of children could also be considered in future research. The effects of risk perception, depending on the nature and duration of the flooding event and its interaction to the socio-demographic factors of individual/household should also be analyzed.

A recent study by Siebeneck and Cova (2012) was focused on understanding how risk perception and location influence individual/household behavior during the evacuation and reentry process. Specifically, the spatial and temporal characteristics of risk perception throughout the evacuation and reentry process; the relationship between risk perception and individual/household compliance with reentry orders; and the role of social influences on the timing of the reentry by households were explored in the research. Using data gathered from the 2008 Cedar Rapids, Iowa Flood, the study found out that the geographic location and spatial variation of risk influenced individual/household risk perception and compliance with reentry. This study is a step forward to understanding factors influencing reentry decision. However, much is to be done in research.

First, examining a longer time period before and after a flood event to establish an accurate baseline for assessing varying risk perception and monitoring how risk perception changes over a longer time scale should be done. In addition, the interrelationships between hazards, risk perception, and risk communication throughout the reentry process should be explored. Emphasis should be placed on identifying the specific threats present during the reentry phase and how emergency managers can use knowledge of these threats to create more effective reentry messages. In addition, future studies should examine the role of experience with previous reentry on timing and compliance with reentry orders. Also, factors according to the context of developing or developed countries should be considered. In terms of reentry compliance, the response of people in developing countries may vary from those in developed countries due to differences in culture, available resources and capacity of enforcement.

To consider complex factors in understanding reentry decision, a methodology that addresses the interrelationships of the factors significant to it should be used. Methodology such as discrete choice models under the utility maximizing framework could better capture the behavioral context of the reentry decision. More so, clustering and identifying of regressors should be treated with extra care.

In reentry planning and modeling part, the following could be the questions to be addressed. How does understanding of how people organize when moving back to their homes, the timing of their movement, the mode of transport they use as well as with whom they are moving could influence the planning process? Knowledge on these could contribute to the demand that would be generated during specific timings and mode of transport.

3. SUMMARY AND CONCLUSIONS

There are various aspects on evacuation that needs to be decided at the individual/household level and at the level of local and national authorities. Although identification is not an issue, its complexity is rather immense and compounded in a modeling exercise and actual situation. The individuals/households choice to evacuate is to be considered in every emergency situation, as this is the input for evacuation travel demand. This should be anticipated by the authorities in coming up with a sound and evacuation plan.

Studies such as in USA shows that majority of households comply with evacuation orders. However, when they leave, they use their own vehicle and generally took more than one car when evacuating. This has implications in the traffic flow problem. Further this problem is exacerbated by the households taking trailers (Lindell *et al.* 2011). Past transportation modeling studies on flood considered between 1-3 full day evacuation duration which clearly adheres to the past experience on hurricane (Pel *et al.*, 2010; Huibregtse *et al.*, 2010). However, the issue on the use of modes of transport is still ill-addressed in the exercise.

Models developed have mainly sought to estimate evacuation clearance time and identify potential bottlenecks for evacuation planning, key determinant of the evolving traffic flows, the evacuation-related traveler behavior, has been largely simplified by assuming a known O–D demand pattern and/or a compliance rate under prescriptive route guidance (Hsu and Peeta, 2012). Hence, consideration of travel behavior in evacuation models needs to be further done in research.

Travelled distance of the evacuees varies substantially over different areas due to the size and intensity of hazard, and population density of the affected area which are significantly correlated with evacuation date and shelter (Lindell *et al.*, 2011). With this, one can identify that evacuees who have ability to spend will choose to stay in an area which has the absence of hazard. This choice coupled with coherence on community decision can pull a larger travel demand to a specific area and can create traffic congestion in the evacuation destination. Therefore, consideration of these aspects in evacuation planning is necessary.

Risk assessment is one of the key aspects of evacuation process (EMA, 2005). Its result should be considered in the identification of areas subject to mandatory evacuation. Its applicability should be investigated in future researches. Moreover, risk assessment results that are translated to spatial information through risk maps are rather poorly accounted in traffic assignment simulation models. Thus, a careful consideration of risk is a promising improvement in future evacuation transportation simulation exercises.

Most often than not evacuation transportation modeling exercises consider optimizing and simulating the travel time, distance among others from a point of origin to a certain destination. Demand for public shelters is likely to result in traffic congestion. Despite the fact that small fraction of households stay in evacuation shelter, allocation of shelter in a large scale evacuation will remain as a challenge. Likewise, demand in commercial accommodations will likely rise (Lindell *et al.*, 2011). With this volume of households that are likely to use evacuation shelters and commercial accommodations in a short term, congestion in their approach towards targeted locations will likely increase. In worse case, this might lead to a secondary evacuation especially if the planners failed to assign specific evacuation shelters for a certain number of evacuees. This aspect on optimization and simulation-based researches is also understudied. There are only few studies that can be cited for flood evacuation modeling such Na *et al.* (2012) and Stepanov and Smith (2009) as constraint and evacuation clearance time respectively. Thus, future studies should consider the evacuation shelters as a key factor in modeling exercises as they have limitations that can result to congestion in transportation facilities especially in crowded areas. Moreover, it is likely that the traffic demand in the proximate and ultimate destinations increase after the

evacuation. This is more likely to affect the traffic flow in their desired destination as most evacuees tend to use their personal vehicles for evacuation as a result they will utilize these in while they are in the temporary shelters. This is particularly important for flood related disasters that requires at least a month of stay in an evacuation shelters. This will have an implication on the transport planning of areas which are not affected by flood disasters. Thus, the effect of migration from the normal functioning of the host area of evacuees can be an area of future research.

Reentry component of the evacuation process is still understudied and possesses huge opportunities for research. The studies related to modeling reentry were initiated recently. The study conducted by Siebeneck and Cova (2012) have considered limited factors related to reentry decisions. Further studies can be explored on the influence of news and social media on the reentry decision. At the moment, there are no studies related to transport modeling especially on route optimization, traffic assignment simulation, and logistics related to reentry. Therefore, bulk of research could be done in this area.

4. ACKNOWLEDGEMENT

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