OPTIMIZING CROWD EVACUATION IN THE EMERGENCY ROUTE PLANNING PROBLEM

MOHD NOR AKMAL KHALID

UNIVERSITI SAINS MALAYSIA

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OPTIMIZING CROWD EVACUATION IN THE EMERGENCY ROUTE PLANNING PROBLEM

by

MOHD NOR AKMAL KHALID

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"In the name of Allah, most Gracious, most Compassionate"

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AIS	Artificial Immune Algorithm
CCRP	Capacity Constrained Route Planner
DT	Danger Theory
DCA	Dendritic Cell Algorithm
DSS	Decision Support System
ERP	Emergency Route Planning
iEvaP	Integrated Evacuation Route Planning
iEvaP+	Integrated Evacuation Route Planning with Dynamism
NCT	Network Clearance Time
RSD	Relative Standard Deviation

LIST OF PUBLICATIONS

No.	Publications	Related Chapters
	Journals	
1.	Khalid, M.N.A., Yusof, U.K., and Khader, A.T. (2015). "Survey on Crowd Guidance's Optimization Algorithm for Emergency Route Planning and Management Problems.", *An International Journal of Research and Surveys.* Volume 9, Number 3, March 2015. Indexed by Scopus.	2
2.	Khalid, M.N.A. and Yusof, U.K. (2014). "A Crowd modelling Considering Group Cohesion in the Emergency Route Planning Problems." *Australian Journal of Basic and Applied Sciences, Jakarta, Indonesia.* In An International Conference on Computational Modeling and Simulation (ICCMSA 2014). Volume 8, Number 24, Special 2014, December 2014, 33-39. Indexed by ISI.	4
3.	Khalid, M.N.A.; and Yusof, U.K. (2015). "Incorporating Dynamism in Crowd Emergency Evacuation Route Planning Problem: Application to Case Studies." *Completed. Plan for submission the International Journal of Disaster Risk Reduction on April 2015.* Indexed by ISI.	6
4.	Khalid, M.N.A. and Yusof, U.K. (2015). "Immune-Based Approach In Optimizing Emergency Route Planning Problem: Application to Case Studies." *Submitted to the Tenth International Conference of Innovative Computing, Information and Control (ICICIC 2015).* To be converted into journal paper in *Journal of Research and Surveys,* after presentation on August 2015, Dalian, China. Indexed by Scopus.	5 & 6
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5.	Khalid, M.N.A. and Yusof, U.K. (2015). "An Artificial Immune Approach for Optimizing Crowd Emergency Evacuation Route Planning Problem." *In Proceedings of the International Conference on Agents and Artificial Intelligence (ICAART-2015), Lisbon, Portugal.* January 2015, 503-508.	4
6.	Khalid, M.N.A. and Yusof, U.K. (2015). "Incorporating Dynamism in Crowd Emergency Evacuation Route Planning Problem." *Submitted to the 2015 Genetic and Evolutionary Computation Conference (GECCO2015), Madrid, Spain.* July 2015.	5

MENGOPTIMUMKAN PELAN EVAKUASI ORANG RAMAI DALAM MASALAH PERANCANGAN LALUAN KECEMASAN

ABSTRAK

Situasi bencana, yang berlaku secara semula jadi (kebakaran, banjir, taufan) atau buatan manusia (contohnya pengeboman pengganas, tumpahan bahan kimia, dan lain-lain), telah meragut ribuan nyawa, mencetuskan keperluan untuk pemindahan kecemasan. Biasanya, mengoptimumkan pelan pemindahan kecemasan melibatkan berkesanan pemodelan orang ramai dan pemilihan laluan, dimana pelan yang optimum penting dalam masalah perancangan laluan kecemasan (ERP). Pelbagai pendekatan ERP telah dibangunkan dimana diklasifikasikan kepada pendekatan matematik, keputusan sokongan, heuristik, dan meta-heuristik. Ulasan kesusasteraan menyeluruh telah menunjukkan kepentingan untuk merapatkan jurang antara pemodelan dan pemilihan laluan, di mana di mana pendekatan bersepadu dan berdaya maju diperlukan. Dalam kajian ini, satu perancangan pemindahan rangka kerja bersepadu menggunakan model pemindahan orang ramai dan sistem imun (AIS) algoritma tiruan, yang dipanggil iEvaP, telah dicadangkan. iEvaP telah disahkan terhadap Lu *et al.* (2003) dan parameternya telah ditentukan untuk prestasi yang optimum. Di samping itu, untuk merakamkan dinamik dalam orang ramai yang mimik keadaan dunia sebenar, dinamik perpaduan kumpulan dimasukkan dalam rangka kerja ini, dipanggil iEvaP+, membaik pulih pemindahan bersepadu merancang dengan dinamisme. Pendekatan ini telah diuji ke atas data awam dan keputusan telah menunjukkan akan pemindahan pelan yang telah mencatatkan peningkatan sehingga 62% berbanding dengan pendekatan kapasiti dikekang perancang laluan (CCRP) yang dicadangkan oleh Lu *et al.* (2003). Selepas itu, iEvaP+ juga digunakan untuk dua kajian kes untuk menilai keberkesanan dan kebolehan dinaiktaraf dengan keadaan

dunia sebenar. Keputusannya telah menunjukkan pelan pemindahan telah memperolehi peningkatan statistik yang ketara (p-value $\leq$ 0.05091 dalam sebahagian besar keputusan) berbanding dengan pendekatan CCRP.

OPTIMIZING CROWD EVACUATION IN THE EMERGENCY ROUTE PLANNING PROBLEM

ABSTRACT

Disastrous situations, either natural (e.g. fires, floods, hurricane) or man-made (e.g. terrorist bombings, chemical spills, etc.), have claimed the lives of thousands, triggering the needs for emergency evacuation. Typically, optimizing an emergency evacuation plan involves both the effectiveness in crowd modelling and route selection, where an optimum evacuation plan is vital in the emergency route planning (ERP) problem. Various ERP approaches have been developed which are classified into mathematical, decision-support, heuristic, and meta-heuristic approaches. Exhaustive literature reviews have shown the significance of bridging the gap between modeling and routing, where an integrated and viable approach is needed. In this study, an integrated evacuation planning framework utilizing crowd evacuation model and an artificial immune system (AIS) algorithm, called iEvaP, was proposed. iEvaP was validated against Lu *et al.* (2003) and its parameters were calibrated for optimum performance. In addition, to capture the dynamism in crowd that mimics the real world situation, dynamic group cohesion was incorporated to the framework, called iEvaP+, refurbishing the integrated evacuation planning with dynamism. The approach was tested on the public data and the results showed that the evacuation plan charted an improvement of up to 62% compared with capacity constrained route planner (CCRP) approach proposed by Lu *et al.* (2003). Subsequently, iEvaP+ was also applied to two case studies to evaluate its effectiveness and scalability with the real world situation. The results indicated the evacuation plan had obtained statistically significant improvement (p-value $\leq$ 0.05091 in most of the results) compared to CCRP approach.

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Disastrous situation, be it natural or man-made, often lead to emergency situations that require immediate action (Chiu *et al.*, 2007). Examples of natural disasters include hurricanes, floods, landslides, and tsunamis. Examples of man-made disasters include terrorist attacks or bombings, stampedes, and hazard material releases. These disastrous situation have affected populated areas, inducing a situation that is both immediate or life-threatening, which causes the triggering of an emergency response. The usual emergency response team's operation involves evacuating the residents, which typically requires immediate mobilization and time-critical actions that necessitate efficient coordination, space capacity utilization, and availability of emergency logistical resources (Alsnih and Stopher, 2004). Thus, emergency evacuation can be deduced as a solution for human survivability, which is paramount in risk mitigation.

An emergency evacuation can be defined as the removal of residents as quickly as possible and with utmost reliability from areas considered as dangerous zones to safe locations (Saeed Osman and Ram, 2011). The occurrence of disastrous situations tends to spark a very chaotic reaction (Yersin *et al.*, 2008), inducing a large surge of demand (number of evacuees) which exceeds the available resources (pathway capacity). Therefore, planning a suitable evacuation route and identifying the shortest evacuation route before the occurrence of disastrous situations are crucial for an effective evacuation process.

Although evacuation plans can be orchestrated in advance, probable crowd dynamics, especially group-based characteristics (e.g. group formation, group relation, group competition, etc.), may occur, often rendering unfeasible evacuation plan. Therefore, in order to make timely decisions and efficient planning, understanding crowd dynamics is needed in order to enable real-time updates of immediate threats, identify patterns or impacts, and pinpoint crowds' location relative to the hazard source (Radianti *et al.*, 2013). To address these issues, creating a practical yet computationally effective emergency evacuation plan is of utmost importance.

1.2 Challenges of Emergency Route Planning (ERP) Problem

To evacuate crowds effectively is a challenging issue because emergency events may propagate in uncertain ways due to the effect of the perceived environment, space capacity constraining the speed of crowd movement, and shifts in crowd behavior due to psychological aspects (Wang *et al.*, 2008). In the context of planning, emergency evacuation, also known as emergency route planning (ERP), focuses on three important factors (Chiu *et al.*, 2007): the routing of the residents, scheduling the resident egression, and regulating the resident's flow rates. These factors typically centralize on two interrelated continuums: the crowd dynamic and their perceived environment.

Crowds are formed by several or thousands of people that move in a bounded environment with respect to their individual goals in space, avoiding obstacles, blocking, or stampede, and remaining close to friends or family (Yersin *et al.*, 2008). In addition, crowd may regulate their movement in groups or individually. This is dependent on three aspects (Lee *et al.*, 2007; Sharma, 2009): (1) goals and needs; (2) social and physical attributes (e.g. level of interaction, age, or social differentiation); and (3) psychological and situational aspects (stress levels at a respective time or place). The crowd dynamic considered in this particular study, is tuned towards the first two aspects. Group cohesion, which is defined as the tendency for a group to be in unity while working towards a goal or to fulfill the demands of its members (Carron and Brawley, 2000), is one of the crowd dynamics that is considered for this study.

The perceived environments are used to choose the shortest path in time and space that leads to their goal (Yersin *et al.*, 2008). The need for evacuation is crucial for residents in a bounded environment (within a structure or enclosed area) as opposed to those in an open space. As such, there are a number of attributes that can be associated with the bounded environment, including the environment's architectural design (Shukla, 2009), its relation to risk factors (e.g. narrow staircases and corridors, exit's width, etc.) (Park *et al.*, 2007), the environment's evacuation support (e.g. signboards, signposts, etc.) (Wang *et al.*, 2009), and number of exit choices (Pu and Zlatanova, 2005).

With respect to the previously mentioned ERP factors, determining the best route while regulating crowd flow within the acceptable performance of an evacuation plan, poses as another computational challenge. The complex combination of multiple routes and crowd sizes have elicited the need for an effective and efficient ERP approach. Therefore, adopting a suitable ERP approach is vital for successive risk mitigation prior to the occurrence of an disastrous situation.

Various ERP approaches have been proposed, which including a mathematical-based model (Chiu *et al.*, 2007; Chien and Korikanthimath, 2007; Wang *et al.*, 2008, 2009), heuristic-driven model (Lu *et al.*, 2003; Kim *et al.*, 2007; Zeng and Wang, 2009), meta-heuristic model (Cepolina, 2005; Kongsomsaksakul *et al.*, 2005; Banarjee *et al.*, 2005; Yuan and Wang, 2007; Li *et al.*, 2010; Zong *et al.*, 2010), and even others (Fang *et al.*, 2011; Li, 2011; Guo *et al.*, 2011). However, studies on crowd dynamics are rarely emphasized in the ERP community, which induces significant impacts on the evacuation efficiency and crowd survivability (Wang *et al.*, 2008). In order for an effective emergency evacuation plan to be elicited, an optimal routing of the evacuation route, which considers crowd dynamic, should be emphasized. Using the meta-heuristics model applied in the ERP problem, it had been found that, not only it able to reduce the computational complexity (Yuan and Wang, 2007) but it also provides an optimum solution despite their stochastic nature (Yusoff *et al.*, 2008). As such, this motivates this study to adopt a meta-heuristic model as the dominating solution for solving the ERP problem.

1.3 Problem Statement

The problems faced in producing an effective emergency evacuation plan includes the difficulty of incorporating the evacuee's crowd model, determining the best route selection of a specific crowd group with respect to the route capacity constraint, and satisfying the global target (performance measure) of evacuating all evacuees in an evacuation plan. As such, an embedded meta-heuristic approach is applied to optimize the route selection of the crowd while capturing dynamism in crowd. In addition, the efficiency of the proposed ERP approach should be able to be demonstrated in varying crowd sizes. Thus, the main research question of this study is:

How to come out with an optimum evacuation plan for varying crowd sizes that encompasses both the dynamism of crowd evacuation model and efficient route selection?

Figure 1.1 summarizes the scenarios prominent to the ERP problem. There are two main issues within the considered ERP problem. When planning the emergency evacuation, the emergency evacuation plan should consider the complexity factors of the crowd and the environmental constraints (especially within an enclosed area). The first issue suggests designing an appropriate route selection mechanism that focuses on finding optimum evacuation route(s). The second issue is the prominent effect of crowd dynamics, integrated in the crowd evacuation model.

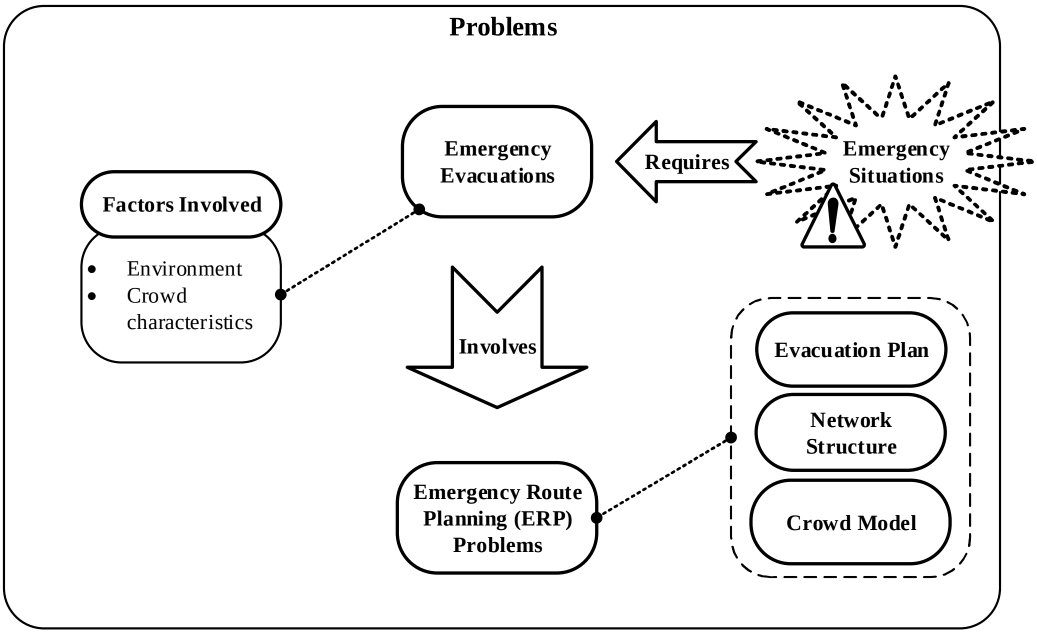

Figure 1.1: Scenarios of the ERP problem

1.4 Goal and Objectives of The Study

To optimize the evacuation plan, an effective optimization technique in routing the crowds of evacuees and a model that captures certain aspects of crowd dynamism, are needed. The crowd model should consider the evacuee's behavior (e.g. group cohesion) where a possible bottleneck of the evacuation could occur while the optimization technique should consider the evacuation constraints (e.g. capacity) where the global time-based performance of the emergency evacuation can be improved. In general, the aim of this research is to develop and provide a dynamic crowd evacuation model and best route selection for optimizing the emergency evacuation plan to fulfill varying crowd sizes. Specifically, there are three objectives this study aims to achieve:

1. To design and propose an ERP approach embedded with a crowd evacuation model and optimization algorithm for optimum emergency evacuation plan.

2. To enhance and evaluate the ability of the proposed ERP approach, where crowd dynamism is incorporated, in producing optimum emergency evacuation plan.

3. To apply and evaluate the overall performance of the proposed ERP approach with dynamism using actual case studies.

1.5 Study Scope and Significance

Solving the ERP problems involve addressing a number of varying factors. Therefore, various parameters, constraints, and behavioral properties which may pose as challenges in solving the underlying problem, are considered. Thus, the scopes and limitations have to be made transparent in order for the study to be manageable. The scopes of this research are given as follows:

1. The abstraction of environment

   The environment involves the building structure which is represented through graph-based networks, known as a logical map. This excludes the signage, lightings, and any other decorations within the building structure. However, the buildings compartmentalized capacity and floor elevation (e.g. staircases) is considered and predetermined and acts as constraints imposed for the basic and dynamic crowd model, respectively.

2. The evacuee properties

   The total number of evacuees within the building structure is known and their locations are predetermined. The considered dynamic factor is specific to only group-related behaviors (e.g. size and compliance). However, distinctive behaviors (e.g. leader), personalized or hidden behaviors (e.g. sabotaging agent), and intuitive characteristics (e.g. profession, age, etc.) are negligible.

3. The emergency services

   Emergency services such as ambulances, medical staff, logistics, and authorized personnel (e.g. fireman, policeman, etc.) are assumed to be readily available for the evacuation planning procedure, thus it is also negligible.

This study is considered crucial as it attempts to bridge the gap between efficient route selection and dynamism of crowd models of an emergency evacuation plan for the ERP problem. The discrepancy of selecting the best route that fulfills the contradictory of the performance measures while the crowd model that adequately captures real-world dynamics of a crowd, had induced a poor evacuation plan and affect crowd survivability. Therefore, this research attempts to minimize this discrepancy. In addition, this research is aligned with the aims of reducing loss of life during actual conduct of the evacuation plan, which is paramount in risk mitigation. Therefore, the success of this research will support the advancement and implementation of risk mitigation policies as well as promoting the chance of human survivability in an actual disastrous situation.

This study is tuned towards modelling an approach that captures dynamism of crowd, such as group formation and levels of interactions, as well as their collective pattern (macro) in the context of ERP problem. In addition, this study also considers formulating the environmental attributes (exits, walls, etc.) for best route selection. Both the dynamic crowd model and the route selection mechanism will compose the evacuation plan for an effective evacuation simulation. In essence, this study is locally focused on the crowd model with dynamism and best route selection mechanisms while globally optimizing the overall evacuation plan. The study's main goal is graphically depicted as in Figure 1.2.

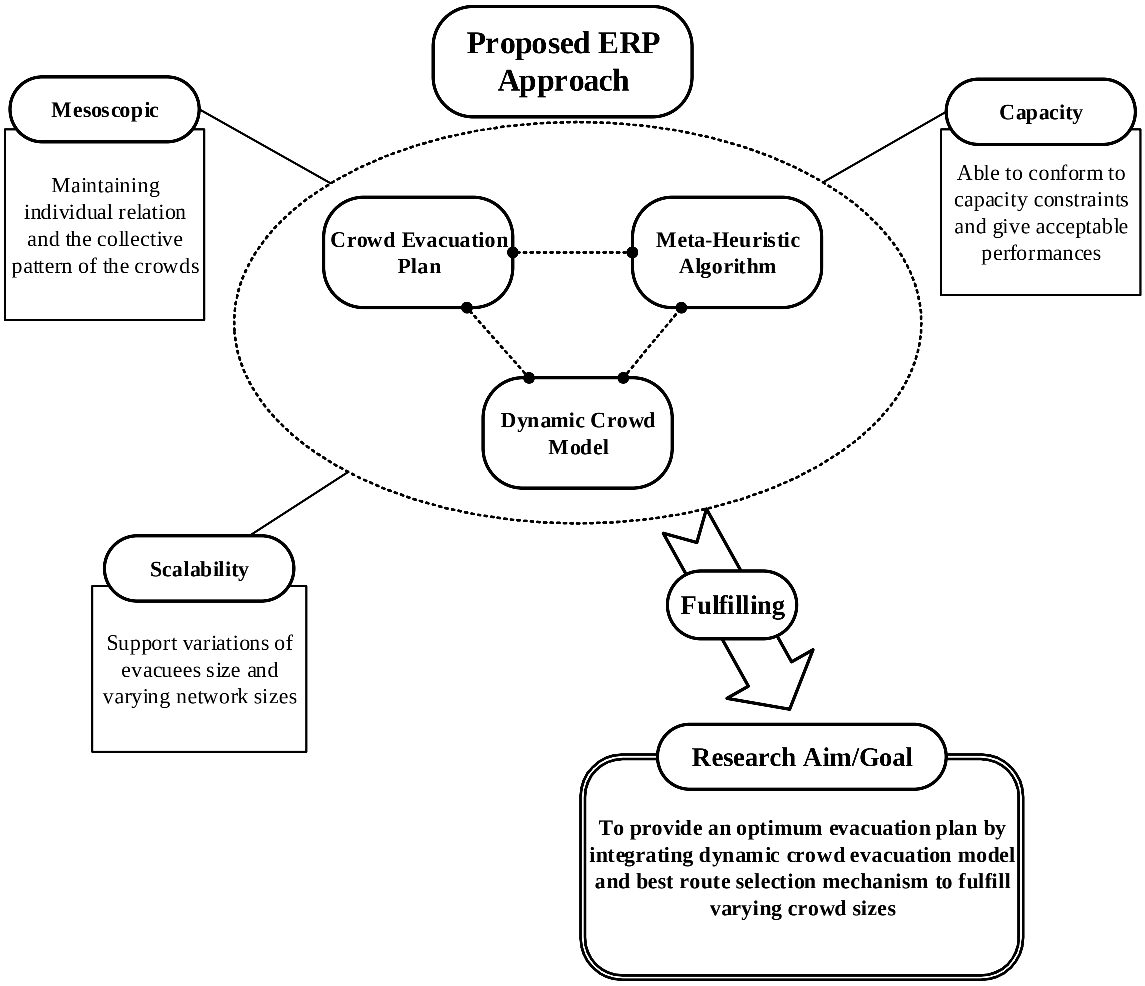

Figure 1.2: The main research goal

1.6 Outline of the Thesis

This thesis is organized into seven chapters. Figure 1.3 shows the structure of the thesis.

Brief descriptions of the content of each chapters are given as follows:

(i) Chapter 1 of the thesis begins with a discussion on the problem background, goal, objectives, scopes and significance of the research topic in general.

(ii) Chapter 2 outlines the important aspects and challenges posed in the domain problems. This chapter also provides some insight of the theoretical background of the focused domain problems as well as prior works.

(iii) Chapter 3 describes the research methodology employed in this research including the research framework, data sources, instrumentation, problem description, performance measures, and experimentation and analysis conducted in the study.

(iv) Chapter 4 elaborates the proposed integrated evacuation planning (iEvaP) approach that is optimized using a meta-heuristic algorithm. iEvaP approach is designed specifically to tailor and solve the ERP problems. The results and evaluation of the proposed crowd evacuation approach is also discussed.

(v) Chapter 5 discusses the enhancement of the proposed iEvaP approach that integrates the crowd dynamic (group formation and in-group compliances), namely integrated and dynamic evacuation planning (iEvaP+) approach. The results and evaluation of the proposed iEvaP+ approach performance is measured while discussion on the effect of considering the dynamic crowd behavior(s) in the model is emphasized.

(vi) Chapter 6 focuses on application of the proposed iEvaP+ approach which incorporates dynamic crowd evacuation model, where detailed analysis on the results are obtained

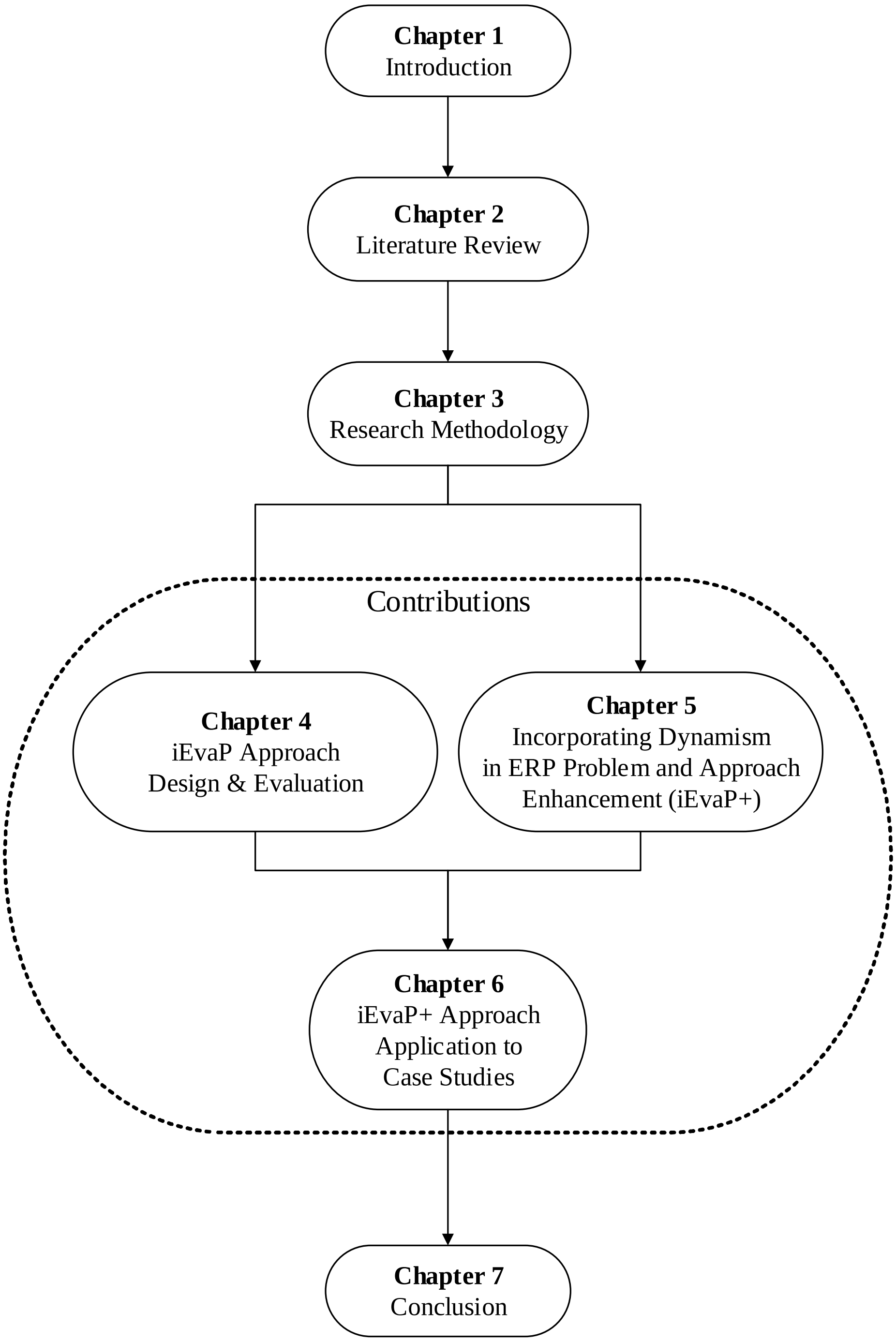

Figure 1.3: Structure of the thesis

using the case studies. In addition, the performance and evaluation of the proposed iEvaP+ approach is also formalized and discussed.

(vii) Finally, Chapter 7 provides the concluding remark regarding the findings and contributions, potential future works, and the outcome of the research in detail.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter will outline the background study of the problem domains considered in this thesis by reviewing the related crowd evacuation approaches in the area of the emergency route planning problems. Throughout this chapter, the outlook of the domain problems will be identified from a top-down perspective of emergency evacuation which will be elaborated in details, whereas the potential gaps will also be highlighted. The organization of this chapter is given as in Figure 2.1.

2.2 Emergencies

Emergencies can be defined as a situation which are induced by a extreme or immediate situation requiring time-critical response that potentially causes loss of human life and related risks (Alsnih and Stopher, 2004). A situation may not be defined as an emergency if the need of time-critical response is not present, absent of chaotic or immediate event, no threat on the human life, or potential risk is not involved. When the emergency response is elicited, evacuation is the typical strategy for mitigating risks which requires immediate mobilization and time-critical actions involving efficient coordination, space capacity utilization, and availability of emergency response resources (Alsnih and Stopher, 2004). However, responding effectively during the needs for an emergency event is crucial.

Emergency response preparation is vital before the occurrence of disastrous situation because the affected region tend to be chaotic (Simonovic and Ahmad, 2005). Communication

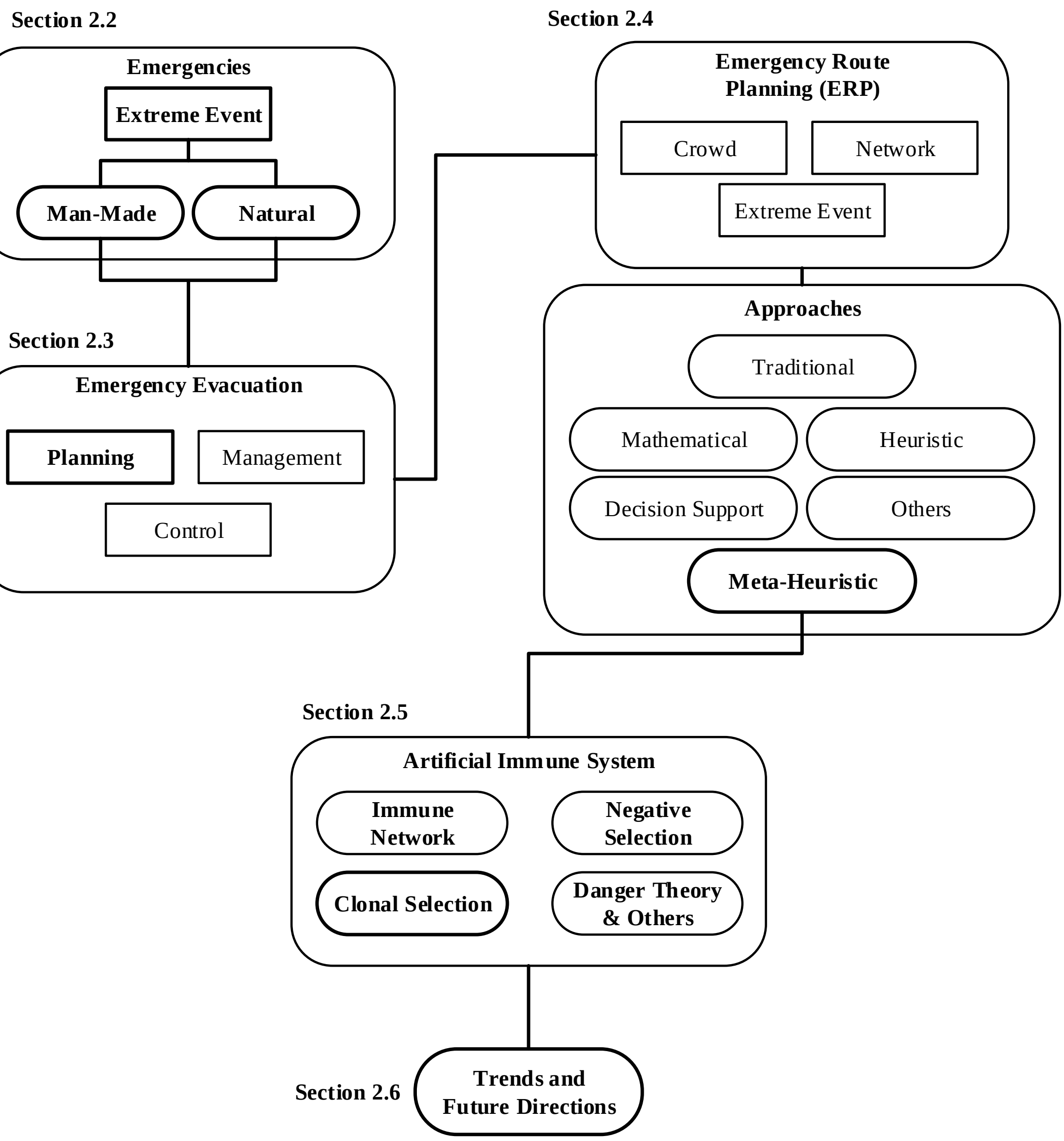

Figure 2.1: The content structure of Chapter 2

and command structures can break down because of logistics or communications failure, causing unpredictable human behavior during the emergency and affect their survivability. Emergency responses are dependent on the available, lead-time predictability in which consequently induces a chaotic response and low level of compliance (Alsnih and Stopher, 2004). Therefore, instead of immediate response which is very unpredictable, proper planning and management before occurrence of disastrous situation are important.

Typically, emergencies can be divided into two broad classes: management and planning. Castle and Longley (2005) had summarized emergency management into four cyclic, management components, which can be broadly interpreted as a longitudinal point-of-views of emergency, which are: (1) Mitigation, (2) Preparedness, (3) Response, and (4) Recovery. These components can be described as follows:

- **Mitigation:** This involves activity such as risk assessment in order to accomplish steps that will limit or, in some cases, eliminates the effects of emergency altogether. This component usually conducted on the pre-event stage.
- **Preparedness:** This crucial task can be important for emergency that cannot be sufficiently mitigated. This management component also limits the loss of life and enhance the response. This component usually conducted on the pre-event stage.
- **Response:** This management component contains activities those that is conducted immediately during or after an event to assist victims, stabilize the situation, and reduces the possibility of secondary event's damage.
- **Recovery:** This involves activity which starts after an emergency (post-event stage) and continues until the community structure returns to normal or operational. Typically, this involves a two step process: short-term recovery that returns vital life-support systems

to minimum operating standards; while long-term recovery may continue for a number of years after a disastrous situation.

Emergency planning involves a multi-leveled decision making processes which can be broadly interpreted as a vertical point-of-views of emergency, which subdivided into three different but interrelated perspectives; strategic, tactical, and operational. Evacuation in a strategic perspective involves assessing the risks and if possible, eliminates the needs for emergency for the long run. This typically conducted through policy amendments or risk mitigation (Castle and Longley, 2005); which are carried out through changing the current policy or operational procedures (i.e. altering the normal routine), or by physical actions which involves preventive activities to minimize the needs for emergency (i.e. reinforcing or relocating structures, posting security guards), respectively.

From a tactical perspectives, planning is carried out to reduce the risks in medium-term, where an advanced technique is used to identify and evaluate risks, define the possible escape route or alternatives routes, develop emergency procedures, ensure coordinated interagency response and inter or intra-agency communications, define a clear chain of command, conduct training, and others (Castle and Longley, 2005). Usually, this tactical perspective of evacuation directly related to both the preparedness and response of the emergency management, which commonly known as the evacuation planning and management.

Evacuee's movement, people behavior, and crowd flow are main classes of studies in the operational perspective. Hajibabai *et al.* (2007) had pointed out that the most disastrous forms of collective human behaviors are stampedes, which induced by panic which often leads to serious fatalities. The ability to enable efficient movement of people in heavily populated enclosures is vitals to the daily operation of large and complex structures. More importantly, it is an essential design feature in the event of emergency situations. To support emergency planning, the operational system model is an essential tool in providing effective decision-making, enhancing the capability of response to disaster, and reducing any adverse impacts on both human beings and surroundings (Lv *et al.*, 2013).

2.3 Emergency Evacuation

In the management perspective, Saeed Osman and Ram (2011) had defined emergency evacuation as the removal of residents from areas that had been considered dangerous zone to safe locations as quickly as possible and with utmost reliability. Tavares and Galea (2009) had defined evacuation during an emergency situation involves the escape movement that the occupant(s) of an enclosure makes. Additionally, Kobes *et al.* (2010) had defined evacuation in a specific emergency context where people in the present of hazards, experiences several mental processes and carry out several actions before and/or during movement to a safe location whether in or out of an enclosed areas.

During emergency evacuation, the most generalized aim is to eliminate the need for emergency for the long run. This typically conducted through policy amendments or risk mitigation (Castle and Longley, 2005); which are carried out through changing the current policy or operational procedures (i.e. altering the normal routine), or by physical actions which involves preventive activities to minimize the needs for emergency (i.e. reinforcing or relocating structures, posting security guards), respectively. In addition, emergency evacuation may also be carried out to reduce the risks through an advanced planning where identifying and evaluating the potential risks, defining the possible escape route or alternatives routes, developing emergency procedures, ensuring coordinated interagency response or intra-agency communications, defining a clear chain of command, conducting training, and others (Castle and Longley, 2005).

Additionally, emergency evacuation studies encompass the way people orientate themselves within a structured, enclosed region. Crowd evacuation process involves activities which can be characterized based on: (1) Awareness of danger, (2) Validation and response from perceived danger, and (3) Movement or egression towards safety (Kobes *et al.*, 2010). During an emergency evacuation, guiding the crowd in an emergency situation is crucial in order to manage and/or mitigate the outcome of the occurring emergency and the risks associated with it. Alternatively, route planning problems can be perceived as one of the main affecting components of the emergency evacuation solution.

In bridging the gaps of evacuation planning and management, four important factors are established which has pioneered the main foundation of the emergency route planning (ERP) problem (Chiu *et al.*, 2007): (1) deciding where to evacuate people (goal); (2) deciding the best routes to take (routing); (3) determining the rate at which evacuees need to be permitted to enter the network from different areas of the regions (flow rate); and (4) determining how to regulate flow rates on these routes (schedule). These decisions are methodologically and computationally challenging due to the following reasons; decision interdependence, simultaneous decision making, and concurrency (Chiu *et al.*, 2007). Therefore, ERP-specific approaches are needed in order to address these challenging issues that are faced during emergency evacuation.

2.4 Emergency Route Planning (ERP)

The cognition of the ERP approaches involves three distinct and inter-related components that are relevant to this study: (1) disasters (critical or disastrous situations), (2) resources (network or route layouts), and (3) demands (crowd of people). When a disastrous situation occurs, crowds will become unruly in their attempts to escape the danger zone (Yersin *et al.*, 2008). However, effect of disaster on the crowd has yet to be realized. Most literatures assumed disaster as figments during the emergency route plan and management. This is done by assuming disaster happens at a certain static location (Kwan and Lee, 2005; Castle and Longley, 2005; Cepolina, 2005; Zong *et al.*, 2010), whereas the actual situation would infer otherwise. Others would categorize disaster as a possible scenario (Lu *et al.*, 2005; Kim *et al.*, 2007; Zeng and Wang, 2009; Li *et al.*, 2010; Fang *et al.*, 2011; Guo *et al.*, 2011) instead of considering disaster as an element of inevitability. Disaster as a possible scenario provides the opportunity to consider a secondary disaster occurrence (i.e. bridge failures or blocked pathway) (Shekhar *et al.*, 2012). In addition, limited literatures stress disaster as an entity which is modelled and propagated through the simulated environment with each passing time (Wang *et al.*, 2008, 2009). Disaster can be propagated by defining the initial state, the transition probability, and the spreading area in a given time horizon.

The network or route layouts are used to model the perceived environments in time and space that enable evacuees to reach their respective goal (Yersin *et al.*, 2008). Network or route layouts (resource) in crowd evacuation involves a continuous models which accomplished by means of a connective networking of a set of destination points that represents the real roadways or network for utilization by the crowd during emergency evacuation. Graph-based method, representing information of the enclosed region of a structure through network of nodes and edges (Kemloh Wagoum *et al.*, 2012), is the most popular method adopted mainly because the destination points can be pre-determined (i.e. exits) or adjustable (i.e. crossings, turning point at the end of a corridor) while the graph's visibility of a minimal network at any location is ensured based on the facility that is within the visibility range of at least one node. As such, logical approximation of the perceived environments is represented and enables integration of variety crowd models.

Crowds are formed by several or thousands of people that move in a bounded environment with respect to their individual goals (i.e. avoiding obstacles, blocking, or stampede, and remaining close to friends or family) (Yersin *et al.*, 2008). Generally, the crowd are modelled based on theoretical models, ranging from analytical ones to those based on matrices or cells (Bandini *et al.*, 2005). Radianti *et al.* (2013) had conducted a study on the existing models which are categorized as microscopic, macroscopic, and mesoscopic models. Microscopic models treat every individual in the crowd as a separate "particle". Several variants of microscopic approach include the encoding of human desires in the form of social force model (Helbing *et al.*, 2000) and representing pedestrian as a node that occupies a cell known as cellular automata (Yuan and Tan, 2011). Macroscopic models describe crowds through their average flow and density. Fluid dynamic model (Helbing *et al.*, 2000), flow tiles (Chenney, 2004), continuum crowd (Treuille *et al.*, 2006), and non-local crowd dynamics (Colombo and Lécureux-Mercier, 2012) are the variants of microscopic models. Bridging the gap between the former two models, mesoscopic models introduce a key concept to understand the relationship between local inter-individual interactions (micro) and collective patterns (macro) (Wang *et al.*, 2008, 2009). Most of the studied literatures have employed microscopic model (Hoogendoorn and Bovy, 2004; Amaldi *et al.*, 2010; Kwan and Lee, 2005; Cepolina, 2005; Fang *et al.*, 2011; Guo *et al.*, 2011) and macroscopic model (Lu *et al.*, 2005; Kim *et al.*, 2007; Zeng and Wang, 2009; Li *et al.*, 2010; Zong *et al.*, 2010; Lv *et al.*, 2013), while only some applied mesoscopic model (Wang *et al.*, 2008, 2009).

One of the core factors that affect ERP problems is the crowd. The ability to assist for an efficient movement of people in heavily populated enclosures or structures is vital to the daily operation of large and complex structures (Hajibabai *et al.*, 2007). More importantly, it is an essential design feature in the event of emergency situations. To support emergency evacuation operation, the crowd model is an essential tool in providing effective decision-making, enhancing the capability of response to disaster, and reducing any adverse impacts on both human beings and surroundings (Lv *et al.*, 2013).

Crowd dynamic, especially grouping, is a common phenomenon where both isolated individual and persons in groups can be found (Qiu and Hu, 2010; Aveni, 1977). Simple scenario such as peoples in museum and shopping mall, family members walk beside each other in a clustered way while friends maintain in loosed-group during their movement. This grouping phenomenon may influences the flow as well as the efficiency in emergency evacuation plan such as the group size, individual characteristic, relationships among groups, and influences among group member (Qiu and Hu, 2010; Moreland *et al.*, 2013). These grouping phenomenon is generally known as the group cohesion, where these cohesive properties (e.g. group size and influences among group member) are vital due to following reasons: (1) The group size determines the group structure and composition of a group; (2) Individual compliance influences a specific group structure in term of their flow rate. Thus, the main interest of this study involves locally focus on the modelling of the crowd dynamic and efficient route selection mechanism while globally focus in optimizing the overall evacuation plan (actual flow rate and performance measure).

2.4.1 ERP Approaches

Traditional ERP approach simply conveys warning and threat descriptions where the need for evacuation is issued via mass media communications to the affected population (Lu *et al.*, 2005). Fire-alarming system is another good example of the traditional ERP approach which conveys warning during an event of fire within a structure. However, this solution do not provide any information as how to escape (Pu and Zlatanova, 2005). Directional Sound Evacuation (DSE) beacons are also another traditional ERP approach during disaster and they can eventually give clear audible navigation to nearest exit (http://www.soundalert.com/dse_buildings.htm), which can be combined with sophisticated analogue addressable Fire Alarm Control Panels (FACP) (e.g. http://www.adt.co.uk/fire_panels.html). However, these kinds of systems still react when fire occurred and unable to give clear insights about situation after the fire alarm is triggered. Another traditional ERP approach is the emergency lighting designed within enclosed area, to allow evacuees to continue their occupancy and assist in finding a safe exit.

Although these traditional ERP approach successfully reaches the affected population, such solution lacks proper planning and management which causes unanticipated effects on crowds such as massive congestion, massive confusion, and chaos. These includes lacks of flexibility, insufficient information, less intelligence, dynamic and/or current information, and lack of means of providing interactivity (Pu and Zlatanova, 2005). Since then, the combined knowledge of practitioners and academicians, have introduced variety of ERP approaches to produce an efficient evacuation plan and manage affected population during disastrous situations.

Table 2.1 summarizes the ERP approaches based on their respective model features, disaster instance, and the adopted algorithm. The model features implies the accountable features in crowd which are based on crowd type, crowd dynamism, and multiple objectives. Crowd dynamism implies the cognition, decision making, and social behaviors of evacuees (Cepolina, 2005), as well as unforeseen incidents and deviations in the subjective judgements (Lv *et al.*, 2013). The disaster instance column highlights the instances of disaster as either figment (assumed scenarios or occurrences) or entity (included in formulation as a moving object or probabilistic occurrence) which is associated with the respective literatures.

DSS approach is one of the earliest ERP approach to produce an evacuation plan and manage affected population by providing timely decision making before and during a disastrous situation. Some examples include: intelligent emergency response system (Kwan and Lee, 2005) equipped with 3-dimensional geographic information system (GIS) representing structures of multi-storey buildings, providing real-time navigation and

Table 2.1: Summary of the approaches in ERP problems

Approaches	Model Features: Model Type	Model Features: Crowd Dynamism	Model Features: Multi Objectives	Disaster Instance: Figment	Disaster Instance: Entity	Algorithm Adopted	Authors
Math-Based	Micro		✓	✓		P-cover model	Jia *et al.* (2007)
			✓	✓		Linear Programming	Amaldi *et al.* (2010)
			✓	✓		Stochastic Programming	Hui *et al.* (2010)
			✓	✓		Linear Programming	Kaisar *et al.* (2012)
	Macro		✓	✓		Mixed-Integer	Sayyady and Eksioglu (2010)
			✓	✓		Mixed-Integer	Bretschneider and Kimms (2011);
			✓	✓		Linear Programming	Lv *et al.* (2013)
		✓	✓		✓	Monte Carlo Method	Zhang *et al.* (2013)
	Meso	✓			✓	Lagrangian Relaxation	Wang *et al.* (2008)
		✓			✓	Stochastic Programming	Wang *et al.* (2009)
					✓	Multi-Agent Model	Qiu and Hu (2010)
Decision Support	Micro	✓	✓	✓		GIS-based DSS	Kwan and Lee (2005)
		✓	✓	✓		Spatial DSS	Castle and Longley (2005)
		✓	✓	✓		Knowldge-based DSS	Pu and Zlatanova (2005)
	Macro	✓	✓	✓		Spatial DSS	Castle and Longley (2005)
		✓	✓	✓		Combo-Hamiltonian Dual Route	Chang *et al.* (2009)
Heuristic	Micro		✓	✓		Capacity Constraint Route Planner (CCRP)	Lu *et al.* (2005)
			✓	✓		CCRP + Intelligent Load Reduction	Kim *et al.* (2007)
			✓	✓		CCRP with Longer Route Preferential	Zeng and Wang (2009)
			✓	✓		improved CCRP	Shekhar *et al.* (2012)
			✓	✓		Shortest + Quickest Path	Kemloh Wagoum *et al.* (2012)
	Macro	✓			✓	Dijkstra Shortest Path	Liu *et al.* (2006)
Meta Heuristic	Micro	✓		✓		Simulated Annealing Algorithm	Cepolina (2005)
		✓		✓		Tabu Search Algorithm	Xie *et al.* (2010)
	Macro		✓	✓		Genetic Algorithm	Li *et al.* (2010)
			✓	✓		Ant Colony Optimization Algorithm	Zong *et al.* (2010)

negotiation within multi-level structures for supporting better emergency management; and GIS-based Spatial-DSS (Castle and Longley, 2005) that integrates topological support and analysis to determine pedestrian distribution, simulation of pedestrian dynamics, and scenario generation functions to aid decision support in emergency management and planning.

Chang *et al.* (2009) had focused on different sets of problems. The author proposed a dual route generation system for two separate but related problems of evacuation: one for rescues and the other for retreat. This method produced a network suggestion in real-time and successfully bridge the two prominent problems in hazard situations, route planning and emergency management problem. However, the setback imposed is, the scales of evacuation are assumed to be “unknown”, which the effect and impacts of the solution may turn out to be infeasible in terms of computational complexity (higher evacuation scale); consequently produces untimely decisions. Pu and Zlatanova (2005) proposed a knowledge-based DSS based on a 3-dimensional indoor geo-information to provide a dynamic, specific, and accurate evacuation route to people with an interactive instructions. Considering the uncertainty of a disaster, dynamic factors had been incorporated where dynamic search tree is used for solution search in the combined logical and geometry model with the consideration of non-spatial information, environmental factors, and human factors in the overall model design.

DSS emphasizes on a timely and accurate decision-making process. However, successful realization of DSS solution is highly dependent on information availability, secured data usage, and complying public privacy (Kwan and Lee, 2005). Other setbacks of DSS include information unavailability of past incidents, timely computational data formalization, and unknown emergency scenario’s evolution, in order to properly prepare and plan for future incidents. Simulation of DSS using a suitable crowd model (micro, macro, or meso) is still debateable due to the lack of evidence (Castle and Longley, 2005). In addition, timely and accurate decision-making remains subjective and may change based on nationality, social, and cultural preferences.

Some studies proposed a prominent ERP approach through the means of mathematical-based algorithm. Wang *et al.* (2008, 2009) had proposed a stochastic programming model with rollout scheme within Lagrangrian relaxation framework for evacuating crowd in a building network. Amaldi *et al.* (2010) had used a linear programming model for evacuating injured people through transport assignment in the context of medium/maxi health-care emergencies, while Hui *et al.* (2010) has used a stochastic programming model to allocate rescue route which compared with a shortest path generated from particle swarm optimization algorithm, respectively. Lv *et al.* (2013) had designed an integer programming model for supporting emergency management under uncertainties.

Sayyady and Eksioglu (2010) had designed a model for transit-dependent residents during a no-notice disasters using a mixed-integer linear model to simultaneously optimize the emergency response with respect to objectives of minimizing the total evacuation time and the number of casualties. A Tabu search algorithm is incorporated to reduce the long running time of the simulation package. Qiu and Hu (2010) had proposed a framework for intra-group and inter-group relationships which effects the crowd modelling behaviors, where an agent-based crowd simulation system is developed. The framework applies vector-based approach to represents the force applied to an individual as well as maintaining the group behavior.

Bretschneider and Kimms (2011) had proposed a basic mixed-integer model which provides a reorganization of traffic routing of a certain area during emergency to minimize evacuation time while prohibiting intersection conflicts. A relaxation approach, namely as the adjustment heuristic, is also integrated to reduce the computational efforts of the time-expended graph of the model. Kaisar *et al.* (2012) had designed a linear programming