SCENARIO BASED DYNAMIC EMERGENCY RESOURCES ALLOCATION UNDER THE CONSIDERATION OF DOMINO EFFECT FOR EARTHQUAKE RESPONSE PLANNING

MAHAMUDUL HASSAN

DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH
24 September, 2019

SCENARIO BASED DYNAMIC EMERGENCY RESOURCES ALLOCATION UNDER THE CONSIDERATION OF DOMINO EFFECT FOR EARTHQUAKE RESPONSE PLANNING

BY

MAHAMUDUL HASSAN

A Thesis Submitted to the
Department of Industrial and Production Engineering,
Bangladesh University of Engineering and Technology
In Partial Fulfillment of Requirements for the Degree of

MASTER OF SCIENCE IN INDUSTRIAL AND PRODUCTION ENGINEERING

DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH
24 September, 2019

CERTIFICATE OF APPROVAL

The Thesis entitled **"Scenario Based Dynamic Emergency Resource Allocation Under the Consideration of Domino Effect for Earthquake Response Planning"** submitted by **Mahamudul Hassan**, Student No. 0413082002, Session – April 2013, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of M.Sc in Industrial and Production Engineering on September 24, 2019.

BOARD OF EXAMINERS

Dr. Shuva Ghosh — Chairman (Supervisor)
Associate Professor,
Department of IPE, BUET, Dhaka

Dr. A.K.M Kais Bin Zaman — Member (Ex-Officio)
Professor & Head,
Department of IPE, BUET, Dhaka

Dr. A.K.M Masud — Member
Professor,
Department of IPE, BUET, Dhaka

Dr. Ferdous Sarwar — Member
Associate Professor,
Department of IPE, BUET, Dhaka

Dr. A.B.M. Alim Al Islam — Member (External)
Professor,
Department of CSE, BUET, Dhaka

CANDIDATE’S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Mahamudul Hassan

This Research Work is Dedicated to My Mother

.

ACKNOWLEDGEMENT

It is a genuine pleasure to express my deep sense of thanks and gratitude to my supervisor, Dr. Shuva Ghosh, Associate professor, Department of Industrial and Production Engineering, for his stalwart supervision. His guidance and instructions throughout the process of the thesis and report writing have provided an excellent level of the thesis. His timely advice and scientific approach helped me to a great extent to accomplish this thesis. Without this guidance and president help this work would not have been possible.

I would like to thanks Dr. A.B.M. Alim Al Islam, Professor, Department of CSE, BUET, external member of my thesis board, for his valuable advice and directions about the coding and optimization of model.

The author would like to thanks all the committee members, Dr. A.K.M Kais Bin Zaman, Professor & Head, Department of IPE, BUET, Dr. A.K.M Masud, Professor, Department of IPE, BUET and Dr. Ferdous Sarwar, Associate Professor, Department of IPE, BUET, for their constructive remarks and for kindly evaluating this thesis.

At the end, the author would like to convey his deepest regard to the almighty ALLAH; the most beneficial and merciful, for helping me become successful in the all difficulties.

ABSTRACT

Earthquake is a natural disaster or catastrophe which can lead to death, property damage leaving huge economic loss in the society. Emergency resource allocation that predominantly conducts with how to effectively and systematically response and distribute necessary resources of rescue teams to the rescue teams to deal emerging incidents of an earthquake and alleviate fatalities and economic issues, has been widely used as one of the most indispensable tools in emergency resource management for natural disasters such as earthquake. To the best of my knowledge, the existing deterministic techniques are utilized on emergency response which is only for used in single incident and too facile to be utilized in complex emergency situations. However, resources are short in supply and response when an earthquake occurred. In such cases, emergency resource allocation model can be utilized for effectively and efficiently allocating resources. Therefore, this study deals with multi objective model that can be utilized effectively in response of food demand, rescue and emergency personnel. The developed model has focused on both risk minimization and food supply to the affected areas; thus, multiple objectives are also fulfilled through this model. This model showed that risk remaining factors are minimized with minimized objective functions and increased adequate food supply. Domino effects were also analyzed to reduce the incidents' propagation that triggers other adjacent units.

Table of Content

List of Figures

List of Table

Chapter 01

Introduction

1.1 Research Background

Earthquakes, tornados, hurricanes, fires, floods are natural disasters or catastrophes which can lead to death, property damage and leave huge economic loss in the society [1, 2]. However, each disaster is distinguished from its own features, earthquakes in the planet have common features such as fire, gas leakage, building collapse and sometimes floods. When an earthquake is considered serious on the Richter scale strikes, disaster management personnel send resources such as rescue teams, medical teams, medicines, ambulance, and foods to the earthquakes affected zone [3]. The actions of the response personnel are aimed to evacuating people, ensuring that affected people are not injured, and preventing further damage. However, the enormity of destruction caused by earthquakes has augmented the need for methodical disaster response planning [4]. Hence, researchers and governments are paying attention to earthquake management for lessening the impact of the earthquake disasters [5, 6]. Usually, disaster management has four phases: preparedness, response, mitigation, and recovery [5], these phases are considered as a continuous process as shown in Figure 1. These mentioned of "disaster management phases" have been utilizing since 1930s to examine, describe and understand disasters and utilizing of emergency management personnel and resources. This study focuses on the "response" phase that predominantly comprises routing, locating, and allocating emergency personnel and resources.

Figure 1.1: The principal phases of disaster management

1.2 Dynamic Emergency Resource Allocation

Dynamic emergency resource allocation is defined as the organized and systematic approach or process of distributing available resources to different places or users in a time-varying situation under any man-made or natural disaster [7]. Dynamic emergency resource allocation aimed at to minimize the emergency cost, response time and routing short path from a rescue team to an affected zone based on road conditions [8]. Moreover, dynamic emergency resource allocation particularly deals with how to quickly and effectively distribute emergency resources such as foods, water, medicines, ambulances, doctors, communications and transportation to minimize fatalities as well as economic losses [8]. Dynamic emergency resource allocation is the most significant and fundamental issues in the "response" phase that provides important references during emergency decision making process. Moreover, it is important for protecting life, maintaining social stability, and reducing economic losses [9].

Each year, almost 5000 disasters are occurred on our planet, and around 75,000 people are died and 200 million people are impacted [10]. These disasters can be classified as natural disasters such as floods, earthquake, hurricanes, fires, tornadoes and man-made disasters such as chemical leakages, social violence, terrorist attacks, and so on [11]. Considering these types of disasters, it is assumed that natural disasters are more devastating because man has less control over it and loss of life is huge within a very short time. Thus, it can be said that systematic and appropriate post-natural disaster rescue approaches can make the losses certainly low. In addition, after the natural disaster occurrence, there are also great possibilities of occurring different types of incidents, those may change their form with the changing of time. It is essential to control the incidents in an appropriate way for stopping the movements of the farther form.

All the places in a city or a country are not affected at the same level when a natural disaster takes place; some areas are highly affected and some are minorly. Considering the level of damage, resource allocation needs to be in different patterns for different areas based on magnitude of risks [12]. However, some areas are not affected in a large scale but might have potential for further large types of occurrence, which may cause a large amount of economic losses and physical damage. Focusing on the potentiality of future risk, the resource allocation for different areas will need to appropriate because concerns have been always revealed regarding funds, resources, fairness among different teams are not exploited properly as expected [12].

Population, path availability, total area, types of industries, types of structure, distance from the allocation point, underground facility, and communication systems are playing a significant influence on planning of proper and systematic allocation of resources after the disaster [13]. Emergency resource allocations after an earthquake, a common and dangerous natural disaster, need a proper and pre-planned way of distribution to minimize the losses [14]. Usually, the two most significant activities when earthquakes occurred are the evacuation of affected people and supply of emergency materials [15]. Here, the rescue of people from the affected area is an important factor and also needs to control the risk of further incidents. Although, the adequate supply of food for the affected people is also needed to consider during allocation. Earthquakes give a few seconds of warning before it takes place, however, sometimes it may have no warning, but every year thousands of people are affected by this natural disaster, thousands of dreams would shatter within a single moment. The way of rescuing the affected people from a different area in response phase, minimizing the risk after the earthquake, allocation of food for the affected people, minimizing the chances of occurring hazardous and chemical incidents are the main problems after the earthquake [16].

Bangladesh is an over-populated country, where there are no systematic approaches or plans to face this devastating natural disaster. In addition, Dhaka city will lose thousands of lives if a medium-range earthquake happens [17]. For minimizing the losses, it is essential to establish a pre-dynamic-plan, which can focus on different area's rescue systems, risk minimization, and other factors associated with this emergency. Dynamic emergency resource distribution or allocation planning is useful for minimizing the physical and economic losses resulting from an earthquake because it deals with multi-factor with different variables with the variable of time horizon [18, 19].

1.3 Domino Effect

1.3.1 Defining Domino Effect

Domino theory was first developed by H.W Heinrich who was a safety engineer. From his statement, an “accident” has a potential sequence that may cause an “injury” [20]. A chain reaction is placed among the domino's factors. These factors are visualized as a chained series standing one after another as shown in Figure 2. When one factor arises, it makes the linkage with the next one, such a chain reaction happened among the factors because each factor is dependent on its previous factor.

According to his theory, there are three "E" of corrective action procedures [20]. The first "E" means Engineering which can control hazards by developing new product designs with changing specifications and changing the production process. The second "E" is Education, by which the safety facts are imposed through workers. The final "E" is the Enforcement of standard operating procedures, rules, and regulations among management as well as workers.

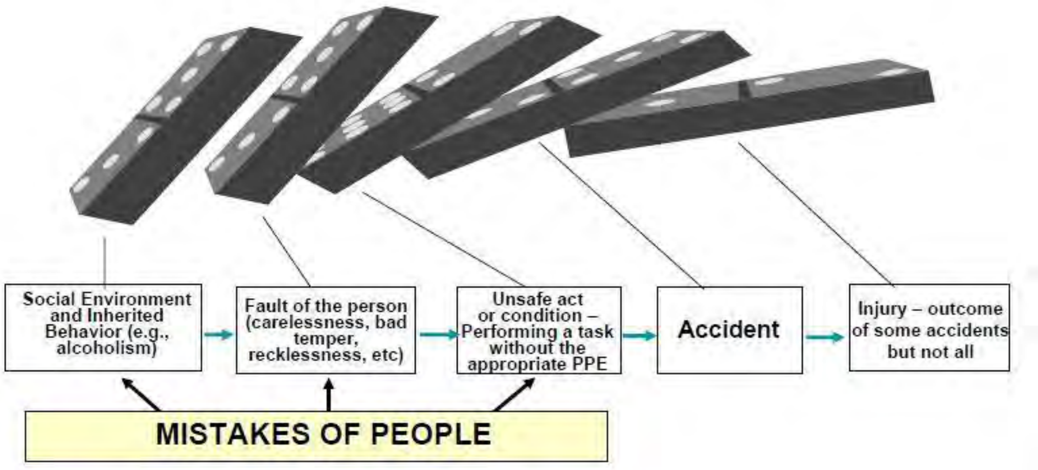

Figure 1.2: Domino Theory by H.W Heinrich (1932)

1.3.2 Domino Effect Analysis

Domino effects arise when the primary event of an accident triggers another adjacent unit of other accidents known as a secondary event by using some escalation vectors. These escalation vectors can be measured by some physical effects such as heat, radiation, pressure, and fire engulfment or explosion depending on primary events. Escalation vectors are used to determining which nearby secondary events are impacted by primary event through comparison with predefined or premeasured threshold values. By making a comparison between escalation vectors and respective threshold values, the preliminary screening of potential secondary events is identified [21]. Figure 3 shows the primary event of an accident X1 can be moved in X2, X3, and X4 secondary events, which may cause another accident. The potentiality of the movement of primary event X1 to X2, X3, and X4 secondary events depends on some escalation vectors which may be identified through some threshold values. The measurement of the possibilities of those movements from primary events to secondary events is known as the Domino effect.

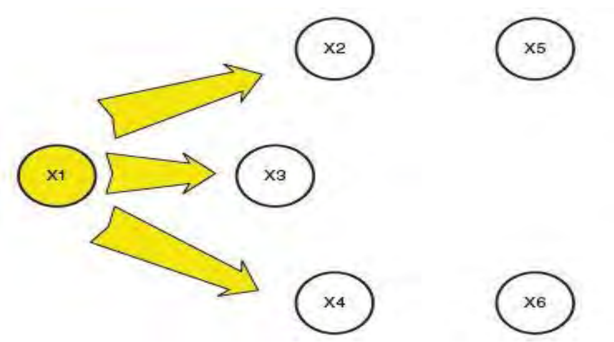

Figure 1.3: Domino Effect Analysis

1.4 Earthquake Response Planning

Generally, resources and personnel are short in a supply chain when earthquakes happen. In such circumstances, disaster management team must use these short supply resources effectively [15]. Potential improvement to the response planning could be obtained by introducing following planning in the response phase.

- Making segmentation of the total earthquake-affected area into different small areas
- Finding out the present or primary event or incident level of each segmented area
- Finding out the secondary event or incident level of each segmented area
- Considering the factors (Population, Path availability, Severity, etc.) for each area in total planning
- Optimizing allocation of resources (Rescue Team, Medical Team, Food and water supply, etc.).
- Minimizing the risk of the after effects of an earthquake

1.5 Objectives with Specific Aims

The objectives of the research are given below;

- To develop an emergency resource allocation model for minimizing risk
- To include a domino effect for considering secondary incidents that may occur from a primary incident after a disaster

1.6 Possible Outcomes

The possible outcomes of this research will be a structural model to allocate emergency resources after a natural disaster like an earthquake, flood, fire incidents, etc. and also a vehicle movement model will be obtained, which will focus on the minimum traveling time and availability of road after a disaster.

1.7 Experimental Design of the Research

The overall methodology for introducing equity in the optimization model for emergency resource allocation toward potential risk minimization shows a vital challenge which must be identified to introduce the equity into earthquakes risk minimization approaches. These challenges have been addressed in the literature [22].

The methodology would be as follows:

- A literature review will be done to find out the present research for emergency resource allocation, recent analysis of earthquakes in the world, and model for scheduling of emergency allocation plan.
- A process will be developed to quantify the risks associated with incidents after an earthquake.
- The Domino effect analysis will be introduced to include secondary incidents that occurred from a primary incident.
- Identification of the secondary incidents that might occur from primary incidents will be done from the literature review.

Chapter 02

Literature Review

The chapter contains an elaborate description of the related theories of this thesis work. Earthquake knowledge, Domino theory, and Emergency resource allocation planning are the three basic key significant points in this thesis work. The definition of earthquake, mechanism, measurements and effects analyses as well as the risk analysis of earthquake in Bangladesh is focused in this chapter. Emphasis and relevant discussion was done on the domino theory and resource allocation models under emergencies.

2.1 Earthquake

2.1.1 Definition of Earthquake

The sudden shake on the earth's surface is generally known as an earthquake. Seismic energies are stored under the large blocks of the earth's surface, any sudden release of this seismic energy through the crust’s fault causes the earth to shake, which is known as an earthquake, where the fault may define as the fracture in the crust [23].

Any natural disasters like geological faults, landslides, volcanic activities, or man-made disasters like mine blast; destroying forest lands and nuclear weapon power test is responsible for creating seismic waves [24]. The earth plates move due to these seismic waves generating an earthquake.

2.1.2 Effects of Earthquake

Both economical and physical losses are involved in the effects of the earthquake. Environmental damages, structural damages, and physical injuries are the common phenomenon [25, 26]. Some most common effects of the earthquake are;

- The sudden rise of the land surface
- Extensive damages to the environment
- Physical losses of assets
- A large number of structural damages and buildings collapse
- Spreading out potential hazards like radiation

- Rise of sea level and attack on coastal areas like Tsunami
- Causes thousands of deaths

2.1.3 Earthquake Risk in Bangladesh

Bangladesh is one of the most among disaster-prone areas in the world. Natural disasters like floods, riverbank erosion, cyclones, and drought are very common to its communities. [27]. Moreover, the country experiences a moderate risk of an earthquake. Several tectonic plates and a large area of the Bay of Bengal can easily create a mild earthquake and as a result, the coastal might get affected by Tsunami at any time. Having a magnitude of 7 or more, an earthquake might cause millions of deaths due to the density of overpopulation, poor structural building design and lack of awareness about earthquakes [28]. According to Raihanul et al. [29] mass awareness program has been conducted among the coastal people and the concerned stakeholders has been warned because of recent earthquakes in Bangladesh for the last seven to eight years. However, there is a lack of proper planning to face an earthquake. Sultana et al. [30] said that India-Burma-Eurasia plate is also having a great risk of earthquake for Bangladesh.

Tectonic plate of Bangladesh has five strong geological fault zones. The fault zones are; Bogra, Assam, Tripura, Sub-Dauki, and Shillong plateau [31] as shown in Figure 2.4. According to Chakravorti et al., the Bogra fault is very near to Jamuna River and Bogra city and it’s a natural fault. During Neogene times and Palaeogene times, it becomes very active due to the movement of the sedimentary piles and bent of the western margin basin [32]. The approximate length of the Dauki fault and Assam fault is 300 kilometers trending east-west and northeast-southwest respectively [33].

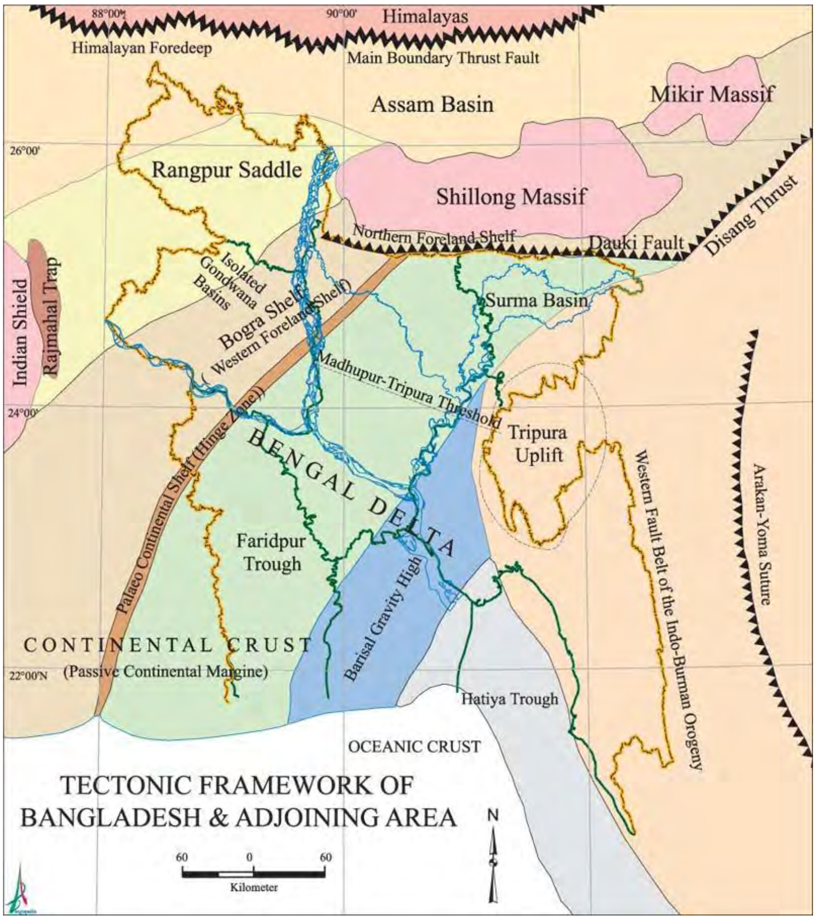

Figure 2.1: Tectonic Zone of Bangladesh (Banglapedia, 2015)

The following table showing the maximum magnitude level of the earthquake that may happen in our country according to the fault zone [34];

Table 2.1: Maximum magnitude level of an earthquake can produce in different fault zone

Name of the fault zone	Maximum magnitude in Richter scale
1. The Bogra zone	7.00
2. The Assam zone	8.50
3. The Tripura zone	7.00
4. The Sub-Dauki zone	7.30
5. The Shillong plateau zone	7.00

According to EDRI (earthquake disaster risk index), Dhaka, the capital of Bangladesh, is in the top twenty earthquake prone cities in the world [35]. In Bangladesh, there are three identified seismic zones according to the earthquake risk level. These risk zones are;

A) High-risk zone (Pink marked in figure 2.5)

B) Moderate risk zone (Yellow marked in figure 2.5)

C) Low-risk zone (light green marked in figure 2.5)

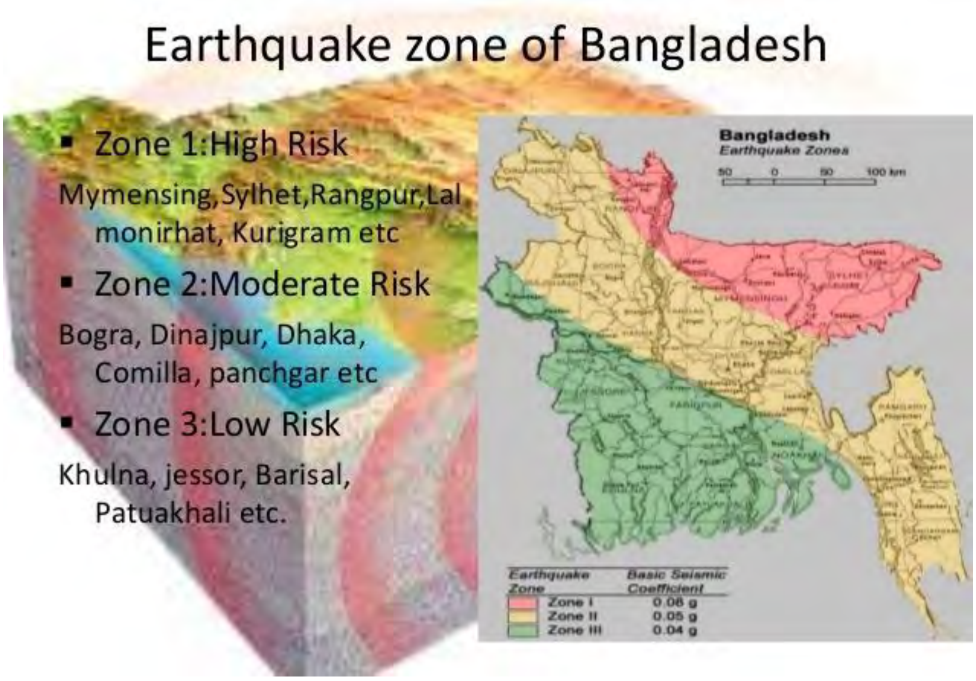

Figure 2.2: Seismic Zone of Bangladesh (Wikimedia, 2015)

2.1.4 Earthquake Chronology in Bangladesh

Historical data about earthquakes are very important to estimate the probability of an earthquake in any area. Akhter, S.H [36] and Banglapedia (2015) [37] stated the following historical data of earthquakes in Bangladesh for the last 250 years 2.4:

Table 2.2: Chronology of Earthquake in Bangladesh

Year	Area of Earthquake	Description
1548	Sylhet and Chittagong region	Floodplains of Meghna, Sylhet, Assam, and Tripura faced liquefaction and land fissures.
1642	Assam- Sylhet region	Moderate intensity.
1663	Assam	Richter scale magnitude more than 8.
1762	Chittagong coast	One of the destructive earthquakes in Bangladesh, which had a magnitude more the 8.5 on the Richter scale.
1775	Around Dhaka	No physical damages.
1787	Sirajganj	In the modified meracllis scale the earthquake having the index of VI to VII happened around Sirajgonj.

1812	Dhaka	Date: 10th April, 11th May MM (modified meracllis) index: VIII
1822	Kishoreganj	Date: 3rd April MM index: VI
1842	Rajshahi	Date: 11th November MM index: V Richter scale index: 7.3
1845	Sirajganj	Date: 23th and 26th July, 6th August MM index: V to VI (for August) Richter scale index: 5.9 and 6.1 (for July)
1846	Mymensingh	Date: 18th October MM index: VI Richter scale index: 6.2
1865	Chittagong	Date: 14th December MM index: VI to VII
1869	Cacher earthquake	Date: 10th January MM index: IV to V Richter scale index: 7.5
1885	Bengal Earthquake	Date: 14th July Richter scale index: 7.0
1897	Great Indian	Date: 12th June MM index: VIII Richter scale index: 8.7
1918	Srimangal	Date: 9th July MM index: VII Richter scale index: 7.6
1923	Meghalaya	Date: 9th September Richter scale index: 7.1
1930	Dubri	Date: 2nd July MM index: V+ Richter scale index: 7.1
1934	Bihar-Nepal	Date: 15th January MM index: VI Richter scale index: 8.4
1935	Pabna	Date: 21th March MM index: VI Richter scale index: 5.9
1943	Assam	Date: 10th October MM index: V to VI Richter scale index: 7.2
1950	Assam	Date: 15th August MM index: IV Richter scale index: 8.4
1954	Monipur- Myanmar	Date: 22th March MM index: V Richter scale index: 7.7
1977	Myanmar Border	Date: 12th May

		MM index: III Richter scale index: 5.7
1988	Myanmer	Date: 6th August MM index: V Richter scale index: 7.3
	Bihar-Nepal	Date: 21th August MM index: V Richter scale index: 7.8
1997	Bandarban	Date: 21th November (23 people died.) MM index: IV Richter scale index: 6.1
2001	Dhaka	Date: 19th December MM index: V to VI Richter scale index: 4.5
2003	Borkol	Date: 27th July MM index: IV Richter scale index: 5.7
2004	Sumatra	Date: 26th December Richter scale index: 9.3 230000 people died in 14 countries.
2006	Narail	Date: 5th AugustMM index: IV to V Richter scale index: 4.2
2008	Manikganj	Date: 20th March Richter scale index: 3.8
	Mymensingh	Date: 27th July Richter scale index: 5.1
	Chandpur	Date: 20th September Richter scale index: 4.5
2009	Bhutan	Date: 21th September Richter scale index: 6.1
	Bay of Bengal	Date: 11th September Richter scale index: 7.5
2010	Dhaka	Date: 10th September Richter scale index: 4.8

2.1.5 Earthquake Risk Factors in Bangladesh

I. Raihanul *et al.*[29], and R.A., Halder *et al.* [38], have discussed some major issues responsible for earthquakes in our country. These are;

a) High population density of our country especially in city areas

b) National Building code is not followed properly.

c) Lack of the use of earthquake wave resistance materials in construction and design

d) Lack of awareness among people about the earthquake

e) Low-quality construction materials

f) Faulty and unplanned design of pile-lines and gas-stations

g) Shortage of emergency exits in high-rise buildings

h) Lack of planning for earthquake management

i) Inadequate facilities of earthquake rescue operations

j) Poor design of roads and highways

2.2 Domino Effect Analysis

2.2.1 Background of Domino Effect Analysis

Since 1947, the domino effect is used as a technical tool for risk assessment [39]. According to Cozzani and Salzano, the domino effect can be defined as "Any primary incidents of an accident can propagate other secondary incidents; as a result, a severe consequence occurs, which could be more than the primary incident" [40]. The Domino effect is also known as the chain of the accident, where this chain of an accident can propagate more incidents from the previous one [41]. Three elements are necessary for this chain of accidents. They are the striking distance of sensitive units from the primary incidents, understanding the abilities of sensitive units to propagate secondary incidents and the probability analysis of the movement of destructive potentials [42]. Three characterized elements are identified in Domino effect accidental sequence analysis. The elements are as follows: [43].

<u>Primary events</u>: This is called the initial stage where the sequence of Domino effect starts.

<u>The potentiality of primary events</u>: This stage shows the capability of primary events to move nearby the secondary events due to the escalation vectors.

<u>Secondary events</u>: These events are the resultant of the primary events which have more powerful consequences.

Again, escalation vectors play an important role which leads the Domino series. According to the escalation vectors, two types of causes are responsible for the accident. The first one is the LSIE (low severity initiating events) which causes minor injuries and the second one is the MAE (major accidental events) which causes the high damage to physical and economic losses [44]. In addition to that, a Domino process also includes at least two subsystems. They are: (i) source subsystem which might create a danger and (ii) target subsystem that might impact on source subsystem.

Kadri et al. [45] discussed that natural or earthquakes disaster and a technological event can impact on a nation and lead to industrial and social crisis. They analyzed the impact of earthquakes on critical building or infrastructure on the basis of Domino effects. Figure 2 represents an overview of principal infrastructure damage happened due to the impact of Domino effect.

Huang et al. [46] analyzed the Domino effect probabilities at various levels for primary impacts and overall scenarios. They mentioned that primary impacts might have more than the escalation vectors which leads to the propagation effects because of the impacts of high intense earthquakes. However, when the Domino effects include diverse sources of incidents, the multiple interaction effect will further propagate them making the scenario more complex [47, 48].

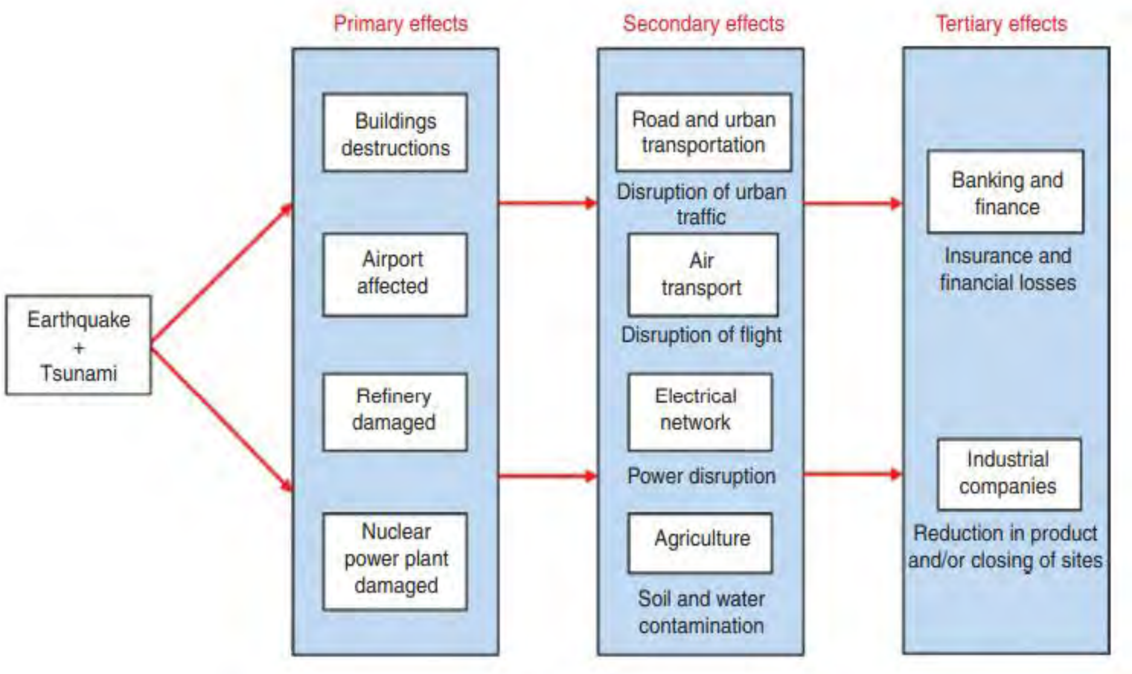

Figure 2.3: Infrastructure damage by the impacts of earthquakes

2.2.2 Process Flow Chart for Domino Effect Analysis

V. Cozzani *et al*. [49] developed the domino accidental sequence's flow chart risk assessment.

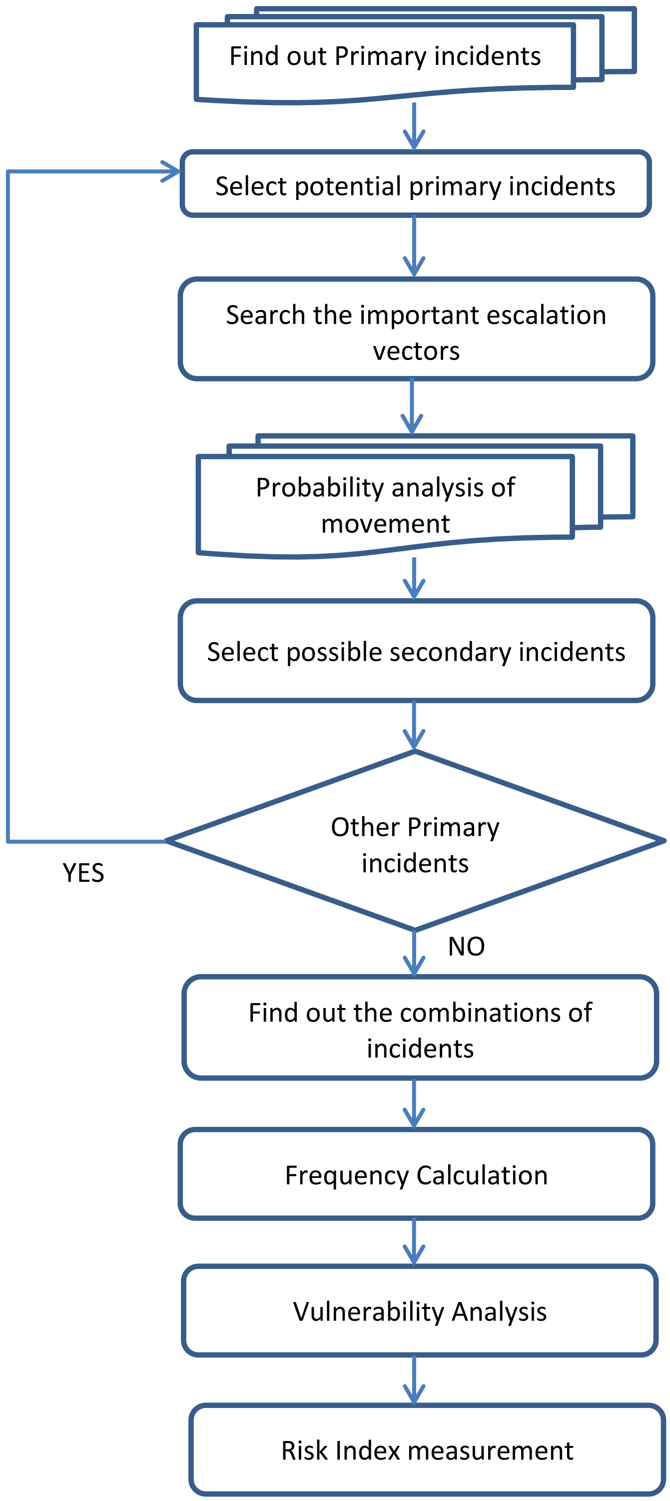

Figure 2.4: Process flow chart for risk assessment of domino Series

2.3 Emergency Resource Allocation Planning (ERAP)

Each year, floods, earthquakes, and other natural disasters cause severe harm in our normal life. Millions of people die and thousands of infrastructures are collapse for these natural disasters with huge economic and physical losses [50]. To minimize the losses, the toughest challenge is to fulfill the demand and provide resources among affected people at varying times during the response and recovery period [51]. The key responsibilities in the response phase are planning for emergency operations, setup centers, medical care, opening shelters, rescue operations and search, firefighting, protection of emergency utility infrastructures, mass care, and facilities management. Besides, cleanup disaster's garbage, economical help, rebuilding structures, lifeline facilities restored, and mental health support are mainly involved in recovery phases [52]. Installation of the early warning system, proper awareness, and training, establishment of alternative emergency service systems are focused in the preparedness phase [53]. An earthquake is an unexpected natural event which needs a proper EIMS (earthquake information management system) to collect data, analyze inputs, and record them for mitigating losses [54].

In earthquake emergency rescue planning, both government and society need to be involved. An emergency rescue plan, strong management policy, and assessment system are important for a country [55]. In 1940, the United States starts working on it and developed EPTG (emergency plan technical guide) and FEP (federal emergency plan) in 1987 and 1992 respectively.

The main challenges of effective disaster management are finding out emergency conditions of affected areas, evacuation operations, and understanding survivors' needs after a large-scale natural disaster like an earthquake [56]. According to W. Yi, and A. Kumara, emergency logistics operations, supply availabilities, and vehicle routing models play a vital role in rescue operation [57]. Due to the structural failures, the transportation of emergency supplies from the distribution center made some delay. Evacuation of affected people and relief operations are two major parts after the earthquake, where evacuations take place in the early state of response and relief operations continue for long period [58].

ERAP has grasped a major attention to the researcher as it has prospective use in disaster management system and emergency scenarios.

Altay [59] developed an integer programming model for the diverse resource multi location for effective and efficient emergency allocation.

Wang et al. [60] proposed a multi objective resource allocation model which can be used to minimize the total allocating costs in large scale disasters. However, this study did not give any solution of some other constraints such as urgency of resources, response time and severity of disaster.

Ceferino et al. [61] developed a model for emergency resource allocation of hospital system during disaster which can assess the loss of hospital systems such as allocation of ambulances, patient transfer and mobile operating systems.

Haung et al. [62] proposed a multi-objective optimization model for emergency resource allocation and they utilized a time space network system for decision update.

The recent studies [63-66] show that emergency resources can meet all disaster incidents and these developed models are suitable for some specific emergency incidents. In practical, emergency resources and rescue teams are limited and most cases serial allocation of resources often lead to lower effectiveness and efficiency when there is a large amount of emergency scenarios. This study aimed to solve dynamic multiple emergency resource allocations for concurrent scenarios by addressing these shortcomings.

Chapter 03

Methodology and Model Formulation

Emergency resource allocation planning is a very critical planning process where risk analysis, real-time calculation, and probability analysis have some great influences. After the earthquake, this emergency resource allocation planning becomes more difficult and time worthy. Besides, the losses both economical and physical will be increased with time. So, a simple, easy and effective emergency resource allocation model is the main focus of this chapter. Bangladesh is one of the moderate risky areas for earthquakes but there are no emergency earthquake resource allocation plans for this type of disaster. Therefore, it is very difficult to establish a new model in this aspect.

3.1 Methodology

ERA problem is another prime stream in this chapter. Caunhye et al. [67] focused on centralized approaches that might be better to drastically improve the coordination among involved multiple parties. The mathematical programming or linear programming is one of the most used techniques to characterize the allocation relations among emergency organization points in a centralized manner. Zhang et al. [68] highlighted on homogeneous emergency rescue team allocation problem with the concern of a precedence relation constraint so as to reduce the total losses and improve the efficiency of disaster response. Response techniques regarding goals of efficiency and effectiveness are made in disaster response optimization system which can be which can be understood as integration of decision-agent, rescue, teams, survivors, relief food, environment and their relations. Thus, attempts have been made to improve the efficiency and effectiveness of response teams, reduce costs, and dissolve environmental issues [69, 70].

- The detailed methodology of the research is given below:
- The objectives and scopes of the research are fixed with visible and realistic possible outcomes in a real-time horizon.
- The related literature reviews are carried out to find out the effects and risks of earthquake in the sense of geological structure in Bangladesh.
- A detailed review of the historical background of the Emergency Resource Allocation problem and planning is done for setting the parameters of the model.

- Identification of risk associated with incidents after an earthquake is done.
- Introduction of the Domino effects to identify primary incidents of risk associated with an earthquake has been created.
- Identification of the secondary incidents that might occur from primary incidents has been done from the literature review.
- A relation between the primary and secondary incidents of Domino effects has been established.
- An emergency resource allocation model is developed with feasible outcomes.
- A programming code of the model for computing outcomes has been set up.
- Relevant data for operating the programming code has been collected.
- Detailed outcomes of the programming code of the model have been analyzed in various aspects.
- Limitations of the model and programming code has been found.
- Detailed analysis of the result of the model in different focusing points and discussion of the emergency resource allocation model is established.
- Effort was put to find out the future scopes of this research.

3.2 Model Formulation

Studies have shown that the proper allocation of rescue teams is important for emergency resource response as the timely coordination and interaction of rescue teams can save people's lives as well as their properties [71, 72]. When an earthquake occurs, rescue team must be organized to maintain teams so that they can response efficiently and quickly to the incidents [73]. After a notable earthquake strikes in a city, the authority responds by sending teams of medical, food and rescue personnel, etc. to the incident. When an earthquake occurs in a city, the decision maker or authority must send at least one team in various areas of the affected city. In this study, I considered that some teams would be sent from the different resource allocation points (RAP). These teams from a RAP could be spitted in various sub teams if multiple areas are affected. Therefore, single objective model is considered. Studies suggest [74, 75, 76] that single objective optimization model is a popular study method in disaster management. Hence, proposed model is constrained integer linear programming (LP) problem which is computationally intractable [77].

3.2.1 Procedure of model formulation

Step-1: Select the targeted affected area and segment this area into some suitable small areas. Denote these segmented areas as A_i, Where i = 1, 2, 3, …… n.

A= Total area

A_1	A_2	A_3
A_4	A_5	A_6
A_7	….	…..
…..	……	A_n

Figure 3.1: Segmented affected area.

Step-2: Determined the population (M_i) , severity (S_i), and food demand (FD_i) for each segmented area.

Step-3: Find out the types of an incident associated after an earthquake disaster. Denote them with I. Also, make a list of incident's state, those are denoted with X. The states start with Null and then increase with the combinations of incidents. The total number of states is 2^n. For example, if three incidents occur after an earthquake, they can be denoted as I_1, I_2, I_3 then the states are seven. They are;

Table 3.1: Example of States formulation

State	Types of Incidents
X_1	Null
X_2	I_1
X_3	I_2
X_4	I_3
X_5	I_1& I_2
X_6	I_1& I_3
X_7	I_2& I_3
X_8	I_1, I_2 & I_3

Step-4: Assign the weight of each state as W(X). The weights are depended on the weight of the primary incident.

Step-5: Domino effect analysis was done to find out the possible movement of each state and the probability of movement. The possible movement of a state is denoted with K and the probability of the movement as P(X).

Step-6: Find out the summation of movement factor (Y) of an affected area from the present state X_j.

Step-7: The risk associated in a segmented area (R) was found out using the population, severity, present incident's state, probability of movement, and weight of states with the help of mathematical equations. After that, find out the total risk (TP) of the affected area by the summation of all risk (R).

Step-8: Assign the resource allocation points (RAP), the total number of the team (T) in each resource allocation point, capability index (H) of each team, percentage of population served by each team (O) at a time.

Step-9: Using the mathematical model, find out the risk minimization (RM) by a team from a resource allocation point to an affected area.

Step-10: Select the path selection index (PSI) and path availability index (PAI)

Step-11: Determine the unfulfilled food demand (UFD) and total average distance (TD) by using the mathematical model

Step-12: Assign the importance factor value of risk (F_R), food (F_F), and distance (F_D)

Step-13: Using the objective function for various combinations of the team (N), send them from resource allocation points to affected areas, find out the minimum value of Z, being satisfied by the constraints. The combination of teams in the minimum objective function value is our target allocation plan.

3.2.2 Symbolic Meaning

Different alphabet and symbols are used to express the mathematical model. These are;

Symbol	Meaning
A	Affected area by an earthquake.
M	Population of the area.
S	Severity of the area
n	Number of segmented areas.
I	Name of incident after an earthquake.

m	Number of incidents.
X	State of incidents.
K	Possible set of movement of one state to another states.
i	Suffix index (1,2,3,………., n)
j	Suffix index (1,2,3,……….., 2^m)
R	Risk associated in each segmented area.
TR	Total risk of affected area.
$P(X)$	Probability of movement of a state to another.
$W(X)$	Weight of a state.
Y_{jk}	Summation of movement factors of an area from present state X_j
RAP	Resource allocation points
L	Total number of resource allocation point (RAP)
l	Suffix index (1,2,3,…….., L)
T	Number of teams in each resource allocation point.
RM	Risk minimization by a team from T_l of RAP_l
H	Capability index of a team.
O	Percentage of population would be served by a team at a time
N_{ij}	Number of team send from RAP_l to affected area A_i
P	Number of path from one resource allocation point to a affected area
p	Suffix index (1,2,3,………P)
PSI	Path selection index
PAI	Path availability index
FD	Food demand of a segmented area.
C_l	Capacity of food supply of a team of RAP_l
UFD	Unfulfilled food demand
D_{li}	Average distance from a RAP_l to A_i
TD	Total average distance
F_R	Factor of importance of risk
F_F	Factor of importance of food
F_D	Factor of importance of distance
N_{min}	Minimum number of team to be send in each affected area A_i

3.2.3 Mathematical Model

1. Risk associated in each segmented area, $R_i = (M_i \times S_i \times Y_{jk})$

$$\text{Where } Y_{jk} = \sum_{k} \{P(X_k) \times W(X_k)\}$$

2. Total Risk of the affected area, $TR = \sum R_i$

3. Risk minimization by a team, $RM_l = \{M_i \times H_l \times O_l \times W(X_j)\}$

4. Total Risk minimization, $TRM = \Sigma \{N_{li} \times RM_{li} \times PSI_{li} \times \sum_{p} (PAI_{lip})\}$

5. Unfulfilled food demand, $UFD = \{ \Sigma FD_i - \Sigma (N_{li} \times C_l)\}$

6. Total average distance, $TD = \Sigma D_{li}$

Objective function, $Z = \min [\{F_R \times (TR - TRM)\} + \{ F_F \times UFD\} + \{ F_D \times TD\}]$

Constrains:

$$N_{li} \geq N_{min}$$

$$\Sigma N_{li} = \Sigma T_l$$

3.2.4 Flow Diagram of the Model

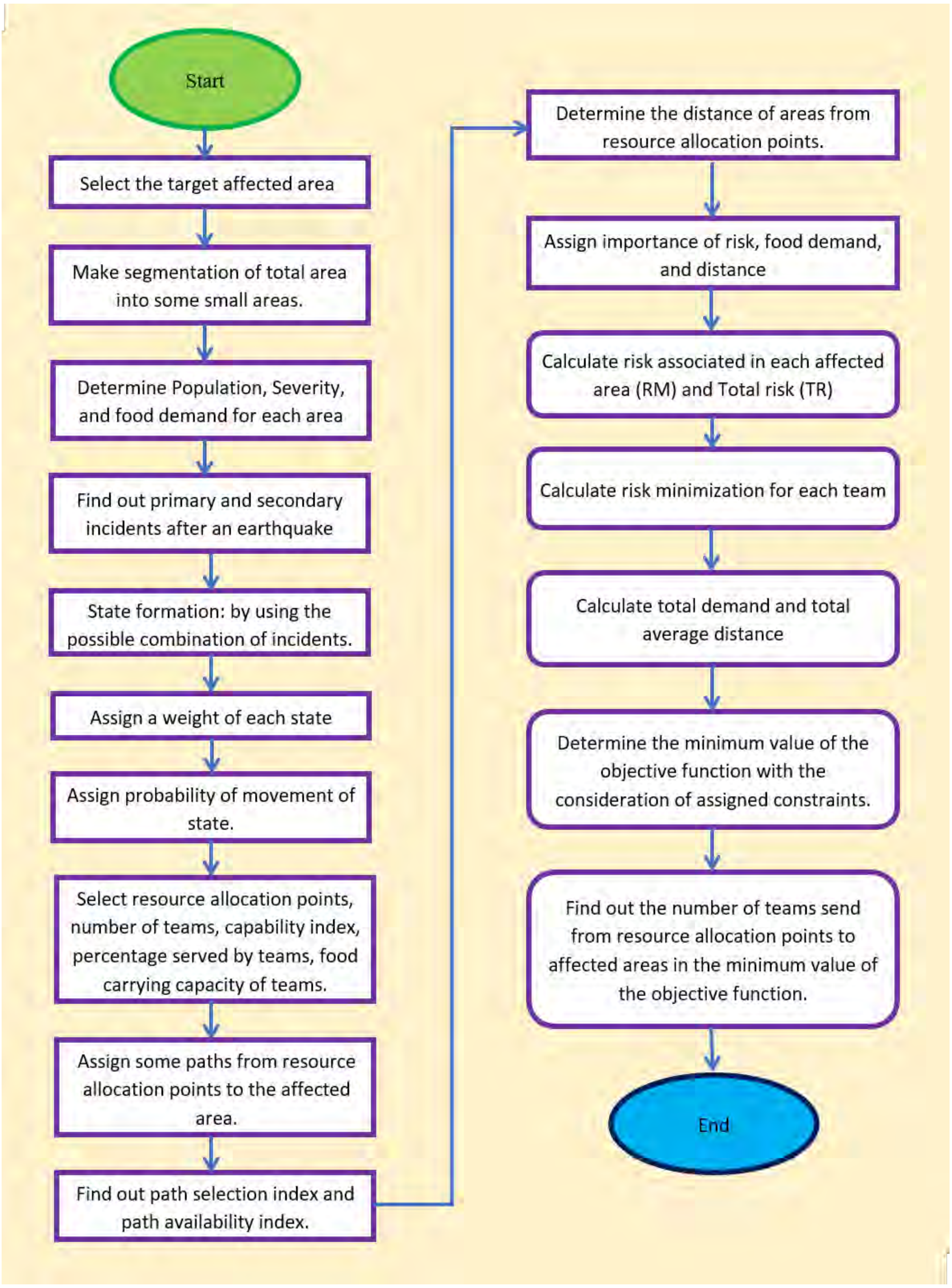

Figure 3.2: Flow diagram of the proposed model

3.2.5 Guideline for Model Formation

Some general guidelines are described here for the functioning of the model. These are;

- The severity of a segmented area should be 1 to 10, where 1 will be the minimum value with low-risk zone and 10 is the highest with maximum risk. This severity depends on the geological position and structural condition of the area. A sample structure is shown here which is used for model formulation;

Table 3.2: Sample structure of measuring the severity of an area.

Severity Consideration Factors	**Value**
If only agricultural land	S=1
If the village area and population under 1000	S=2
If the village area and population more than 1000	S=3
If planned and organized industrial area	S= 4
If an overpopulated industrial area with the gas line	S= 5
If the Industrial area having chemical industry	S=6
If Area having seaport or sea beach or tourist spot	S=7
If the city area but high-rise apartment is not present	S=8
If the city area with high-rise apartment with a crowded population	S=9
If the area has any Nuclear power plant	S=10

- Considering food demand is also critical in this model. Depending on the severity and population of the area, this demand will be increased. Initially, we used a base format to calculate this demand showing in table 3.3. According to expert opinions, this format can be changed.

Table 3.3: Food demand calculation format.

Index	Value
If $S_i = 1$ to 3	20% of the population of the area (M_i)
If $S_i = 4$ to 5	40% of the population of the area (M_i)
If $S_i = 6$ to 7	50% of the population of the area (M_i)
If $S_i = 8$ to 9	80% of the population of the area (M_i)
If $S_i = 10$	100% of the population of the area (M_i)

- Path availability index is highly dependent on the nature of road between resource allocation point and segmented area. The gas line beside the road, high rise building structure, any faulty bridge, etc. have impacts on this index. The presence of hazardous elements under the road or nearby places will increase the probability if not available on the road.

- Movements of states of incidents are based on domino theory determined by the earthquake experts according to the past or previous data analysis of earthquake and present development of the areas.
- Team capability index must be from 1 to 10, according to their performance, training, capability and resource of rescue operations.

Chapter 04

Result Analysis

The detailed analysis of the results is described in this chapter. A case study has been generated to find out the output of the model. The case study is developed focusing on three regions of Bangladesh namely Dhaka, Gazipur and Narayanganj. Data such as population, distance, and severity etc. were collected for this case study from Bangladesh Bureau of Statistics. The results were analyzed in various aspects as the output of the developed model.

4.1 Case Study

The performance of the developed model has been determined in this section. To conduct the research, Dhaka, Gazipur and Naraynganj city were focused as they are densely populated areas. Data were collected for this purpose. Severity index was determined based on population and number of houses in an area as shown in Table 4.1.

4.1.1 Data Collection

The following data about target three cities are collected for the case study;

Table 4.1: Collected data for three cities (Source: Bangladesh Bureau of Statistics)

SL	Area Name	Area Code	Population	Number of houses	Severity
1	Adabor	**101**	203989	49600	6
2	Badda	**102**	536621	129673	7
3	Bangshal	**103**	120382	35410	5
4	Biman Bandar	**104**	10626	2262	4
5	Cantonment	**105**	131864	25956	5
6	Chak Bazar	**106**	156147	31057	5
7	Dakshinkhan	**107**	255931	63899	6
8	Darus Salam	**108**	159139	40064	5
9	Demra	**109**	226679	52982	6
10	Dhamrai	**110**	412418	94776	6
11	Dhanmondi	**111**	147643	33169	5
12	Dohar	**112**	226439	49400	6
13	Gendaria	**113**	137721	29591	5
14	Gulshan	**114**	253050	59149	6
15	Hazaribagh	**115**	185639	43740	6

16	Jatrabari	**116**	443601	101815	7
17	Kafrul	**117**	396182	95575	6
18	Kadamtali	**118**	370895	87701	6
19	Kalabagan	**119**	118660	23692	5
20	Khilgaon	**120**	327717	77904	6
21	Khilkhet	**121**	130053	31141	5
22	Keraniganj	**122**	794360	177970	7
23	Kotwali	**123**	62087	11614	4
24	Lalbagh	**124**	369933	83809	6
25	Mirpur	**125**	500373	117450	7
26	Mohammadpur	**126**	355843	81754	6
27	Motijheel	**127**	210006	47119	6
28	Nawabganj	**128**	318811	70757	6
29	New Market	**129**	49523	7824	4
30	Pallabi	**130**	596835	143332	7
31	Paltan	**131**	59639	10541	4
32	Ramna	**132**	200973	41976	6
33	Rampura	**133**	224079	50162	6
34	Sabujbagh	**134**	376421	88777	6
35	Savar	**135**	1385910	359084	8
36	Shabagh	**136**	68140	8707	4
37	Shyampur	**137**	184062	43243	6
38	Sher-E-Bangla Nagar	**138**	137573	29652	5
39	Sutrapur	**139**	211210	43474	6
40	Tejgaon	**140**	148255	29622	5
41	Tejgaon Ind. Area	**141**	146732	34875	5
42	Turag	**142**	157316	38660	5
43	Uttara	**143**	179907	39123	5
44	Gazipur Sadar	**201**	1344024	328515	8
45	Tongi	**202**	476350	120624	7
46	Kaliakair	**203**	483308	116749	7
47	Kaliganj	**204**	265276	57770	6
48	Kapasia	**205**	342162	79928	6
49	Sreepur	**206**	492792	122872	7
50	Araihazar	**301**	376550	77462	6
51	Sonargaon	**302**	400358	89565	6
52	Bandar	**303**	312841	73173	6
53	Narayanganj Sadar	**304**	1323600	313312	8
54	Siddirganj	**305**	256760	60290	6
55	Rupganj	**306**	534868	122140	7

Red mark: Resource allocation points. Blue mark: Affected areas

4.1.2 Problem Formulation

- A sample problem was developed for this case study. First 4 areas are selected as the target affected area presented in Table 4.1.

Table 4.2: Target affected area for problem

Area	Area Name	Area Code	Population	Number of house	Severity	Present State
A-1	Dakshinkhan	**107**	255931	63899	6	X_3
A-2	Jatrabari	**116**	443601	101815	7	X_4
A-3	Mohammadpur	**126**	355843	81754	6	X_3
A-4	Dhanmondi	**111**	147643	33169	5	X_5

- Four incident are listed here after an earthquake; these are
  1. Incident-1, I_1= Gas leakage
  2. Incident-2, I_2= Fire
  3. Incident-3, I_3= Building Collapse
  4. Incident-4, I_4= Explosion

  Base weight assign for these incidents are 2, 4, 8, 16 respectively.
- 16 States are formulated from these 4 incidents described in Table 4.3.

Table 4.3: State formation from primary incidents

State	Identity	State	Identity
State 1 = X_1	Null	State 9 = X_9	Gas Leakage + Building Collapse
State 2 = X_2	Gas Leakage	State 10 = X_{10}	Gas Leakage + Explosion
State 3 = X_3	Fire	State 11 = X_{11}	Building Collapse + Explosion
State 4 = X_4	Building Collapse	State 12 = X_{12}	Fire + Gas Leakage + Building Collapse
State 5 = X_5	Explosion	State 13 = X_{13}	Fire + Gas Leakage + Explosion
State 6 = X_6	Fire + Gas Leakage	State 14 = X_{14}	Gas Leakage + Building Collapse + Explosion
State 7 = X_7	Fire + Building Collapse	State 15 = X_{15}	Fire + Building Collapse + Explosion
State 8 = X_8	Fire + Explosion	State 16 = X_{16}	Fire + Gas Leakage + Building Collapse + Explosion

- Based on the incident's magnitude, each state is weighted shown in Table 4.4 ;

Table 4.4: Weight of state

WX_1	0	WX_9	2+8=10
WX_2	2	WX_{10}	2+16=18
WX_3	4	WX_{11}	8+16=24
WX_4	6	WX_{12}	2+4+8=14
WX_5	8	WX_{13}	2+4+16=22
WX_6	2+4=6	WX_{14}	2+8+16=26
WX_7	4+8=12	WX_{15}	4+8+16=28
WX_8	4+16=20	WX_{16}	2+4+8+16=30

- Based on the incident weight, possible movements of each state are represented in Table 4.5.

Table 4.5: Possible movement of states

X_1	→		X_2	X_3	X_4	X_5			
X_2	→		X_6	X_9	X_{10}				
X_3	→		X_6	X_7	X_8				
X_4	→		X_8	X_{10}	X_{11}				
X_5	→		X_7	X_9	X_{11}				
X_6	→		X_{12}	X_{13}					
X_7	→		X_{14}	X_{15}					
X_8	→		X_{13}	X_{15}					
X_9	→		X_{12}	X_{14}					
X_{10}	→		X_{13}	X_{14}					
X_{11}	→		X_{14}	X_{15}					
X_{12}	→		X_{16}						
X_{13}	→		X_{16}						
X_{14}	→		X_{16}						
X_{15}	→		X_{16}						

- Assign the probabilities of movement of states (Assumption).

Table 4.6: Probabilities of movement of states

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	Total
X_3						0.3	0.4	0.3									1
X_4								0.4		0.4	0.2						1
X_5							0.5		0.2		0.3						

- Two resource allocation points are selected for this problem and team's information are given below in the table 4.7.

Table 4.7: Resource allocation point's information

SL	**Area Code**	**Area Name**	**Number of Teams**	**Team's Capability index**	**Food Carrying Capacity**	**Number of Path in Affected Areas**	**Path Availability Index**
RAP_1	143	Uttara	7	6	4000 pcs	2,2,2,2	(0.5, 0.6) (0.5,0.7) (0.4,0.7) (0.6,0.8)
RAP_2	306	Rupganj	9	5	5000 pcs	2,2,3,2	(0.6,0.45) (0.5,0.8) (0.7,0.6,0.5) (0.7,0.4)

4.1.3 Computational Representation of Coding

The python programming coding language (Pycharm) is used here for visualize the model (detail coding are included in appendix). Figures 4.1(a) to 4.1(g) show the console of coding for each criteria. Based on the mass of the population in an area, the severity index is selected. Higher population will be higher severity index. From Figure 4.1(b), it can be seen that possible movements of area 107 (Dakshinkhan) are (gas + fire), (fire + Building collapse) and (fire + explosion). Based on Domino effects, if fire can be resolved from the first movements building collapse and explosion could be resolved.

```
Enter no of areas: 4
Enter area code for A1: 107
Enter area code for A2: 116
Enter area code for A3: 126
Enter area code for A4: 111
+------+-----------+----------+
| Area | Population | Severity |
+------+-----------+----------+
| 107  |  255931.0  |   6.0    |
| 116  |  443601.0  |   7.0    |
| 126  |  355843.0  |   6.0    |
| 111  |  147643.0  |   5.0    |
+------+-----------+----------+

Enter no of incidents: 4
Enter Incident 1: Gas
Enter Incident 2: Fire
Enter Incident 3: Building Collapase
Enter Incident 4: Explosion
Enter base for weight factor: 2
+-------------------+---------------+
|      Incident     | Weight Factor |
+-------------------+---------------+
|        Gas        |      2.0      |
|        Fire       |      4.0      |
| Building Collapase|      8.0      |
|     Explosion     |      16.0     |
+-------------------+---------------+

+----+------------------------------------
```

Figure 4.1(a): Computational representation of coding

```
+----+----------------------------------------------+---------------+
| Sl | State                                        | Weight Factor |
+----+----------------------------------------------+---------------+
| 1  | NULL                                         |      0.0      |
| 2  | Gas                                          |      2.0      |
| 3  | Fire                                         |      4.0      |
| 4  | Building Collapase                           |      8.0      |
| 5  | Explosion                                    |      16.0     |
| 6  | Gas + Fire                                   |      6.0      |
| 7  | Gas + Building Collapase                     |      10.0     |
| 8  | Gas + Explosion                              |      18.0     |
| 9  | Fire + Building Collapase                    |      12.0     |
| 10 | Fire + Explosion                             |      20.0     |
| 11 | Building Collapase + Explosion               |      24.0     |
| 12 | Gas + Fire + Building Collapase              |      14.0     |
| 13 | Gas + Fire + Explosion                       |      22.0     |
| 14 | Gas + Building Collapase + Explosion         |      26.0     |
| 15 | Fire + Building Collapase + Explosion        |      28.0     |
| 16 | Gas + Fire + Building Collapase + Explosion  |      30.0     |
+----+----------------------------------------------+---------------+

A1 code : 107
Enter State: 3
Possible movements:
(Gas + Fire)
(Fire + Building Collapase)
(Fire + Explosion)

Enter probability for movement : Gas + Fire : 0.3
Enter probability for movement : Fire + Building Collapase : 0.4
Enter probability for movement : Fire + Explosion : 0.3
```

Figure 4.1(b): Computational representation of coding

```
A2 code : 116
Enter State: 4
Possible movements:
(Gas + Building Collapase)
(Fire + Building Collapase)
(Building Collapase + Explosion)

Enter probability for movement : Gas + Building Collapase : 0.4
Enter probability for movement : Fire + Building Collapase : 0.4
Enter probability for movement : Building Collapase + Explosion : 0.2

A3 code : 126
Enter State: 3
Possible movements:
(Gas + Fire)
(Fire + Building Collapase)
(Fire + Explosion)

Probability for movement : Gas + Fire : 0.3
Probability for movement : Fire + Building Collapase : 0.4
Probability for movement : Fire + Explosion : 0.3

A4 code : 111
Enter State: 5
Possible movements:
(Gas + Explosion)
(Fire + Explosion)
(Building Collapase + Explosion)

Enter probability for movement : Gas + Explosion : 0.5
Enter probability for movement : Fire + Explosion : 0.2
Enter probability for movement : Building Collapase + Explosion : 0.3
```

Figure 4.1 (c): Computational representation of coding

Area	State	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
107	3						0.3			0.4	0.3						
116	4							0.4		0.4		0.2					
126	3						0.3			0.4	0.3						
111	5								0.5		0.2	0.3					

otal Risk 103392872.60000001

Area	Risk
107	19348383.6
116	42230815.2
126	26901730.800000004
111	14911943.0

```
nter Number of Resource Allocation Points: 2
nter Area code of RAP-1: 143
nter Number of teams in RAP-1: 7
nter Weight of teams in RAP-1: 6
nter Food Capacity of teams in RAP-1: 4000
nter Area code of RAP-2: 306
nter Number of teams in RAP-2: 9
nter Weight of teams in RAP-2: 5
nter Food Capacity of teams in RAP-2: 5000
```

Figure 4.1(d): Computational representation of coding

RAP	Number of teams	Weight	Food Capacity
143	7	6	4000
306	9	5	5000

```
Number of paths from RAP-143 to Area-107: 2
Enter Path Availability Index 143-107-1:0.5
Enter Path Availability Index 143-107-2:0.6
Number of paths from RAP-143 to Area-116: 2
Enter Path Availability Index 143-116-1:0.5
Enter Path Availability Index 143-116-2:0.7
Number of paths from RAP-143 to Area-126: 2
Enter Path Availability Index 143-126-1:0.4
Enter Path Availability Index 143-126-2:0.7
Number of paths from RAP-143 to Area-111: 2
Enter Path Availability Index 143-111-1:0.6
Enter Path Availability Index 143-111-2:0.8

Number of paths from RAP-306 to Area-107: 2
Enter Path Availability Index 306-107-1:0.6
Enter Path Availability Index 306-107-2:0.45
Number of paths from RAP-306 to Area-116: 2
Enter Path Availability Index 306-116-1:0.5
Enter Path Availability Index 306-116-2:0.8
Number of paths from RAP-306 to Area-126: 3
Enter Path Availability Index 306-126-1:0.7
Enter Path Availability Index 306-126-2:0.6
Enter Path Availability Index 306-126-3:0.5
Number of paths from RAP-306 to Area-111: 2
Enter Path Availability Index 306-111-1:0.7
Enter Path Availability Index 306-111-2:0.4
```

Figure 4.1(e): Computational representation of coding

```
nter Path Availability Index 306-111-2:0.4

-----------+----------------------------+--------------------------------------+---------------------------+------
---------------------------+-----------------------------------------------+
   Area    | Number of path from RAP-143 | Path availability index from RAP-143 | Number of path from RAP-306 | Path a
lability index from RAP-306 | Percentage of population can be served in Area |
-----------+----------------------------+--------------------------------------+---------------------------+------
---------------------------+-----------------------------------------------+
 Area-107 |            2             |              [0.5, 0.6]              |            2              |
   [0.6, 0.45]             |                 8.0%                     |
 Area-116 |            2             |              [0.5, 0.7]              |            2              |
    [0.5, 0.8]             |                 8.0%                     |
 Area-126 |            2             |              [0.4, 0.7]              |            3              |
 [0.7, 0.6, 0.5]           |                 8.0%                     |
 Area-111 |            2             |              [0.6, 0.8]              |            2              |
    [0.7, 0.4]             |                10.0%                     |
-----------+----------------------------+--------------------------------------+---------------------------+------
---------------------------+-----------------------------------------------+
otal Food Demand: 586744.7

nter weight for risk: 0.7
nter weight for food: 0.2
nter weight for dist: 0.1
nter minimum number of teams in an area: 2
```

Figure 4.1(f): Computational representation of coding

```
+----------+-----+-----+-----+-----+
|   143    |  7  |  0  |  0  |  0  |
|   306    |  2  |  3  |  2  |  2  |
+----------+-----+-----+-----+-----+

Z= 68027292
Remaining Risk= 97035059
Unfulfilled food demand= 513744
Average distance= 15
+----------+-----+-----+-----+-----+
| RAP\Area | 107 | 116 | 126 | 111 |
+----------+-----+-----+-----+-----+
|   143    |  7  |  0  |  0  |  0  |
|   306    |  3  |  2  |  2  |  2  |
+----------+-----+-----+-----+-----+


Total iterations: 9416

Final Result
Z= 63507677
Remaining Risk= 90578466
Unfulfilled food demand= 513744
Average distance= 16
+----------+-----+-----+-----+-----+
| RAP\Area | 107 | 116 | 126 | 111 |
+----------+-----+-----+-----+-----+
|   143    |  0  |  5  |  0  |  2  |
|   306    |  2  |  5  |  2  |  0  |
+----------+-----+-----+-----+-----+
```

Figure 4.1(g): Computational representation of coding

4.1.4 Output of the Case Study Obtained from Model

After the problem formulation, the case was solved by the programming code and the following result has obtained;

Minimum Value of Objective function, Z= 63507677

Remaining Risk, TR-TRM= 90578466

Unfulfilled Food Demand, UFD= 513744

Table 4.8: Output of the sample problem

	A_1	A_2	A_3	A_4	Total
RAP_1	**0**	**5**	**0**	**2**	**7**
RAP_2	**2**	**5**	**2**	**0**	**9**

4.2 Result Analysis

a) Objective Function Value in Relation to the Total Risk Reimaging Factor and Unfulfilled Food Demand Factor

From the objective function value shown in Figure 4.2, it is observed that unfulfilled demand (UFD) factor and total risk remaining (TR- TRM) factor have linear relationship with the objective function values. Figure 4.2(a) shows that the value of objective function decreases with the increasing of unfulfilled demand factor which minimizes the objective function. On the other hand, from Figure 4.2(b) shows opposite phenomenon in considering F_R. However, both F_F, and F_R intersected at 0.45. These results interpreted that if the F_F increases objective function will be minimized and if the F_R increases objective function will be maximized and vice versa in constant distance.

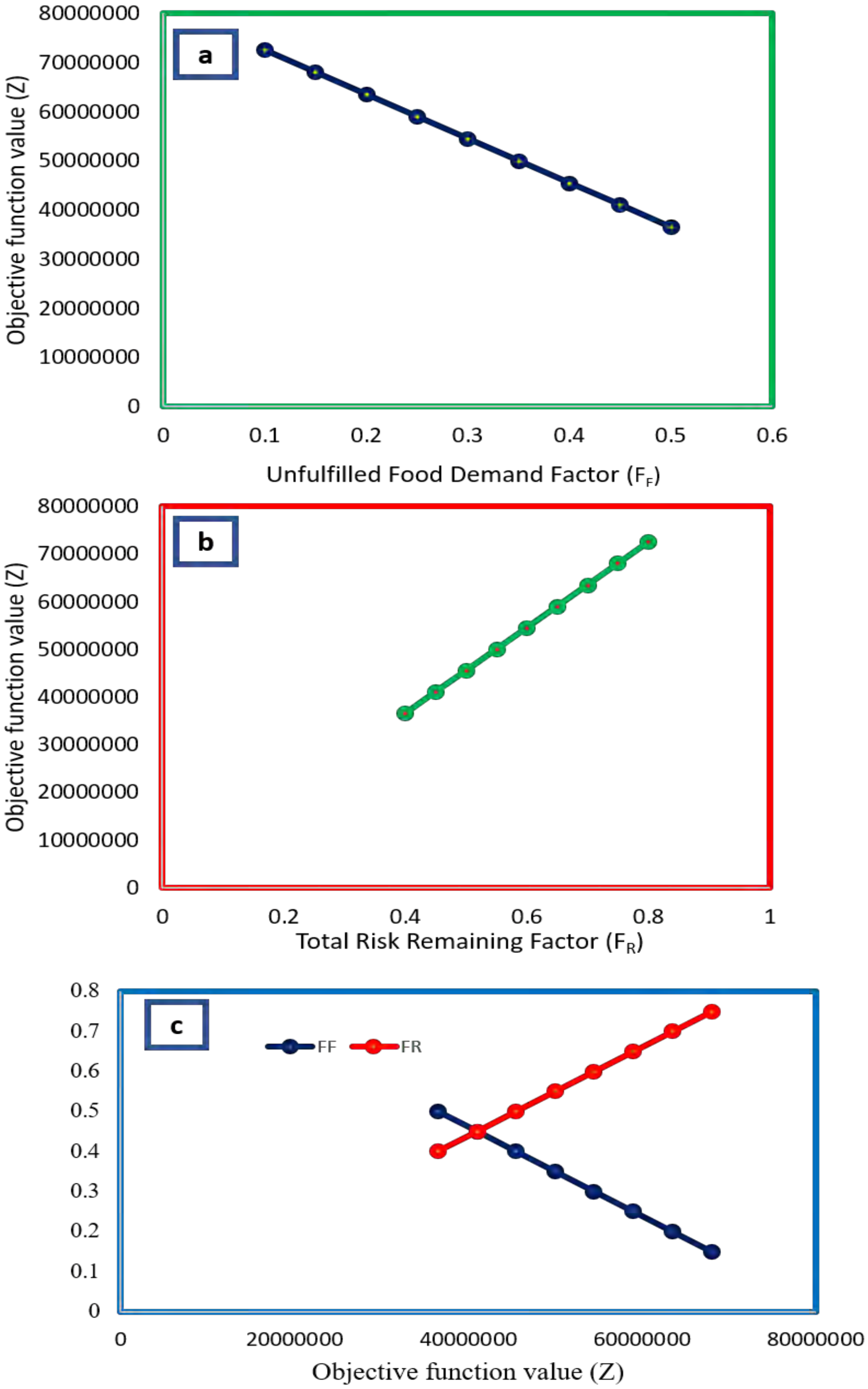

Figure 4.2: Objective function (Z) value in relation to the (a) unfulfilled food demand factor (F_F) (b) total risk remaining (F_R), (c) both the unfulfilled food demand and total risk remaining factor in constant distance

b) Objective function (Z) value in relation to the resource allocation point (RAP)

From the Figure 4.3(a), the results shows that variations of number of resource allocation points increases the objective function Z values minimize and both variations and equal distribution of teams shows that Z values and risk remaining value are minimum as shown in Figure 4.3(a) and (b). In comparison with RAP4 and RAP5 the Z and R value is less; this is due to less variations of number of teams. However, risk remaining values R are less as compared to Z values that shows resource teams have a great influence on decreasing R values [78, 79] and all interpreted results in comparison to RAP shown in Table 4.8. In addition, if the variations of team locations less the Z value are low as compared to higher variations, this is because of distance variations. If all the 16 teams are coming in same location, the Z value is less as shown in Figure 4.3 and Table 4.8 considering RAP 1.

Table 4.8: Z and R values of various resource allocation points (RAPs)

Number of resource allocation points	RAP Code	Number of teams	Z	R
1	143	16	63031692	89895916
2	143	7	63507677	90578466
	306	9		
3	143	5	62493747	89129852
	306	6		
	201	5		
4	143	4	62268955	88808578
	306	4		
	201	4		
	125	4		
5	143	4	63499104	89136791
	306	3		
	201	3		
	125	3		
	122	3		

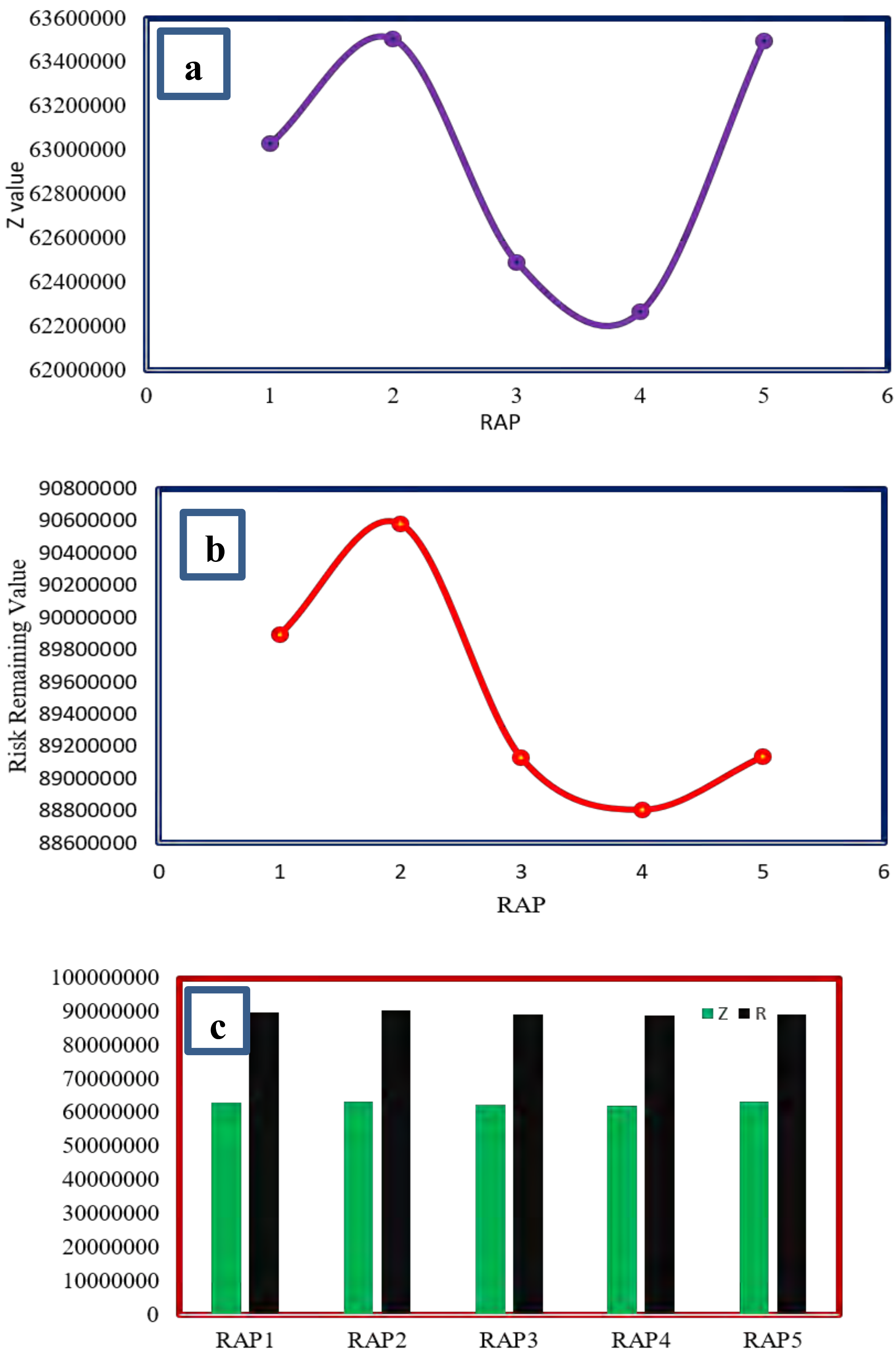

Figure 4.3: Objective function (Z) value in relation to the resource allocation point (RAP), (b) Risk remaining value (R) in relation to the RAP, (c) comparison of both Z and R values.

4.3 Limitations of the Model

- This model considers only three factors (risk mitigation, food demand, and distance) but other factors after an earthquake are not considered here.
- Emergency resource allocations (rescue team, medical support, and food supply) are mainly focused here while the vehicle routing model is absent in the model.
- Probability analysis in the domino effect and path availability index is not calculated directly in the model while the values are obtained by the experts.

Chapter 05

Conclusion and Recommendations

5.1 Conclusion

This study has considered a useful and practical emergency resource allocation problem which is very significant in emergency response to earthquake. During the earthquake, allocating emergency resources to coexistent incidents in a parallel mode is challenging and intractable. Based on the realistic emergency resource allocation and contribution, an emergency resource allocation model has been developed to minimize the risk factors for food, risk and distance. However, this study is seen as a primary step towards a more technically feasible pioneer for solving complex emergency resource allocation problems effectively and efficiently from the view of actual emergency needs, which might help the disaster management system and developers. The model was developed successfully and following conclusions have been made.

- The model shows that the value of objective function decreases with the increase of unfulfilled demand which minimizes the objective function and objective function is minimized while risk remaining factor also has less value.
- Risk remaining values are less as compared to objective function (Z) values that shows emergency resource teams have a great influence on decreasing risks remaining values which is the ultimate target of this study.
- For resource allocation point 4 (RAP4), minimum objective functions and risk remaining values were found which signify that equal distribution of resource

team from multiple points have great influence on minimizing objective functions and risk remaining values.

- The model has focused on both risk minimization and food supply to the affected areas, so multiple objectives are also fulfilled through the model. Both the operations; sending rescue teams and food supply are necessary for an earthquake affected area. This type of combined action can easily optimize risk and minimize the losses both physically and economically.
- In most of the cases, a primary incident of an accident or disaster can be converted into different types of secondary incident. Facing these secondary incidents, after a disaster, is very difficult work. In this model, domino effect concept is induced which might reduce the recurring chances of secondary incidents in the affected areas.

5.2 Recommendation for Future Work

- This model could not integrate with geographic information system maps. In future, this model could be integrated with GIS maps, thus, the emergency response teams can understand and visualize essential information for quick response to incidents.
- Most of the probabilities were obtained from the expert opinions. However, an equation-based probability calculation part can make the model more efficient.
- The air transportation mode for very emergency rescue operation can be added in the model which enriches the feasibility of the model.
- Types of vehicles and speed of vehicles can be added in the model which increases the strength of the model. A vehicle routing model will add more features in the emergency resource allocation model.

Reference

[1] Adeagbo, A., Daramola, A., Carim-Sanni, A., Akujobi, C. and Ukpong, C., 2016. Effects of natural disasters on social and economic well being: A study in Nigeria. *International journal of disaster risk reduction*, *17*, pp.1-12.

[2] Su, Zhaopin, Guofu Zhang, Yang Liu, Feng Yue, and Jianguo Jiang. "Multiple emergency resource allocation for concurrent incidents in natural disasters." *International journal of disaster risk reduction* 17 (2016): 199-212.

[3] Ghosh, S. and Gosavi, A., 2017. A semi-Markov model for post-earthquake emergency response in a smart city. Control Theory and Technology, 15(1), pp.13-25.

[4] Doocy, S., Daniels, A., Packer, C., Dick, A. and Kirsch, T.D., 2013. The human impact of earthquakes: a historical review of events 1980-2009 and systematic literature review. *PLoS currents*, *5*.

[5] Peña-Mora, Feniosky, Joyce K. Thomas, Mani Golparvar-Fard, and Zeeshan Aziz. "Supporting civil engineers during disaster response and recovery using a Segway mobile workstation Chariot." *Journal of computing in civil engineering* 26, no. 3 (2012): 448-455.

[6] Luscombe, R. and Kozan, E., 2016. Dynamic resource allocation to improve emergency department efficiency in real time. *European Journal of Operational Research*, *255*(2), pp.593-603.

[7] Meechang, Kunruthai, Natt Leelawat, Jing Tang, Akira Kodaka, and Chatpan Chintanapakdee. "The acceptance of using information technology for disaster risk management: A systematic review." *Engineering Journal* 24, no. 4 (2020): 111-132.

[8] Huang, Y., Fan, Y. and Cheu, R.L., 2007. Optimal allocation of multiple emergency service resources for protection of critical transportation infrastructure. *Transportation Research Record*, *2022*(1), pp.1-8.

[9] Wex, F., Schryen, G., Feuerriegel, S. and Neumann, D., 2014. Emergency response in natural disaster management: Allocation and scheduling of rescue units. *European Journal of Operational Research*, *235*(3), pp.697-708.

[10] Van Wassenhove, L.N., 2006. Humanitarian aid logistics: supply chain management in high gear. *Journal of the Operational research Society*, *57*(5), pp.475-489.

[11] Caunhye, A.M., Nie, X. and Pokharel, S., 2012. Optimization models in emergency logistics: A literature review. *Socio-economic planning sciences*, *46*(1), pp.4-13.

[12] Zolfaghari, Mohammad R., and Elnaz Peyghaleh. "Implementation of equity in resource allocation for regional earthquake risk mitigation using two-stage stochastic programming." *Risk analysis* 35, no. 3 (2015): 434-458

[13] Mostafizi, Alireza, Haizhong Wang, Dan Cox, Lori A. Cramer, and Shangjia Dong. "Agent-based tsunami evacuation modeling of unplanned network disruptions for evidence-driven resource allocation and retrofitting strategies." *Natural Hazards* 88, no. 3 (2017): 1347-1372.

[14] Nedjati, A., 2017. Humanitarian Logistics: Optimization Techniques for Emergency Preparedness and Post-Earthquake Response.

[15] Najafi, M., Eshghi, K. and Dullaert, W., 2013. A multi-objective robust optimization model for logistics planning in the earthquake response phase. *Transportation Research Part E: Logistics and Transportation Review*, *49*(1), pp.217-249.

[16] McEntire, D., 2012. Understanding and reducing vulnerability: from the approach of liabilities and capabilities. *Disaster Prevention and Management: An International Journal*.

[17] Sinha, D.K., 2007. *Natural disaster reduction: South East Asian realities, risk perception and global strategies*. Anthem press.

[18] Chang, M.S., Tseng, Y.L. and Chen, J.W., 2007. A scenario planning approach for the flood emergency logistics preparation problem under uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), pp.737-754.

[19] Luscombe, R. and Kozan, E., 2016. Dynamic resource allocation to improve emergency department efficiency in real time. *European Journal of Operational Research*, *255*(2), pp.593-603.

[20] Ninkovich, F., 1994. *Modernity and power: a history of the domino theory in the twentieth century*. University of Chicago Press.

[21] Assael, M.J. and Kakosimos, K.E., 2010. *Fires, explosions, and toxic gas dispersions: effects calculation and risk analysis*. CRC Press.

[22] Davidson, R., Nozick, L., Dodo, A. and Xu, N., 2005, June. Equity in regional earthquake mitigation investment. In *Symposium on Risk Modeling and Loss Reduction Strategies for Natural and Technological Hazards, Part of Ninth International Conference on Structural Safety and Reliability–ICOSSAR* (Vol. 5, pp. 19-23).

[23] https://www.kean.edu/csmart/observing/.20earthquake.php [last access on 10 Sep, 2019]

[24] Saldivar-Sali, A. and Einstein, H.H., 2007. A landslide risk rating system for Baguio, Philippines. *Engineering Geology*, *91*(2-4), pp.85-99.

[25] Ferreira, T.M., Maio, R. and Vicente, R., 2017. Analysis of the impact of large scale seismic retrofitting strategies through the application of a vulnerability-based approach on

traditional masonry buildings. *Earthquake Engineering and Engineering Vibration*, *16*(2), pp.329-348.

[26] Stevenson, J.R., Becker, J., Cradock-Henry, N., Johal, S., Johnston, D., Orchiston, C. and Seville, E., 2017. Economic and social reconnaissance. *Bulletin of the New Zealand Society for Earthquake Engineering*, *50*(2), pp.343-351.

[27] Alam, E., 2016. Earthquake and tsunami knowledge, risk perception and preparedness in the SE Bangladesh. *J. Geogr. Nat. Disast*, *6*, pp.1-7.

[28] Paul, B.K. and Bhuiyan, R.H., 2010. Urban earthquake hazard: perceived seismic risk and preparedness in Dhaka City, Bangladesh. *Disasters*, *34*(2), pp.337-359.

[29] Islam, R., Islam, M.N. and Islam, M.N., 2016. Earthquake risks in Bangladesh: causes, vulnerability, preparedness and strategies for mitigation. *Arpn J Earth Sci*, *5*(2), pp.75-90.

[30] Sultana, S., Rahman, U. and Saika, U., 2013. Earthquake Cause Susceptibility and Risk Mitigation in Bangladesh. *ARPN Journal of Earth Sciences*, *2*(2), pp.2006-2013.

[31] Roy, S., 2014. Probabilistic prediction for earthquake in Bangladesh: Just how big does the earthquake have to be next years?. *Open Journal of Earthquake Research*, *2014*.

[32] Chakravorti, B.K., Kundar, M., Moloy, D.J., Islam, J. and Faruque, S.B., 2015. Earthquake forecasting in Bangladesh and its surrounding regions. *European Scientific Journal*, *11*(18).

[33] Steckler, M.S., Akhter, S.H. and Seeber, L. 2008. Collision of the Ganges–Brahmaputra Delta with the Burma Arc: implications for earthquake hazard, *Earth and Planetary Science Letters*, *273*(3-4), pp.367-378.

[34] Sharfuddin, M., 2001. Earthquake hazard analysis for Bangladesh.

[35] Davidson, R., Villacis, C., Cardona, C. and Tucker, B., 2000. 'A project to study urban earthquake risk worldwide. In *Proc., 12th World Conf. on Earthquake Engrg*.

[36] Akhter, S.H., 2010. Earthquakes of dhaka. *Environment of Capital Dhaka—Plants wildlife gardens parks air water and earthquake. Asiatic Society of Bangladesh*, pp.401-426.

[37] Google, http://en.banglapedia.org/index.php?title=Earthquake [last access on 10 Sep, 2019].

[38] English, G., Campos, L.C. and Parkinson, J., 2017. Water market actors in Dhaka: strengthening earthquake resilience and preparedness.

[39] Kadri, F., Châtelet, E. and Chen, G., 2013. Method for quantitative assessment of the domino effect in industrial sites. *Process Safety and Environmental Protection*, *91*(6), pp.452-462.

[40] Cozzani, V. and Salzano, E., 2004. Threshold values for domino effects caused by blast wave interaction with process equipment. *Journal of Loss Prevention in the process industries*, *17*(6), pp.437-447.

[41] Khakzad, N., Khan, F., Amyotte, P. and Cozzani, V., 2013. Domino effect analysis using Bayesian networks. *Risk Analysis: An International Journal*, *33*(2), pp.292-306.

[42] Khan, F.I. and Abbasi, S.A., 1998. DOMIFFECT (DOMIno eFFECT): user-friendly software for domino effect analysis. *Environmental modelling & software*, *13*(2), pp.163-177.

[43] Cozzani, V., Gubinelli, G. and Salzano, E., 2006. Escalation thresholds in the assessment of domino accidental events. *Journal of hazardous materials*, *129*(1-3), pp.1-21.

[44] Cozzani, V. and Salzano, E., 2004. The quantitative assessment of domino effect caused by overpressure: Part II. Case studies. *Journal of hazardous materials*, *107*(3), pp.81-94.

[45] Kadri, F., Birregah, B. and Châtelet, E., 2014. The impact of natural disasters on critical infrastructures: A domino effect-based study. *Journal of Homeland Security and Emergency Management*, *11*(2), pp.217-241.

[46] Huang, K., Chen, G., Yang, Y. and Chen, P., 2020. An innovative quantitative analysis methodology for Natech events triggered by earthquakes in chemical tank farms. *Safety science*, *128*, p.104744.

[47] Chen, C., Reniers, G. and Zhang, L., 2018. An innovative methodology for quickly modeling the spatial-temporal evolution of domino accidents triggered by fire. *Journal of Loss Prevention in the Process Industries*, *54*, pp.312-324.

[48] Zeng, T., Chen, G., Yang, Y., Chen, P. and Reniers, G., 2020. Developing an advanced dynamic risk analysis method for fire-related domino effects. *Process Safety and Environmental Protection*, *134*, pp.149-160.

[49] Cozzani, V., Gubinelli, G., Antonioni, G., Spadoni, G. and Zanelli, S., 2005. The assessment of risk caused by domino effect in quantitative area risk analysis. *Journal of hazardous Materials*, *127*(1-3), pp.14-30.

[50] Wex, F., Schryen, G., Feuerriegel, S. and Neumann, D., 2014. Emergency response in natural disaster management: Allocation and scheduling of rescue units. *European Journal of Operational Research*, *235*(3), pp.697-708.

[51] Comfort, L.K., Ko, K. and Zagorecki, A., 2004. Coordination in rapidly evolving disaster response systems: The role of information. *American behavioral scientist*, *48*(3), pp.295-313.

[52] Altay, N. and Green III, W.G., 2006. OR/MS research in disaster operations management. *European journal of operational research*, *175*(1), pp.475-493.

[53] Gasparini, P., Manfredi, G. and Zschau, J., 2007. *Earthquake early warning systems*. Berlin: Springer.

[54] Ajami, S. and Fattahi, M., 2009. The role of earthquake information management systems (EIMSs) in reducing destruction. *Disaster Prevention and Management: An International Journal*.

[55] Ren, P., Xu, Z. and Gu, J., 2016. Assessments of the effectiveness of an earthquake emergency plan implementation with hesitant analytic hierarchy process. *International Journal of Information Technology & Decision Making*, *15*(06), pp.1367-1389.

[56] Sheu, J.B., 2014. Post-disaster relief–service centralized logistics distribution with survivor resilience maximization. *Transportation research part B: methodological*, *68*, pp.288-314.

[57] Yi, W. and Kumar, A., 2007.\ Ant colony optimization for disaster relief operations. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), pp.660-672.

[58] Bodaghi, B., Palaneeswaran, E. and Abbasi, B., 2018. Bi-objective multi-resource scheduling problem for emergency relief operations. *Production Planning & Control*, *29*(14), pp.1191-1206.

[59] Altay, N., 2013. Capability-based resource allocation for effective disaster response. *IMA Journal of Management Mathematics*, *24*(2), pp.253-266.

[60] Wang, Y. and Sun, B., 2018. A multiobjective allocation model for emergency resources that balance efficiency and fairness. *Mathematical Problems in Engineering*, *2018*.

[61] Ceferino, L., Mitrani-Reiser, J., Kiremidjian, A., Deierlein, G. and Bambarén, C., 2020. Effective plans for hospital system response to earthquake emergencies. *Nature communications*, *11*(1), pp.1-12.

[62] Huang, K., Jiang, Y., Yuan, Y. and Zhao, L., 2015. Modeling multiple humanitarian objectives in emergency response to large-scale disasters. *Transportation Research Part E: Logistics and Transportation Review*, *75*, pp.1-17.

[63] Wang, D., Qi, C. and Wang, H., 2014. Improving emergency response collaboration and resource allocation by task network mapping and analysis. *Safety science*, *70*, pp.9-18.

[64] Wang, S.S., Wang, Y. and Sun, J., 2007, August. An optimized emergency resources allocation algorithm for large-scale public emergency. In *2007 International Conference on Machine Learning and Cybernetics* (Vol. 1, pp. 119-123). IEEE.

[65] Boonmee, C., Arimura, M. and Asada, T., 2017. Facility location optimization model for emergency humanitarian logistics. *International Journal of Disaster Risk Reduction*, *24*, pp.485-498.

[66] Xu, W., Ma, Y., Zhao, X., Li, Y., Qin, L. and Du, J., 2018. A comparison of scenario-based hybrid bilevel and multi-objective location-allocation models for earthquake emergency shelters: a case study in the central area of Beijing, China. *International Journal of Geographical Information Science*, *32*(2), pp.236-256.

[67] Caunhye, A.M., Nie, X. and Pokharel, S., 2012. Optimization models in emergency logistics: A literature review. Socio-economic planning sciences, 46(1), pp.4-13.

[68] Zhang, C., Liu, X., Jiang, Y.P., Fan, B. and Song, X., 2016. A two-stage resource allocation model for lifeline systems quick response with vulnerability analysis. European Journal of Operational Research, 250(3), pp.855-864.

[69] Wang, D., Qi, C. and Wang, H., 2014. Improving emergency response collaboration and resource allocation by task network mapping and analysis. Safety science, 70, pp.9-18.

[70] Wex, F., Schryen, G., Feuerriegel, S. and Neumann, D., 2014. Emergency response in natural disaster management: Allocation and scheduling of rescue units. European Journal of Operational Research, 235(3), pp.697-708.

[71] Bharosa, N., Lee, J. and Janssen, M., 2010. Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises. Information Systems Frontiers, 12(1), pp.49-65.

[72] Lu, Y. and Xu, J., 2014. The progress of emergency response and rescue in China: a comparative analysis of Wenchuan and Lushan earthquakes. Natural hazards, 74(2), pp.421-444.

[73] Waugh Jr, W.L. and Streib, G., 2006. Collaboration and leadership for effective emergency management. Public administration review, 66, pp.131-140.

[74] Su, Z., Zhang, G., Liu, Y., Yue, F. and Jiang, J., 2016. Multiple emergency resource allocation for concurrent incidents in natural disasters. International journal of disaster risk reduction, 17, pp.199-212.

[75] Zheng, Y.J., Ling, H.F., Xu, X.L. and Chen, S.Y., 2015. Emergency scheduling of engineering rescue tasks in disaster relief operations and its application in China. International Transactions in Operational Research, 22(3), pp.503-518.

[76] Zheng, Y.J., Ling, H.F. and Xue, J.Y., 2014. Disaster rescue task scheduling: An evolutionary multiobjective optimization approach. IEEE Transactions on Emerging Topics in Computing, 6(2), pp.288-300.

[77] Papadimitriou, C.H., 1981. On the complexity of integer programming. Journal of the ACM (JACM), 28(4), pp.765-768.

[78] Yuan, Y., 2008. Impact of intensity and loss assessment following the great Wenchuan Earthquake. Earthquake Engineering and Engineering Vibration, 7(3), pp.247-254.

[79] Wang, J., Tepfenhart, W. and Rosca, D., 2009. Emergency response workflow resource requirements modeling and analysis. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 39(3), pp.270-283.

Appendix

The python programming code:

```
from prettytable import PrettyTable
import copy
from math import sin, cos, sqrt, atan2, radians


in_file = open("input.txt", "w")

def input_(str=None):
    if str is None:
        input()
        return
    inp = input(str)
    global in_file
    in_file.write(str+" : "+inp+"\n")
    return inp


# load no of paths
no_paths = dict()
paths_file = open("paths.txt").readlines()
for line in paths_file:
    line = line.replace("\n", "")
    c1, c2, n = line.split(" ")
    c1, c2, n = int(c1), int(c2), int(n)
    if c1 not in no_paths:
        no_paths[c1] = dict()
    no_paths[c1][c2] = n

# load area info from file
area_info_file = open("area_info.csv").readlines()[2:]
area_info = dict()
for line in area_info_file:
    line = line.replace("\n", "").split(",")
    area_info[int(line[2])] = (line[1], line[3], line[4], line[5],
float(line[6]), float(line[7]))

# input area codes
area_codes = []

for i in range(int(input_("Enter no of areas: "))):
    area_code = int(input_("Enter area code for A" + str(i + 1) + ":
"))
    if area_code not in area_info:
        print("Area code not found")
        input_()
        exit(0)
    area_codes.append(area_code)

# print areas
t = PrettyTable(["Area", "Population", "Severity"])
for c in area_codes:
    t.add_row([c, float(area_info[c][1]), float(area_info[c][3])])
print(t)
print()
```

```
# input incidents
incidents = []
for i in range(int(input_("Enter no of incidents: "))):
    incidents.append(input_("Enter Incident " + str(i + 1) + ": "))

# print incidents
base = float(input_("Enter base for weight factor: "))
t = PrettyTable(["Incident", "Weight Factor"])
for i in range(len(incidents)):
    t.add_row([incidents[i], base ** (i + 1)])
print(t)
print()


def find_incident(incident):
    for i in range(len(incidents)):
        if incidents[i] == incident:
            return i


# find states
q = [[]]
states = []
while True:
    if len(q) == 0:
        break
    head = q[0]
    q = q[1:]
    states.append(head)
    for i in incidents:
        if i not in head:
            next = copy.deepcopy(head)
            next.append(i)
            cont = False
            for j in range(len(next) - 1):
                if find_incident(next[j]) > find_incident(next[j +
1]):
                    cont = True
            if cont:
                continue
            q.append(next)


def state_str(state):
    if len(state) == 0:
        return "NULL"
    ret = ""
    first = True
    for j in state:
        if first:
            ret += j
            first = False
        else:
            ret += " + " + j
    return ret


def state_weight(state):
    global base
    w = 0.0
    for j in state:
```

```
        w += base ** (find_incident(j) + 1)
    return w


def superset(s1, s2):
    for i in s1:
        if i not in s2:
            return False
    if len(s2) == len(s1) + 1:
        return True
    return False


# print states
t = PrettyTable(["Sl", "State", "Weight Factor"])
t.align["State"] = "l"
for i in range(len(states)):
    state = states[i]
    w = state_weight(state)
    t.add_row([str(i + 1), state_str(state), str(w)])
print(t)
print()

# input possible movement probability
prob_memory =dict()
RX = dict()
possible_movements = dict()
for i in range(len(area_codes)):
    while True:
        print("A" + str(i + 1), "code : " + str(area_codes[i]))
        state = int(input_("Enter State: ")) - 1
        RX[area_codes[i]] = state_weight(states[state])
        if not 0 <= state < len(states):
            print("Invalid State")
            input_()
            exit(0)
        PM = []
        print("Possible movements: ")
        for s in range(len(states)):
            if superset(states[state], states[s]):
                print("(" + state_str(states[s]) + ")")
        print()
        if state in prob_memory:
            for s, prob in prob_memory[state]:
                PM.append((s, prob))
                print("Probability for movement : " +
state_str(states[s]) + " : "+str(prob))
        else:
            for s in range(len(states)):
                if superset(states[state], states[s]):
                    prob = float(input_("Enter probability for
movement : " + state_str(states[s]) + " : "))
                    PM.append((s, prob))
        s = 0.0
        for p in PM:
            s += p[1]
        possible_movements[area_codes[i]] = (PM, state)
        print()
        if s != 1:
            print("Probability sum must be 1")
            print()
```

```
        else:
            prob_memory[state] = PM
            break

# print possible movements
h = ["Area", "State"]
for i in range(len(states)):
    h.append(str(i + 1))
t = PrettyTable(h)
for area in area_codes:
    row = [str(area), possible_movements[area][1]+1]
    for i in range(len(states)):
        add = ""
        for move in possible_movements[area][0]:
            if move[0] == i:
                add += str(move[1])
        row.append(add)
    t.add_row(row)
print()
print("Probability of movements for states")
print(t)

risk = dict()
total_risk = 0.0
for area in area_codes:
    r = 0.0
    for move in possible_movements[area][0]:
        r += move[1] * state_weight(states[move[0]])
    r *= float(area_info[area][1]) * float(area_info[area][3])
    risk[area] = r
    total_risk += r
print()
print("Total Risk", total_risk)
t = PrettyTable(["Area", "Risk"])
for area in area_codes:
    t.add_row([area, risk[area]])
print(t)

# input RAP
print()
fullfilled_food_demand = 0
RAPS = []
for i in range(int(input_("Enter Number of Resource Allocation
Points: "))):
    area = int(input_("Enter Area code of RAP-" + str(i + 1) + ": "))
    if area not in area_info:
        print("Area code does not exist.")
        exit(0)
    n_teams = int(input_("Enter Number of teams in RAP-" + str(i + 1)
+ ": "))
    weight = int(input_("Enter Weight of teams in RAP-" + str(i + 1)
+ ": "))
    food = int(input_("Enter Food Capacity of teams in RAP-" + str(i
+ 1) + ": "))
    fullfilled_food_demand += n_teams * food
    RAPS.append((area, n_teams, weight, food))
print()

# print RAP
t = PrettyTable(["RAP", "Number of teams", "Weight", "Food
Capacity"])
```

```
for RAP in RAPS:
    t.add_row([RAP[0], RAP[1], RAP[2], RAP[3]])
print(t)
print()

# input percentage of population can be served
O = dict()
for area in area_codes:
    s = float(area_info[area][3])
    if 1 <= s <= 3:
        O[area] = 0.15
    elif 4 <= s <= 5:
        O[area] = 0.10
    elif 6 <= s <= 7:
        O[area] = 0.08
    else:
        O[area] = 0.05
    #O[area] = float(input_("Percentage of population can be served
in Area-" + str(area) + ": "))
print()

# input paths
paths = dict()
for RAP in RAPS:
    RAP = RAP[0]
    for area in area_codes:
        # for p in range(int(input_("Enter number of paths from RAP-"
+ str(RAP) + " to Area-" + str(area) + ": "))): # from file
        number_of_path = no_paths[int(RAP)][int(area)]
        print("Number of paths from RAP-" + str(RAP) + " to Area-" +
str(area) + ": " + str(number_of_path))
        for p in range(number_of_path):
            prob = float(input_("Enter Path Availability Index " +
str(RAP) + "-" + str(area) + "-" + str(p + 1) + ":"))
            if RAP not in paths:
                paths[RAP] = dict()
            if area not in paths[RAP]:
                paths[RAP][area] = []
            paths[RAP][area].append(prob)
    print()
print()

# print paths
h = ["Area"]
for RAP in RAPS:
    RAP = RAP[0]
    h.append("Number of path from RAP-" + str(RAP))
    h.append("Path availability index from RAP-" + str(RAP))
h.append("Percentage of population can be served in Area")
t = PrettyTable(h)
for area in area_codes:
    row = ["Area-" + str(area)]
    for RAP in RAPS:
        RAP = RAP[0]
        row.append(len(paths[RAP][area]))
        row.append(str(paths[RAP][area]))
    row.append(str(O[area]*100)+"%")
    t.add_row(row)
print(t)

total_food_demand = 0
```

```
for area in area_codes:
    s = int(area_info[area][3])
    p = float(area_info[area][1])
    if s <= 3:
        total_food_demand += p * 0.2
    elif s <= 5:
        total_food_demand += p * 0.4
    elif s <= 7:
        total_food_demand += p * 0.5
    elif s <= 9:
        total_food_demand += p * 0.8
    else:
        total_food_demand += p


unfullfilled_food_demand = total_food_demand - fullfilled_food_demand
if unfullfilled_food_demand < 0:
    unfullfilled_food_demand = 0

print("Total Food Demand:", total_food_demand)
print()

T = dict()
for RAP in RAPS:
    T[RAP[0]] = dict()
    for area in area_codes:
        T[RAP[0]][area] = float(area_info[area][1]) * RX[area] *
RAP[2] * O[area]


riskw, foodw, distw = 0, 0, 0
while True:
    riskw, foodw, distw = float(input_("Enter weight for risk: ")),
float(input_("Enter weight for food: ")), float(
    input_("Enter weight for dist: "))
    if not 0.999999999 <riskw + foodw + distw <1.000000001:
        print("Sum must be 1")
    else:
        break



areas = [area for area in area_codes]


def disti(a, remaining, pos, res):
    if pos == len(a):
        res.append(a)
        return
    if remaining == 0:
        res.append(a)
        return
    if pos == len(a) - 1:
        a[pos] = remaining
        disti(a, 0, pos + 1, res)
        return
    for i in range(remaining + 1):
        na = copy.deepcopy(a)
        na[pos] = i
        disti(na, remaining - i, pos + 1, res)
```

```
def dist(lat1, lon1, lat2, lon2):
    R = 6373.0

    lat1 = radians(lat1)
    lon1 = radians(lon1)
    lat2 = radians(lat2)
    lon2 = radians(lon2)

    dlon = lon2 - lon1
    dlat = lat2 - lat1

    a = sin(dlat / 2) ** 2 + cos(lat1) * cos(lat2) * sin(dlon / 2) **
2
    c = 2 * atan2(sqrt(a), sqrt(1 - a))

    distance = R * c
    return distance


comb = []
RAPS_ = []
for RAP in RAPS:
    t = RAP[1]
    RAP = RAP[0]
    RAPS_.append(RAP)
    res = []
    a = [0 for i in range(len(areas))]
    disti(a, t, 0, res)
    comb.append(res)

final = None
value = float("inf")
r_, f_, d_ = 0, 0, 0

fout = open("output.csv", "w")
for i in RAPS_:
    for j in areas:
        fout.write("RAP-" + str(i) + ",")
fout.write("\n")
for i in RAPS_:
    for j in areas:
        fout.write("Area-" + str(j) + ",")
fout.write("Z" + ",")
fout.write("Remaining Risk" + ",")
fout.write("Unfulfilled food demand" + ",")
fout.write("Average distance" + ",")
fout.write("\n")
fout.close()
fout = open("output.txt", "w")
fout.close()

iterations = 0


def print_res(fi, z, r, f, d):
    global iterations
    iterations += 1
    z = int(z)
    r = int(r)
    f = int(f)
```

```
    d = int(d)
    print("Z=", z)
    print("Remaining Risk=", r)
    print("Unfulfilled food demand=", f)
    print("Average distance=", d)
    global areas, RAPS_
    h = ["RAP\Area"]
    for area in areas:
        h.append(area)
    t = PrettyTable(h)
    fout = open("output.csv", "a")

    for i in range(len(RAPS_)):
        RAP = RAPS_[i]
        row = [str(RAP)]
        for j in range(len(areas)):
            row.append(fi[i][j])
            fout.write(str(fi[i][j]) + ",")
        t.add_row(row)
    fout.write(str(z) + ",")
    fout.write(str(r) + ",")
    fout.write(str(f) + ",")
    fout.write(str(d) + ",")
    fout.write("\n")
    fout.close()
    print(t)
    fout = open("output.txt", "a")
    fout.write("Z=" + str(round(z, 2)) + "\n")
    fout.write("Remaining Risk=" + str(r) + "\n")
    fout.write("Unfulfilled food demand=" + str(f) + "\n")
    fout.write("Average distance=" + str(d) + "\n")
    fout.write(str(t))
    fout.write("\n")
    fout.write("\n")
    fout.close()


min_team = int(input_("Enter minimum number of teams in an area: "))


def best(a):
    global final, value, min_team, total_risk, areas, RAPS_, T,
paths, unfullfilled_food_demand, distw, riskw, foodw, r_, f_, d_
    if len(a) == len(RAPS_):
        okay = True
        cou = [0 for i in range(len(areas))]
        for i in a:
            for j in range(len(areas)):
                cou[j] += i[j]
        for i in cou:
            if i < min_team:
                okay = False
        dist_, ps, minim = 0.0, 0, 0.0
        for i in range(len(RAPS_)):
            for j in range(len(areas)):
                pai = 0
                for k in paths[RAPS_[i]][areas[j]]:
                    pai += k
                minim += a[i][j] * T[RAPS_[i]][areas[j]] * pai *
int(100 / len(paths[RAPS_[i]][areas[j]]))/100
                if a[i][j] > 0:
```

```
                    ps += 1
                    dist_ += dist(area_info[RAPS_[i]][4],
area_info[RAPS_[i]][5], area_info[areas[j]][4],
                                  area_info[areas[j]][5])
        if ps > 0:
            dist_ /= ps

        unfullfilled_risk = total_risk - minim
        v = unfullfilled_risk * riskw + unfullfilled_food_demand *
foodw + dist_ * distw
        if okay:
            print_res(a, v, unfullfilled_risk,
unfullfilled_food_demand, dist_)
            print()

        if okay and v < value:
            final = a
            value = v
            r_ = unfullfilled_risk
            f_ = unfullfilled_food_demand
            d_ = dist_
        return
    pos = len(a)
    for i in comb[pos]:
        b = copy.deepcopy(a)
        b.append(i)
        best(b)


best([])

print()
print()
print("Total iterations:", iterations)
print()
print("Final Result")
fout = open("output.txt", "a")
fout.write("Final result\n")
fout.close()
fout = open("output.csv", "a")
fout.write("Final:\n")
fout.close()
print_res(final, value, r_, f_, d_)
print()
input_()
```