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Review of evacuee mobilization challenges causing time-lag: Conceptualizing a new framework

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Abstract

This paper explores the concept of evacuation mobilization as a protective decision-making process and builds a theoretical framework that captures the factors from the perspective of risk communication. As a critical step in the decision process of disaster evacuation, in practice, mobilization has been overlooked. This study aims to embrace the varied yet inconsistent factors to a theoretical framework built upon the Protective Action Decision Model (PADM). A comprehensive review of literature of seminal and recent studies exploring the factors of mobilization and the major risk communication studies were used to build the theoretical framework explaining the variance of evacuation mobilization. Upon reviewing the aspects and factors of evacuation mobilization, this study asserts that the PADM is the most appropriate framework among those examined to theorize this process in evacuee decision-making. Specifically, the stages of receiving environmental cues and information, pre-decision processes, and perceptions, sequentially determine the on-going decision process of mobilization. This study fully discusses the issues surrounding evacuation mobilization and invites further empirical studies on early-warning disaster evacuations and more accurate simulations for late or no-warning evacuations. It also offers suggestions on how to mitigate the potential harm caused by extended mobilization.

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Introduction

Moving people out of harm's way before a hazard strikes is oftentimes the preferred method to protect lives and is termed as 'evacuation', referring to 'the withdrawal actions of persons from a specific area because of a real or anticipated threat or hazard'[1]. This statement identifies a generally accepted idea that an overwhelming threat is 'out there' or is believed to be there, triggering evacuation warnings/ recommendations from scientific experts, public administrators, and social groups as the best protective measure for the general population. These warnings and recommendations are dependent on the type of hazard and the lead time available for disseminating the warnings. For example, in the case of a hurricane or cyclone, the populations at risk can be made aware of the threat at least a week in advance, so that they can take evacuation decisions early on. However, in the case of a tornado or an earthquake hazard, the lead time to predict its generation is likely to be a few short minutes, subsequently exacerbating evacuation decision making.

Furthermore, even when the risk area populations comply with evacuation orders, the timing of their departure might be delayed and not match with what the emergency management professionals intend and plan for. Oftentimes, this lag may be due to a lack of trust in government orders[2], or an attempt to validate the information received, from multiple sources, or personal experiences[3], lack of trust in professionals' technical suggestions[4,5], difficulties in decision-making due to family situations[6,7], spending extraordinary time to pack belongings and getting vehicles ready[8], or lack of modes of transport due to socio-economic barriers[9–11]. Such evacuation delays can trigger additional disaster management problems. For example, those who take a longer time to gather belongings would be less likely to survive a short-notice or no-notice disaster. Further, heads of households or emergency managers charged with implementing effective evacuations would fail to meet their objectives and save lives. Delayed evacuations would also increase congestion on evacuation routes, putting more people in harm's way.

Alternatively, Japan has a tradition of 'Tendenko', which calls for people to evacuate immediately when there is a tsunami warning, without waiting for others – which is believed to be an effective, albeit arguably difficult order for family members and caregivers. This strategy is touted to have saved hundreds of lives during the 2011 Tōhoku Tsunami response[12]. It is also like the instructions received before takeoff on a flight, when one is asked to wear your oxygen mask first before helping others.

Hence, it is necessary to establish an attitude among evacuees to minimize any delay after the decision to evacuate is made[13]. But a more important task for evacuation managers and experts is to know the mechanism causing such a delay and prepare for it in advance. The unpredictable time gap

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between decision and action of evacuation can result in variations in the levels of congestion on the transportation systems[14,15]. Spending a lot of time packing essentials before leaving home can lead to delays in entering the evacuation route, and, consequently, extend the clearance time and cause unnecessary losses on the road[8,16]. Not only can these issues be alleviated, but the evacuation simulations can also be more accurate once the answers to what lead to this delay in evacuation action-taking are available.

The literature suggests a few factors in risk communication and explain why potential evacuees may not behave as experts and governments expect. Physical cues of the environment, social contexts of evacuation information sharing, components of the warning messages, and potential evacuees' characteristics play important roles in their decision making[17]. Mental judgment aside, the physical or situational conditions of evacuees can limit or facilitate their final actions in evacuation[17–19].

A shared assumption of the major evacuation literature, applied to this paper as well, views evacuation as not the result of the upcoming hazard directly. Rather, it is the perceived risk that drives the evacuees to leave their homes[20,21]. The key argument is that inadequate or uneven expectations of risk may lead evacuees' reactions to differ from each other. Residents believe they are in danger, not only because of the hurricane ruining their assets and lives, but also other possible consequences of the evacuation before or after the hurricane which may put their property and personal safety in danger. These risks are argued to be embedded within the societal surroundings of evacuees, as well as in the individual and group processes[1,22–24].

However previous studies related to evacuation time estimates and activities, and those related to evacuation as a preferred hazard adjustment are fragmented and decades old. Thus we follow the call by notable disaster scholars like Kasperson et al.[25] and Lindell & Perry[17], for holistic theories/frameworks to better explain this phenomenon, to find mitigating solutions to reduce evacuation times. Following a review of seminal articles we propose a theoretical framework to capture the factors contributing to this lag time. Evacuation studies conceptualize 'evacuation time' as a series of time spans, in which the authority issues the order, the residents receive the information, the evacuees make the decision to leave, and they take a series of actions including coming back from work, grabbing necessities and household members, and rushing toward the nearest highway[3,26]. The framework focuses on the time span between evacuees' decision to evacuate and their actual departure time. This lag is termed 'mobilization', consistent with other studies[13,27], and will be used herein to indicate this concept of time lag.

The following sections review the studies directly targeting mobilization, discuss mobilization in a broad framework of risk communication, and introduce three specific frameworks exploring the causations in risk communication. These frameworks are the mental models (MM) approach, the social amplification of risk framework (SARF), and protective action decision model (PADM). After examining these frameworks, this study identifies the factors in each stage (i.e. cues and information, pre-decision process, perceptions, and mobilizations) determining the variance of mobilization time. A propositional framework concludes the discussion and calls for future empirical studies of evacuation mobilization.

The time gap for evacuation

Evacuation is a key component of emergency operations planning, especially because of unexpected problems arising from non-compliance and/or shadow evacuation, leading to overload in the transportation system and unnecessary loss of assets and lives. Hence, the time to evacuate becomes critical in this field as it determines the occupancy level of the transportation corridors during an evacuation. Also, the increasing public demand of effective and efficient services, corresponding with more and more severe weather along the coastline of the United States, has triggered practitioners and academicians to invest more effort in evacuation studies[14].

Scholars have tried to estimate the time gap between one's decision to evacuate and the time of actual departure. This gap is a critical component in gauging the clearance time—a gap between the evacuation order and the last evacuee leaving the official risk area. For instance, Lindell[9] identifies two important components of hurricane evacuation time before an evacuating household enters the transportation system, namely warning receipt time and evacuation preparation time. They jointly include several preparation items (such as luggage packing and vehicle preparation). Dixit et al.[13] term this concept 'mobilization time' and argue that certain household characteristics and risk perceptions may lead to a variance in mobilizing. Numerous scholars also define this concept as evacuation 'delay' and 'waiting'[10], 'traffic loading rates'[11], 'preparation time'[11,28], 'logistical preparation'[29], 'mobilization' of evacuees[13,27], and so on. This paper employs the terminology of Dixit et al.[13] of 'mobilization time', referring to the time gap between the decision to evacuate and the actual departure.

Three noteworthy publications bring the concept of evacuee mobilization to the research of evacuation timing. Sorensen[27] attempts to answer the question 'when do we leave?', in which mobilization time is a key step in a path model illustrating the factors and procedures influencing the time of departure from a site of a hazardous material spill. He assumes that evacuees begin to mobilize right after hearing the first warning of the event, and until the departure from home. This article particularly answers a big question raised by Sorensen & Mileti[30], 'when do people evacuate?' Sorensen[27] also explores the warning system structure, the evacuees' social context, social structure, physical constraints, and risk perceptions. He posits that the degree of personalization offered by the system (warning system) is the only significant factor explaining the variance in mobilization time of evacuees. That is, the more sources by which the warnings are made personal, the longer an evacuee spends on mobilization.

Not assuming an evacuee deciding to leave at the time of warning reception, Dixit et al.[13] define mobilization as 'the difference between the time at which the decision to leave is made and the actual time of departure'. Like Sorensen[27], the measure of this concept is calculated by two self-report questions — the time the evacuation decision was made and the time of departure. Again, only a few social-economic variables are statistically significant (home ownership, household size, and income) to explain the variance of mobilization time. A major contribution of the article by Dixit et al.[13] is a technical risk level measured based on the locations of residents (which can also be defined as a probability). This measurement

indicates that the concept of 'risk' can be both a probability and evacuees' perceptions affected by a recent hurricane experience.

Lindell et al.[28] further clarified the distinction between risk perception and probability. They argued that the geographic location is a measure of an evacuee's probability affected by a hazard, which does not necessarily determine the risk perception and, henceforth, the actions. Thus, the risks that really matter could only be the perceptual ones. Lindell et al.[28] used the concept of 'preparation' (e.g. traveling from work to home, gathering household members, and packing items) to represent the time gap between decision and departure of evacuation. But their focus still overlapped with the 'mobilization' concept in the other two studies. Interestingly, Lindell et al.[28] did not find that social characteristics explained the variance in preparation time, which was the opposite of the findings by Dixit et al.[13]. More importantly, they found that the location of homes (distance to the coastline) had a negative relationship with preparation times. That is, the closer an evacuee household lived to the coastline, the longer they took to mobilize. They reasoned that a higher risk of storm surge close to the coastline would require residents to spend more time protecting their properties[13].

These three seminal studies help to illustrate the difficulties practitioners face when estimating time required to mobilize evacuees. Other empirical studies from recent years also suggest similar inconsistent results from population to population[31–36]. Although, these studies are helpful in highlighting the challenges, they also suggest that a structured framework for possibly quantifying of this time 'gap' is yet to be established. Such a framework, that draws from the afore mentioned studies, needs to incorporate psychological factors, risk perception concepts, time for preparedness activities, and household types and size in evacuation decision-making. The following section revisits the key components of risk perception and discusses some existing models that helped inform the creation of the new framework.

An outcome of risk communication

The theoretical issues revealed by the mobilization studies mentioned earlier are possibly due to the behavioral nature of mobilization. In other words, there is a need for addressing the essential driving force of behaviors in emergency situations to explore the factors influencing the mobilization action. As such individual and group risk perceptions are the very key to our understanding of mobilization as a response to emergency events.

Human beings have multiple means to develop risk perceptions. Individually, previous 'knowledge' of risk would help a resident identify danger, or such perceptions may be influenced by individual characteristics[22]. As a group, the collective behaviors rely on the members' sense-making procedure, determined by the input information, regarding the disaster[23]. On the community or a higher level of social structures, trust and distrust between resident groups, or between citizens and governments, may increase risk perception[4,24].

It is noticeable that risk perceptions, along with the behavioral consequences, rely heavily on the evacuee's ability to personalize or process the information prior to decision making. In response to certain risky events, the affected actors would receive or obtain messages regarding the event from their social and natural environments. Each recipient then translates these messages through a mental process, influenced by the recipient's psychological and social contexts which are keys to risk communication.

Two theoretical frameworks/approaches have been well established covering the whole risk information processing that links the personalization procedure to the responsive action taken. Lindell & Perry[3,17,29] proposed the protective action decision model (PADM), while Kasperson[5,37] developed the social amplification of risk framework (SARF) to incorporate the fragmented studies about risk perception. Aside from these frameworks, a Mental Model (MM) approach was introduced by Bostrom et al. and Morgan et al.[38,39] to assist practitioners in reducing the gap between the perceptions of experts and laypeople. All the three frameworks capture the process, at least partially, communicating experts and laypersons but differ in their assumptions of a 'true' level of risk and the extent to which the risk communication influences protective actions. The following content discusses the three frameworks/models in detail.

The Mental Models (MM) approach

The MM approach was originally developed with a different aim compared to the other two frameworks. The SARF and PADM are designed to model individual's formation of risk perception, while the MM approach is a practice guide for experts and authorities to manipulate and streamline 'layperson's' risk estimates. Like a policy-making procedure, the MM approach begins with the identification of a problem—the gap between experts' and laypersons' understanding of risk regarding a particular hazard. The expert view is recommended to be modeled using influence diagrams, containing the structural causations between multiple factors and the potentially hazardous consequences[39]. Next, the 'mental models' of the regular citizens (laypersons) are carefully examined using a research design based on the expert models. Both models are established by surveying the individual members of the two groups. Finally, a communication strategy is developed to close the expert-layperson knowledge gap, with an evaluation procedure assuring the effectiveness of the risk communication[39].

The practitioner-oriented MM approach does not theorize the causation mechanism leading to comprehension gaps between experts-layperson. This characteristic brings a noticeable difference between the MM approach and the other two frameworks — the risk-specificity. In other words, the application of MM requires detailed examination of a particular risk event, else the expert-layperson gap cannot be effectively closed or is ignored which is detrimental. Such a requirement makes the utilization of MM to vary greatly from case to case, such that seldom is a 'common' structure observable in the MM as is evidenced in the PADM and SARF[40] models.

Hence, the MM may not be an appropriate platform to model and predict people's perceptions and actions in risk communication. The simplification of the social actors (experts vs. laypersons) can compensate for the costly, complex event modeling procedure, but Morgan et al.[39] conceded that multiple actors did exist in risk communication and their participation was valuable for the best result. They also accepted that expert perspectives were not always identical, if ever. Still, there have been no amendments to the model capturing these concerns[40]. On the practitioner side, however,

the MM approach is useful in identifying and closing the perceptual gaps between experts and citizens.

Social Amplification of Risk Framework (SARF)

The other two frameworks are on the theoretical side and have been revised or added to in the past few years. Kasperson et al.[25] developed the conceptual framework, 'social amplification of risk', seeking to build an interdisciplinary method to examine the individual risk realization. Their major argument is that risk perception and behavioral reactions are created and amplified by certain psychological and social processes. They added to this notion[37] by bring in the attenuation effect, arguing that the transformation of risk information via different 'stations' might either increase or decrease an individual's perceived risk level and their response behaviors. A key argument applicable to this proposal is that a person's social environment and psychological procedures will determine their risk perceptions and responses (Fig. 1).

A widely accepted understanding of SARF indicates a two-stage impact after the risk event has been identified. The risk event, which assumes a hazard with a certain probability, will trigger the information flow among different social groups and individuals. The first stage, then, illustrates the potential 'stations' that may amplify or attenuate the perceived risk level. The information about the risk may come from different sources (e.g. personal experience and direct/indirect communication), be transferred via various channels (e.g. individual senses and social network), be amplified/attenuated by the social stations (i.e. opinion leaders, government agencies, news media), enter the individual stations (i.e. decoding, heuristics, interpretation), and shape the institutional and social responses (i.e. attitude changes, protests).

The second stage is called the 'ripple effects', containing the secondary consequences after the strike of the disaster and beyond the initial impacts on the society. Such influences originate from the directly affected individuals, rippling over the local communities, professional groups, stakeholders, and the whole society. The ultimate impacts, then, can reach economic, administrative, legislative, and public interests. However, the second stage may not be applicable to all risk events, such as an evacuation occurs prior to a hurricane.

Regardless of the stages, SARF contends that amplified or attenuated risk perceptions can lead to individual, organizational, and societal outcomes that cannot be anticipated at the beginning of the risk event. The risk event, which assumes a hazard with a probability, will trigger the information flow among different social groups and individuals, leading to responsive/protective behaviors that are sometimes unpredictable for emergency managers.

Protective Action Decision Model (PADM)

The framework of PADM (Fig. 2), nonetheless, aims to model the protective behaviors in a more predictable way. It begins with a set of cues and messages received by a decision maker[3,17,29]. The construction process of risk is then initiated by what the decision maker sees, hears, feels, and smells. In the first stage, PADM combines the information sources, communication channels, and the information receiver's mental, physical, social, and economic characteristics.

Of special note in this model is the consideration of the physical constraints to the risk communication process. In the context of hurricane evacuation, the evacuees have certain patterns in which risk perceptions are shaped by information and knowledge, and consequently realized actions.

For example, Lindell & Perry[17] published a four-stage process in warning response: (1) Risk identification (e.g. 'will the hurricane attack my community?'); (2) Risk assessment (e.g. 'do I need to leave?'); (3) Risk reduction (e.g. 'is it possible to leave?');

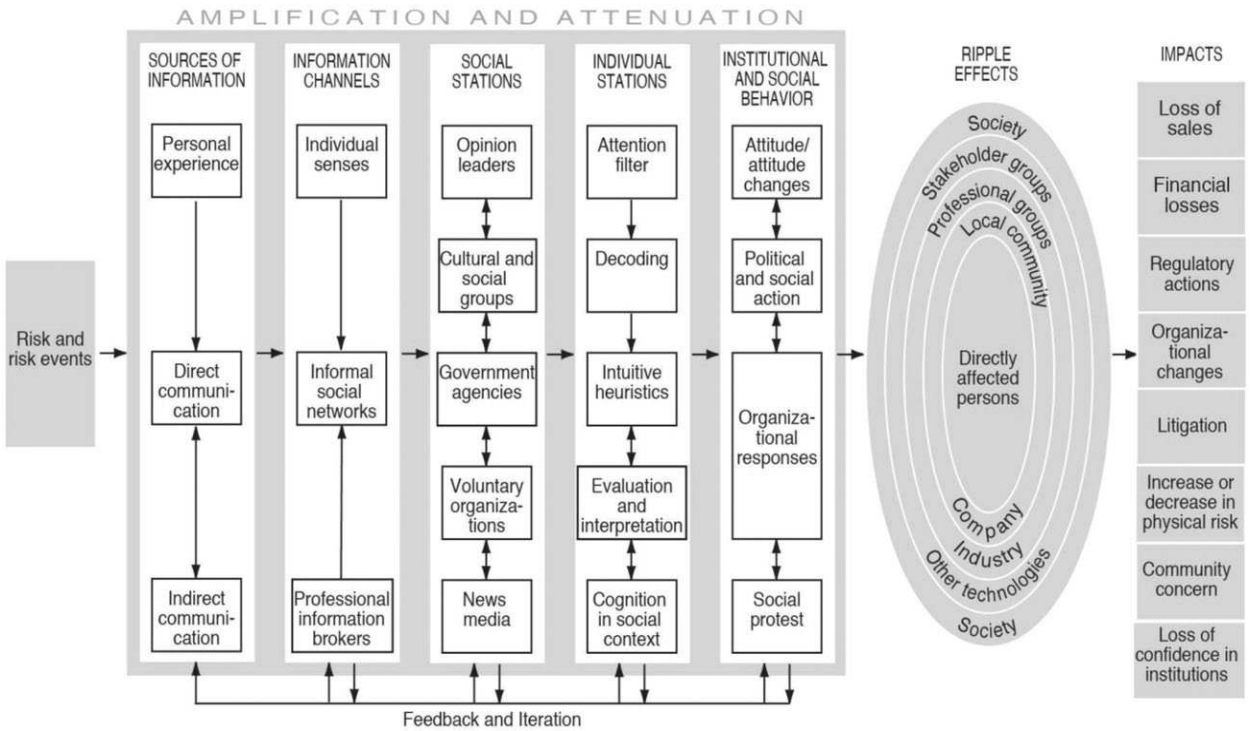

Fig. 1 The framework of social amplification and attenuation of risk[41].

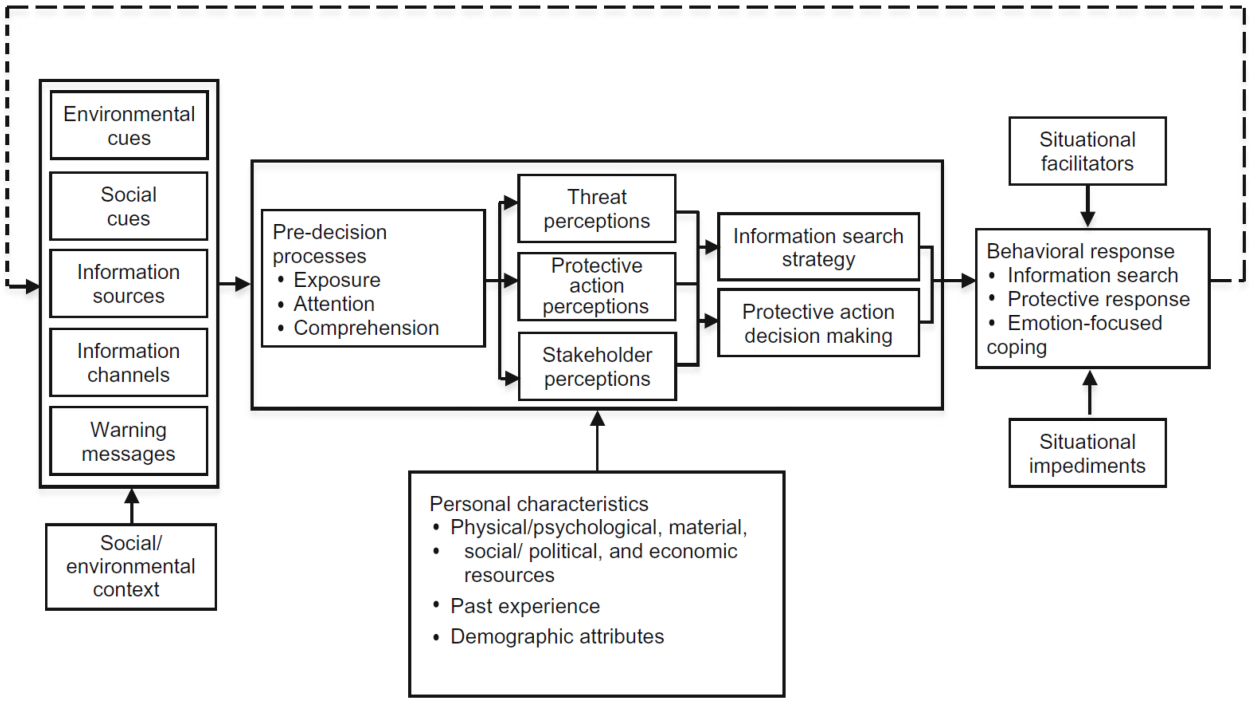

Fig. 2 The framework of the protective action decision model[42].

(4) Protective response (e.g. 'I am leaving for sure'). The first two stages are the formation of risk perceptions, while the third stage plays as a realistic constraint to limit the response options in the fourth step to the decision maker. Lindell & Perry[29] provided some examples of such factors including ones strength, impediments to seeing and hearing, language barriers, finances and access to vehicles. The term 'physical', however, is more specific in their article, indicating the capability of the human body only. The other constraints outside the social background are categorized as the 'environmental context', such as 'the geophysical, meteorological, hydrological, or technological processes' directly connected to the residents' locations.

Lindell & Perry[29] identified three sets of activities in the second stage of psychological personalization: pre-decisional processes, perceptions, and protective decision making. The SARF, also illustrates this step in a similar manner: attention filters, decoding, heuristics, interpretation, and contextual cognition[37]. Essentially, this stage describes the internal steps and factors in a decision maker's mental map leading him/her to the final decision of protective actions.

Following the psychological and perceptual processing, Lindell & Perry[29] proposed the third stage in PADM, which illustrates the individual action taking in response to the risk and the feedback loop in the risk communication process. This stage again can be viewed as a more thoughtful counterpart of 'feedback and iteration' along with the station 'individual behaviors' of the SARF. The major contribution, compared to the SARF, in this stage is the consideration of 'situational facilitators'. These facilitators, such as mobility and physical disability, are the same as the 'physical environmental components' in the first stage of PADM per se. Therefore, they indicate the possibility that physical constraints can play important roles in both shaping the risk perception and implementing the decisions.

The elements in the SARF, therefore, indicate the existence of objective risks that can be transformed to statistical probabilities once being analyzed by the experts. That is, all the decision-making is based on the calculated probabilities of whether certain risk events will occur. As its name illustrates, the SARF assumes 'unpredictable' social consequences and resident risk perceptions, even if experts and emergency managers try to disperse the 'correct' information[43]. However, this argument does not capture the possibility of experts not agreeing with each other, and the essential difference between an ex-ante estimate and the ex-post result of a hazard. In other words, it assumes that the risk of a hazard can be both objective (expertise) and subjective (laypeople) and can be both an estimate (before the disaster) and a fact (measured after the disaster)—depending on the context of the discussion.

The physical factors specified in PADM are not extensively discussed in SARF, such as the locations of the residents, the health conditions, the mobility of evacuees, and the number of valuable assets. It is arguable that these factors can be addressed by other stations: for instance, the location may determine an individual's contact to the hazard or be a component of the risk information; the health and belongings can be reflected by the age and income. Although studies applying the SARF rarely examine the physical factors systematically, some findings in other fields can help us identify the possibilities to incorporate these factors in the SARF. An example is a locational concept 'residual risk'[44] illustrating the probability that a flood may exceed the capacity of a levee. This concept is known to the experts but possibly not familiar to residents. Moreover, Siebeneck & Cova[45] discovered that the location of residents can shape their risk perceptions and hazard-responsive behaviors.

Therefore, the PADM is a more appropriate platform than SARF to build the new framework examining the links among risk personalization, risk perception, and the mobilization

process as protective action decision-making. Specifically, PADM consistently assumes a constructed risk perception, has unified units of analysis, and has a clear-cut definition of the action-taking stage, allowing more accurate examination of evacuees' mobilization. Some elements of the MM approach and SARF and other related studies are employed to assist in the development of the new framework.

Factors of evacuation as a protective action

In observance of the similarities, merits, and drawbacks of both frameworks, this paper employs the first and second stages of protective action decision model (PADM) to capture the evacuation mobilization process. The following section discusses the concepts and causations in this framework (Fig. 3).

Cues and information

The first stage in the theoretical model identifies six factors influencing the pre-decision processes. Among them, the environmental cues signal the onset of threat, such as sights, sounds, and smells[29]. Based on this definition, these cues may not be applicable to all-hazard evacuations, if some hazards like a hurricane) cannot be directly observed during evacuations which can be hours or days prior to it making landfall.

Next, the social cues are more frequent and noticeable during evacuation decision making[46,47]. These cues, referring to other people's behaviors transmitting risk information[29], may include seeing other people's evacuation, hearing, or noticing business closing, etc. Lindell & Perry[29] argued that these cues are one of the steps in a 'classic six-component communication model', which are followed by channel, message, receiver, effect, and feedback. Therefore, the information sources can be a network of different organizations and individuals providing information of the hazard and assistance[29]. Such information would then be transmitted via a variety of channels (e.g. print, electronic, or face-to-face method) and finally, and possibly, reach the target population as the warning messages[29].

The PADM defines the risk information receiver's characteristics as people's physical, psychomotor, or cognitive abilities, and their economic-social resources[29]. In the decision making of evacuation, vehicle ownership can be a physical constraint to potential evacuees. Psychologically, evacuees' abilities to gain information may vary based on their age and ethnicities[48]. The economic-social characteristics and, similarly, the 'social stations' in the social amplification of risk framework (SARF) mainly assess evacuees' societal background as the members of identifiable groups. Social characteristics are often viewed as the reference to make assumptions of a group of people's mental and behavioral patterns, such as what indicated by the concept 'social vulnerability'[49]. On the other hand, personal characteristics can have more variance from case to case. That is, some evacuees may not react to a risk event in the exact same way due to their experiences and personalities but behave following some patterns shared by their societal attributes[46].

Pre-decision processes

According to Lindell & Perry[29], the creation of risk perception must go through the pre-decision processes, including exposure ('whether people receive information'), attention ('whether people heed information'), and comprehension ('whether people understand information'). These concepts can be operationally captured by self-report questions as well as observations of their final behaviors reflecting their understanding of the information. For instance, the respondents of a survey may report that they had received evacuation or hurricane-related information from several sources, which indicated that they noticed their exposure to these messages.

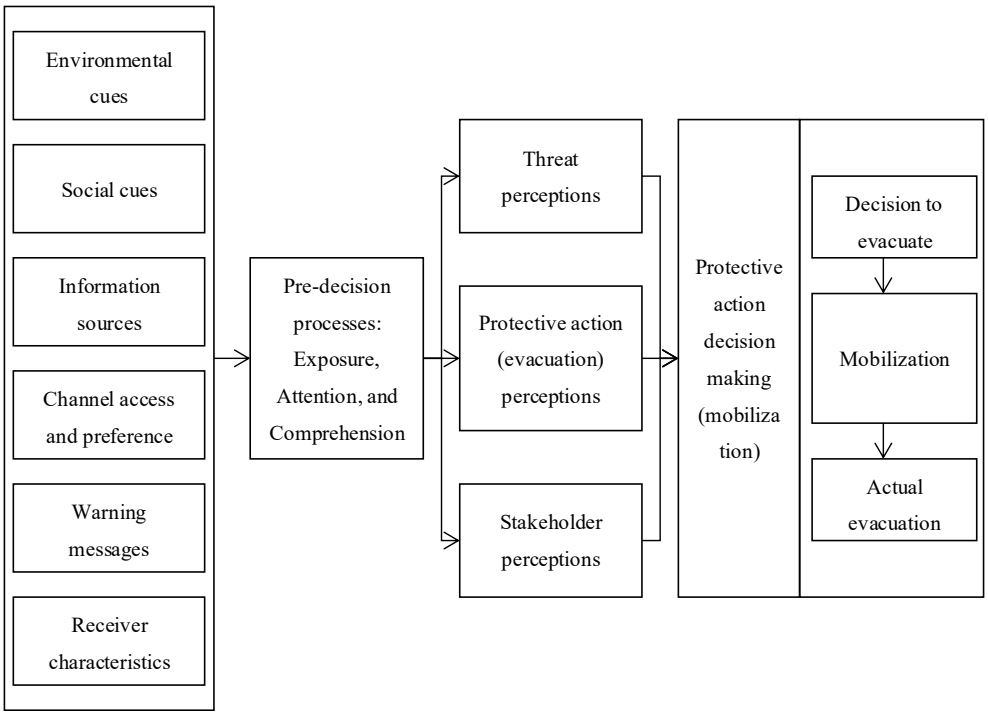

Fig. 3 Theoretical model for protective action mobilization time.

The respondents' comprehension of the message can be indirectly observed from the respondents' evacuation behaviors. In other words, if a respondent household not only received the information but also evacuated, then, arguably, they heeded and comprehended this information. Nonetheless, measuring solely the concept of 'exposure' might not be possible, as long as there is not an 'objective' observation that guarantees the distribution of information, even if the recipients do not heed or notice it.

Perceptions

Lindell & Perry[29] identified three types of perceptions shaped in evacuees' minds—threat, protective actions, and stakeholders. To begin with, the threat perceptions are composed by 'people's expectations of the personal impacts from an extreme environmental event'[29]. These perceptions can be categorized into two subtypes—personal impacts and hazard intrusiveness. The personal impacts may represent the impact area residents' perception of death, injury, property damage, and disruption to their daily activities caused by the hazard. The hazard intrusiveness is however not targeting the impacts; rather, it captures personal or friends and relatives' experiences of similar events, as well as the residents' proximity to the hazard.

Potential evacuees may also be concerned about the risk induced by the following protective action-taking (i.e. evacuation). These concerns are hazard and resource-related[29]. The hazard-related perceptions may contain the expected efficacy in protecting people and property, as well as the hazard adjustment utilities that can be used for other purposes. On the other hand, the resource-related perceptions can be the required costs, time, effort, skills and knowledge, and other transaction costs involved in the evacuation.

The final type of perceptions is placed on the stakeholder's expertise, trustworthiness, and responsibilities in dealing with the hazard, which is named stakeholder perceptions in PADM[29]. These stakeholders can be government agencies, professionals, media, and interest groups. Their influence on the residents' decision-making may be reflected by the form of their power over the residents' perceptions. That is to say, the more powerful or important a stakeholder is to the evacuees, the higher the probability that the evacuees follow the stakeholder's lead.

An on-going protective action—mobilization

The focus on mobilization instead of evacuation departure illustrates the concern of the on-going nature of protective action taking. Lindell et al.[28] noticed and discussed the time spent by evacuees to prepare for departure but did not specifically articulate that the protective action of evacuating is a process rather than at a single time point. Similarly, Lindell & Perry[29] argued that evacuees would often wait until the last minute to implement the protective action because the threat was not immediate enough to stop them from procrastinating. On the other hand, they admitted that those evacuees might still be searching for information to verify the answers to their own questions. Thus, it can be more helpful for our understanding of evacuation actions (and any other protective actions) once this concept—implementing protective actions—is treated as a time span. Additionally, this concern can capture the notion that a household of evacuees might leave as different groups but made the evacuation decision at the same time.

Some recent works on tsunami evacuations and simulations report that the decision time before evacuation departure is a strong predictor of the mortality rate[50–52]. These studies term this period before evacuation the "milling time" which covers a variety of activities, such as collecting information, gathering household members, and packing necessary belongings[52]. Practically, the milling time captures not only the mobilization time between the decision and departure of evacuation but also the period after hearing the evacuation order (or siren/alarm) when evacuees are struggling to make the decisions. Admitting the complexity of precisely modeling this period, these studies randomize the variation of the milling time from 0-20 min[50,51] to 0–40 min[52] in their simulations.

Other studies in the meantime can also reflect our concerns about the protective action decision as a period versus a definitive time point. For example, Kuligowski's study[53] on wildfire evacuation adopts the same definition of mobilization time as this paper (i.e., after the decision and before movement). However, Sun and Sun's research[54] on tsunami and earthquake evacuations defines "mobilization" same as the "milling time" in the previously mentioned tsunami simulation studies. Other scholars equate "mobilization time" to "preparation time" that begins with receiving evacuation orders[55,56]. Their research domains include hurricanes, wildfires, and tsunami but their findings still sparingly suggest a few predictors without systematically examining all possible causes. Sadri et al.'s[56] meta-analysis of evacuation decision-making date the latest efforts of modeling mobilization back in 2013, indicating that this research gap exists nowadays.

Discussion and conclusions

Adding to the literature focusing on the mobilization times, this paper offers a comprehensive examination of the social-psychological processes that contribute to delayed evacuation. It presents a review of the Mental Models (MM) approaches, Social Amplification of Risk Framework (SARF) and the Protective Action Decision Model (PADM), and evaluates their suitability in better conceptualizing the factors influencing delays in evacuation mobilization (Table 1). The review

Table 1. Summary of advantages and disadvantages of reviewed models.

Model	Advantages	Disadvantages
Mental Models Approach	Provide practical guidance; Help close expert-citizen gap in risk communication	Model every risk event separately; Inadequate theorization
Social Amplification of Risk Framework	Interdisciplinary perspective; Model multiple units of analysis	Limited range of topics in risk communication research; Not focused on predicable explanations
Protective Action Decision Model	Aim at predicable explanations; Accept "subjective" risk perceptions in protective action decision-making	Psychological processes are difficult to observe; Ambiguity in defining decision time

suggests that the three steps articulated in the PADM (i.e. information and cues to pre-decision process; pre-decision process to perceptions; perceptions to mobilizations) best captures the evacuation mobilization process among the three models.

The new framework built on PADM can inspire future empirical studies of the mobilization time. A hazard with longer time allowing residents to evacuate, such as a hurricane, flooding, tornado, or even a tsunami, can offer the empirical data in a 'stretched' time span for authorities and evacuees to ferment the mobilization process. A longer pre-disaster time after the first cue can trigger the authorities to implement evacuation plans, process the risk communication, and leaves the evacuees plenty of time to struggle with their decision-making. It can be a little challenging to measure an evacuee's risk perceptions, as they can change over the stages rapidly and subconsciously. So future studies of this kind should place more emphasis on the wording in each survey question or follow up with participants during the entire disaster evacuation.

For the mobilization in no-warning hazards, on the other hand, this framework can also help to explain the behavioral patterns of evacuees. The theoretical framework of the mobilization process can be especially supportive for evacuation simulations. For instance, the pre-decision processes and the three types of perceptions echo the psychology factors, such as social identities[46] and group-following preferences[57] during evacuation decision-making.

Practitioners may find this topic useful and reevaluate the decision-making patterns of evacuees and reduce the mobilization time as it is a component of overall evacuation timing. The perceptions of coming threat may not have the same impact on the timing factors of evacuation—the decision, the mobilization, and departure. That is, the current risk communication techniques, although demonstrated effective theoretically, do not always lead to preferable outcomes, such as evacuating certain neighborhoods faster than others while keeping the shadow evacuees at home. A comprehensive examination of the evacuee mobilization should be able to reveal the mechanisms guiding people to respond to a life-threatening hazard, and eventually assist evacuation managers to better anticipate the traffic flow. As one of the most developed models, the PADM is taking the lead among these models reviewed in guiding the federal government (i.e., Federal Emergency Management Agency) already. The rest models and approaches are yet to be documented and evaluated by disaster management organizations from a policy perspective[58].

On a broader scale, this paper provides future studies a reference to capture the risk communication's influence on specific disaster response and behavioral topics. Each of the frameworks reviewed in earlier sections has its targets. For instance, the SARF may help political stakeholders to understand and foresee the societal consequences following a risk event that has or will have happened; social workers or emergency response teams will probably find the MM approach useful, as their target audience is limited within a community or neighborhood. It is also valuable, for the theorists, to compile or adjust these frameworks and make them more suitable for a greater portion of the topic spectrum of risk communication.

Conflict of interest

The authors declare that they have no conflict of interest.

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