A Systems Thinking in Natural Disaster Management: Evacuation Preparedness

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Abstract—A natural disaster is the effect of the earth's natural hazards, for example, floods, tornadoes, hurricanes, volcanic eruptions, earthquakes, heat waves, or landslides. The occurrence has affected the losses of financial, environmental and human life's in recent years. In dealing with this, evacuation is a challenging issue, since the evacuees found difficulties to find the best or optimal evacuation routes especially in the high-rise building. Furthermore, with the complex man made infrastructures and human behavior during the evacuation process, the wayfinding task process getting increasingly difficult. The process becomes critical, especially during an ongoing hazard present in the building. Although there are many researchers contribute in the evacuation methodology, most of it only focus on human's movement rather than modeling the positive system behavior towards evacuation. This paper presents the systematic modeling of the evacuation preparedness in the building by applying Systems Thinking approaches. The idea is to change the system behavior into a system point of view and study the connection between sub-systems. As a result, this report lays the foundation of systems thinking in two perspectives: human-beings and the preparedness.

Key-Words: - Systems Thinking; Evacuation; Preparedness; Systems; System Behavior; Natural Disaster Management; Evacuation Model

1 Introduction

A natural disaster effect of the earth's natural hazards, for example, floods, tornadoes, hurricanes, volcanic eruptions, earthquakes, heat waves, or landslides. Therefore, in the event of any disaster, human must evacuate to save themselves. Evacuation is the process of transfer to a safer location from the location of a particular disaster in order to protect life and enable the treatment given to the injured person [1].

In conjunction with the purpose of evacuation due to the crisis of sudden and uncertainty, a proper natural disaster management is needed. Disaster management is an enormous task since they are not confined to any specific location. It is a natural process that poses a threat to property and human life. Disaster management plays an important role to support the need by reducing, preventing and optimizing the effects of the disaster. In addition, it is in line with the need of the preventive measures and emergency management plan as proposed by [2].

Fig. 1 shows the natural disaster management cycles that consist of four phases: mitigation, preparedness, response and recovery in the cyclic process; whereby the other process starts from the end of one phase [1].

Fig. 1 Disaster management cycles

Although all phases play an important role, mitigation and preparedness phase is the most important because all the improvements are the expected occurrence of an event. Therefore, there's a need to focus on three areas: raising awareness, enhancing resiliency, and

encouraging preparedness [2] as pre-disaster initiatives and long-term thinking in response and recovery.

Evacuation of a high-rise building is a challenging issue since the evacuees found the difficulties to find the best or optimal evacuation routes. As stated in the National Fire Protection Association (NFPA), a "high-rise building" is defined as a building greater than 75 feet (25m) in height where the building height is measured from the lowest level of fire department vehicle access, to the floor of the highest occupiable story. With the complex man made infrastructures and human behavior in high-rise building during the evacuation process, the wayfinding task getting increasingly difficult. Getting out of the building during the emergency poses special challenges even though such building has been supported by appropriate exits, alarms, emergency lighting, communication systems, and sprinkler systems. The process becomes critical, especially during an ongoing hazard present in the building such as fire or hazardous gas. Therefore, it is crucial to prepare in advance for safe evacuation of the high-rise building.

2 Problem Statement

During an emergency situation, evacuees need to decide what to do, where to go, how to evacuate and who to follow in such a critical situation. A study by [3][4] proven that some people like to stay and only begin to evacuate when they know the reason why the bell rang. In contrary, supposed evacuees need to make a decision by the time available in order to minimize the evacuation time and to avoid injuries related to ongoing hazard such as fire or hazardous gas. Most of the times, they do not know, which is the best path that they should follow in order to reach an exit since they are unfamiliar with the overall architectural design of the building. Despite the agent based wayfinding methodology such as [3] claimed they were able to guide human evacuate safely, unfortunately there is no guarantee the agents know all the exits or have the information of any hazard spreads during the evacuation. In addition, there is a possibility of the evacuees went back to the original place previously visited. This behavior causes congestion at the exit and collision with other evacuees who go to other exits [3]. Consequently, the increasingly critical situation may lead to mistakes by people who want to escape.

Other issues in the decision are the exit choice; in which determine the travel path and affect travel times. A survey for developing an emergency evacuation database by [5] indicated that 19.5% will use the familiar exit while 50.1% choose the nearest exit in a supermarket; however, it's contrary during the real evacuation drill where 45.3% choose emergency exit and 54.7% preferred familiar exit. On the other hand, a similar exit choice study in a supermarket by [6] gained the same result between data collection and actual evacuation drill. Another study on an exit choice decision at a university by [7] claimed, on average of 73% choose the main entrance and 27% use the alternative exit. Thus, it is concluded that the decision on the exit choice is varied depending on the person's behavior and types of building.

Several of evacuation models have been developed, as a purpose to overcome the crowd problems and panic behavior during their find a way out. For example, a decision support system, specific methodologies; using agent or multi-agent, wireless system, cellular automata, lattice gas, social force, fluid-dynamic, game theory and animal approaches. In spite of manageable to guide evacuees navigate from the building; it has its own vulnerability. A review by [8][9][10] stated as follows:

- Most of the study using simulation based model - needs to be related to real-world data.
- The choice of methods depends to some degree on the complexity of the simulation environments, the density of agents and their physical interactions, the diversity of their behaviors (psychological states and physiological characteristics).
- The microscopic and the macroscopic ones cannot be combined to model human behavior, e.g. The human body is not dynamic as fluid.
- The evacuation model needs to focus on how people make sense of their wayfinding environment - through color of signage and individual wayfinding criteria.
- Most of the evacuation models only consider the movement of humans towards the shortest path. It should study how the decision-making processes of the people proceeds in emergency incidents.

Some studies believe panic is the most human behavior disastrous form during crowd, which leads to fatalities as people are crushed or trampled [9]. Nevertheless, in a contrary study by [10] has revealed that panic is not a usual response of human, especially

in the initial stage when they have just acquired the cue. The spreading of flame and smoke may create panic and lead to unusual behavior. The decorations and lighting of the building also may sometimes mislead evacuees into choosing the wrong evacuation route.

However, providing a good cue in a systematic approach is something challenging. Thus, this report proposes a systems thinking approach to model the evacuation preparedness. This is similar to the system software development, whereby the systematic approaches in computerizing manual tasks have proven minimizing the time taken, save cost and avoiding unnecessary stress.

3 Systems Thinking: Theory and Examples

In this section, we clarify the two concepts which are central to this paper: "theory of system thinking" and "examples of systems thinking".

3.1 Theory of Systems Thinking

Systems thinking is a conceptual framework to make the full patterns of the system behavior clearer by seeing the whole structures that underlie complex situations [11]. Systems thinking answers the basic questions (why, what, where, how, who and when) while finding the solution to the problem at hand. The system is interrelated each other rather than linear cause and effect chains, where we might see the change process instead of only the snapshots.

Five characteristics of systems thinking have been described by [12] as:

- Thinking of the "big picture"
- Balancing short-term and long-term perspectives
- Recognizing the dynamic, complex and interdependent nature of systems
- Taking into account both measurable and non-measurable factors
- Remembering that we are all part of the system in which we are functioning, and we influence those systems even as we are being influenced by them

In reality, people facing problem in different perspective, and concern in different issue, but they applied systems thinking because they perceive the need to change how they or others think. It does not solve the problem automatically, but it reframed the problem and the solution. The same basic concepts on how we solve our daily problem; we view our problem, then think what is the outcome, next the rationality each of the outcomes and how to overcome the problem [13].

Systems thinking and practice began to evolve leading to a division of systems thinking, in which broadly classified into two traditions called as "Hard" and "Soft" systems. The fundamental of hard systems thinking approach assuming that the system is precise, well-defined, and quantifiable. One of the hard approaches is System Dynamics, which encompasses qualitative (e.g. Causal loop diagrams and influence diagrams) and quantitative (e.g. Simulation models) causal model techniques. Therefore, it's able to map and simulate the dynamic behavior of complex "real world" problems [11][14].

On the other hand, soft systems thinking is hard to define precisely, an abstract idea and depends on our perspective. Soft system identified the boundaries, interfaces, controls, helps us to predict the behavior and explores the problem situation from multiple viewpoints. So, the system models are developed relevant to particular views and being compared to the perceived world. Strategic Options Development and Analysis (SODA) and Soft Systems Methodology (SSM) are the soft system approaches methodologies in problem solving [11][14].

3.2 Examples of Systems Thinking

Systems thinking ideas have been emphasizing and common use in many different disciplines, including education, business and management, engineering, physics, military science, agriculture, weather forecast, public health, planning, evaluation and other physical sciences [13][15]. Systems thinking can influence many of the existing concepts, theories and knowledge in each of these fields. For example, the approaches use in improving the public's health towards tobacco by understanding the factors contributing to tobacco use, to inform strategic decision making about which efforts might be most effective for reducing tobacco use and tobacco-related disease; and to serve as an exemplar for addressing other public health problems. Through hard systems thinking approach, Fig. 2 shows how does the four key priority areas interrelated each other in improving the public's health towards tobacco health awareness [15].

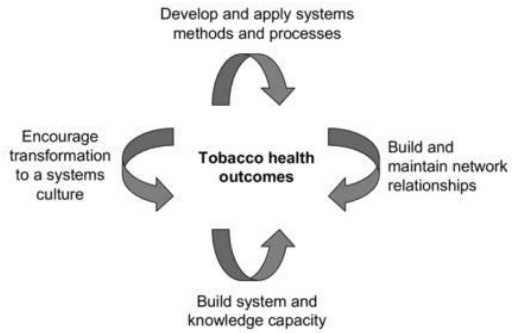

Fig. 2 Integrative systems thinking framework for complex systems in public health

Second simple example adopting soft systems thinking methodology is Leave Application System. The main purpose of the system is to have a convenient, fast and efficient leave management as a system based. Without the system, the management had to manage a variety of human behaviors for leave application. In contrast, human being is a part of the system - as an administrator and users of the system. Therefore, they are more aware and the management can handle the unnecessary problems. The effectiveness of the application has been agreed by the registrar of Universiti Teknikal Malaysia Melaka (UTeM) in Malaysia. The system has a systematic process and procedure with easy and user-friendly application. It sets the occupant behavior to use the system; in which means they cannot take any leave if they are not entering or applying through the system. The system solves the complexity of manual application, for example, being as a mechanism for communication enhancement (no more manual form and verbal communication), save cost (paperless and low stationary consumption), save time (auto prompt through email – applying/approving leave and no filing task) and save space for storage cabinet. Hence, all the data available in the database and can be retrieved easily. Indirectly, with the soft enforcement, slowly occupants switch their paradigm and behavior by following the system as a normal routine.

4 Systems Thinking Approaches in Evacuation Preparedness

This section defines what is a "system", its elements, evacuation preparedness system, and elaborates how soft systems thinking approaches used in evacuation preparedness.

4.1 Definition of System and Its Elements

A system is defined as a grouping of parts that operates together for a common purpose. The behavior of each element affects the behavior of the whole. There are six elements of a system as in Fig. 3 [14] consists of boundary, environment, observable interactions, subsystem, control mechanism and emergent properties.

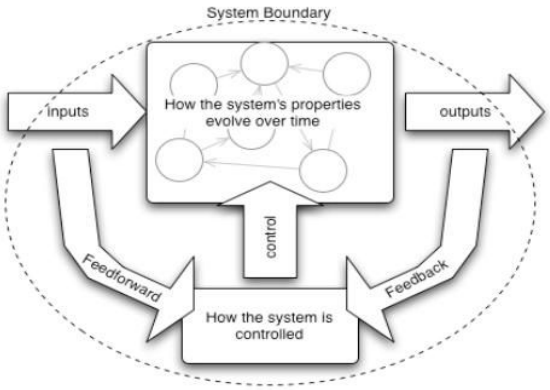

Fig. 3 Conceptual picture of a system

4.2 Evacuation Preparedness System

During an emergency situation, life safety is the main priority. According to [16] and Fire and Rescue Department of Malaysia, a key element of preparedness is the development of plans. It is defined as a continuous and integrated process involving a wide range of activities and resources from multi-sectoral sources. The main objectives of the preparedness are to save lives, minimize disaster damage, and enhance disaster response operation with the involvement of governments, organizations, and individuals. In an organization, the preparedness must comply with OSHA's regulations for an emergency action plan are covered in OSHA standard 29 CFR 1910.38, *"Employee Emergency Plans and Fire Prevention Plans"*[16], as in Fig. 4 shows the summary of the plan.

In the case of a building evacuation, preparedness plan will involve various aspects of preparation, both mentally and physically. There are things that can and cannot be done and what should be done. During fire evacuation, the wayfindings process is focusing more on the first sub-system: emergency escape procedures and emergency escape route.

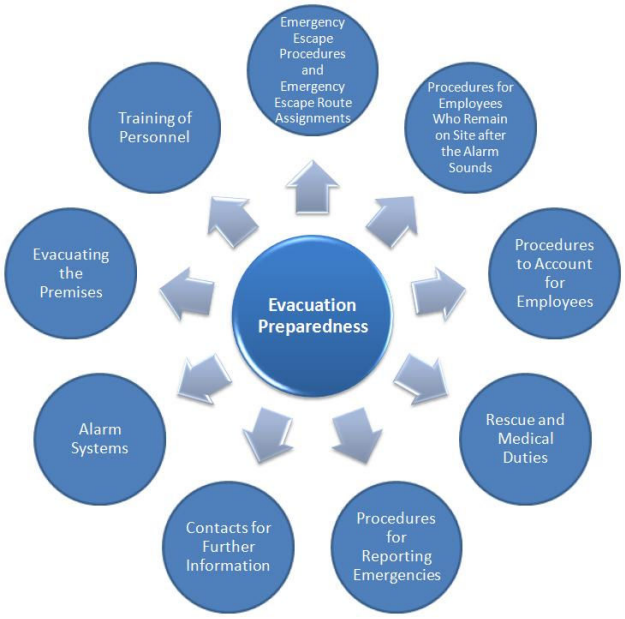

Fig. 4 General evacuation preparedness system

4.3 Systems Thinking in Evacuation Preparedness

This section addresses the way how a systems thinking approach can be used in evacuation preparedness, especially in wayfinding problems during evacuation. Systems thinking aims to identify the dynamic complexity existing in organizations by looking at multiple cause-and-effect relationships over time [11]. In evacuation system, preparedness involves establishing authorities and responsibilities for emergency actions and garnering the resources to support them. Inherent in the conceptual picture of a system, the evacuation preparedness is intertwined, interrelated and depends on each other (Fig. 5). It is oriented to the identification and understanding of complex relationships in the evacuation preparedness.

The purpose of the idea presented is to stimulate on how human can evacuate themselves in any emergency evacuation, although they are not familiar with the building or environment and without help from any human as agents.

- Input: natural disaster
- System Behavior: evacuation preparedness system in way finding, what is the procedure and how to navigate?
- Involvement: employee and fire personnel
- Output: Time/duration taken to evacuate, safely evacuate, types of damage and value of losses
- Control: Need specific control mechanism (system)
- System Boundary: not familiar with the building, spread of hazard and human behavior

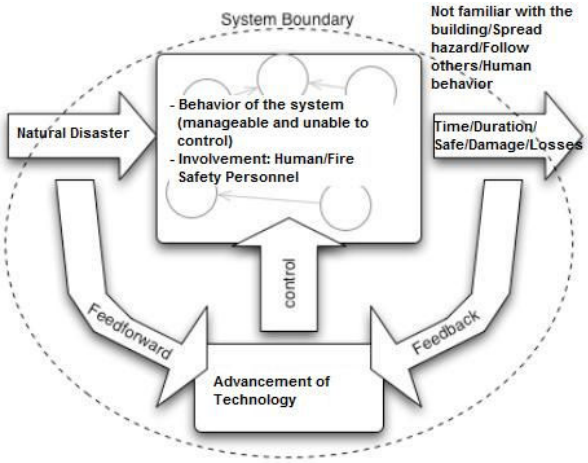

Fig. 5 Conceptual picture of an evacuation preparedness system: wayfinding solution

Systems thinking principles can become valuable principles of the evacuation's process: the ability of the organization to manage the evacuation preparedness as a system, treating wayfindings problems during an evacuation as problems of a system and start the system-integrated solutions. It can result from the impacts in evacuation preparedness performance as follows:

- Application of innovation: Helps to integrate new ideas to an evacuation process
- Strategic planning: Understanding the system behavior, observe as interrelation system and able to solve the problem
- Proactive management: Manage to describe and view the "real world" problem into a more systematic approach.

5 Conclusions and Future Work

Based on the background of the problem provided, the evacuation preparedness in emergency situations is the area for improvement. Due to the complexity in building environment and human perspective issues, most of the existing methodologies and techniques are not able to help evacuees to evacuate safely especially during an ongoing hazard present in the building. With a systems thinking approach, it helps us to understand a system as a whole,

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incorporating various concepts; in which might combine the technical and non-technical issues to support and solve the problem. It answered the basic question (why, what, where, how, who and when) for the specific problem. Therefore, with the point view of evacuation preparedness as a system and supported by the control, feedback and feedforward; it becomes efficient evacuation of a building in the event of natural disaster and warranting quick escape.

In order to enhance the systems thinking interventions in evacuation preparedness, soft system methodology approach (SSM) can be considered in order to study the relation of parts in the wider picture. It can be applied through emphasizing the importance of considering SSM for improving multi-criteria decision making in complex systems.

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