UNMANNED AERIAL VEHICLE ASSISTED EMERGENCY RESOURCE ALLOCATION IN DISASTERS

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Abstract

The fast response to a disaster is a key factor in rescuing victims who are trapped in the affected areas. The high amount of casualties as well as life and medical resource allocation cause the complexity of the disaster rescuing. This thesis concentrates on developing a multi-objective (MO) optimization model and adopts an algorithm named Probabilistic Solution Discovery Algorithm (PSDA) to generate a set of Pareto solutions on account of (i) the affected location, (ii) the amount of victims in the affected location, (iii) the amount of resource, including food, water and medicine, (iv) the location of the resource, (v) the deployment of UAVs. PSDA is used to solve the MO model, and each of the Pareto solutions is an emergency rescuing strategy.

The UAV flight path is another key point which leads UAV to cover every affected section efficiently without collision with obstacles, e.g. buildings, trees and telegraph poles on the path, and to deliver life resource and collect information of victims. This research proposes a path planning algorithm to make sure the distance of the planned path is minimum.

Five study cases are provided to validate the perspectives. The results of resource allocation are generated with the five aforementioned factors. As for path planning simulation, obstacles are generated randomly in a 200m*200m area with a start point and five destinations. The coordinates of the start point and the destinations are unchangeable. The planned paths are simulated by MATLAB.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning.

Signature of student

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Chapter 1

Introduction

1.1 Background

The quantity of natural disasters around the world has doubled over the past 30 years. Especially in the countries on Ring of Fire, such as Indonesia and New Zealand. Between 1998 - 2003, the disasters occurred in Indonesia are more than 640. The tsunami in Aceh in 2004 caused more than 230,000 victims. In 2007, the number of catastrophes happened in Indonesia reached 379, including 152 flooding, 57 landslides and 70 tornadoes. Research of the Epidemiology of Disasters stated that global natural disasters caused more than US$ 2.5 trillion economic losses from 1994 to 2013. The earthquakes happened in Haiti and other countries around it and the Indian Ocean Tsunami resulted in greater than 600,000 deaths, and millions more injured or homeless. The cyclone Nargis in 2008 hit the northern Indian Ocean and Myanmar. It led to 84,500 people killed, 53,800 people missing, and 37 towns devastated. The earthquake which occurred in Pakistan in 2005 killed 75,000 people and made 106,000 people injured. The severe damage is associated with poor constructions. The aid, rescue and relief efforts cost more than US$ 5.4 billion. In 2005, a fatal hurricane named Katrina attacked the Gulf Coast and led to US$ 81 billion economic losses. The earthquakes in New

Zealand also leads to victims and economic loss. From 2000 to 2009, the earthquakes listed with a magnitude of 6.0 or greater are more than 16. The famous Christchurch earthquake which happened in 2011 resulted in the population of Christchurch fallen by 9000 approximately. In addition, other natural disasters, for example, typhoon and earthquakes, make thousands even millions of people homeless or dead, and even billions economic loss. Therefore, disastrous rescue has become a worldwide problem.

When rescue is on an operation, the number of difficulties could be the obstacles for rescuing. During and after disasters, wire and wireless communication are intercepted, and traffic on road is also destroyed. The living conditions in the disastrous areas are abominable. Epidemic diseases spread which are caused by bacteria and virus generated from dead bodies of livestock and wild animals. People who become victims are not able to move out of the disastrous areas and they cannot connect to the areas outside of the disastrous areas, and even face to death due to the diseases and a shortage of food, water and medicine. Victims need aid, relief support, life resources and medical services.

Muaafa, Concho and Ramirez-Marquez (2014) claimed that most life resource deployment strategies are generated manually by professional people associated with their experience. Because disasters could attack anywhere at any time, the allocation of resources can be complicated due to difficult situation analysis. Furthermore, the current information could be inaccurate so that accomplishing rescue tasks are often hindered by unpredictable problems. In addition, the requirements and the situations of victims in areas attacked by disasters could change as time goes on. As a result, the final solutions might not be the best and need to be improved by using state-of-the-art models and solutions. Take disaster management in Kenya for example, ‘an adequate level of preparedness required to address its significant risk profile has not been achieved’ (Nabutola, 2012) because a unified policy framework of the government has not been formed so that the people in Kenya still suffer from natural disasters.

1.2 Motivation

The first technical challenge aims to provide medical help to victims who are trapped in the disasters and allocate resources, including living goods and medical stuff (Hadi, Varianto, Trilaksono & Budiyono, 2014) (Lin, Shah, Mauntel & Shah, 2018). The difficulties of the task include four aspects. 1. How to collect victims' information, for example, injured or not, if they are non-life-threatened. What do they need, food, water or medicine? What kind of medicine do they require? 2. The locations of the victims. Where are the victims exactly? Under the debris of buildings or in the spacious square. How to deploy life and medical resources? What locations are the best spots for allocating life and medical resource? 3. The path to the victims. How to select the shortest routes to reach victims efficiently. 4. How to make the total budget for supporting the rescuing minimum?

The objects of this research are to minimize total cost (TC, cost of emergency vehicles, water and food which are necessary for emergency medical rescue) and response time (RT, the total time it takes to deliver victims from disastrous sections to TEUs) (M. H. Muaafa, 2015) (M. Muaafa, Concho & Ramirez-Marquez, 2014). A model named Multiple-Objective (MO) Optimization will be used to facilitate the efficiency of emergency medical rescue strategies characterized by the selection of: (1) Temporary Emergency Unit (TEU) locations, (2) routes of emergency UAVs, and (3) amount of life resource to transport to each TEU. The MO model optimizes the combination of response time and total cost. An evolutionary algorithm named Probabilistic Solution Discovery Algorithm (PSDA) will be used to solve the multi-objective optimization model. The algorithm is used to generate multiple emergency medical response solutions – where each strategy represents a solution – and find an approximate set of Pareto optimal solutions. This method can help decision-makers to estimate the trade-offs using strategies with different response time and cost values.

Moreover, establishing a temporary wireless network for victims who are trapped by the disaster is another technical challenge. The network is designed to cover an affected area to provide wireless communication coverage for victims. It could ensure the bandwidth and quality of service (QoS) for text, call and video communication. These services, in the thesis, will depend on UAVs. Before UAVs departure, the optimal paths, which are based on optimal energy efficiency and optimal distance, need to be planned. Therefore, UAV path planning is another crucial problem.

Due to the various limited height which UAV is allowed to reach constrained by distinct laws in different countries, and UAVs are used to establish a temporary network by using the BSs carried on them, the height is also ruled in order to guarantee the quantity of wireless communication between mobile phones of victims and the BSs on UAVs. In addition, there will be a great number of destroyed buildings, poles in urban areas and trees in the suburb. They are probably on the path along which UAVs have to move. Therefore, the UAVs must avoid these obstacles while they are flying from an area to the other, even to multiple destinations. This will result in three problems which need to be optimized, e.g. flight path distance, time elapsed to complete the tasks and the energy consumption. Each problem is a single objective optimization problem. UAV has to bypass the obstacles on its way to other destinations. It will fly directly to another area if there is no obstacle. Hence, the whole path consists of the arc path and straight path. The path planning algorithm will be introduced to develop the optimal path from a start point to multiple destinations.

Planning UAV path (Bortoff, 2000) is the third challenge which is based on the start point, destination points and locations of obstacles. The goal is to set an optimal path, which bypasses every obstacle on the way in the shortest distance, from start point to multiple destinations. And also, the path will be planned to cover every destination in a disastrous area.

1.3 Contributions

Two major contributions are proposed to collect health information of victims and set UAV flying path in advance before allocating resource optimally based on the various situation.

Contribution 1. Resource allocation in disastrous area.

Before allocating a resource, the information of victims, e.g. number, location, amount of food, water and medicine is required. Mobile Edge Network (MEN), which is comprised of UAVs, is designed to support to collect the information. This contribution elaborates i) how to establish MEN and ii) how to allocate resource optimally based on the information collected by MEN.

i). UAVs play the role of nodes in MEN. Communication devices such as small cells or minor base stations on board of UAV are able to provide wireless coverage to victims who depend on MEN to communicate with medical servers outside of the affected areas. Furthermore, these Nodes can connect with other Nodes nearby illustrated in Figure 1.1.

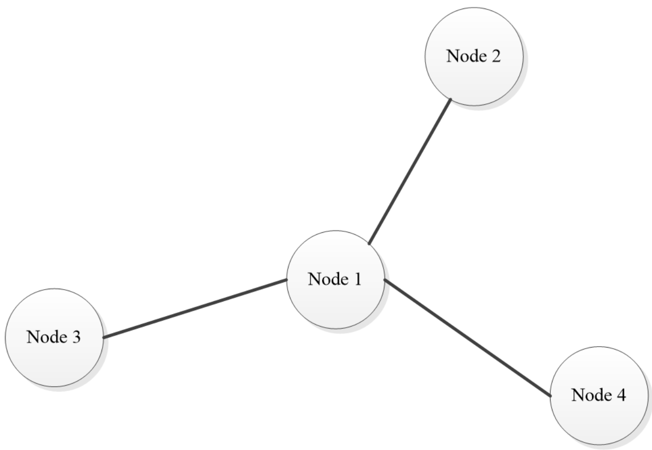

Figure 1.1: Node Topology

The whole MEN will be constructed by the topology shown in Figure 1.1. Data collected by UAVs can be sent to the servers which are deployed in the terminals in

MEN for processing, saving and re-transmission.

The superiorities of UAV are high mobility, including fast-moving, short response time, convenient deployment and be passable to the places where people cannot reach. MEN can provide wireless communication resource to victims. It also can offer information of victims to control centre or rescuing agencies to make rescue strategies.

ii). The collected information is a parameter which passes into Pareto algorithm. The algorithm is able to work out the optimal resource allocation solution, including total cost, response time and optimal amount and deployment of UAVs. This will be detailed in chapter three.

Contribution 2. Information collection path planning. This contribution will present a path planning algorithm to set optimal path which UAV move along to complete tasks as collecting information and delivering life resource. UAV paths need to be planned before they fly to destinations where victims are trapped. It is probably that one UAV has to move to multiple destinations from start point. And there could be obstacles such as buildings, telegraph poles on their flight paths. It is necessary to plan paths for UAVs to make them flying autonomously. Contribution 1 cannot be realized until UAV paths have been planned. This is the basis of contribution 1.

1.4 Thesis Structure

The thesis's structure is depicted in Figure 1.2. The remainder of this thesis contains an introduction of relevant background knowledge, followed by a description and comprehensive discussion of resource allocation and path planning algorithms. The extensive simulation study cases are then presented to validate and compare these two major algorithms. The chapters of the thesis are organized as follow:

Chapter 2 proposes a new research construct based on the existing literature studies. And then, it explains a background introduction of DeH. The two major research questions related to the technology of the resource allocation and the UAV path planning are introduced.

Chapter 3 presents how to create a temporary network with UAVs and collect information by using the network. Then the collected data are passed to the Pareto algorithm as parameters to give solutions which help to allocate the resource. In addition, an optimal path which bypasses obstacles is set to navigate UAVs to cover all the sections in the disastrous area to complete missions, e.g. collecting information of victims and delivering life resource.

Chapter 4 presents the extensive simulation studies and discussion on Perato algorithm and path planning algorithm. The simulation studies have confirmed that the Pareto algorithm can plan optimal solutions for resource allocation and has explained that the correlation of the two major factors, the total cost and the response time, in various disaster situation and deployment of UAVs. In addition, the amount and the location of TEU can also be worked out for optimizing the rescuing effect. Finally, UAV path planning has been simulated in MATLAB. The simulation has presented various path planning in distinct disastrous condition.

In Chapter 5, contribution and findings are concluded. In addition, some possible research directions to advance the algorithms are proposed in the future work.

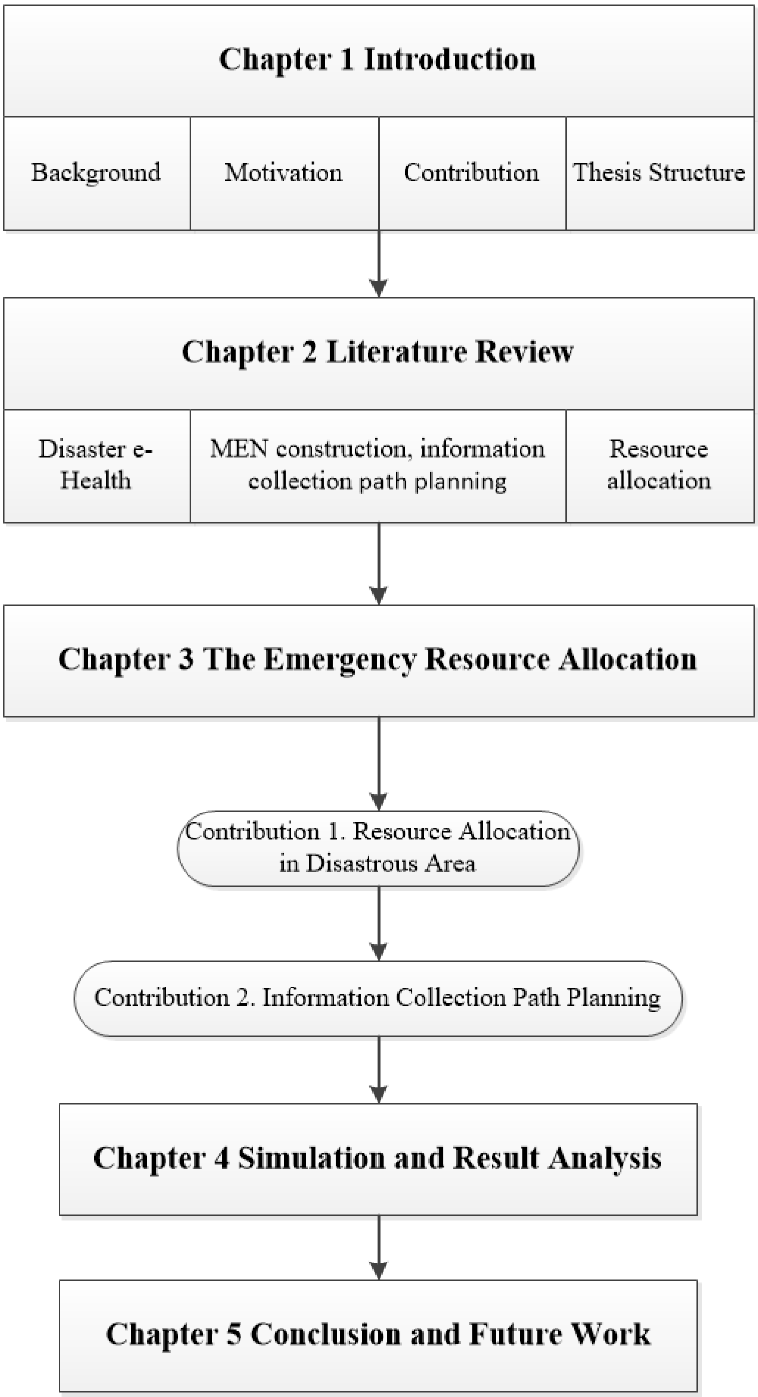

Figure 1.2: Thesis Construction

Chapter 2

Literature Review

2.1 Introduction

Disaster Electronic Health (DeH) is a new-born area of research and endeavour, including disaster management, disaster and emergency medicine. When a disaster happens, health professionals and emergency rescuers have the central roles in responding and providing disaster healthcare services to the victims, and the communication among these three groups is therefore crucial to ensure effective interventions and life-saving. While immediately after a disaster, the normal terrestrial infrastructure is often seriously compromised and cannot guarantee coverage and reliable communications services which become critical barriers to above disaster relief.

The UAV-assisted temporary network is used to provide wireless communication to collect the information of victims. The information contributes to health professionals and emergency rescuers to make strategies, and facilitates the inter-department coordination and cooperation to increase the efficiency of response and rescue as well.

On the other hand, life resource, including food, water, and medicine, is the key factor to maintain injured victims alive. However, damaged traffic and infrastructures on the ground cannot support resource transportation. Aerial transportation is proposed.

UAV is used to deliver the resource due to its aerial mobility, such as high movability, fast response, hovering, and vertical landing.

This research is motivated by the above challenges and it aims to study how to use a UAV assisted network to provide the important resource allocation needed for disaster eHealth applications. The key objective is to build a system prototype to validate the effectiveness and efficacy of the proposed solution.

The research area of this thesis consists of three areas. DeH, Resource Allocation, and Temporary Network & UAV Path Planning shown in Figure 2.1.

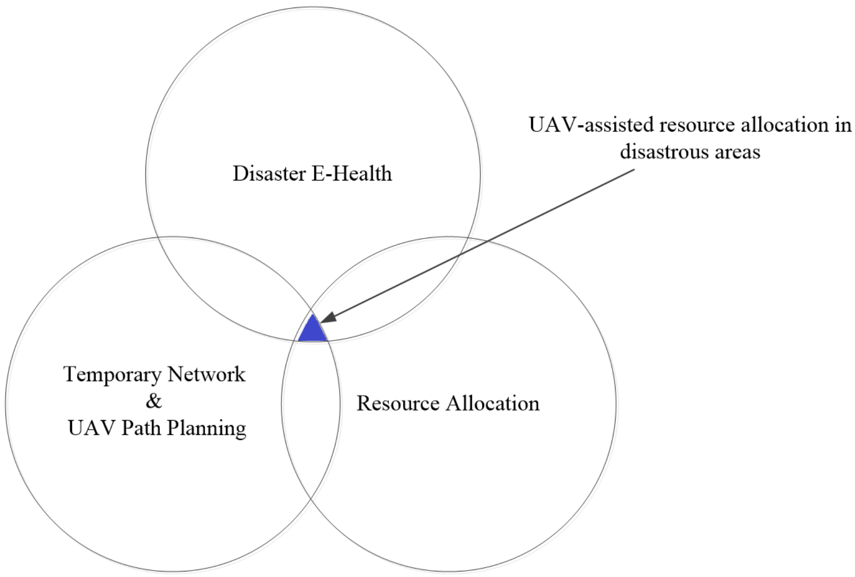

Figure 2.1: Research Area

The overlapped blue section is the research area of this thesis. The three areas were reviewed, and the overlapped area was found. The research was built on the overlapped area. The next part of this section is divided into three paragraphs to introduce the objective and the related references.

2.2 Disaster Electronic Health

Disaster eHealth is an emerging area of research and endeavour, including disaster management, disaster and emergency medicine (Norris et al., 2015). It provides available resources such as food, water and medical services. Traditionally eHealth systems have been considered to enable technologies for health care organisations, but the novel eHealth systems include therapeutic approaches – often based around mobile devices that are intended to assist with self-care or lifestyle modification (Parry, Madanian & Norris, 2016). The researchers also claimed that Disaster eHealth is a new area of research and endeavour. Disaster management and disaster medicine are both critical for allowing important information to be gathered and situational awareness in disastrous areas. In addition, how to manage healthcare services and medicine in a disastrous area are discussed.

The quantity of natural disasters around the world has doubled over the past 30 years (Organization, 2008), and the damage caused by the disasters is overwhelming. "Disasters are a growing global phenomenon". New Zealand often suffers natural disasters(Al-Shaqsi et al., 2013). "On Tuesday Feb 22, 2011, at 1251 h local time, a 6·3 magnitude earthquake struck Christchurch", "6659 people were injured and 182 died in the initial 24 h" (Ardagh et al., 2012). These disasters have resulted in the sustainable flexibility and necessity of DeH (Parry et al., 2016). Table 2.1 listed part of the references. They took some data about damage caused by real natural disasters for example. The disasters destroyed a great number of homes, killed hundreds of people and caused a serious economy loss. The examples illustrated the importance and necessity of DeH.

Due to the high mobility of UAVs, they could be used to assist disaster search and rescue, coverage of an area, constructing a temporary network, delivering goods, and implementing tasks day and night (Hayat, Yanmaz & Muzaffar, 2016)(Oettershagen et al., 2018). They also play an important role in monitoring real-time disaster, such as the flood in the desert (Abdelkader, Shaqura, Claudel & Gueaieb, 2013). In Table 2.1, the second reference has presented that the privacy information which is collected from the victims should be preserved, especially preserving data security and privacy during transmission (Sahi, Lai & Li, 2016). Another privacy-preserving mechanisms for enhancing the security and privacy of information from patients is proposed to meet privacy requirements in E-health (Pussewalage & Oleshchuk, 2016)(Narayan, Gagné & Safavi-Naini, 2010). In addition, the coordination between interagencies and organizations is the key point for reducing the problems of communication (Kapucu, 2006).

Table 2.1: References related with DeH

Authors	**Key Ideas and Findings**
(Norris et al., 2015)	A new paradigm that applies information and e-health technologies to improve disaster health planning and response before, during, and after a disaster is required to support disaster management, medicine and e-health technology.
(Abbas, Madanian & David, 2016)	A disaster is an event which is destructive or an ecological impact, and most of the time it cannot be managed within local health professionals or emergency managers. And the disaster could cause poor communication between the two groups. The research attempts to improve collaborative action between them.

(Webb & McEntrie, 2008)	This article provided an introduction of emergency management in New Zealand which is always suffered from a variety of natural disasters. It discussed that the laws and regulation have been formulated to enhance the emergency management to deal with the disasters in New Zealand.
(Van Den Berg, Van der Velden, Yzermans, Stellato & Grievink, 2006)	This paper researched the mental health of people who survived after a disaster, they had a different course of general health, physical role limitations, and mental health problems. It concluded that disaster affected the mental health of victims.
(Burkle Jr, 2001)	The article discussed that accurate and efficient information is important for emergency management. And it proposed Health Information Technology (HIT) standards to solve the challenge of integrating information from disparate healthcare resources in order to facilitate the interoperation among the departments included in search and rescue.
(Milutinovic & De Decker, 2013)	1.Dispatch centre and system tiers are proposed to deal with privacy-preserving data. Because all commercial parts of the system, such as the dispatch centre, are not able to see the data passing by. 2. These systems are not able to request any data stored in the base stations of patients. The base stations themselves impose access control and authenticate the requesting parties. 3. Caregiver access to patient data in order to request urgent caregiver's assistance.

(Parry, Madanian & Norris, 2018)	In order to take good care of injuries and take good care of potential diseases by using DeH appliances, and this article explains how to design the appliances and the considerations are proposed.

The crucial problem is the quality of wireless communication from the disastrous areas to interagencies and organizations. It is probably that the terrestrial communication infrastructures could be damaged by disasters. Therefore, it is necessary to make different departments in interagencies and organizations collaborate well. The architecture of satellite emergency communication is more available to enhance the communication among these agencies in the emergent events (Chronaki et al., 2008). In the rural and low-income areas of the developing world, such as Kenya, have established a management agency to deal with disasters (Bagula, Mandava & Bagula, 2018) (Nabutola, 2012).

Sutjiredjeki et al. (2009) claimed that in disastrous conditions, mobile telemedicine is considered as a novel approach to alleviate time and space barriers between rescue workers and the patients. In disastrous areas, medical tools might not reach the patients which are injured. Telemedicine service can connect rescue workers with hospitals via satellite, improving medical care greatly. The researchers take Indian Ocean's tsunami in 2004 for example, telemedicine was provided to save casualties along the coastal areas devastated by the disaster. It demonstrates the application of mobile telemedicine system which could be considered as the real application of eHealth. The system consists of mobile telemedicine kit, base unit and integrated health services. It comprises blood pressure, a heart rate monitor, ECG monitor, thermometer etc. The integrated health services can be used in rural areas and it also can monitor and also can be used on the system to record and report patients' healthy situation and data.

Abass et al. (2016) claimed that information technologies are used increasingly in disaster management, especially for communication and improving situational awareness. Rapid and accurate communication between the specialists is literally vital. Moreover, successful e-health implementations depend critically on information sharing and integrated workflow. Similarly, mobile communication between disaster victims and responders, which facilitates rapid information exchange. Interagency Communication in Disaster Healthcare concerns the critical communication between key agencies in a disaster, which are the emergency management and disaster medicine communities. Meaningful communication between the emergency management and disaster medicine sectors before, during, and after disasters can be improved by establishing a temporary network with UAVs. Each UAV can play as a mobile communication node in the temporary network in charge of creating, controlling and enhancing communication among medical personnel and victims in disastrous areas. However, creating an effective communication network for emergencies is a challenge, because it may conflict with the organizational structure developed during routine times. Most of the time, information in emergencies is complex. As summarised in Figure 2.2, disasters in one or more locations may break out simultaneously, and it would result in the increase of density of communication and uncertain events. Therefore, boundary spanners should develop and maintain effective partnerships with other sector organizations prior to emergencies to share information and resources in order to make an effective decision to provide better service to the public.

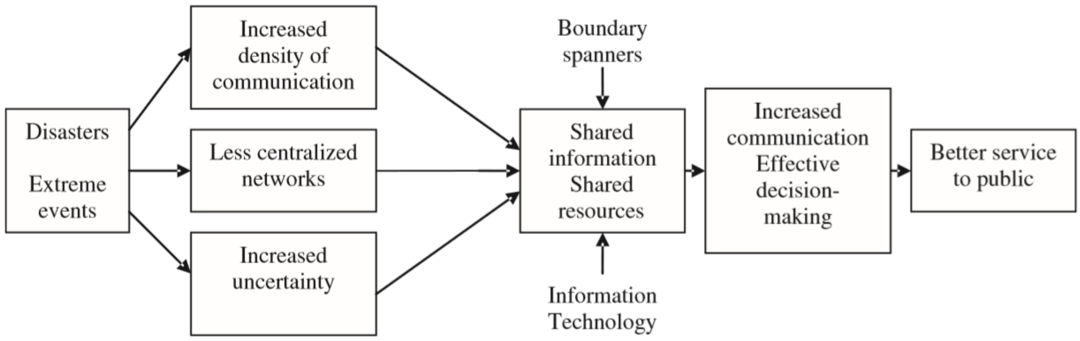

Figure 2.2: Interorganizational Communication and Coordination in Emergencies

Furthermore, Emergency agencies have to make rescue approach to meet the all-disaster requirement of victims facing limited time, budget and life resource (Parker, Barnett, Fews, Blodgett & Links, 2005). Because various organizations, and even universities have been focusing on establishing and developing competencies for health agencies to deal with post disasters and enhance medical services (Subbarao et al., 2008). Take the United States for example, "It is well known that the United States currently spends more per capita on health care than any other nation. Much of this expenditure, about $1.8 trillion, is spent on medical costs associated with chronic diseases such as diabetes, heart disease, and cancer" (James & Walsh, 2011). These emergency agencies focus on preparedness of resouce allcation and medical service before a disaster (Gowan, Sloan & Kirk, 2015), and after a disaster, household disaster preparedness for food, water, medicine and power supplied by batteries plays a significant role in rescuing and surviving (Strine, Neff & Crawford, 2013). Finally, it is necessary to deal with some special event. Actually, the disaster also causes mental health problems (Goldmann & Galea, 2014), for example, people exposed to Hurricane Katrina are suffered from mental disease (Galea et al., 2007). In this thesis, the technology of DeH will be introduced to rescue victims and mitigate the damage caused by disasters.

Chronaki et al. (2008) represented that satellite communication combined with local WiFi in disaster areas will make the efficiency of communication improve. It prompts the Satellites for Epidemiology (SAFE) architecture to ensure the efficiency and correction of communication from disaster area to hospitals and volunteer rescue workers. SAFE system provides emergency satellite-WiFi network infrastructure. SAFE system consists of a van equipped with DVB-RCS terminal and internet access for communication and satellite with which the van communicates with. The satellite can connect to other locations which are able to provide rescue stuff and workers such as hospitals and volunteer communities due to the destruction of communication in disastrous areas. The SAFE architecture can be summarised as below.

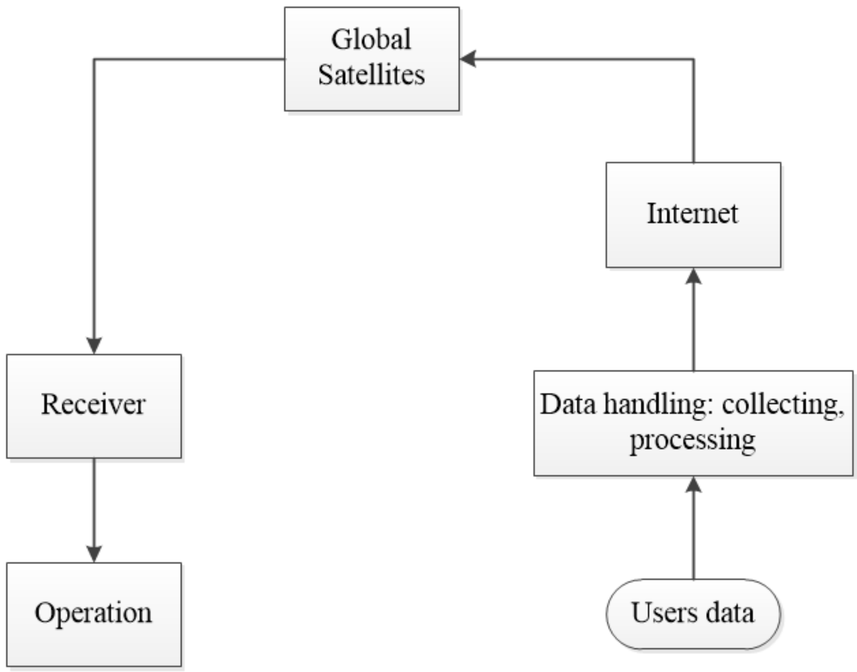

Figure 2.3: SAFE architecture

The architecture is divided into three components. Globalstar field, operation field, and data handling field. This constructure can be considered as remote medical operation. Network of expert centres is able to interoperate with other networks by communicating with satellites. Casualties data are collected by the networks, and sent to satellites after they are processed. The satellites are relays which are used to transmit the processed data to a remote receiver. In Figure 2.3, the receiver is coordination van in operation field.

As for data privacy and security, Milutinovic & De Decker (2013) noted that the requirements for elderly and injured people are growing. As eHealth systems manage personal and health-related data, protection of privacy is paramount. A novel eHealth system has been developed for protecting private data. In disastrous areas, there could be a large number of requirements. To the victims who need to be rescued and cured, their personal data should be private and stored securely.

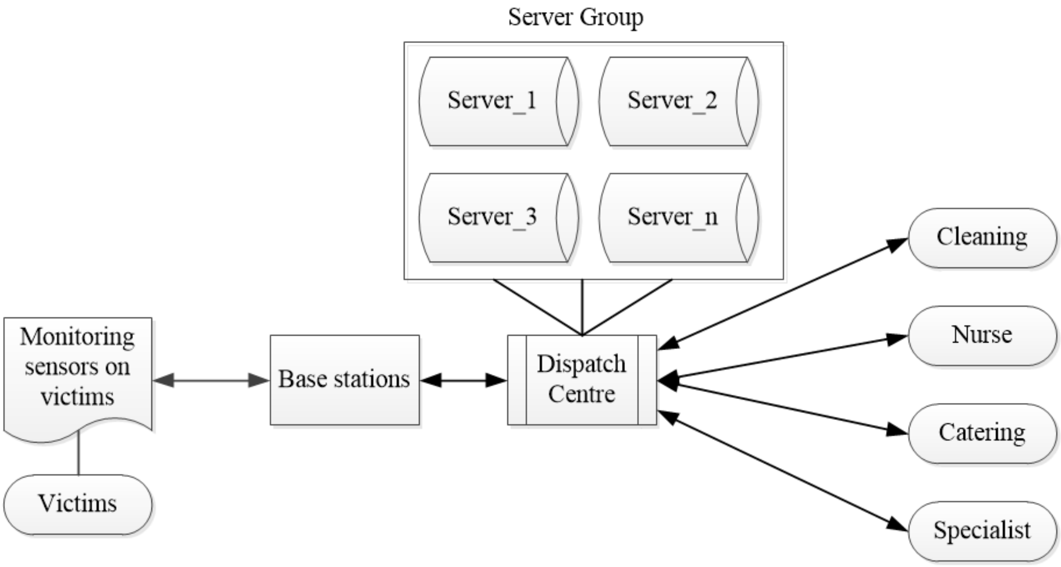

Figure 2.4: The global architecture of the privacy-preserving eHealth system

The global architecture of the privacy-preserving eHealth system is summarised in Figure 2.4. Dispatch centre receives a great amount of data from various kinds of uses, including patient, nurse, cleaner, catering service and specialist. In disastrous areas, victims are similar to the patient in the figure. The base station in the figure is replaced by UAV-assisted network.

Khan et al. (2014) demonstrated that the recent developments and deploy in remote healthcare systems. A secure cloud-based mobile healthcare framework using wireless body area networks (WBAN) is presented. It focuses on securing communicating and data saving and it comprises two aspects. First, it intends to secure the inter-sensor communication by using the key generation plan in WBAN. Second, the medical records are securely stored in the hospital community cloud to preserve patients' privacy data.

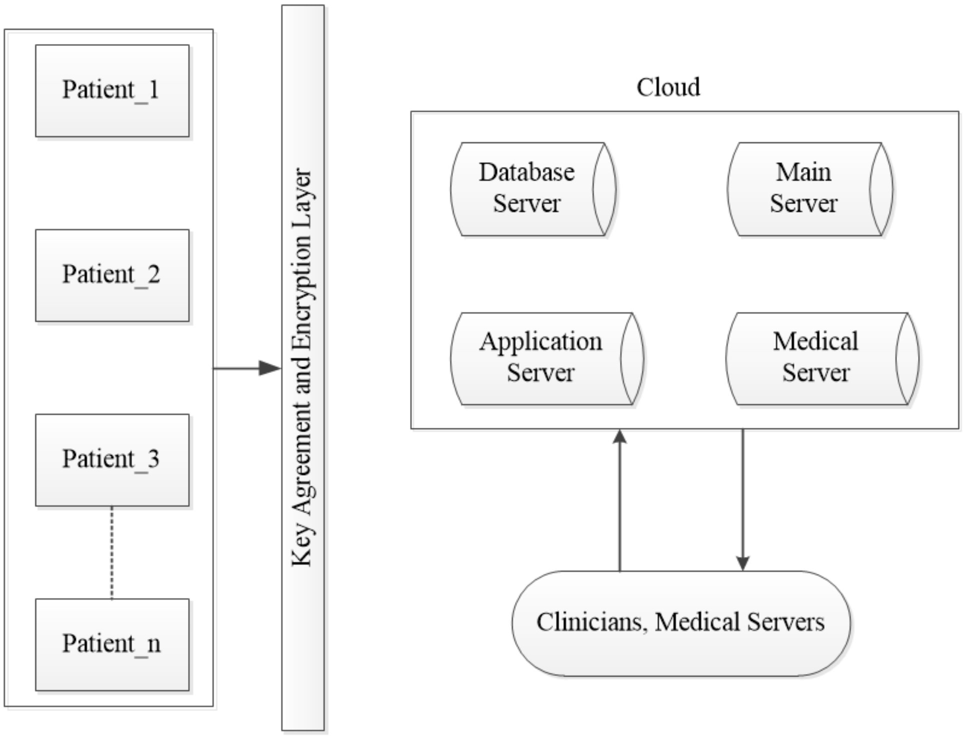

Figure 2.5: Cloud based healthcare system architecture

Figure 2.5 illustrates the architecture of a cloud-based healthcare system. Specified properties of patients are stored in the database. These data are gathered by area networks, e.g. PAN and WBAN. Information of each patient is stored in a personal server (PS), and merged in main server in hospital community could for clinicians. The idea enlightened the victims' information storage and process.

Masip-Bruin et al. (2016) represented how to improve the efficiency of data processing among disastrous area, hospitals and volunteer works in order to deal with problems as soon as possible. Fog could be the edge of the cloud, and it is much closer to the disastrous area. Hence, fog can detect, collect and process data at the first time, and relative workers such as doctors, nurses, rescue volunteers etc., can make decisions to cope with the situation immediately.

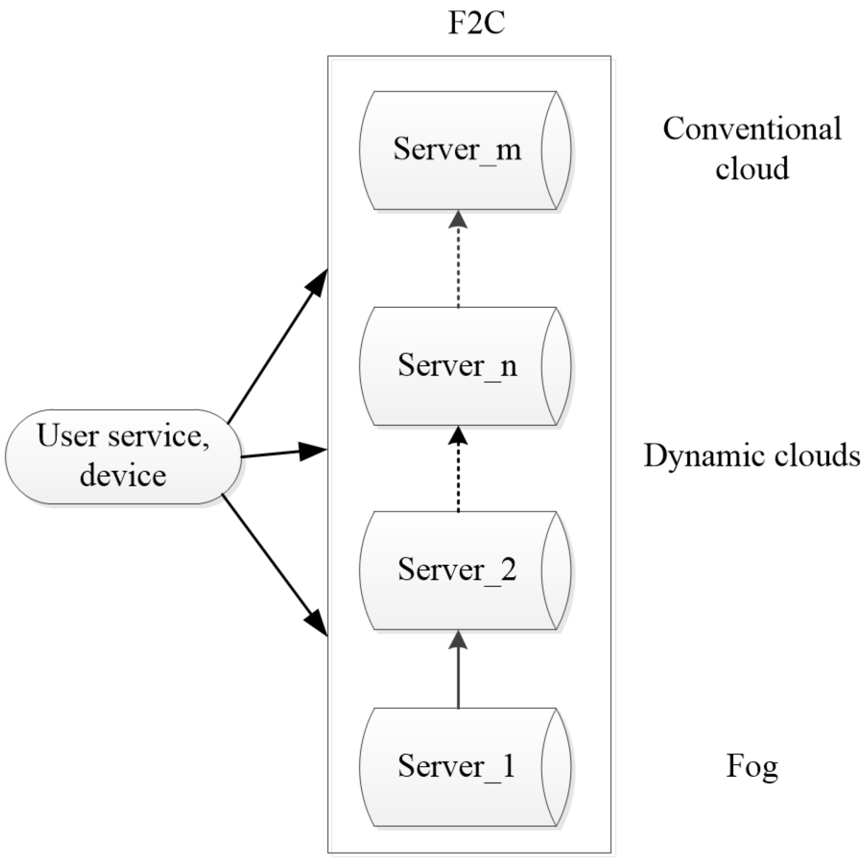

Figure 2.6: F2C Architectural Model

Figure 2.6 demonstrates the layers of a F2C architecture. Fog is at the edge of cloud. Users access to fog in the beginning. Fog is capable of providing algorithms to process users' requirements instead of the cloud. Hence, the efficiency of data process increases in fog.

2.3 Temporary Network & UAV Path Planning

UAV has spread out around the world, and played a role in civil application, e.g. fire detection and monitoring, especially in communication application after a disaster happens. Normally, terrestrial communication infrastructure, e.g. base stations and cables, are destroyed by disasters, such as earthquake, typhoon and tsunami. Power and communication are out of service in disastrous areas. Temporary network is required to guarantee affected people connecting with medical servers and emergency agencies out of the disastrous area.

Table 2.2 listed the references related to the fields which UAV takes part in, including search and rescue, UAV-assisted network, UAV path planning, navigation, collision avoidance, disaster monitoring and detection, and cargo delivering. These articles present methods to establish a temporary network and keep communication connection with the emergency rescue centre. The main purpose is to create an air-ground integrated mobile edge network with multi-UAVs which are similar to nodes in a wireless sensor network. The multi-UAVs in the edge network keep connecting with each other for collecting and transmitting data, and monitoring natural disaster as well. Computation performance and network latency are the two key points. Take the edge virtualized network functions for example, it focuses on minimising end-to-end latency. In addition, it is also important to plan multi-UAV flight paths to avoid a collision.

Table 2.2: References related with Temporary Network Construction and Path Planning

Authors	**Key Ideas**
(Shakhatreh et al., 2018)	This article proposed some challenges about deploying UAV, including charging challenges, swarming challenges, collision avoidance, networking and security-related challenges.

(Cziva, Anagnostopoulos & Pezaros, 2018)	For reducing end-to-end latency, the paper formulates that in order to minimise end-to-end latency from all users to their associated virtualized network functions (vNFs), the Edge vNF placement problem is formulated to allocate vNFs to a distributed edge infrastructure.
(Chmaj & Selvaraj, 2015)	This article focuses on data collection, navigation, path planning, collision avoidance, tracking, coordination with other UAVs, object detection, and fire detection and monitoring.
(Guimarães, Sakai, Alberti & de Souza, 2016)	Wireless nodes which are inside the coverage area are scheduled to connect to sink node to transmit data directly. UAVs can be considered as the nodes in mobile WSN, and each UAV is able to act as the node to deliver information to sink UAV.
(Cheng, Xu, Shi, Zhou & Shen, 2018)	The paper presents a novel air-ground integrated mobile edge network (AGMEN) which can address the network issues, such as communication, caching, and computing of the edge network. UAVs can also be deployed flexibly in AGMEN.

(Fouad et al., 2017)	Quadrotor UAV is a kind of multi-engine drone which has four rotors. Each rotor consumes energy provided by battery on board UAV to keep flying guesture, for example, flying forward and backward, swinging, hovering and rotating.
(Erdelj, Król & Natalizio, 2017)	This article focused on the joint situation that WSN and UAV can play a cooperated role in disaster management, including early warning systems which are capable of monitoring and forecast. The applications of multi-UAV are disaster information collection and sharing, temporary communication system, search and rescue missions.
(Nikouei et al., 2018a)	The article presented that edge computing is used to address the challenges in many delay-sensitive applications, and helps to reduce network latency.

After the data are collected by UAV-assisted network, and then transmitted to clinicians via the cloud for monitoring patients health condition, measuring the physiological values of the body. Connecting WBANs (wireless body area networks) to the cloud will increase scalability, and overall performance of the system by sharing resources with a large number of devices in the cloud. The goal of this work is to develop a generic, reliable, easily deployable, and secure ubiquitous architecture for a cloud-based UAV (Khan, Ali, Abbas & Haldar, 2014). However, it is likely that the latency of cloud-based network could not meet the demand in emergency events. To decrease delayed properties, e.g. shipping time ("the time it takes the UAV to move into a suitable position"), data transmission time and deal with delayed data transmission (Asadpour, Giustiniano, Hummel, Heimlicher & Egli, 2013), edge network provides edge computing to shrink the information analysis time (Nikouei et al., 2018a) (Nikouei et al., 2018b).

In this project, the objects are establishing a wireless temporary network named Mobile Edge Network (MEN) and planning UAV path which is designed as a flexible network with UAVs (Singh & de Silva, 2018) (Zeng, Zhang & Lim, 2016). In Indonesia, the temporary network is constructed by balloons which take communication devices in the air and establish a wireless connection with a ground station to provide communication coverage (Qiantori, Sutiono, Hariyanto, Suwa & Ohta, 2012) (Yanmaz, Hayat, Scherer & Bettstetter, 2014). In this thesis, the temporary network is constructed by multi-UAV which enable wireless communication network consists of small base stations on board UAVs to serve users on ground (Wu, Zeng & Zhang, 2018). The coverage will get smaller while UAVs get higher altitude (Waharte, Trigoni & Julier, 2009). During the search and rescue, complex terrains consist of mountains, rivers, valleys and debris which are not passable have to be considered. In some special scenarios, traditional terrestrial infrastructure deployment is not effective or feasible (Sun, Xu, Ng, Dai & Schober, 2018). Multi-UAVs are able to fly to these locations to operate various application, such as delivering resource, collecting information of victims, supervising and monitoring the density of victims in affected area (Olsson, Kvarnström, Doherty, Burdakov & Holmberg, 2010) (A. Trotta, Andreagiovanni, Di Felice, Natalizio & Chowdhury, 2018), and even creating a temporary network over the unpassable areas (Bürkle, Segor & Kollmann, 2011). As nodes in wireless sensor network (WSN) and Ad-Hoc network (Bekmezci, Sahingoz & Temel, 2013) (Gupta, Jain & Vaszkun, 2016), multi-UAVs can be considered as the nodes in MEN gathering and transmitting data (Araghizadeh, Teymoori, Yazdani & Safari, 2016) (Masip-Bruin, Marín-Tordera, Alonso & Garcia, 2016) (Aliyu, Chizari & Abdullah, 2013) and act as relay nodes to support wireless communication (Fan, Cui, Jin, Yang & An, 2018). The communication among UAVs depends on the minor base stations on board of UAVs. For example, if UAVs are equipped with minor 5G base stations, the 5G network could be created (Chiaraviglio et al., 2018). On the other hand, providing emergency voice channel to victims is also important, because victims are able to offer more information via emergency call (Reynaud, Rasheed & Kandeepan, 2011) (Deaton, 2018).

Path planning and energy consumption are two key points. How to select an appropriate path from deployment location to the destination? Anytime Algorithms calculate path segments between the start point and final destination to avoid obstacles in 3D space (Sujit & Beard, 2009). Another method presented that sensors fixed on UAVs could be considered in future work to avoid obstacles in 3D coordination. The method is likely to be used for flying over a group of obstacles (Deming & Perlovsky, 2007). The path planning algorithm has been proposed in this thesis for UAV flying stealthy through obstacles to a destination based on two algorithms. One is a two-step path-planning algorithm (Bortoff, 2000) and the other is path-planning based on Bezier Curves (Ingersoll, Ingersoll, DeFranco & Ning, 2016). As for energy consumption, all the actions of UAV including moving (direct flying, circling, ascending and descending) and hovering consume energy in each time slot (Amorosi, Chiaraviglio, D'Andreagiovanni & Blefari-Melazzi, 2018). Each action consumes a different amount of energy. Therefore, the energy consumption varies based on distinct missions (Jiménez, Chiaraviglio, Amorosi & Blefari-Melazzi, 2018), and locations where UAV implement tasks. For example, in cities, UAV has to avoid various tall and dense buildings in case of collision, and in a rural area, in general, such environmental hazards are not as serious as them in city. It is not necessary for UAV to consume more energy to avoid the obstacles (Waharte & Trigoni, 2010). The flight endurance of UAV can be extended by installing solar panels, and these panels are able to provide small stations on board of UAV (Zhang, Meo, Gerboni & Marsan, 2017) (Sun, Ng, Xu, Dai & Schober, 2018). When multi-UAVs are deployed, recharging is a big problem . It depends on the selection of recharging spot and the distribution of UAVs (Trotta, Felice, Montori, Chowdhury & Bononi, 2018).

The 5G networks are required to provide much faster data transmission and to support emerging use-cases related to the Internet of Things (IoT), Device-to-Device (D2D) Communications and Broadcast-like services which are revolutionizing non-disaster communications. These innovations could be applied to disaster situations where their systematic use can save lives, accelerate recovery and create a resilient society. A UAV-assisted mobile edge network infrastructure has been proposed (Narang et al., 2017), of which the UAVs can host micro Base Stations (BSs) and edge computing resources so as to dynamically move over the zones where the terrestrial mobile network is not properly working. The numerical results have confirmed that the UAV-based mobile edge architecture can guarantee good coverage to users, even if the number of traditional BSs that are not working correctly is large.

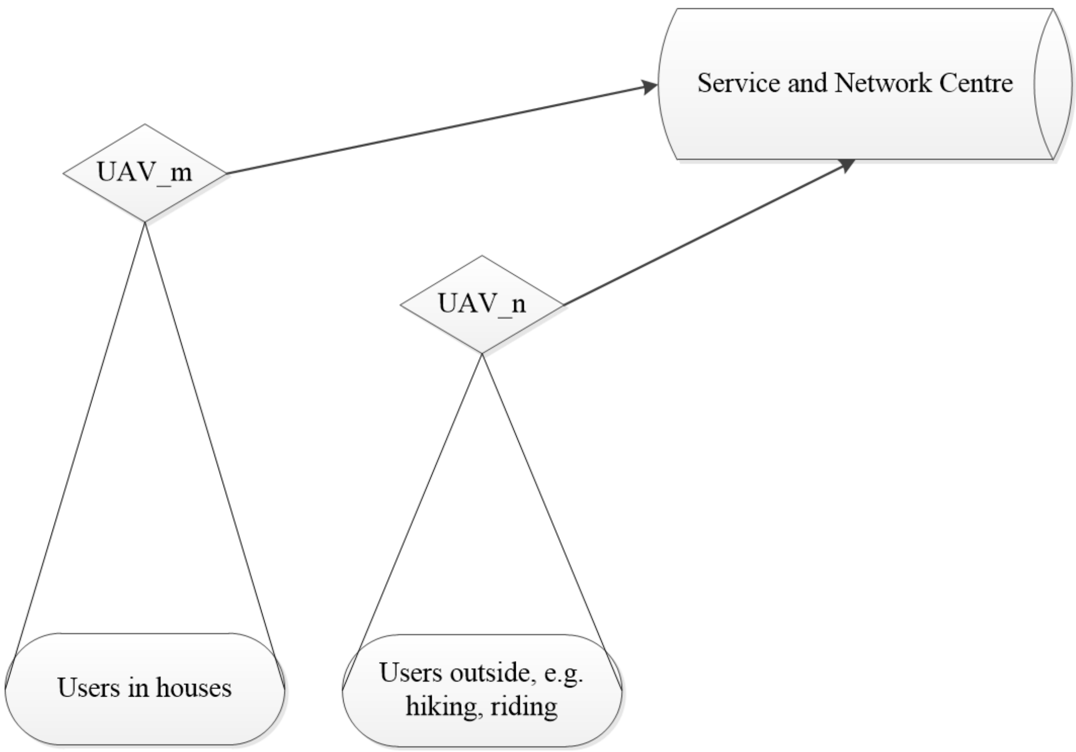

Figure 2.7: UAV-Assisted Edge Infrastructure (Narang et al., 2017)

Figure 2.7 summarises a UAV-assisted temporary network architecture. In the triangular zone, UAVs with small cells on board play a role of an aerial minor base station in charge of providing wireless communication coverage to terrestrial users. No matter base station on the ground is damaged or not, the people who are trapped by a disaster are capable of accessing to the network to report their real-time situation, and even calling for rescue.

The boom of mobile data traffic forces network operators to deal with the capacity shortage is presented (De Pellegrini, Massaro, Goratti & El-Azouzi, 2017). The deployment of mobile phones or data cells in 5G networks shall increase radio access capacity. Mobile edge computing (MEC) technologies can be used to manage dedicated cache memory at the edge of mobile networks. MEC is a kind of network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network. The basic idea behind MEC is that by running applications and performing related processing tasks closer to the cellular customer, network congestion is reduced and applications perform better. MEC technology is designed to be implemented at the cellular base stations, and enables flexible and rapid deployment of new applications and services for customers. Combining elements of information technology and telecommunications networking. MEC also allows cellular operators to open their radio access network (RAN) to authorized third-parties, such as application developers and content providers.

2.4 Resource Allocation

UAV powered by batteries on board (Lee, 2017) is a good vehicle to deliver cargos, especially in the disastrous area or some places where people and terrestrial vehicles cannot arrive (Park, Kim & Suh, 2018). Distinct types of drones, such as fixed-wing, quadrotor, have different loading capacity (Vergouw, Nagel, Bondt & Custers, 2016).

Table 2.3: Different UAV used for the delivery of cargo (O'Driscoll, 2017)

	Fixed wing	**Multi-rotor**
Range	About 20 km	About 80 km
Payload	Up to 5 kg	Up to 2 kg
Launch	Catapult	Vertical
Variations	Gas or electric	Gas or electric
Advantages	• Long range & More efficient • Heavier payloads than multi-rotor • More stable flying • Well established concept with the weight of aerospace engineering behind it	• Maneuverability in small spaces • Vertical takeoff and landing • Generally cheaper • Can fly with
Disadvantages	• Large space required for take-off and landing (no VTOL) • Limited maneuverability in small spaces • General emergency landings	• Payload and range limit • Generally more complex designs requiring expert maintenance and trained staff at health centers

For example, UAV named *The RQ-11 air vehicle* is able to carry 4.4 lb payload (Carey, 2014). Helicopters are able to deliver goods to these special locations, however it will cost much more expensive. Compared with helicopters, UAV is relatively smaller and more flexible. Nowadays, UAVs have been used to deliver food. For example, delivering Tacos (Gilbert, 2012). In this research, the main purpose is to discuss delivering life resource, e.g. food, water and medical stuff (Lin et al., 2018) (Faust, Palunko, Cruz, Fierro & Tapia, 2017) to people who are trapped in affected areas by

UAV after disasters. Due to the complex terrestrial situation, UAV which is capable of vertical takeoff and landing (Jo & Kwon, 2017) is more applicable. UAV can be developed to complete dropping goods missions (Hadi et al., 2014), and even the weight of payload and flight distance of UAV can be enhanced (Chipade, Abhishek, Kothari & Chaudhari, 2018) to evacuate victims from disastrous area to medical service centres and delivering cargos from supply centres (Ozdamar & Yi, 2008).

Table 2.4 listed the papers to prove that UAV is capable of delivering cargos. Due to the delivery capability, UAV can be utilized to deliver goods and life resource, e.g. food, water and medicine to victims who are trapped in disastrous areas.It is necessary for disaster management to consider how to allocate life resource before and during an emergency affected by natural hazards (Minciardi, Sacile & Trasforini, 2009).

Table 2.4: References related with Resource Allocation

Authors	**Key Ideas**
(M. H. Muaafa, 2015)	The algorithm of calculation of resource allocation the code has been presented by the author different results depend on distinct imput parameters.
(Cox, Nagy, Skoog, Somers & Warner, 2004)	The article listed some kinds of UAV capable of delivering. Aerosonde: a payload weight ranging from 4.5 to 11 lb (2 to 5 kg) depending on the desired endurance; Altair: 660 lbs (300 kg) internally and up to 3000 lbs (1361 kg) on external wing stations; Yamaha RMAX: a payload of about 65 lbs (30 kg), a flight time of about 90 minutes, and range of about 5.5 nm (10 km).

(Clarke, 2014)	The article made an indication of the more likely candidate applications is provided by a long-stading use of drones. It also gave some detailed example, e.g. in Japan, where, through 1990s, over 1000 aerial devices weighing 50-60 kg and with a payload of 20-30 kg, were used for crop-spraying.
(Song, Park & Kim, 2018)	When UAVs are used in logistics system, limited flight time, limited loadable products and delivery efficiency need to be addressed by the algorithem MILP (Mixed Integer Linear Programming)
(Lambert & Patterson, 2002)	Disaster preparedness should be considered by transportation agency. response time, cost, efficiency and recovery actions also should be considered by post-disaster management.
(Wex, Schryen, Feuerriegel & Neumann, 2014)	Earthquakes, tsunamis and hurricanes cause tremendous harm every year, rescue units must be allocated and distrbuted as soon as possible and disastrous management has to implement efficiently.

(Yang, San & Chang, 2016)	When UAV is flying, ground station or control center manage or track the path along which UAV is moving along in order to moniter real time status of UAV.

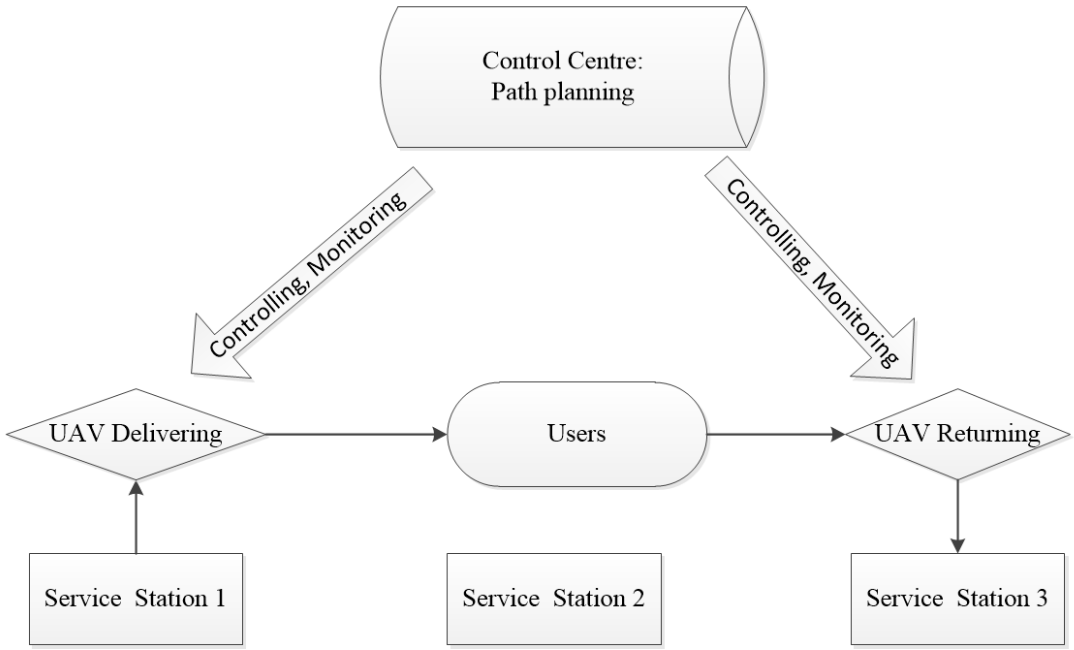

Figure 2.8: UAV Logistics System

Figure 2.8 displays a UAV logistics system. UAV is controlled remotely by a control centre to carry cargos from a service station to a specified person and then returns to another service station. In complex situations, multi-UAVs are required to complete multi-tasks.

If a large-scale disaster happens, it will cause overwhelming resource demand. This is critical to allocate resource rationally (Arora, Raghu & Vinze, 2010). Distributing and delivering multiple life resources efficiently is another important factor for rescuing victims in disastrous area (Su, Zhang, Liu, Yue & Jiang, 2016).

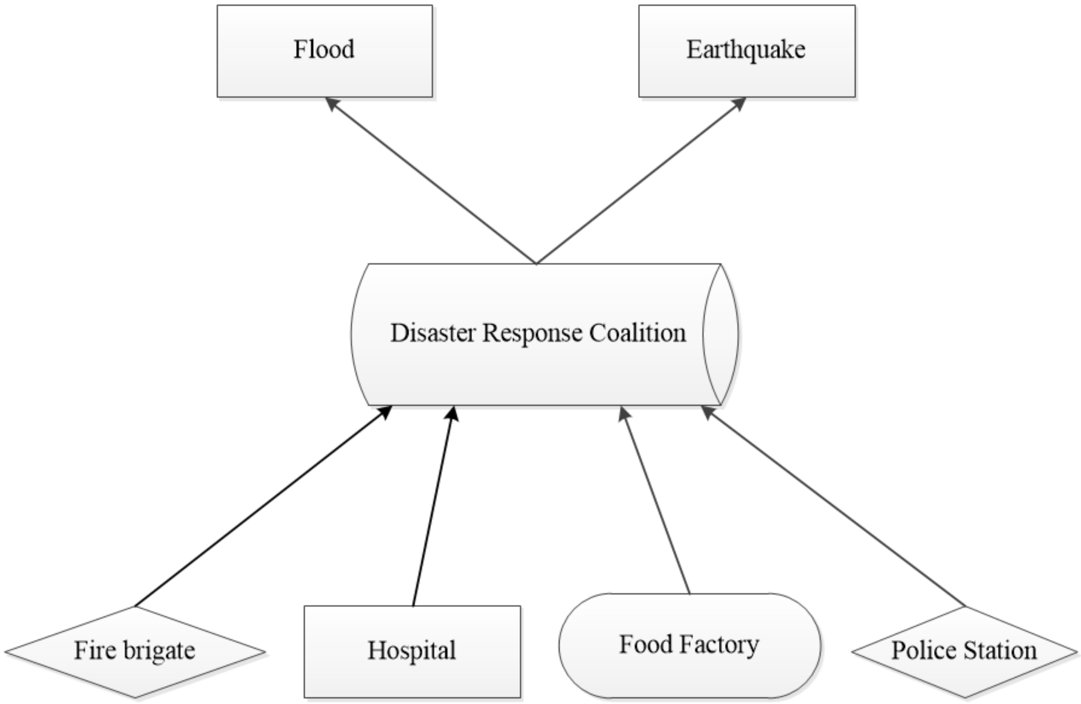

Figure 2.9: Disaster Response Coalition (DRC)

Figure 2.9 demonstrates the coordination of a set of rescue agencies. All departments in the DRC collaborate to respond to emergency events in a disaster.

At present, how to allocate resource in a disastrous area effectively and efficiently has been improved (M. Muaafa et al., 2014) (Chacko, Rees & Zobel, 2014). In general, emergency resource storage which consists of multi-objective cargos is complicated and the resource is necessary for emergency management to implement rescue action smoothly (Wang, Yang & Zhu, 2012) (Liu & Zhao, 2007). Optimal assignment of a resource to affected areas (Fiedrich, Gehbauer & Rickers, 2000) is also required. High efficiency and reliability response emergent management system helps decision makers to set an optimal plan for search and rescue (Shan & Yan, 2017). Furthermore, distinct types of organizations can collaborate to make life resource delivery smooth in the tough situation of damaged buildings and destroyed traffic(Luis, Dolinskaya & Smilowitz, 2012) and even to deal with more than one disasters happen in different cities simultaneously (Doan & Shaw, 2019).

2.5 Summary

In this chapter, the three research areas and the research structure were first given on an introduction. And their relationship was presented. In the last three sections, each area was elaborated. The main purpose of this research is to enhance search and rescue efficiency by fast response and UAV-assisted life resource allocation.

Response time is a key factor which is used to measure the efficiency of disaster rescue. The shorter the response time is, the higher efficiency will be. UAV-assisted resource allocation is an effective way to support the disaster rescue. Before allocating life resource, allocation strategies should be made in advance. The strategies depend on the emergent situations, e.g. the density and the location of victims, the amount of life and medical resource, including food, water and medicine. The information of victims is collected by a UAV-assisted temporary network.

Therefore, in the next chapter, how to establish the temporary network is introduced at first. After collecting the necessary data, UAV-assisted allocation strategies is generated. And then, UAV path planning is presented, because the allocation depends on the navigation of the path.

In chapter four, the results of resource allocation and UAV path planning are simulated. As followed by the analysis, the effect of the research is shown.

Chapter 3

The Emergency Resource Allocation

In this chapter, three perspectives were selected to elaborate regarding the emergency resource allocation. They are UAV assisted mobile edge network architecture, resource allocation system model and formulations, and information collection path planning.

Firstly, the mobile edge network architecture is constructed by UAVs which play an important role of nodes in the network similar to wireless nodes in the Ad-Hoc network. UAVs in the network are used to provide wireless coverage to victims who are trapped in affected areas by disasters. With the coverage, victims are able to text and call to medical servers out of the areas, and even talk to them via video. On the other hand, UAVs can collect information on victims with the support of the network.

Secondly, the resource allocation system model elaborates life resource, e.g. food, water and medicine, are allocated by UAVs due to their high mobility and delivery. The resource is allocated based on the real situation which consists of distribution and amount of victims, and requirement of life resource. Furthermore, response time and total cost which are consumed by delivering resource are formulated.

Thirdly, the UAV path is planned for information collection. The purpose of path planning is to navigate UAVs bypass all of the obstacles on the path while they are flying to multi-destinations without any collision. The distance of the path is set to the shortest.

3.1 UAV Assisted Mobile Edge Network Architecture

Mobile Edge Network (MEN) is a kind of distributed networks which locates on border of the cloud network. The cloud network plays a role in a central network which is responsible for processing a great amount of data, especially in an emergent situation.

MEN provides edge computing which is a distributed computing mainly or thoroughly performed on distributed devices considered as edge nodes. The purpose of MEN is to offer server and communication resources, data collection, data process and data storage. Edge computing puts applications, data analysis and energy consumption of computing out of central network. It pushes some portion of applications to MEN from the central network. Furthermore, MEN is able to reduce the amount of data which have to be removed, transaction and the distance the information must travel. Hence, transmission costs, network delay will be decreased. Quality of service (QoS) and time efficiency will be increased.

In a disastrous area, terrestrial communication facilities such as base stations may be devastated. Due to the mobility, UAVs could be used to construct the temporary network to collect health data from victims who are trapped and even at risk and to transmit the data to the edge network. Generally, the data could be processed in cloud servers. In order to increase time efficiency, the data will be sent to edge servers by UAVs directly, and the strategies will be generated in edge servers. After that, these specified strategies will be dispatched to staff in medical centres, e.g. emergency medical service (EMS), temporary emergency units (TEU) and hospitals. Figure 3.1 demonstrates the framework of MEN. Figure 3.2 explains how strategy generates. Considering cyber security and transmission efficiency, the collected data should be compressed and encrypted before transmitting followed by decrypted and decompressed after the control centre receives them.

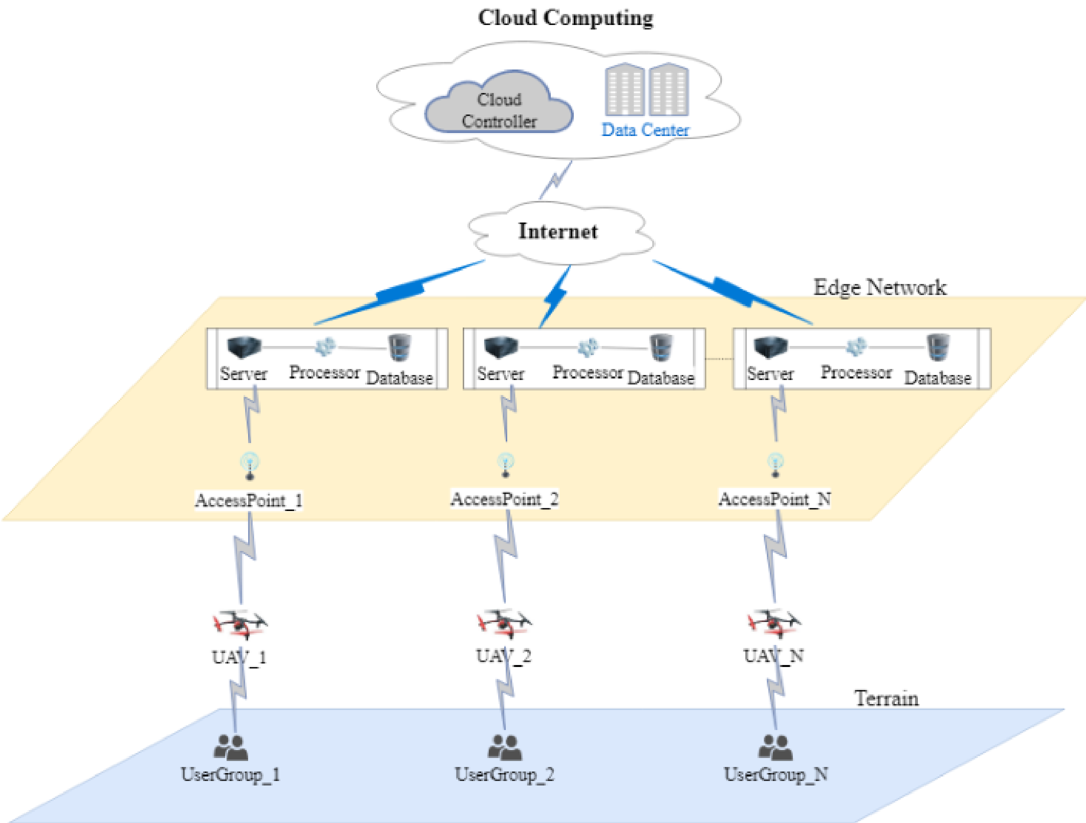

Figure 3.1: Framework of MEN

The infrastructure could be destroyed by the disaster. Roads are out of service. Buildings are collapsed, and networks are broken off. Victims trapped in the disastrous cannot connect with caregivers and medical servers, e.g. nurses and doctors out of the area. It is emergent to detect the circumstances in the area, especially the number and the traumatic condition of victims. The victims consist of two groups, slightly wounded and serious injuries. The objective of the networks is to provide communication resource to the slightly wounded victims to connect with the outside. On the other hand, the networks could collect healthy data from the serious injuries for the medical servers in order to make appropriate strategies to implement rescue action. This thesis will propose how to establish temporary mobile networks with UAVs over the disastrous area. Figure 3.3 shows the logical relationships of three tiers of the mobile edge network. The bottom tier is used to establish links between victims and UAVs before collecting health information. The data transmission tier is in charge of transmitting data to edge servers. The origin data will be processed via four steps. 1). categorizing the data into four groups which are related to a number of victims, medicine, water and food; 2). compressing data for saving memory space; 3). encrypting data for network security and data privacy; 4). dispatching data to all the central servers. The algorithm in the top tier is used to generate strategies based on the processed data. The data will be the input parameters of the algorithm.

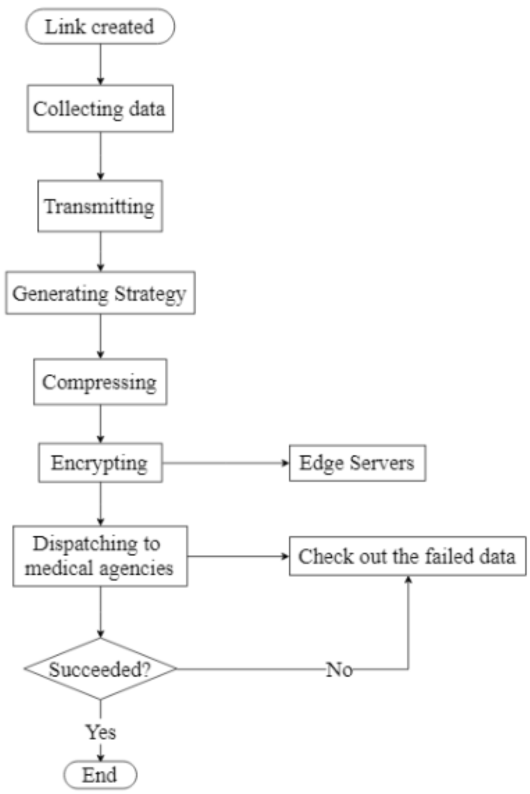

Figure 3.2: Flow of Data Process

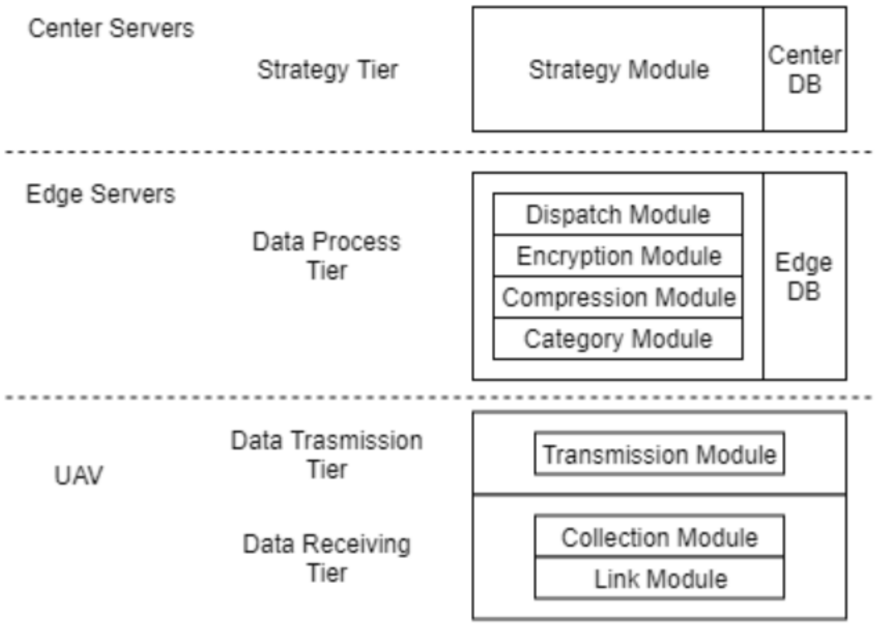

Figure 3.3: Logic Tiers of Mobile Edge Network

3.1.1 Unmanned Aerial Vehicles and Their Constraints

UAVs are chosen due to the special functions which are hovering, vertical landing, and even autonomous travelling. Each UAV could provide coverage if it is equipped with a base station. Similar to a ground base station, the coverage is able to provide the communication resource to the victims. In addition, UAVs play the role of nodes in the temporary networks over a disastrous area. The number of nodes needs to change with the size of the area to achieve the requirement of various task execution. UAVs are able to add to tasks to extend the coverage of the temporary networks. If the disastrous area shrinks, UAVs can be deleted from the networks. Any UAV in the networks could be replaced with another one in case of lack of energy. In addition, BSs errors and other mechanical breakdowns also make the UAVs out of service.

In various actual scenarios, UAVs are able to promote time efficiency due to their high mobility. UAVs could travel much faster than people and even vehicles on roads without the terrestrial constraints, e.g. traffic lights, rivers, forest and hills. They are able to fly to any direction directly and land vertically, thereby they do not need a long runway from which planes take off. In addition, UAVs do not need to avoid obstacles such as people and cars on roads. It is possible that high buildings and trees might on their way, they could fly higher to avoid them or bypass them with autonomous navigation. The terrestrial situations could change very frequently as time passing by, from forest to lakes, from roads to buildings which people and ground vehicles cannot arrive. UAVs are able to fly to these locations conveniently.

However, payload capacity and flight endurance are the two major challenges. Several civilian UAVs are able to carry a payload. "Aerosonde: a payload weight ranging from 4.5 to 11 lb (2 to 5 kg) depending on the desired endurance", "Altair: 660 lbs (300 kg) internally and up to 3000 lbs (1361 kg) on external wing stations", "Yamaha RMAX: It has a payload of about 65 lbs (30 kg), a flight time of about 90 minutes, and range of about 5.5 nm (10 km)." (Cox et al., 2004) "An indication of the more likely candidate applications is provided by a longstading use of drones in Japan, where, through the 1990s, over 1000 aerial devices weighing 50-60 kg and with a payload of 20-30 kg, were used for crop-spraying" (Clarke, 2014). In general, the flight endurance of quadrotors is around 30 minutes due to the limitation of energy supplied by batteries. On the other hand, charging time is two to seven times longer than flight time. Table 3.1 illustrates the flight time and charging time of various UAVs (Flynt, 2018).

As for Hubsan H501S in Table 3.1, seven are needed at least to ensure task continuously. It will increase cost and electric energy consumption, and even more staff are required to maintain the drones. The expectation is to extend operation time and shrink charging time. This is the major problem which this thesis intends to fix. The detail will be elaborated in Section Four.

Table 3.1: Flight Time and Charing Time of UAVs

Brand	Max Flight Time	Charging Time
DJI Mavic 2 Zoom	31 minutes	90+ minutes
DJI Mavic Pro	27 minutes	60+ minutes
Blade Chroma 4K	30 minutes	60+ minutes
DJI Phantom 4 Pro	30 minutes	210 minutes
Traxxas Aton Plus	25 minutes	90 minutes
Yuneec Typhoon H	25 minutes	50+ minutes
DJI Phantom 3 Standard	25 minutes	60+ minutes
Yuneec Q500+	25 minutes	120 minutes
Parrot Bebop 2	24 minutes	55+ minutes
UPair One	18 minutes	90 minutes
Hubsan H501S	20 minutes	150 minutes

3.1.2 Establishment of the Mobile Edge Network

This thesis will propose the actual functions of the aerial network which have considerable attention. This section will detail the structure MEN for a disastrous area and the flow which generates the final strategy. The main purpose is search and rescue (SAR) victims suffered by the disaster based on providing communication resource for victims to connect to caregivers and medical servers out of the area. SAR has to face seven problems, 1). data collected by the UAVs, 2). UAVs energy limitations, 3). environmental hazards (e.g. winds, trees), 4). Coverage, 5). Bandwidth, 6). Information security and privacy, 7). Construction.

A. Data collected by the UAVs

1). Objective

Assume that a disaster struck a city. Some parts of the city were affected by the disaster. It resulted that people in the related locations were suffered. Some of them might be injured severely and some were suffered slightly. The disastrous circumstance needs to be detected to estimate the various medical and life resource requirements of these victims. However, the roads may be devastated thoroughly so that ground vehicles cannot pass, and the communication could be interrupted. Before the decision of rescuing strategies, the affected parts of the city should be detected to collect accurate and comprehensive information about the victims, including number, health conditions and requirements. The mobile edge network can help to fix the problem. In the thesis, centralized topology is used to establish a temporary network due to its simplicity in terms of collecting and processing data on-board the UAVs. Figure 3.4 promotes the construction of the network. The network is composed of a disastrous area, multi-UAV networks, edge storage and cloud service. In Figure 3.4, the BS on each UAV is able to establish a temporary wireless network to cover a range of an area where victims are trapped. In the coverage, victims have the opportunity to connect to the BS and upload the health data and requirement to the UAV. The data will be transmitted to edge servers. The data will be categorized, packed and dispatched to all the service centres. Figure 3.5 explains the process.

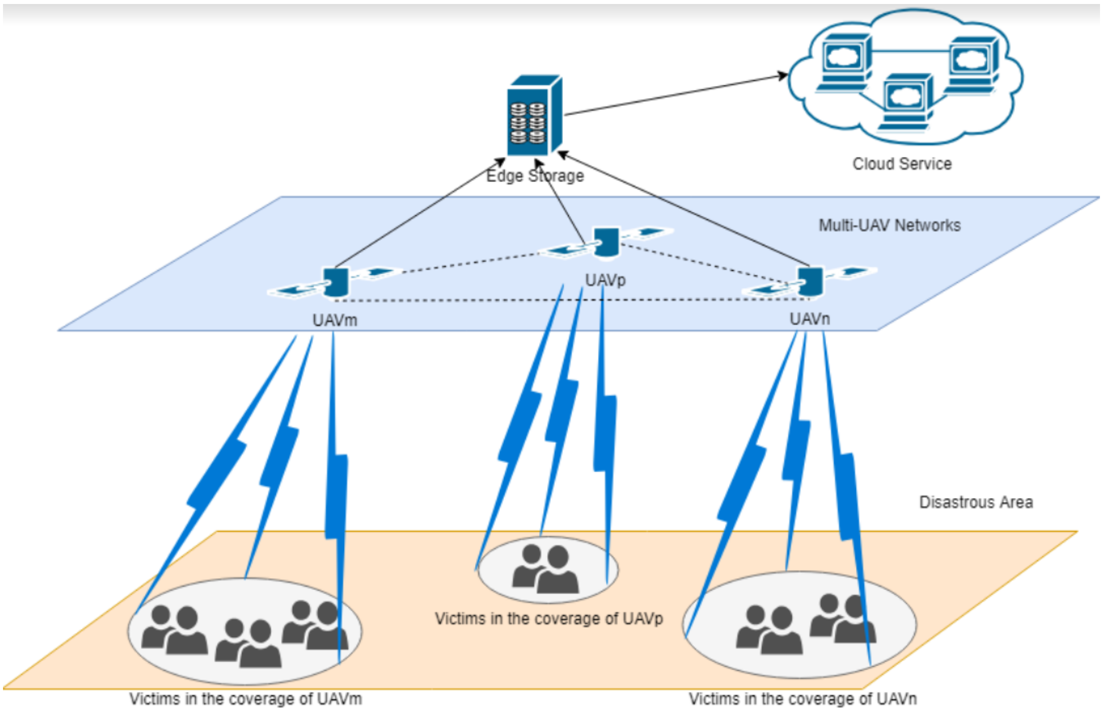

Figure 3.4: An overview of Multi-UAV network architecture

Collected data from every UAV are transmitted to edge servers. The data are composed of the number of victims in the specified area, kinds of medicine and amount

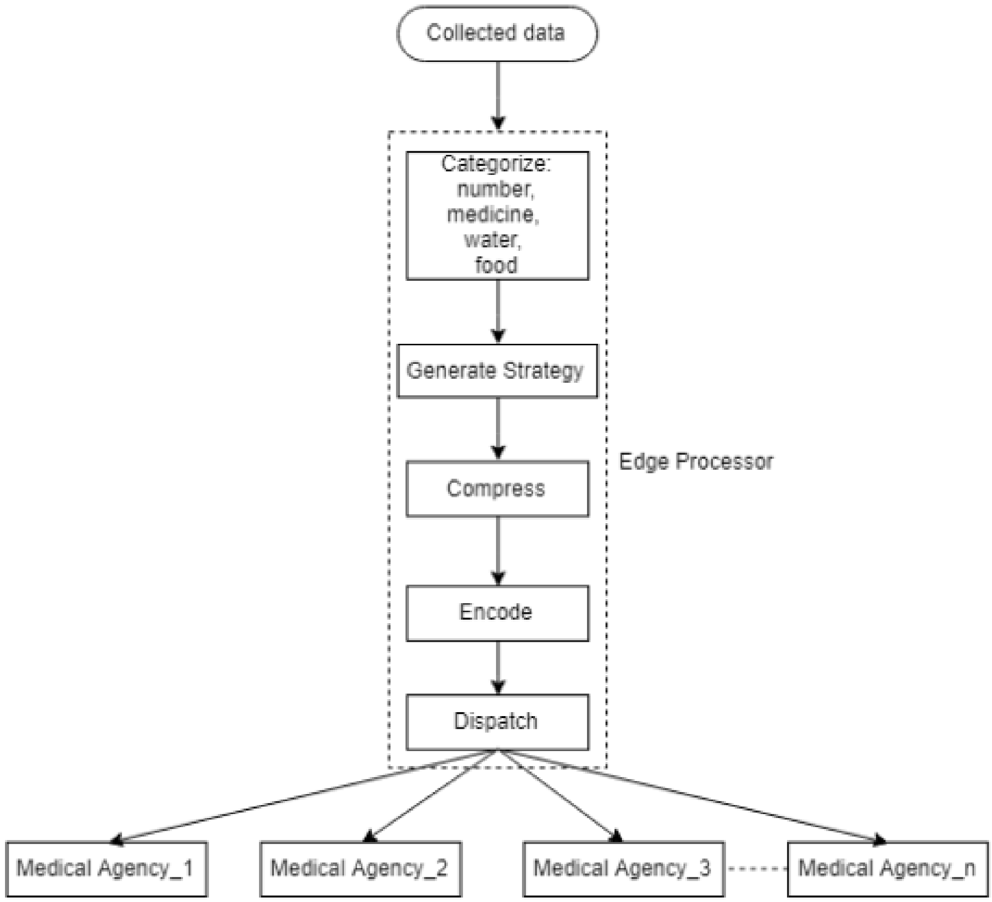

Figure 3.5: Data Process

of water and food. These data will be categorized in the edge servers into four groups which are number, medicine, food and water. In order to save storage capacity and increase transmission efficiency and security, the data will be compressed and encoded before dispatching to all the central servers. Each centre server is in charge of an area. They will work out the related strategy for the area.

2). Constraints

In the ideal case, the optimal scheme is that the whole areas can be covered by the prepared UAVs. However, it is possible that the deployed UAVs are not sufficient to cover all of them, and the limited budget will be another constraint. Thirdly, the energy will also be the constraint due to the limited battery power. This constraint will result in a short range of UAVs. Fourthly, the payload. The current battery power limits the weight of payload which UAVs are able to carry.

B. UAVs energy limitations

One of the critical flaws of the UAV is the limitation of their flight time. If the solar battery is on-board, the flight time would be longer. If the UAV is replaced for recharging batteries, the recharging time should be shorter due to the combination of the general recharging and the solar energy.

C. Environmental hazards.

Trees, buildings and telegraph poles could be the obstacles on their flight paths. Each UAV has to be capable of avoiding them and even avoiding collisions with other UAVs. In addition, the wind is the other threat which is possible to blow UAVs out of the original path even destroy them.

D. Coverage

UAVs play a critical role in the temporary network due to the lose of the communication infrastructure on ground caused by the disaster. They could be the only tools to re-establish and support communication to victims. In the network, UAVs are used as communication or relay nodes to provide connections between victims and rescuers and to collect health information from victims, and then to carry it to edge servers.The purpose is to offer communication coverage associated with victims.

However, the communication range is a constraint due to the limited coverage of the onboard BSs on UAVs. The mobile edge network could fix this problem with the support of multi-UAVs which are able to create continuous connectivity.

E. Bandwidth

Another key point is the bandwidth of the network. It is expected that the bandwidth is able to sustain a large number of victims to establish links to UAVs. The data transmission rate is also a crucial factor which depends on the network bandwidth.

F. Information security and privacy

Medical servers need accurate information of victims for providing related medication. The health information of each victim should be classified and stored separately with a unique identity. On the one hand, the accuracy of information can be guaranteed. On the other hand, victims' privacy can be preserved.

G. Construction

While the construction of the network is processing, the synchronization will be particularly important. Connectivity creation of any two UAVs should not be interrupted by other UAVs. Only if the connectivity is done, another UAV is admitted to take part in. Furthermore, the previous link should be maintained while another link is being built.

3.2 Resource Allocation System Model and Formulations

It has become common that UAVs are used in logistics services to deliver goods.

The advantages of UAV are fast, efficient and even unaffected by the obstacles. Some UAVs can fly at a top speed of 63 mph. That is more than 100 kilometres per hour, even faster than automobiles. Ground vehicles encounter many stationary and dynamic obstacles, e.g. people, buildings, trees, cars on the delivery roads. The traffic lights and traffic jams can also be obstacles, especially in emergency situations. In addition, they also need support to cross the areas such as rivers and seas which ground vehicles cannot pass. Compared with these vehicles, UAVs cannot be affected by traffic congestion. All the obstacles on the ground do not impede UAVs on its flight path. Hence another advantage of UAV is timesaving. They also are able to provide service to customers who are trapped on islands or in mountainous areas. If they are used in urban areas, quick and precise delivery service will be provided. Furthermore, quadrotor UAVs are more stable. They can hover and drop packages slowly. Taking off and landing vertically are also their advantages to pick up and deliver goods efficiently. A commercial company named Pulse Aerospace, has already demonstrated that approximately one hour of flight time and delivery of 11 pounds with a drop mechanism. The Payload cells in table 1 indicate that it is feasible for UAVs to deliver goods. As for suburb areas and disastrous areas, many of which are inaccessible to ground vehicles or even rescuers on foot. UAVs can be used to deliver medicine and life resource such as food and water.

However, delivering goods with UAV has pros and cons.

The main constraints of UAV are energy provided by batteries. It also constrains the operating time of UAV. The limited energy cannot sustain UAV for a long journey and a long flying time compared with commercial aircraft. But, the service range could also be extended via creating relay sites with recharging batteries at designated posts. From Figure 2.2, the range of UAVs with fixed wing can cover 160km. They will be able to reach longer distance with the relay sites. The energy consumption and energy efficiency will be introduced in Section 4.5 which will discuss the optimization in regard to a flying path and energy usage.

Take disaster relief and management of Auckland for example, in order to describe disastrous relief distinctly, Auckland is divided into 15 blocks marked with numbers. The necessary resources are allocated in relative blocks, such as emergency UAVs, food and water, see in Figure 3.6.

The emergency medical service (EMS) and the hospital which are considered as MCs are located in blocks 1, 9, 11 and 14. The MCs keep on standby all the time. They are able to operate in case the disaster happens. Hospital is deployed in block 14 which is in Spark Arena, as this block is near the main road. Medical supply depends on good traffic. Three EMS are located in the fixed blocks in the map. Block 1 adopts an EMS which can provide medical services to the north shore. The second EMS is deployed in Block 9 where is Aotea Square. In Block 11, it has the third EMS which is near

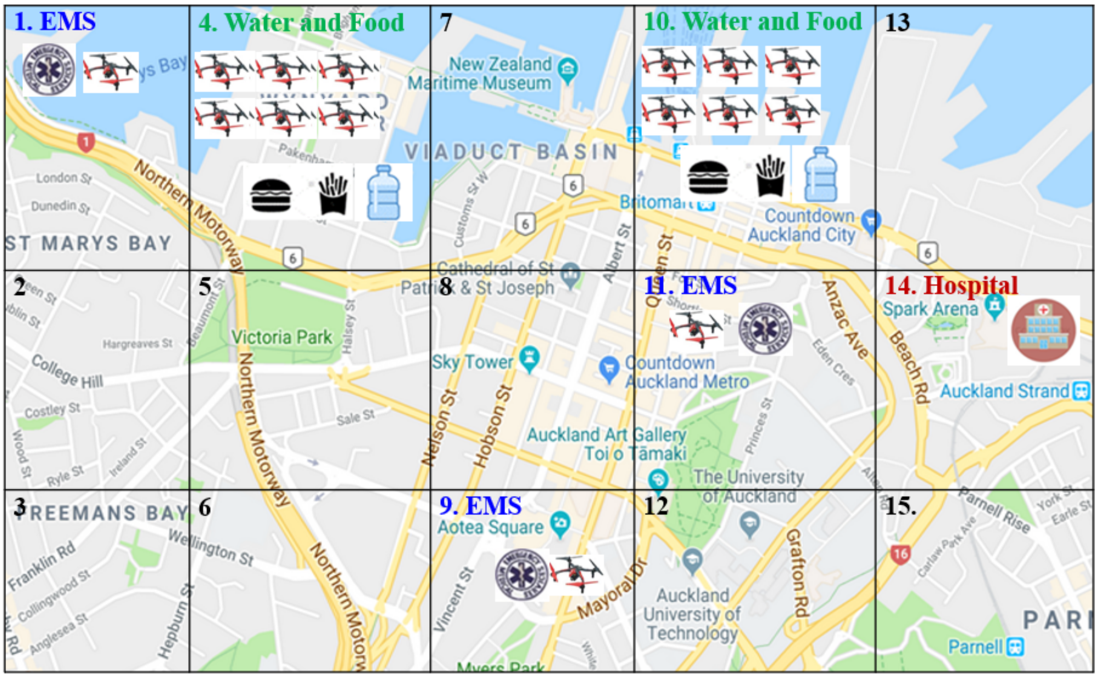

Figure 3.6: Blocks and resource allocation

Queen Street which the critical street in Auckland. It is likely that there would be more victims around Queen Street. The coverage of the medical service of the whole map is covered by the service range of the EMSs and the Hospital. The medical services could be provided to any part of the map as soon as possible. Block 4 and Block 10 are deployed with water and food. Because block 4 and block 5 are harbours. The locations are convenient to load and unload water and food by shipments. Roads are probably to be destroyed so that cargos could not be transported. For a port city, transporting cargos with ships is a good choice. In addition, multiple UAVs are deployed in these blocks. The function of the emergency UAVs consists of two aspects. One is offering medical service by the UAVs prepared in the EMSs and the Hospital. The other is responsible for delivering food and water respectively in block 4 and block 10.

These relief blocks are allocated in advance, and in fixed locations. When a disaster happens, each of the 15 blocks is possible to be affected. The number of victims in the affected blocks is distinct. It means that even though the medical service has covered all the blocks, if the ones which are further away from the MCs and there are more victims. Moreover, the road connected MCs and affected blocks are destroyed, the ground vehicles and rescuers on foot cannot reach there. It is necessary to create a temporary emergency unit (TEU) around the blocks to provide relief service. The TEUs must be in the optimal location for providing service to all of the victims in the affected blocks, and the supply from resource locations can be offered to TEUs in the minimum time. Therefore, the number and the location of the TEUs need to be optimized. In this research, they are worked out by the evolutionary algorithm developed by Python.

Assume that a natural disaster attacked Auckland, the affected blocks were blocks 2, 3, 6, 7 and 13. Figure 3.7 illustrates the affected blocks and the number of victims.

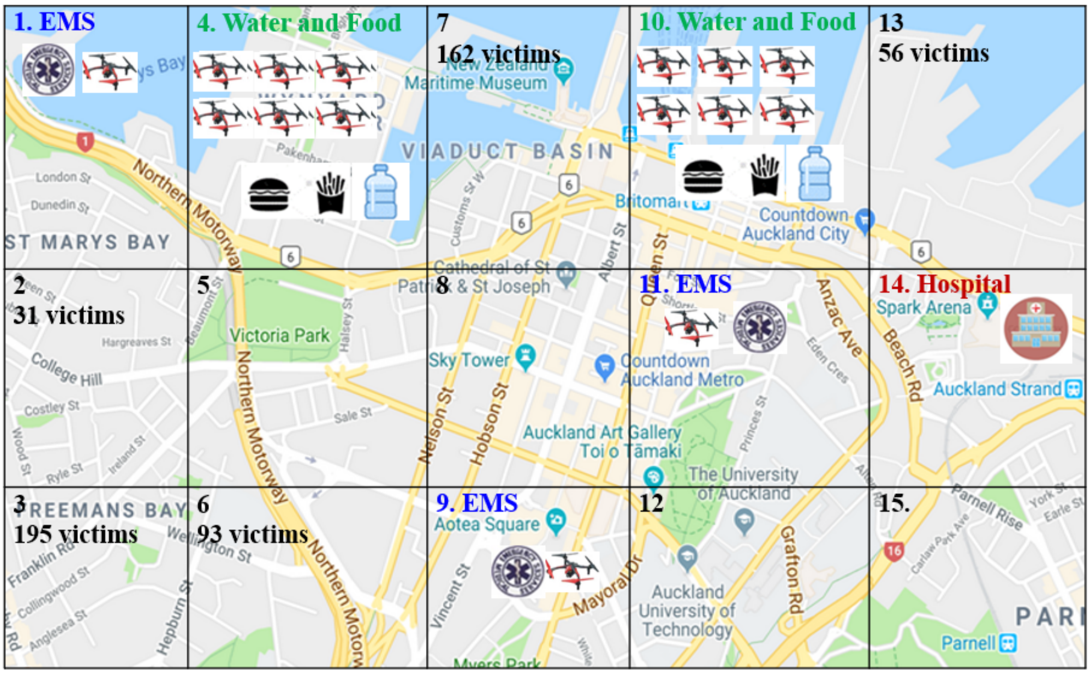

Figure 3.7: Affected Blocks and Victims

According to the information of the prepared conditions (MCs and life resource allocation) and the damage (disastrous blocks and victims), the number and the location of TEU(s) were worked out. In this case, one TEU was required and located in Victoria Park in block 5 (Figure 3.8) by the algorithm. Due to a large square in the park, there could be sufficient space for medical service and life resource delivery.

When the rescuing operation is performing, the required amount of food and water were delivered to TEU to meet the demand from the victims in closest blocks 2, 3 and 6. In addition, the number of UAVs was obtained by the algorithm and they were deployed in the TEU for medical service, life resource delivery and temporary network establishment. Figure 3.9 demonstrates that the victims in block 7 and 13 were served by the UAVs from the EMS in block 11 and the hospital in block 14, and the UAVs in blocks 4 and 10 were also responsible for the victims in blocks 7 and 13.

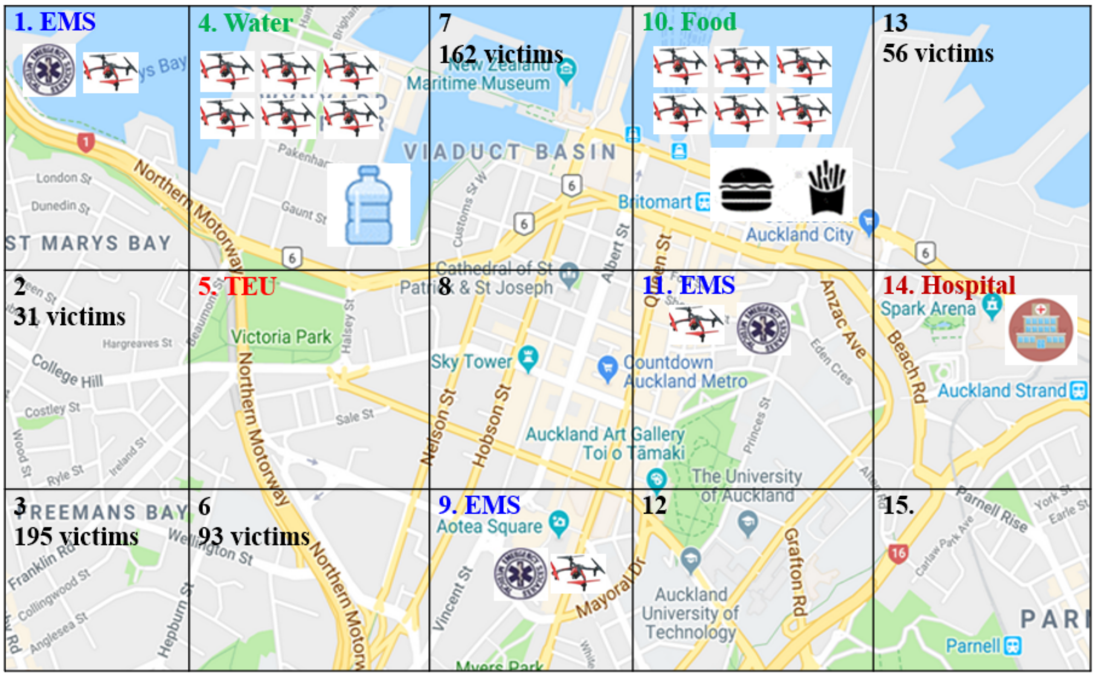

Figure 3.8: TEU Location

Based on the MO model described in section 1.2, the heuristic algorithm is prompted. It consists of four steps: generation, evaluation, sorting, and update. Each generation of the algorithm generates an optimal solution. Each solution represents an emergency medical response strategy. Each response strategy has different TEU locations, different dispatching configurations for emergency vehicles, and different evacuation plans for transporting life resource.

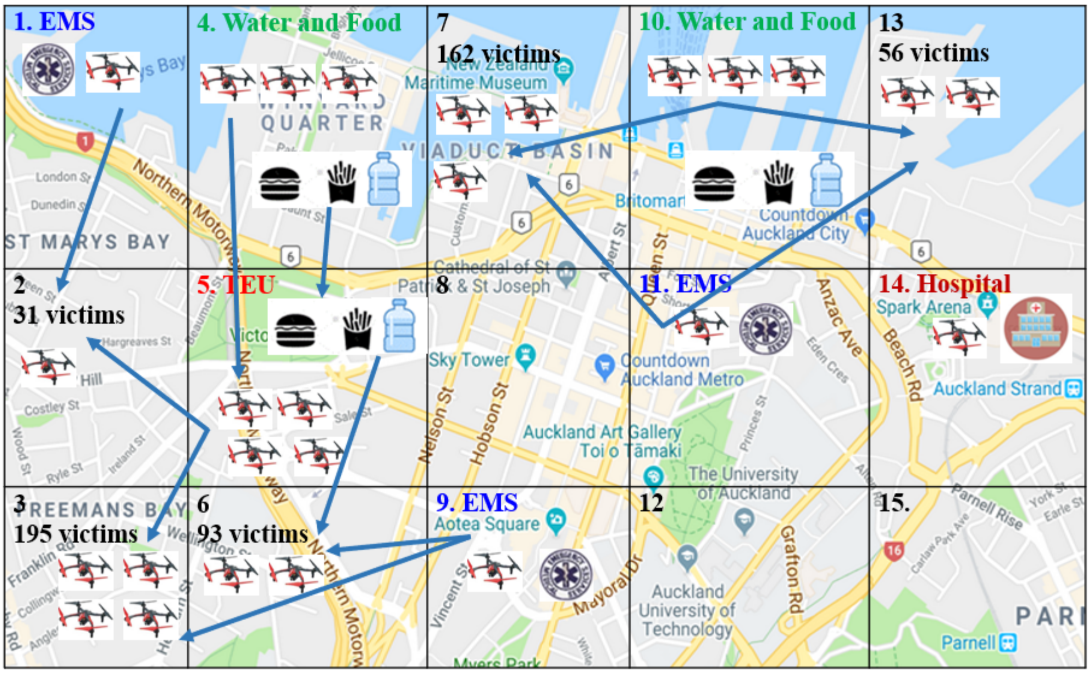

Figure 3.9: Resource Allocation and UAV Deployment

According to the three key points, which are the way of formulating problems, the MO model and the evolutionary algorithm, a theory about disastrous rescuing will be described below.

The EMSs and the hospital are necessary. Water, food and UAVs are also critical which are deployed in different blocks in Auckland map. Before a disaster happens, the affected blocks in a city cannot be predicted. After it happened, the roads could be destroyed so that the traffic is broken off. Resource delivery becomes a critical problem need to be fixed at the beginning. However, it is likely that the affected blocks are quite far away from the life resource blocks and MCs. Therefore, the situation promotes the formation of TEU(s). The formation of TEU(s) depends on the current situation, including the affected blocks, the number of victims in different blocks, the amount and the location of life resource (food and water) and medicine, the location of MCs, and the range, flying time and payload of UAVs. The price of the consumed resource is also critical. Figure 3.10 will specify the input and the output of the algorithm detailed.

These situations are the input parameters of the evolutionary algorithm. The algorithm is able to work out the number and location of TEU(s) which suit(s) the current situation and the required UAVs for each TEU.

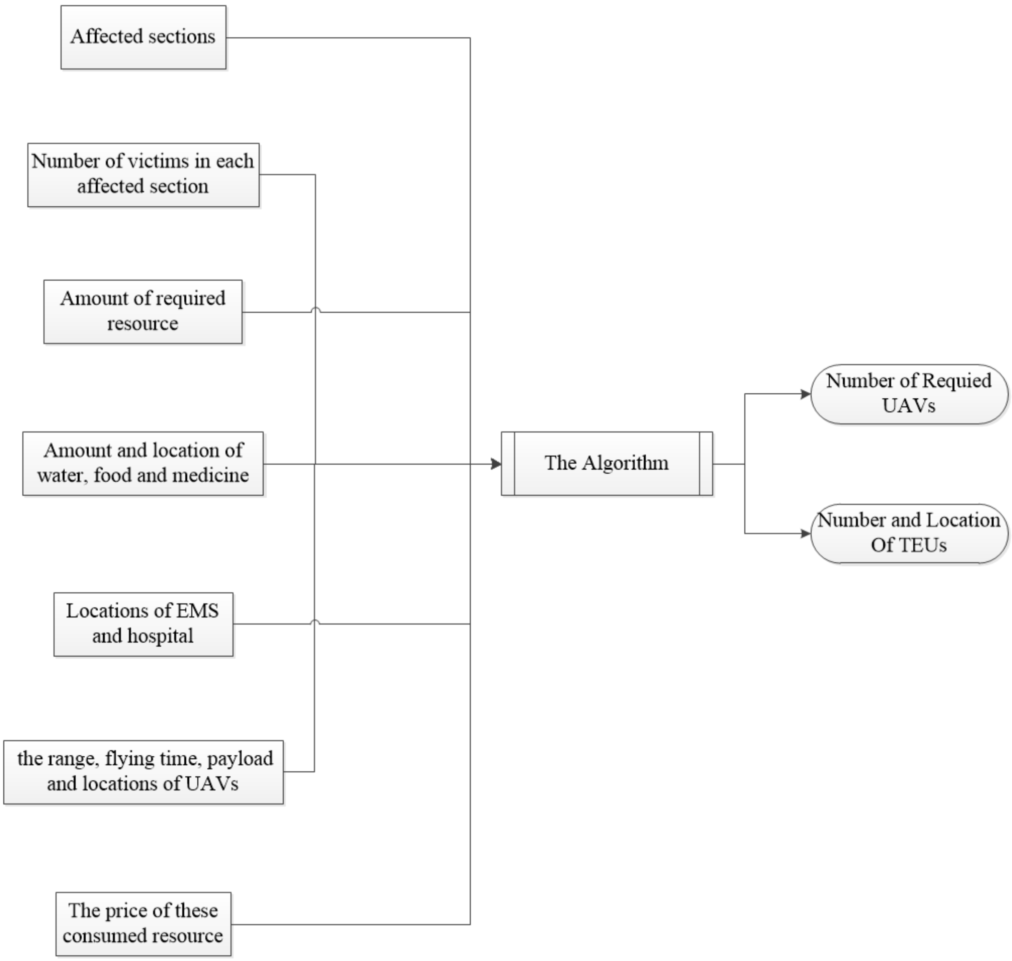

Figure 3.10: Calculation Of TEU and UAV

After the disaster happened, no matter natural disaster or manmade disaster, saving victims as many as possible are expected. The response time (RT) of relief organization will be paramount. In case of an emergency, the shorter the RT is, the more victims will be saved. Actually, the RT is constrained by the budget of the organization as well. Because rescuing resource, e.g. UAVs, food, water and medical facilities, need to be sustained by funds. If more relief facilities are put into service, more funds will be consumed. However, the minimum total cost (TC) is expected due to the finite budget.

In order to find the balance between min RT and min TC, they are considered as the two objectives. The formulation of min RT and min TC will be presented to calculate the minimum values.

$$\min TC = \sum_i \sum_j H_{ij} * d_{ij} * A^C + \sum_j \sum_k V_{jk} * d_{jk} * A^C +$$
$$\sum_j C_j^F * TEU_j + \sum_i \sum_j H_{ij} * A^P + W^T + F^T ......(1)$$

TC (Total Cost) = sum

(number of UAVs dispatched from MC_i to TEU_j

* the distance between block i and j

* operation cost of each emergency UAV

+ amount of life resource delivered from TEU_j to block k

* distance between block j and k

* operation cost of each emergency UAV

+ the initial cost of allocating a TEU in a given block j * TEU_j

+ number of UAVs dispatched from MC_i to TEU_j

* the procurement cost of each emergency UAV

+ total cost of consumed water + total cost of consumed food)

$$\min RT = \frac{\sum_i \sum_j H_{ij} * t_{ij}}{\sum_i \sum_j H_{ij}} + \max_{1 \le j \le N} \left(\frac{\sum_k 2 * V_{jk} * t_{jk}}{Z_j} \right) ......(2)$$

RT (Response Time) = sum

(number of UAVs dispatched from MC_i to TEU_j * time from block i to block j)

/ sum (number of UAVs dispatched from MC_i to TEU_j)

+

max (

sum (2 * amount of life resource to be delivered from TEU_j to block k

* time from block j to block k)

/ the total number of emergency UAVs dispatched to a TEU_j)

The symbols in the formulation will be commented below.

t_{jk}: time from block j to block k.

TC: total time.

RT: response time.

W_i: water from water center to block i.

W^C: cost of single unit of water.

W^T: total cost of water.

F_i: food from food center to block i.

F^C: cost of single unit of food.

F^T: total cost of food.

U: UAV, assumed that there is one UAV hovering in the sky of Auckland for patrolling.

d_{ij} and d_{jk} represent the distances between block i and j and block j and k, respectively.

A^C: the operation cost of each emergency UAV, including transportation from life resource center to TEUs and from TEUs to affected blocks.

A^P: the procurement cost of each emergency UAV.

C_j^F: the initial cost of allocating a TEU in a given block j.

V_{jk}: amount of life resource to be delivered from TEU_j to block k.

V_k: the delivered amount of life resource in block k.

H_{ij}: number of UAVs dispatched from MC_i to TEU_j.

EV_i: number of emergency UAVs available at medical center in block i.

I: number of blocks, 15 blocks.

Z_j: the total number of emergency UAVs dispatched to a TEU_j.

TEU in block j is indicated as TEU_j. Each TEU_j has two statuses,1 or 0.

TEU_j = 1 means that a TEU is deployed at block j.

TEU_j = 0 means that no TEU is allocated at block j.

MC_i (medical center): EMS and hospital.

Constraints will be described below.

$$\sum_j TEU_j \leq 1 \qquad \forall j = 1,2,...,I......(3)$$

"I" means there are *"I"* blocks in all in disastrous area.The summation of the number of TEU in I blocks is no less than one. It means there is one TEU in disastrous area at least.

$$\sum_j V_{jk} \leq 1 \qquad \forall j,k = 1,2,...,I......(4)$$

$$\sum_j H_{ij} < EV_i \qquad \forall i,j = 1,2,...,I......(5)$$

V_{jk} (the summation of amount of life resource to be delivered from TEU_j to block k) = V_k (the delivered amount of life resource in block k).

H_{ij} (the summation of number of UAVs dispatched from MC_i to TEU_j) < EV_i (number of emergency UAVs available at medical center in block i).

$$W^T = \sum_i W_i * W^C \qquad \forall i = 1,2,...,I......(6)$$

$$F^T = \sum_i F_i * F^C \qquad \forall j = 1,2,...,I......(7)$$

W^T (total cost of consumed water) = sum (

water from water center to block i * cost of single unit of water)

F^T (total cost of consumed food) = sum (

food from food center to block i * cost of single unit of food)

3.3 Information Collection Path Planning

Resource allocation is based on victims' information collected by UAVs. Before taking off to collect information, the path has to be planned in advance due to avoiding the damaged infrastructures while UAVs are travelling. This section will demonstrate how to plan UAVs path to avoid the obstacles and the simulation of the paths, and the path will be minimized by direct path planning algorithm and arc path planning algorithm. Furthermore, Bezier Curve will be used to optimize the path and compared with the path planning algorithm.

3.3.1 Models

The path planning problem is modeled as a constrained, single objective optimization problem. The objective is to minimize the total length of the distance which UAVs will travel along. The length is presented by a function f with respect to a number of designed variables. The disastrous area and the obstacles will be simulated in a 2D coordinate with horizontal axis x and vertical axis y. The obstacles will be generated randomly with constraints of position and radius. The simulated disastrous area is set as an area of 200 x 200 meters.

The obstacles will be generated randomly constrained by the conditions below.

i. The scale of the area is set to 200*200. The x axis is horizontal with the range between 0 and 200, 0 <= x <= 200. The y axis is vertical. The range is also between 0 and 200, 0 <= y <= 200.

ii. Start point (0, 0), final point (200, 200).

iii. Set 40 as the total number of obstacles in the area.

iv. Circles are simulated as obstacles. The radius r of all the obstacles are set between 3 and 6.

v. The circles are not overlapped.

vi. The circles are not tangent with each other.

vii. Five destinations are set as (200,25), (0,75), (200,125), (0,175) and (200,200). The start point is (0, 0).

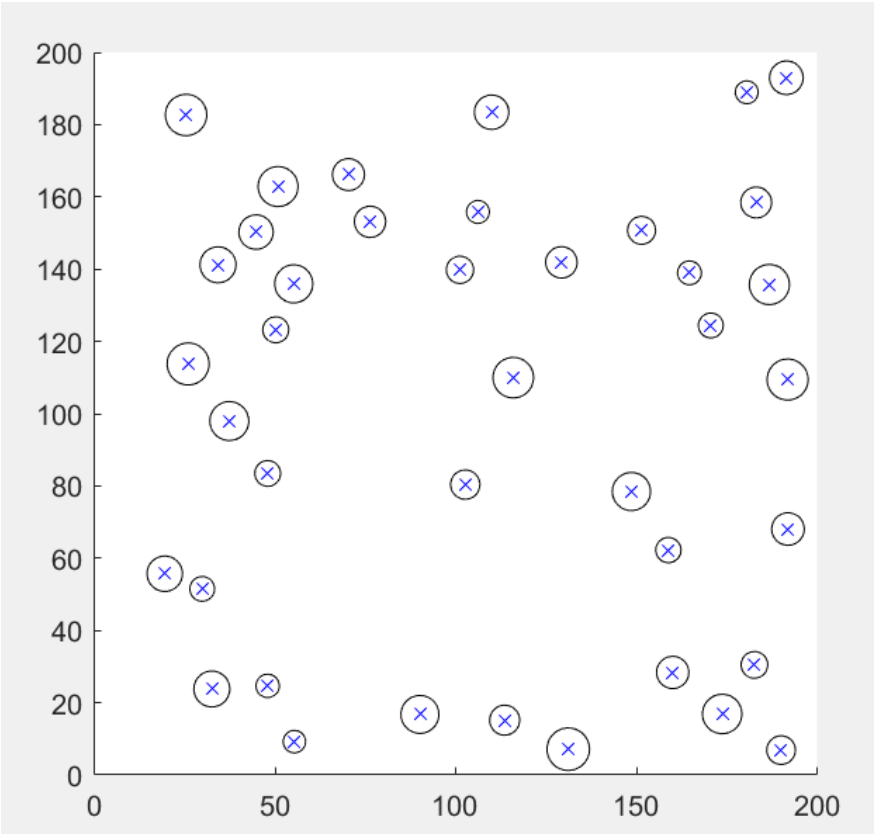

Figure 3.11: Random Obstacles

Figure 3.11 has listed random circles in the fixed area. No overlapping, no tangency. Next section will introduce the algorithm to illustrate how to plan five paths from the start point to the final point through the multiple destinations.

3.3.2 The Algorithm

The algorithm is composed of path planning and calculation of path length. The path planning algorithm consists of direct path planning and arc path planning.

A.Path planning Algorithm

The path which UAV moves along consists of two parts. The direct path from a point to another without obstacles on its path and the arc path which bypasses obstacles to avoid collision. The algorithm consists of ***direct path planning algorithm*** and ***arc path planning algorithm***. The two kinds of paths will be constructed by the points approximately which will be obtained by the path planning algorithm.

Only if the first path is worked out to bypass the obstacles by the algorithm, other paths can be generated with the same algorithm.

Here, two layers of circulation will be introduced. The outer circulation is utilized to locate other obstacles which need to be avoided. And then, the inner circulation is used to generate the specified path. The algorithm will be presented followed.

Assumed that an ***n*2*** matrix named ***ObsM*** (obstacle matrix). The first column represents x coordinate, the second column represents y coordinate. The coordinates are arranged in ascending order of x from top to bottom. Each row represents the coordinate of a point.

For example, $(x_1, y_1), (x_2, y_2), (x_3, y_3), \ldots, (x_n, y_n), x_1 < x_2 < x_3 < \ldots < x_n$. There are ***n*** obstacles which are simulated as blue circles. (x_n, y_n) represents the coordinate of the centre of the circle.

$$\textbf{ObsM} = \begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ \ldots & \ldots \\ x_n & y_n \end{bmatrix} \ldots\ldots(8)$$

Develop the first path from the start point (0, 0) to the first destination (200, 25). This is one of the five paths. Then a loop can be set to generate other four paths using the same algorithm.

The pseudocode which demonstrates how to plan paths which set out from the initial point to all the other destinations is listed below.

for traversal *Des*

for traversal *ObsM*

Calculation of *line*

Calculation of *d*

if (d <= (r + ws/2))

Find $P_{0(x,y)}$ and $P_{10(x,y)}$

Generate $P_{1(x,y)}$,$P_{2(x,y)}$...$P_{9(x,y)}$

plot *arc* and *line*

Store tangential points and curved line points respectively in relative files.

else

Go to next obstacle

end

end

end

Table 3.2: Explanation of the Variables

Des	All the destinations
ObsM	All the obstacles
d	the distance between the line and the center of the obstacle
r	the radius of the current obstacle
ws	wingspan of the UAV
line	the line between current point and destination point
$P_{0(x,y)}$ and $P_{10(x,y)}$	the appropriate points which are tangent to the circle through the current point and the destination point. $P_{0(x,y)}$ is the first point on the circle and $P_{10(x,y)}$ represents the tenth point.
$P_{1(x,y)}$,$P_{2(x,y)}$...$P_{9(x,y)}$	the points which are used to split the arc into ten segments.
plot *arc* and *line*	draw the arc and direct path based on these points $P_0, P_1, ..., P_{10}$

Why are the tangential points chosen? As for the current path, the direct line is comprised of three parts.

i) a path from the start point to the first tangential point of the first obstacle;

ii) paths from the last tangential point of the current obstacle to the first tangential point of the next obstacle;

iii) a path from the last tangential point of the current obstacle to the final destination at the end of the current path.

The detailed step is demonstrated below.

initial:

Set the start point and the end point.

(X_{cur}, Y_{cur}) = (0, 0);

(X_e, Y_e) = (200, 25);

start:

Step 1. Make a straight-line ***L*** from the start point to the end point.

Connect start point (X_{cur}, Y_{cur}) and the end point (X_e, Y_e) with a straight line. The general line equation is displayed below.

$$Ax + By + C = 0......(9)$$

$$A = (Y_e - Y_{cur}))......(10)$$

$$B = (X_{cur} - X_e)......(11)$$

$$C = X_e * Y_{cur} - X_{cur} * Y_e......(12)$$

Put the parameter into the equation to get the values of A, B and C.

Step 2. Calculate the distance between the centre of the circle and the line (represented by ***d***)

$$d = abs(A * ObsM_x + B * ObsM_y + C)/sqrt(A^2 + B^2)......(13)$$

abs() is an absolute function. It returns a positive value. Because d cannot be passive.

Step 3. Find the obstacle which intersects with the line.

Go through the centres of all the obstacles stored in ***obs_sorted*** to estimate the distances from the centre points to the line. Then do some judgments to determine that whether the line intersects with an obstacle. It means that determining whether ***d*** is longer than the summation of the radius ***r*** of the circle and ***ws/2*** (half wingspan of UAV). Not intersected, if yes. Intersected if the distance is no longer than the radius ***(r + ws/2)***. There will be three branches.

1) If there is no obstacle or the current spot is a destination, return.

2) If un-intersected ***(d > (r + ws/2))***, it means that the UAV will fly through without a collision. The obstacle can be ignored. Detect the next obstacle. If there is no obstacle, UAV flies to the destination directly. End the current circulation. Go to the next destination.

3) If intersected ***(d <= (r + ws/2))***, it means that the line intersects with the new circle or the line is tangent to the new circle. Determine that the centre of the circle is above the line or below it. Set the new circle in terms of the centre of the current circle and the new radius ***(r + ws/2)***. Make two tangential lines with the current new circle and the current point. The UAV has to circle close to the circle in case of a collision. In order to find the shortest path to bypass the obstacle, there are five steps to achieve this goal.

i) The general line equation is introduced to calculate the yl coordinate on the line.

$$y = kx - kX_{cur} + Y_{cur}......(14)$$

$$k = (Y_e - Y_{cur})/(X_e - X_{cur})......(15)$$

The $ObsM_x$ coordinate of the circle corresponds with the x coordinate on the line. ***k*** is the scope of the current line. (X_{cur}, Y_{cur}) is the current point on the line.

if $y_l < ObsM_y$, the line is below the centre of the circle.

if $y_l >= ObsM_y$, the line is above the centre of the circle.

ii) Calculate tangential lines of the circle with the current point (X_{cur}, Y_{cur}). The tangential points, the centre point of the circle and the current point comprise a Right Triangle.

$$\begin{cases} (X_o - X_{cur})^2 + (Y_o - Y_{cur})^2 = (x_t - X_{cur})^2 + (y_t - Y_{cur})^2 + (r + ws/2)^2......(16) \\ (x_t - X_o)^2 + (y_t - Y_o)^2 = (r + ws/2)^2......(17) \end{cases}$$

(X_0, Y_0) is the coordinate of the centre of the current circle. (x_t, y_t) is the tangential point on the circle.

There are two solutions to xt and yt respectively. Because of two tangential points $P_{t1}(x_{t1}, y_{t1})$ and $P'_{t1}(x'_{t1}, y'_{t1})$.

iii) Similar to ii), the tangential point, the centre point of the circle and the end point comprise a Right Triangle.

$$\begin{cases} (X_o - X_e)^2 + (Y_o - Y_e)^2 = (x_t - X_e)^2 + (y_t - Y_e)^2 + (r + ws/2)^2......(18) \\ (x_t - X_o)^2 + (y_t - Y_o)^2 = (r + ws/2)^2......(19) \end{cases}$$

There also are two solutions to x_t and y_t respectively. Because of two tangential points $P_{t2}(x_{t2}, y_{t2})$ and $P'_{t2}(x'_{t2}, y'_{t2})$.

iv) Select the two tangential points. If the centre is above the line ***L***, the above tangential points are selected, otherwise, the below tangential points are selected. Here, assumed that $P_{t1}(x_{t1}, y_{t1})$ and $P_{t2}(x_{t2}, y_{t2})$ on the current circle are selected and ***L*** is below the centre.

v) Save tangential points in file "tangentPoint_n.txt". These points will be used to construct a direct path later. The step i) to step v) consist of the ***direct path planning algorithm***.

4) Split the arc of the new circle into nine segments. The number of segments could be changed according to the situation. The more segments there are, the more accurate will be. The distances of ***x*** coordinate of the ten points (the eight points plus P_{t1} and P_{t2}) are equal. Then ***y*** coordinates of the eight points will be worked out according to the equation.

$$(x - x_n)^2 + (y - y_n)^2 = (r + (ws/2))^2 \quad n = 1, 2, 3, ..., 8......(20)$$

Now, the coordinates of the ten points are obtained. $P_{t1}(x_0, y_0)$, $P_1(x_1, y_1)$,$P_2(x_2, y_2)$.... .....$P_8(x_8, y_8)$, $P_{t2}(x_9, y_9)$.

5) Save tangential points in file "curve-linePoints_n.txt". These points will be used to construct the arc path later. The ***arc path planning algorithm*** is composed of step 4) and 5).

Furthermore, the ten consecutive points will be put into Bezier curve equation as the parameters later for comparison.

6) Make a straight-line L_f from the point P_{t2} to the end point. At present, P_{t2} is the current point.

7) Go to ***start***. It enters the next circulation to plan a path to avoid next obstacles for the current path.

8) If the UAV reached the first destination. The first destination will be set as the

second initial point, and then implement ***the path planning algorithm*** repeatedly until it arrives at the final destination.

i) Quit the circulation, if all the paths are planned and make sure UAV is able to reach the final destination (200, 200).

As for the files "tangentPoint_n.txt" and "curve-linePoints_n.txt", the coordinate of tangential points and points on arcs are saved in them respectively. ***n*** means the ***nth*** path to the ***nth*** destination. The format of the two files is the same as the matrix ***ObsM***. The first column is associated with ***x*** coordinate, and the second one is related to ***y*** coordinate.

$$\mathbf{(x, y)} = \begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ \cdots & \cdots \\ x_n & y_n \end{bmatrix} \ldots\ldots(21)$$

The format of "tangentPoint_n.txt" and "curve-linePoints_n.txt" In order to plot the planned path, MATLAB provides a function named ***plot (x, y)***. Put the ***(x, y)*** in the function, the path will be plotted. Figure 3.12 below demonstrated a random result of multiple path planning as an example. The first path is from (0, 0) to (200, 25). The second path is between (200, 25) and (0, 75). The third path is from (0, 75) to (200, 125). The fourth one is between (200, 125) and (0, 175). The last path is from (0, 175) to (200, 200). The green lines indicate the multiple paths. It is obvious that the UAV has arrived at the final destination (200, 200) from the start point (0, 0) without any collision.

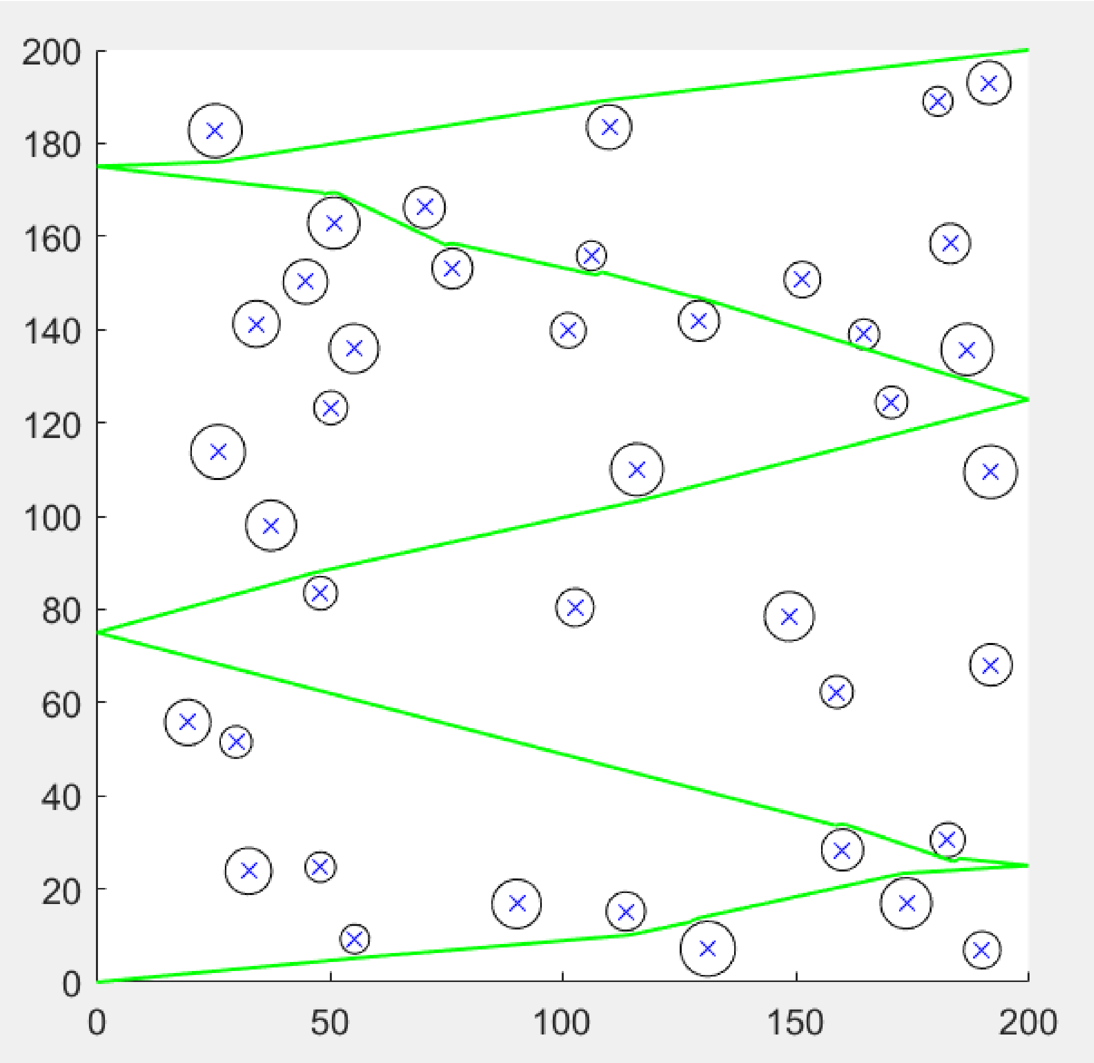

Figure 3.12: Simulated Multiple Paths

B. Path length Algorithm

The whole path is composed of direct paths and arc paths. The length of the direct path is calculated by the equation below.

$$(x_m - x_n)^2 + (y_m - y_n)^2 = l^2 ......(22)$$

l is the distance between $P_m(x_m, y_m)$ and $P_n(x_n, y_n)$ which are stored in the file "tangentPoint_n.txt ".

for traversal *Des*

Get coordinates of the tangent point from tangentPoint file

for traversal *coordinates*

Generate *distance* between two points using $\sqrt{(x_m - x_n)^2 + (y_m - y_n)^2}$

Accumulate the *distance*

end

end

The length of an arc path is worked out by the inverse trigonometric function ***asin(x)*** which is provided in the library of MATLAB. ***x*** stands for the length of the side of the triangle which is opposite the angle. The new radius ***(r + ws/2)*** has been obtained. Then the length of the arc can be calculated in terms of ***x*** and ***(r + ws/2)***. All of the coordinates of the tangent points are stored in the file "curve-linePoints_n.txt". The detail will be elaborated in the next section.

for traversal *Des*

Get coordinates of the tangent point and radius *r* of obstacles from curve-linePoints file

while !Eof

calculate arc length: *2*r*asin((length of consecutive two tangent points)/2*r)*

Accumulate the *arc length*

end

end

3.3.3 Optimization

A. Distance Optimization

It is possible that there could be more than one destinations in the disastrous area, the whole fly path of a UAV is divided based on the number of destinations. If there are n destinations, the path will be divided into n sections.

section_1 = [startPoint, destination_1];

section_2 = [destination_1, destination_2];

section_3 = [destination_2, destination_3];

...

section_n = [destination_(n-1), destination_n];

Based on the objective-oriented theory (OO), each section could be considered as an object which contains the (x, y) two dimensions coordinates of each point on the straight and curved lines. These coordinates will be written into individual files for independence in order to maintain conveniently later. If the coordinates of all points are put into one file or one variable, the amount of the data will be extremely large. It will be very difficult to find the specified points. Next section will introduce how to programme exactly.

In the research, the total distance consists of the distance of the five paths which are aforementioned. They are Path1 [(0, 0), (200, 25)], Path2 [(200, 25), (0, 75)], Path3 [(0, 75), (200, 125)], Path4 [(200, 125), (0, 175)], Path5 [(0, 175), (200, 200)].

Objective function:

$$\min D_{total} = L + D_{arc}......(23)$$

L: length of direct path;

D_{arc}: length of arc path.

Constraints:

a) ***d*** is no shorter than the radius of the obstacle (***r***) plus half of the UAV wingspan (***ws/2***).

d >= (r + ws/2)

b) the radius of obstacles is between 3 and 6

3 <= r <=6

c) ***x*** coordinate of obstacle is between ***r*** and (***200 - r***).

r <= x <= (200 - r)

d) **y** coordinate of the obstacle is between ***r*** and (***200 - r***).

r <= y <= (200 - r)

Take $Path_1$ for example. The path is composed of curves which around the obstacles and direct lines. O_n (*n = 1,2,3, ...,10*) represents the ***nth*** point on the curved line which bypasses the obstacle ***i*** (*i = 1,2,3, ...,k*). i represents that there are ***k*** curved lines in all which bypass obstacles in the coordination. In other words, there are ***k*** obstacles, which are on $Path_1$, have to be avoided. ***j*** (*j =1,2,3, ...,l*) represents that there are ***j*** direct paths from the start point to the first destination.

The distance of $Path_1$ will be displayed by the equation below.

$$D_1 = \sum_{i \in ObsM} Arc_i + \sum_{j \in DirectPath} L_j ......(24)$$

i = 1,2,3. . . k; j = 1,2,3. . . l.

Equation 9 shows that there are four obstacles on Path1. Therefore, $Path_1$ consists of four arc paths (Arc_i) and five direct paths (*L*). Hence, ***k*** = 4, ***l*** = 5. The start point, end point and all of the tangential points on section_1 are stored into a file named "tangentPoint_1.txt". The coordinates are ordered by the direction which UAV goes forward. All of the points on curved lines on section_1 are written into another file named "curve-linePoints_1.txt". The coordinates are also ordered by the direction of UAV movement. The calculation of the length will be demonstrated below.

I. Calculation of Direct Paths

The length of direct lines is the distance between two points.

$$L = L_1(startP, TP_1) + L_2(TP_2, TP_3) + ...$$

$$+L_n(TP_{2n-2}, TP_{2n-1}) + L_{Final}(TP_{2n}, EndP))......(25)$$

TP_n: the ***nth*** tangential point, *n = 1,2,3,...,m*

Based on Equation 10, one of the direct line L_n in $Path_1$ is expressed below.

$$L_n = ((TP_{(2n-2)x} - TP_{(2n-1)x})^2 + (TP_{(2n-2)y} - TP_{(2n-1)y})^2)^{0.5}......(26)$$

Hence the length of the five direct lines in $Path_1$ is formulated as

$$L_{Path1} = \sum_{1 \le n \le 5} L_n......(27)$$

The total length of the direct path in all sections is

$$L = \sum_{n \in Sections} L_{Pathn}......(28)$$

II. The calculation of approximate arc length.

The length of arc line is approximate to the length of nine segments which consists of 10 consecutive points. Point_1 and point_2 compose segment_1, point_2 and point_3 comprise segment_2…and segment_9 consists of point_9 and point_10. Every 10 points in the file "curve-linePoints_1.txt" are put in an array. Path1 has four arcs. In order to calculate the length of these arcs, two layers of circulation will be introduced.

The first layer is used to calculate the approximate length of the current arc. The second layer is the number of array, as known as the number of arcs. The approximate length of each arc will be worked out separately. Eventually, the total length of the arcs on $Path_1$ will be obtained:

$$Arc_{Path1} = \sum_{i \in ObsM} \sum_{1 \leq s \leq 9} length_s......(29)$$

$ArcPath_1$: the total length of arcs in $Path_1$;

$length_s$: the length of segment *s* in each arc;

i: the index of obstacles;

s: the index of segments.

The total length of arcs in all sections is

$$Arc = \sum_{n \in Sections} Arc_{Pathn}......(30)$$

III. The Arc Length Calculated by Inverse Trigonometric Function Section 1 presented the calculation of approximate length. This section, the length of the arc will be worked out by inverse trigonometric function ***asin()***. Figure 3.13 shows the relationship between the arc and the segment P_1P_2.

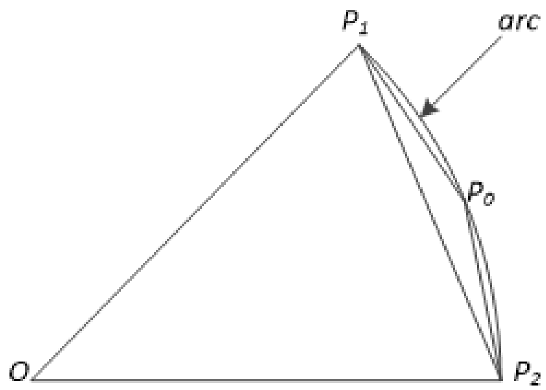

Figure 3.13: Arc and Segment

The direct distance between points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ will be represented by D_{p2p}.

$$D_{p2p} = ((x_2 - x_1)^2 + (y_2 - y_1)^2)^{0.5} ......(31)$$

The arc length D_{arc1} will be calculated by using inverse trigonometric function ***asin()***. The total length of the arcs around all the circles will be shown by D_{arc}.

$$D_{arc1} = 2 * r * asin(((x_2 - x_1)^2 + (y_2 - y_1)^2)^{0.5}/(2 * r))......(32)$$

$$D_{arc} = \sum_{n \in segments} 2 * r * asin(D_{p2p}/(2 * r))......(33)$$

r: the radius of the current new circle.

IV. The Arc Length Calculated by Bezier Curves. According to coordinates of curvedPoints obtained previously, these coordinates are put into the second order Bezier Curves equation to generate Bezier Curves as parameters.

$$B(t) = (1 - t)^2 * P_0 + 2(1 - t)tP_1 + t^2 * P_2, 0 \le t \le 1......(34)$$

In the beginning, P_0, P_1 and P_2 are the three points selected from the file "curve-linePoints_1.txt" in order. P_0 is the first point, P_1 is the second point and P_2 is the third one. *B(t)* is between P_0 and P_2 decided by *t*. If *t* is equal to 0, *B(t)* is P_0. If *t* is equal to 1, *B(t)* is P_1. *B(t)* is the point worked out with consecutive *t*. The Bezier Curve is decided by *B(t)*. In this case, the values between 0 and 1 are [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1]. Take these values in the equation, nine points between P_0 and P_2 can be figured out. The nine points will form ten segments with P_0 and P_2. The length of each segment can be worked out by the formula for the distance between two points. The result is the approximate length and it is shorter than the length of the arc worked out by *the Inverse Trigonometric Function.*

B. Elapsed Time Optimization

The optimal time depends on the optimal length and speed. In this research, UAV flies along a direct path or bypasses the obstacle along the optimal arc. One is V_{p2p}, the other is V_{obs}. The total time is

$$time = T_{obs} + T_{p2p} ......(35)$$

T_{obs}: the time which a UAV takes to fly bypass obstacles. T_{p2p}: the time which a UAV takes to fly from a point to the other directly.

$$T_{obs} = D_{arc}/V_{obs} ......(36)$$

$$T_{p2p} = D_{p2p}/V_{p2p} ......(37)$$

D_{arc}: the distance of arc line;

D_{p2p}: the distance of direct line;

V_{obs}: the velocity of bypassing an obstacle;

V_{p2p}: the velocity of fly directly from one point to another.

The velocity of bypassing an obstacle V_{obs}, and the velocity of fly directly from one point to another V_{p2p} have been set to fixed values. Therefore, as long as the optimal distance of arc line D_{arc}, the distance of direct line D_{p2p} are worked out, the optimal time will be obtained.

3.4 Summary

In this chapter, the three areas were proposed, including the establishment of the UAV-assisted network, solutions of resource allocation, deployment of UAV, and how to plan an optimal path to navigate UAV to complete tasks. The algorithms for resource allocation and UAV path planning were presented.

The UAV-assisted network is an emergency temporary network which is created after a disaster happens as soon as possible. The purpose of the network is collecting victims' health information. Then the data are transmitted to the control centre for decision-makers to make solutions to allocate life and medical resource. The solutions focus on generating the minimum response time and the total cost by adopting an algorithm named PSDA.

UAV-assisted victims' information collection depends on the location of the people who are trapped, as well as resource allocation. Make sure that UAVs fly to the locations without any collision. It is necessary for UAV to bypass all of the obstacles on the paths. The path planning algorithm solved the problem.

In the next chapter, the simulation of resource allocation and UAV path planning will be implemented to verify the algorithms.

Chapter 4

Simulation and Analysis

In the previous chapter, the models of resource allocation and UAV path planning were proposed, and the algorithms of the two perspectives were also introduced. This chapter demonstrated the results by running the resource allocation code which were developed by Python and simulating the path planning in MATLAB. The simulation was comprised of five study cases. The first to the third study cases explained the correlation among response time, total cost, deployment of UAV, and a number of victims in various affected areas. The fourth illustrated that the location of TEU depended on the distribution of EMS. The fifth study case simulated UAV paths were planned distinctly according to various random distributions of obstacles.

4.1 Simulation Environment Configuration

The emergency response strategy for the simulation was generated through the implementation of the PSDA. The algorithm was coded in Python and run on a laptop computer with Intel Core I5-7200U, 2.5GHz and 2.7GHz processors, 8 GB RAM, and a Windows 10 operating system. In the implementation process, four generations were run with 1000 solutions in each generation.

The final data which are generated by Python code will be demonstrated in tables below. “Total Cost” consists of the expense of UAVs, travelling cost, TEU, water and food. The fixed cost of food, water and TEU originates from Table 4.1, Table 4.2 and Table 4.3. In this thesis, the food and the water are deployed in section 4 and 10, respectively. If they are deployed in distinct sections, the price will be recalculated listed in the tables. All the price in the tables is assumed for the simulation.

Table 4.1: Food Prices

Section	1	2	3	4	5	6	7	8
Prices(NZD)	1200	1500	1500	1290	1202	1202	1300	1400
Section	9	10	11	12	13	14	15	
Prices(NZD)	1290	1700	1700	1340	1340	1290	1700	

Table 4.2: Water Prices

Section	1	2	3	4	5	6	7	8
Prices(NZD)	100	500	500	290	202	202	300	400
Section	9	10	11	12	13	14	15	
Prices(NZD)	290	700	700	340	340	290	700	

Table 4.3: TEU Prices

Section	1	2	3	4	5	6	7	8
Prices(NZD)	18200	54000	54000	29000	20200	20200	34000	34000
Section	9	10	11	12	13	14	15	
Prices(NZD)	29000	70000	70000	34000	34000	29000	70000	

This research presented an MO optimization method which helps to make the optimization of the combination of the response time, cost and emergency UAVs and to design the response tactics to a disastrous event. The model obtains the locations of emergency units in Auckland which have non-life-threatening injuries but need medical service, and dispatches emergency UAVs to deliver life resource. An evolutionary algorithm called PSDA was used to acquire the approximate Pareto set of optimal solutions where each solution represents an emergency response strategy. This method enables decision-makers to tradeoff response strategies based on values of response time and cost of TEU, emergency UAVs, water and food.

In the future, this research will consider other aspects. Firstly, offering services to different victim categories based on the extent of injuries. Secondly, providing longer range UAVs with heavier payload to reach further affected and impassable areas where ground vehicles cannot reach. Thirdly, establishing temporary or permanent relay sites for UAVs to recharge.

4.2 Study Case 1: Correlation of Response Time and Number of UAV

In this section, four experiments will be discussed. The public test parameters are set before the experiments. The speed of UAV is set to 30mph. Travelling from one section to TEU costs $10 per mile.

4.2.1 Configuration

It is assumed that the Auckland city has been divided into 15 sections. A disaster event attacked each section and left victims with non-life-threatening injuries who need medical service immediately. Table 4.4 - 4.6 present three scenarios of victim distribution. In general, more victims cause longer response time. If the number of victims changes, response time will be changed. In order to eliminate the side effect, the number of victims in each section of every scenario is set to be equal. Three scenarios are set to find the regularity. The number of victims in scenario 2 is as twice as it in the scenario 1. The number of victims in scenario 3 is doubled as in scenario 2. The number of victims increasing regularly is also set to search for the regular change of the correlation.

Table 4.4: Victims of Scenario_1

Section	1	2	3	4	5	6	7	8
Number	200	200	200	200	200	200	200	200
Section	9	10	11	12	13	14	15	Total
Number	200	200	200	200	200	200	200	3000

Table 4.5: Victims of Scenario_2

Section	1	2	3	4	5	6	7	8
Number	400	400	400	400	400	400	400	400
Section	9	10	11	12	13	14	15	Total
Number	400	400	400	400	400	400	400	6000

Table 4.6: Victims of Scenario_3

Section	1	2	3	4	5	6	7	8
Number	800	800	800	800	800	800	800	800
Section	9	10	11	12	13	14	15	Total
Number	800	800	800	800	800	800	800	12000

Assume that UAVs are deployed in sections 1, 4, 9, 11 in advance. The total number of UAV consists of 40, 80 and 120, increasing regularly. Each number is divided into five groups. Table 4.7 - 4.21 demonstrates the deployment of each group in advance.

Table 4.7: Deployment_1 of 40 UAV

Section	1	4	9	11
Number	10	10	10	10

Table 4.8: Deployment_2 of 40 UAV

Section	1	4	9	11
Number	31	3	3	3

Table 4.9: Deployment_3 of 40 UAV

Section	1	4	9	11
Number	3	31	3	3

Table 4.10: Deployment_4 of 40 UAV

Section	1	4	9	11
Number	3	3	31	3

Table 4.11: Deployment_5 of 40 UAV

Section	1	4	9	11
Number	3	3	3	31

Table 4.12: Deployment_1 of 80 UAV

Section	1	4	9	11
Number	20	20	20	20

Table 4.13: Deployment_2 of 80 UAV

Section	1	4	9	11
Number	74	2	2	2

Table 4.14: Deployment_3 of 80 UAV

Section	1	4	9	11
Number	2	74	2	2

Table 4.15: Deployment_4 of 80 UAV

Section	1	4	9	11
Number	2	2	74	2

Table 4.16: Deployment_5 of 80 UAV

Section	1	4	9	11
Number	2	2	2	74

Table 4.17: Deployment_1 of 120 UAV

Section	1	4	9	11
Number	30	30	30	30

Table 4.18: Deployment_2 of 120 UAV

Section	1	4	9	11
Number	114	2	2	2

Table 4.19: Deployment_3 of 120 UAV

Section	1	4	9	11
Number	2	114	2	2

Table 4.20: Deployment_4 of 120 UAV

Section	1	4	9	11
Number	2	2	114	2

Table 4.21: Deployment_5 of 120 UAV

Section	1	4	9	11
Number	2	2	2	114

Similar to the distribution of victims, the total UAV number is set to 40, 80 and 120. The number of two groups increase linearly. In this research, UAVs are deployed in section 1, 4, 9 and 14 in advance which is represented by an array defined as

$$TotalUAV[x_1, x_2, x_3, x_4]$$

x_1: the number of UAV deployed in section 1,

x_2: the number of UAV deployed in section 4,

x_3: the number of UAV deployed in section 9,

x_4: the number of UAV deployed in section 14.

The location of deployed UAV is not changed to another location. Because food and water are deployed in section 4 and section 10. If the location of UAV is changed, it will cause the response time change. In the situation, it is difficult to find the correlation between the number of UAV and the response time. For the sake of generality, two ways are adopted. First is average deployment. The number of UAV in each of the four sections is exactly the same. Second, extreme deployment. One of the four sections contains the UAV much more than the other three sections. The two kinds of deployment are set to examine whether response time is affected by the maximation of UAV in one of the four sections.

4.2.2 Simulation Result and Analysis

Scenario_1

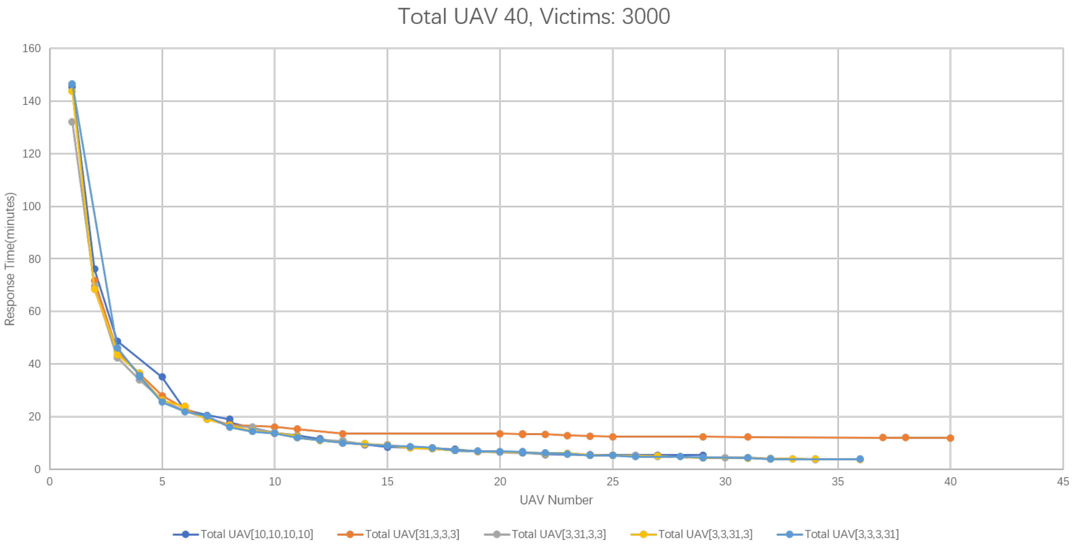

Figure 4.1: S1_RT_UAV_40_Victims_3000

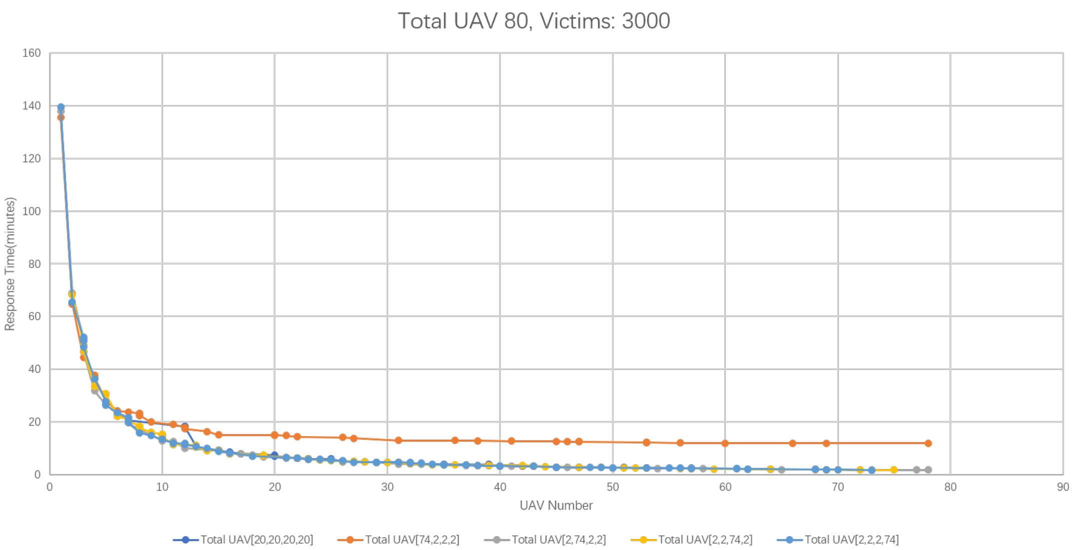

Figure 4.2: S1_RT_UAV_80_Victims_3000

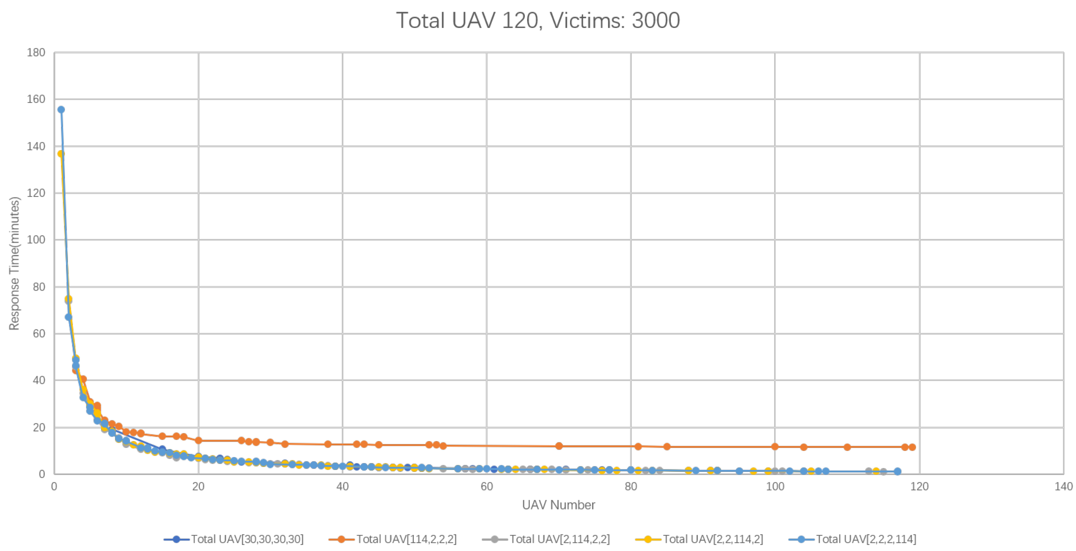

Figure 4.3: S1_RT_UAV_120_Victims_3000

Scenario_2

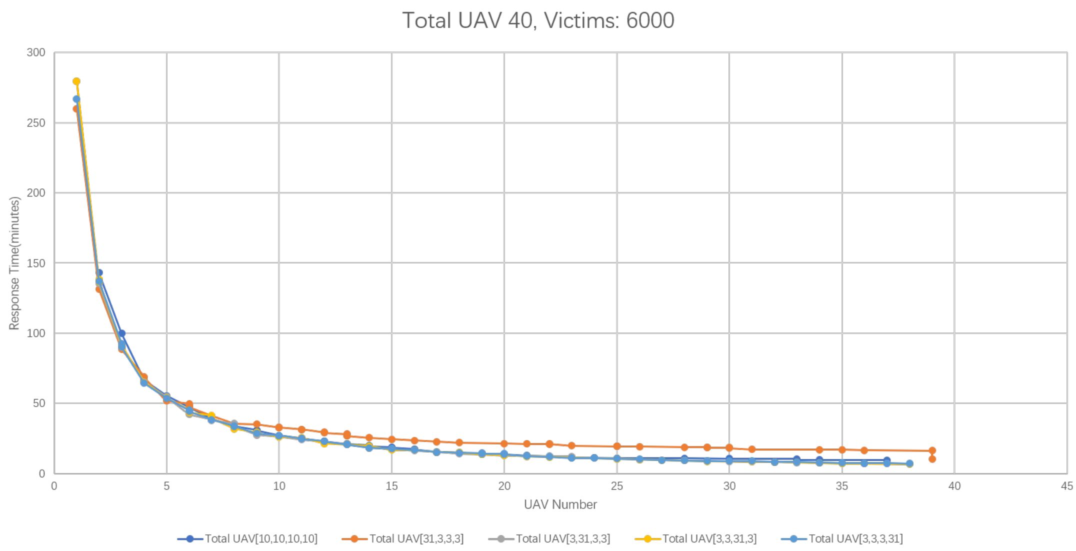

Figure 4.4: S2_RT_UAV_40_Victims_6000

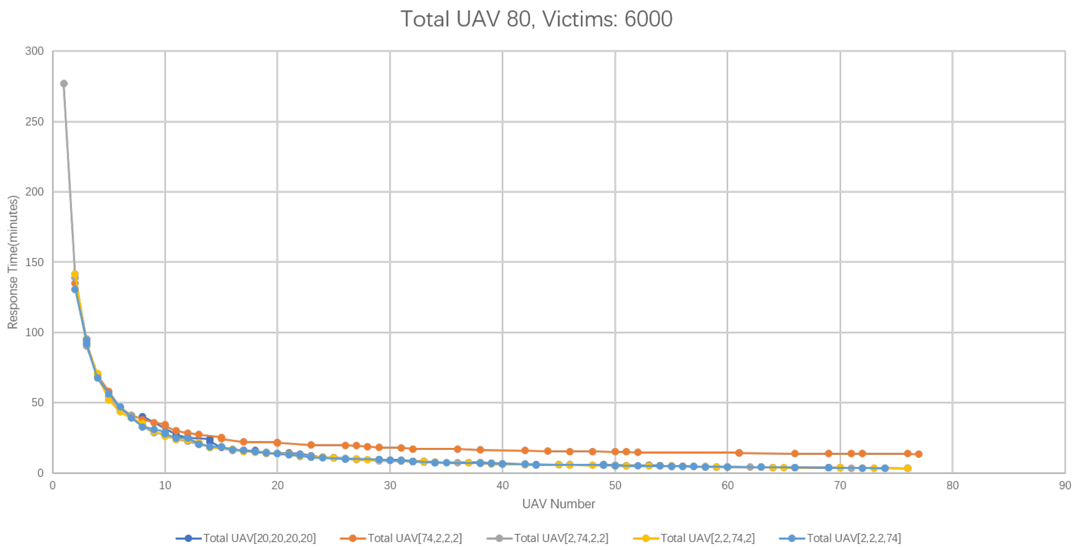

Figure 4.5: S2_RT_UAV_80_Victims_6000

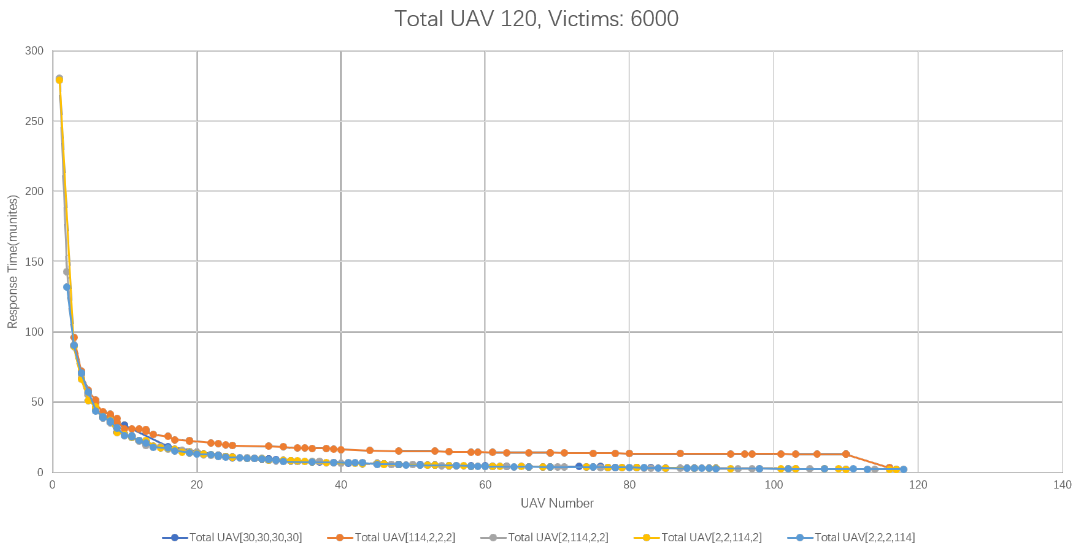

Figure 4.6: S2_RT_UAV_120_Victims_6000

Scenario_3

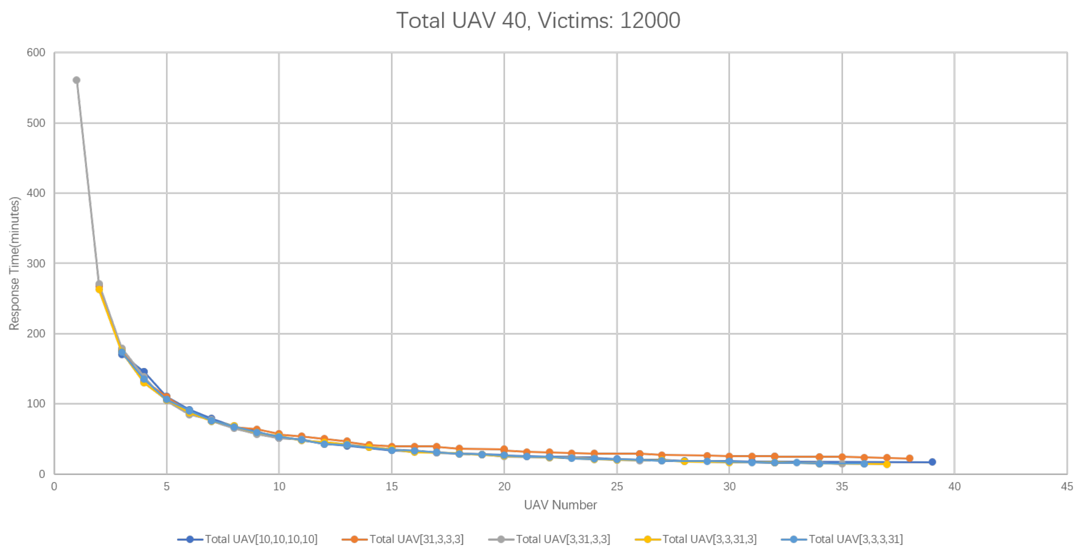

Figure 4.7: S3_RT_UAV_40_Victims_12000

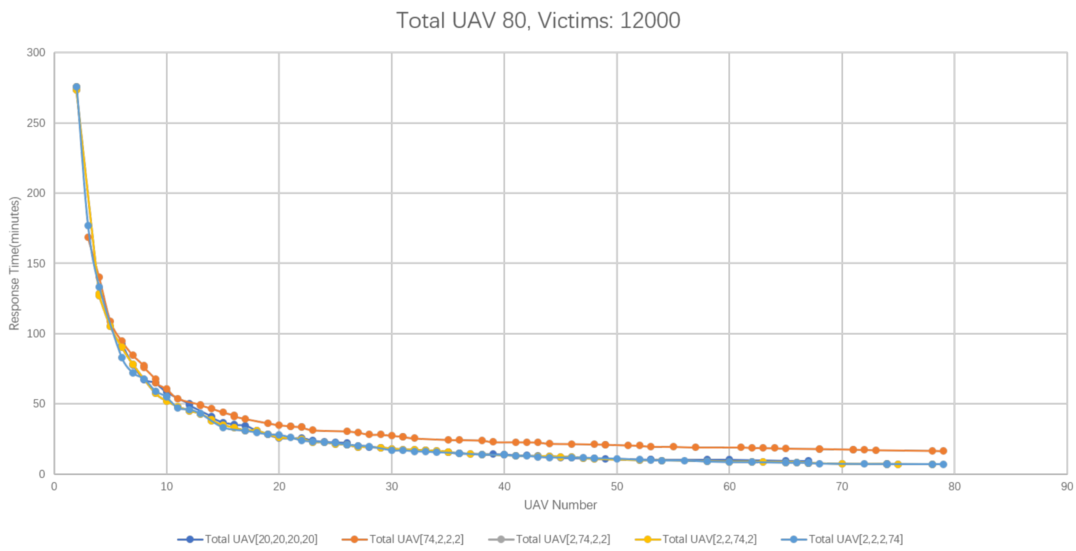

Figure 4.8: S3_RT_UAV_80_Victims_12000

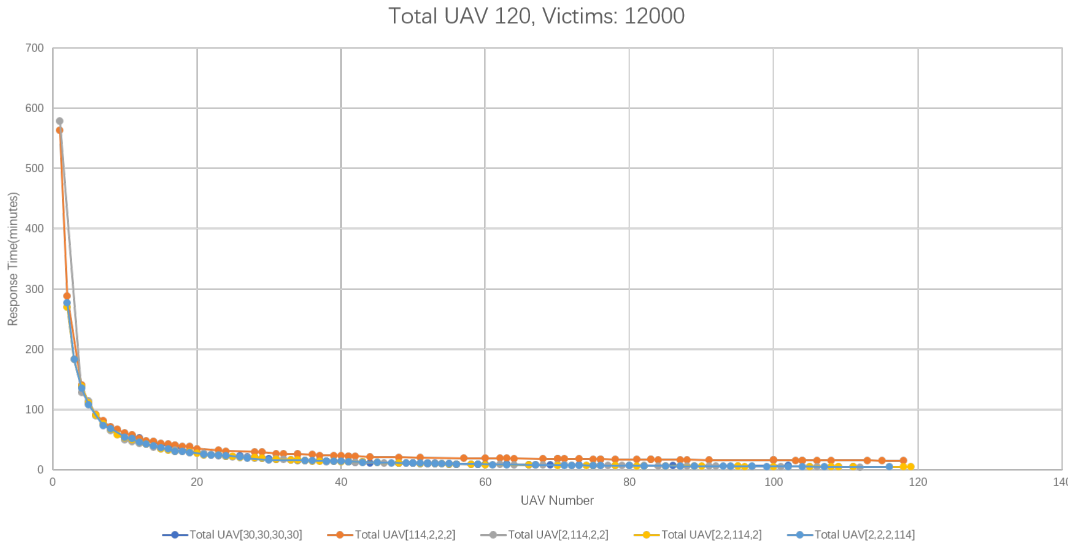

Figure 4.9: S3_RT_UAV_120_Victims_12000

In Figure 4.1, $TotalUAV = [31, 3, 3, 3]$, it presents that 31 UAVs are deployed in section 1. In section 4, section 9 and section 14, three UAVs are deployed in each section. From Figure 4.1 to 4.9, each figure represents five kinds of UAV deployment with the same total number, and consists of five curves. Every curve demonstrates the correlation between UAV deployment and response time. In each figure, four lines are overlapped and one is separated which indicates that if most of the UAVs are deployed in section 1, the response time will be longer. Figure 3.6 shows the sections where UAVs are deployed. The algorithm PSDA worked out that TEU was located in section 11 in this case. Section 1 is the farthest from section 11. The distance causes the longest Response Time.

Furthermore, every curve in these figures has a turning point. The point indicates the optimal UAV needs to be deployed. The reason is that if the number of UAV is smaller than the value which the turning point indicates, the response time will increase fast. If it is bigger than the value, the response time will decrease slowly. Therefore, the turning point explains the optimal number of UAV. Table 4.22 - 4.24 demonstrate the optimal points with the specified population.

Table 4.22: Population: 3000

Total UAV	40	80	120
Optimal Number of UAVs	8	10	12
Response Time	19.081	13.425	11.367

Table 4.23: Population: 6000

Total UAV	40	80	120
Optimal Number of UAVs	8	11	14
Response Time	33.876	25.016	18.041

Table 4.24: Population: 12000

Total UAV	40	80	120
Optimal Number of UAVs	9	15	18
Response Time	59.391	33.237	30.78

The figures demonstrate the trend that deploying more UAVs in advance will decrease the response time. Whatever how many the affected victims are, e.g. 3000, 6000 or 12000, the trend will not change. However, although the number of victims increases linearly, the correlation between the number of UAV and the response time is not linear. The turning points are the optimal values which could be explained from two followed perspectives.

1. Total number and deployment of UAV are unchangeable and the number of affected victims increases linearly.

The optimal number of UAV and the response time increase. Because the response time is related to the distance between the location of deployed UAVs and the location of TEU. If most of UAV are deployed closer to TEU, the response time will be shorter.

2. The number of affected people is not changed, but the total number and deployment of UAV increase.

The optimal number of UAV increases and the optimal response time decreases. Because if more UAVs are deployed, more UAVs can be selected to carry out rescuing tasks.

4.3 Study Case 2: Correlation of Response Time and Total Cost

4.3.1 Configuration

Total Cost comprises the price of food, water and TEU. TEU costs the prices of facilities and land where it is located. The prices are listed in Table 4.1 to Table 4.3. In addition, the distribution and the number of victims and UAVs are same as Experiment 1, which are listed in Table 4.1 to Table 4.18. The number and the distribution of UAV and victims are the same as Study Case 1.

4.3.2 Simulation Result and Analysis

Scenario_1

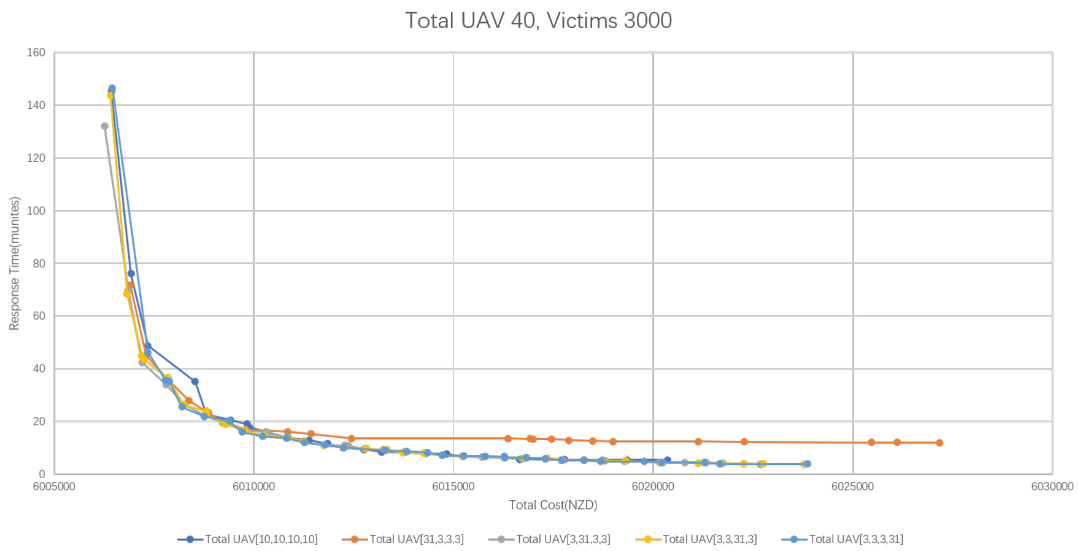

Figure 4.10: S1_RT_TC_UAV_40_Victims_3000

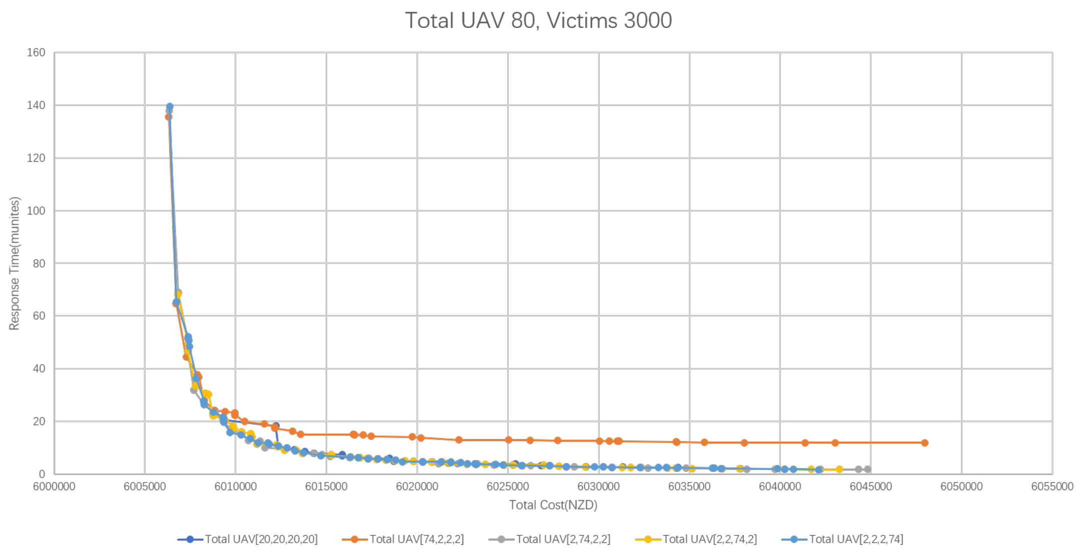

Figure 4.11: S1_RT_TC_UAV_80_Victims_3000

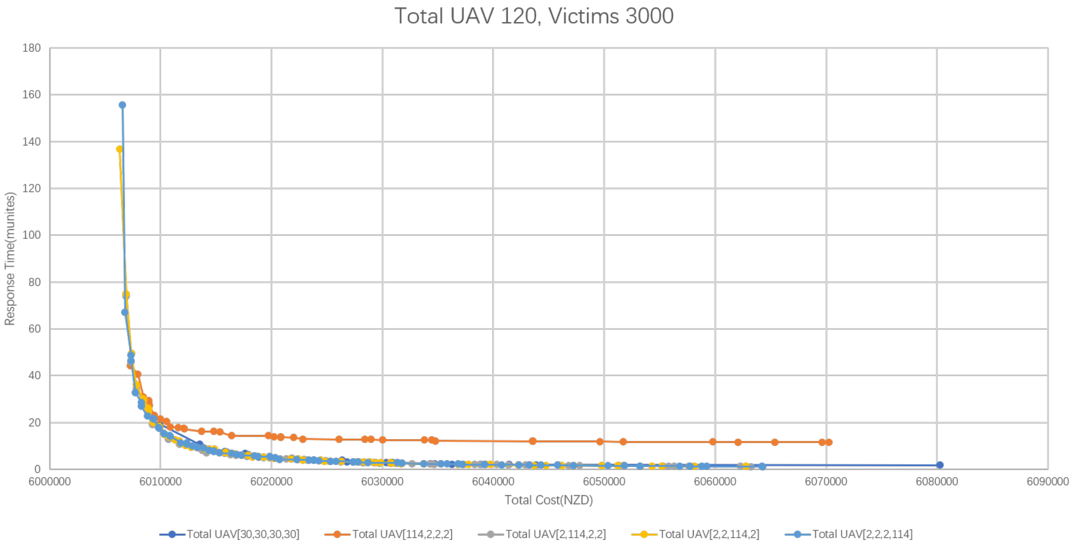

Figure 4.12: S1_RT_TC_UAV_120_Victims_3000

Scenario_2

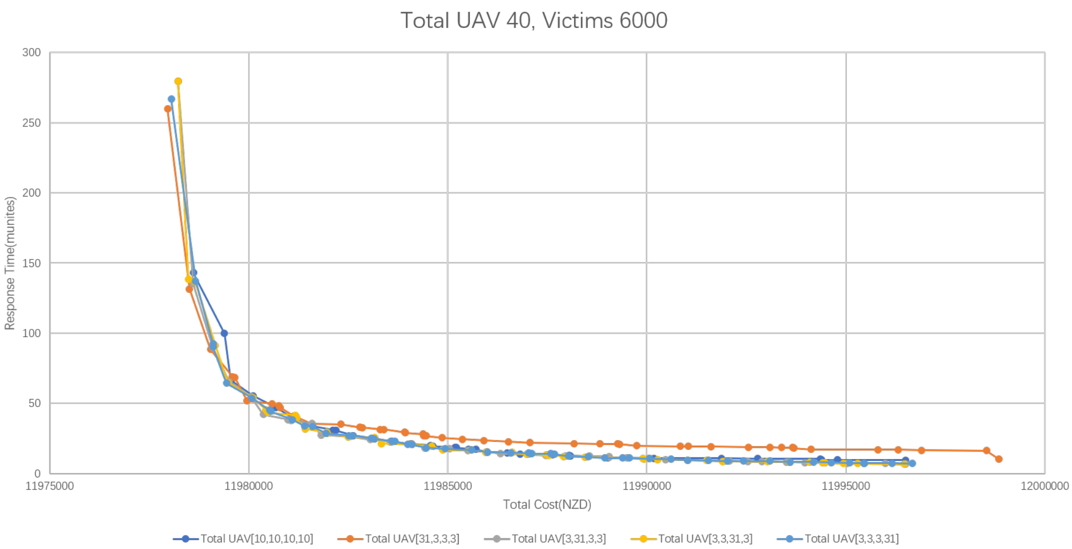

Figure 4.13: S2_RT_TC_UAV_40_Victims_6000

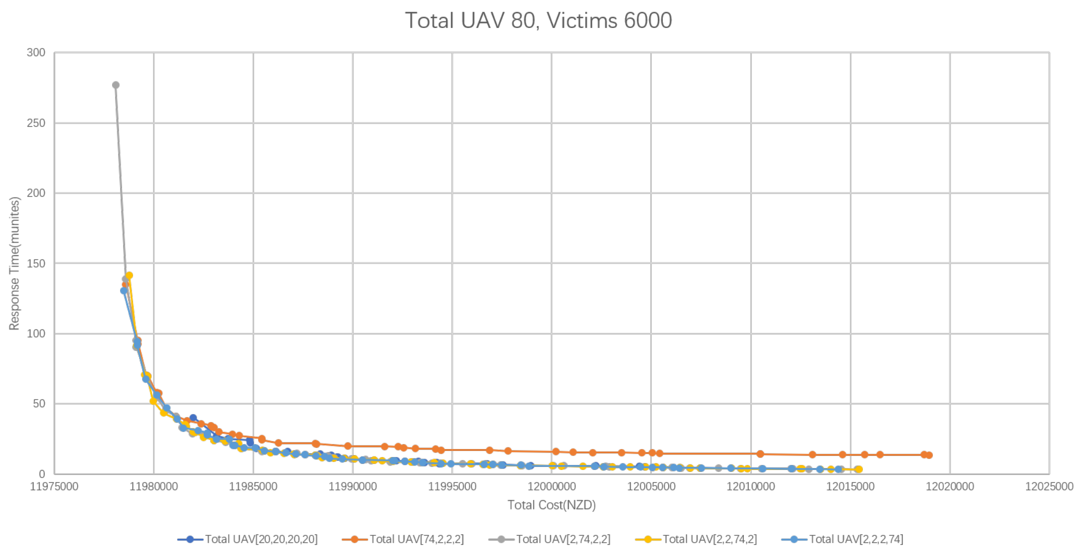

Figure 4.14: S2_RT_TC_UAV_80_Victims_6000

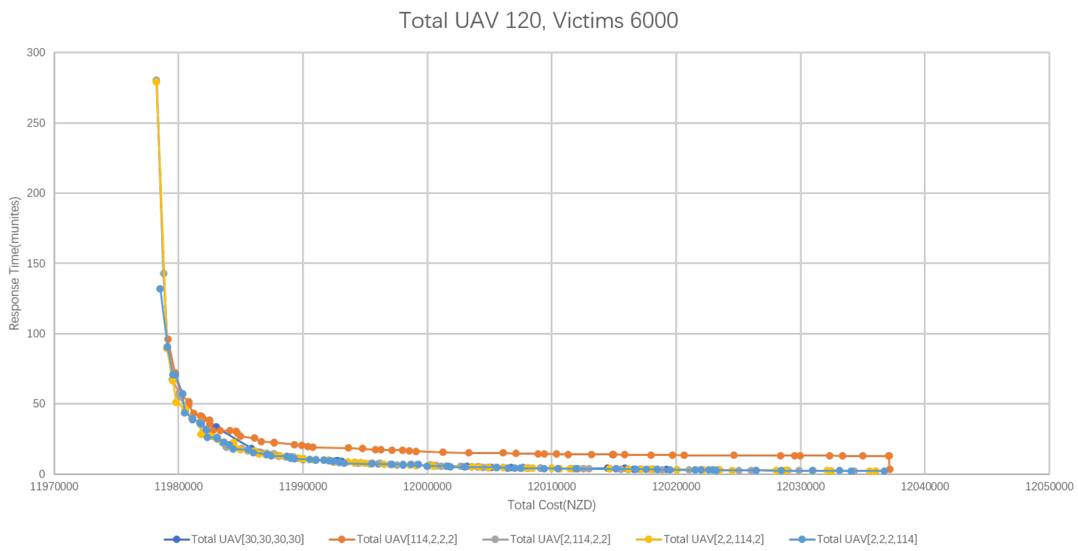

Figure 4.15: S2_RT_TC_UAV_120_Victims_6000

Scenario_3

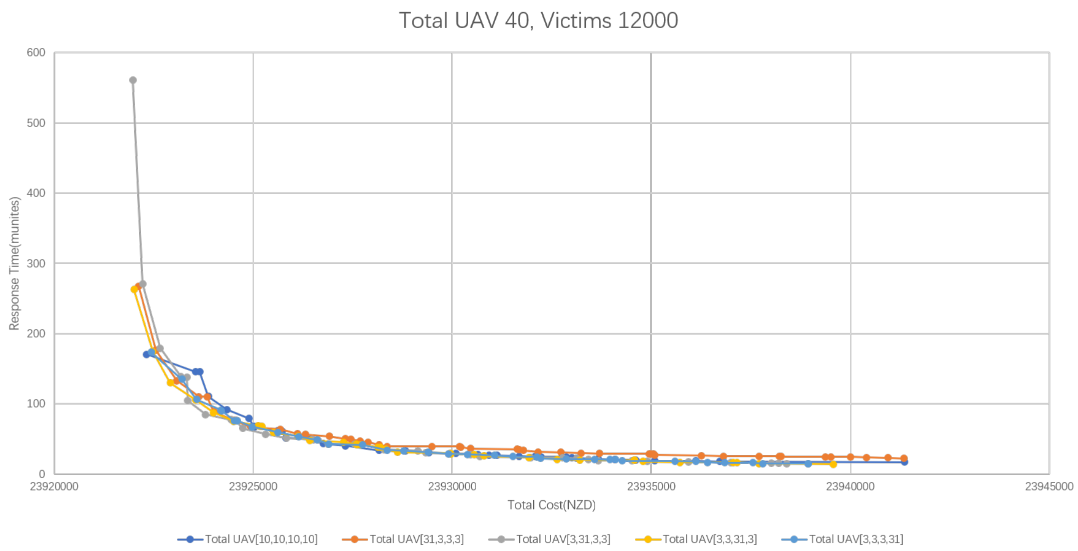

Figure 4.16: S3_RT_TC_UAV_40_Victims_12000

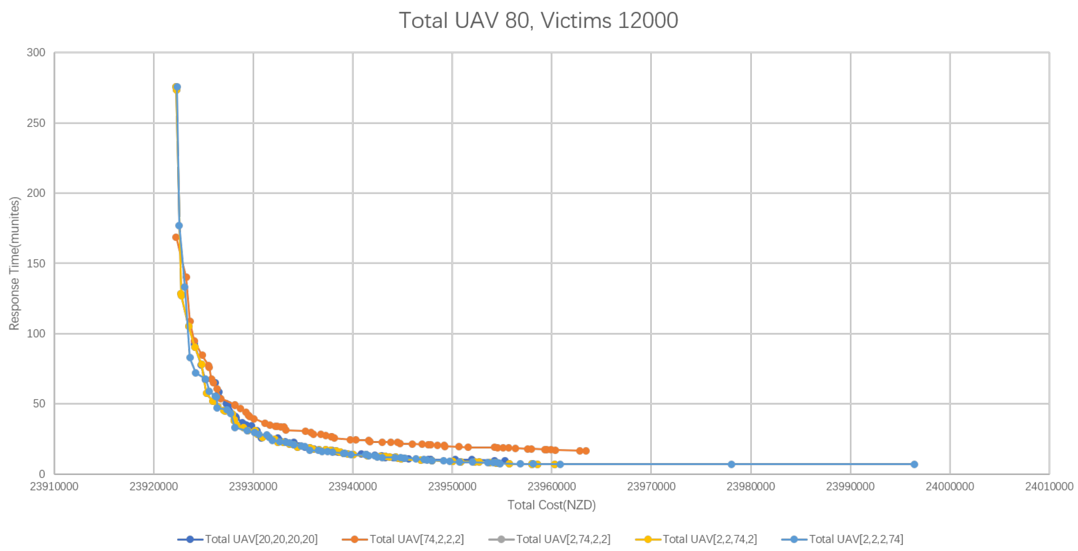

Figure 4.17: S3_RT_TC_UAV_80_Victims_12000

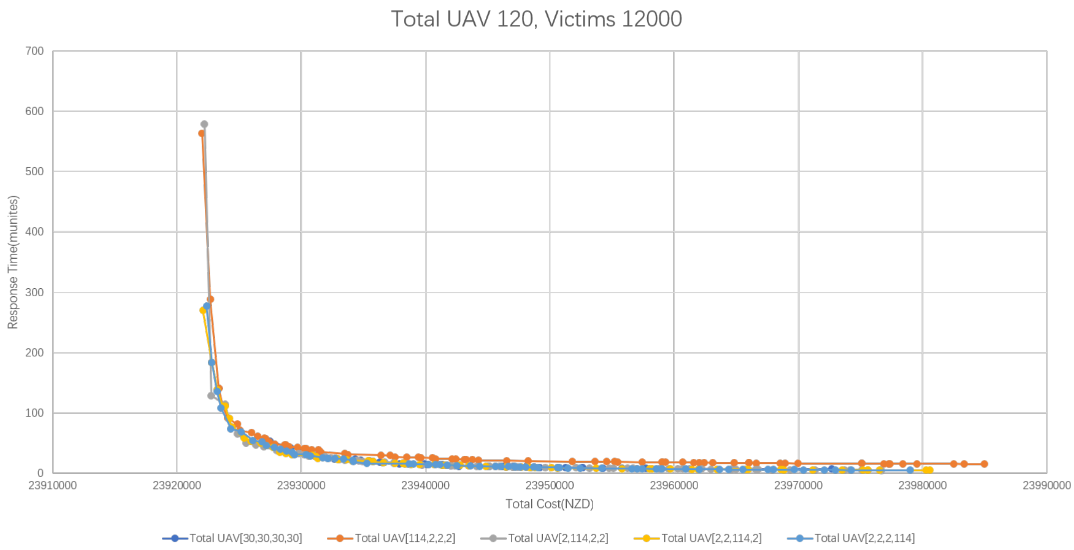

Figure 4.18: S3_RT_TC_UAV_120_Victims_12000

Each figure is composed of five curves which almost overlap. It shows the correlation between Response Time and Total Cost. In general, response time is inversely proportional to total cost. It means that if more UAVs and life resource are deployed, more victims will be rescued, and the response time will be shorter. Each curve in every figure has a turning point. That is the optimal point which indicates the best solution. The change of the shortest response time and the minimum total cost will be explained via two perspectives.

i).The number of deployed UAV is unchangeable and the number of victims increase doubled.

ii). The amount of victims is unchangeable and the number of deployed UAV multiples. Table 4.25 will list the fastest response time and the minimum total cost.

Table 4.25: EMS Distribution and TEU Location

	Victims 3000	Victims 6000	Victims 12000
UAV 40	$606262; 3.90min	$11977963; 6.85min	$23922007; 14.35min
UAV 80	$6006339; 1.76min	$11978086; 3.41min	$23922049; 7.14min
UAV 120	$6006342; 1.15min	$11978220; 2.27min	$23922097; 4.54min

Each figure is composed of five curves which almost overlap. It shows the correlation between Response Time and Total Cost. In general, response time is inversely proportional to total cost. It means that if more UAVs and life resource are deployed, more victims will be rescued, and the response time will be shorter. Each curve in every figure has a turning point. That is the optimal point which indicates the best solution. The change of the shortest response time and the minimum total cost will be explained via two perspectives.

i).The number of deployed UAV is unchangeable and the number of victims increase doubled.

ii). The amount of victims is unchangeable and the number of deployed UAV multiples. Table 4.25 will list the fastest response time and the minimum total cost.

4.4 Study Case 3: Correlation of Number of Victims, Response Time and Total Cost

4.4.1 Configuration

This case study will illustrate the correlation between response time and total cost when the number of victims multiplied. In order to discover the correlation without side effect, the total number of UAVs will not change (80 UAVs), and they will be deployed in unchangeable sections which are Section 1, 9, 11, 14. The deployed number in each section is [20,20,20,20], [74,2,2,2], [2,74,2,2], [2,2,74,2], [2,2,2,74]. Table 4.4 to Table 4.6 represent the number and the distribution of the victims. Table 4.7 - 4.21 present the distribution of UAV.

4.4.2 Simulation Result and Analysis

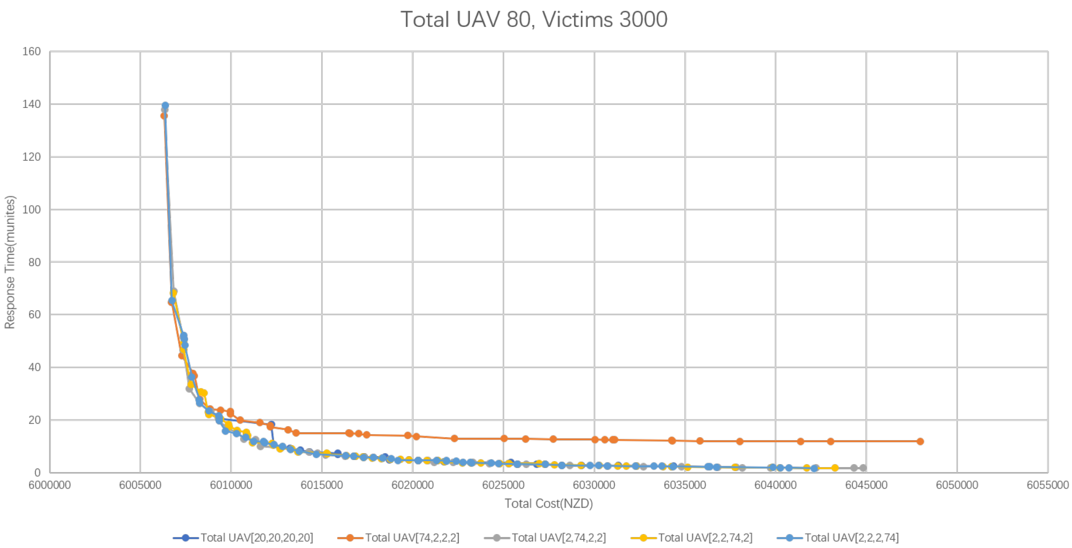

Figure 4.19: S1_RT_TC_UAV_80_Victims_3000

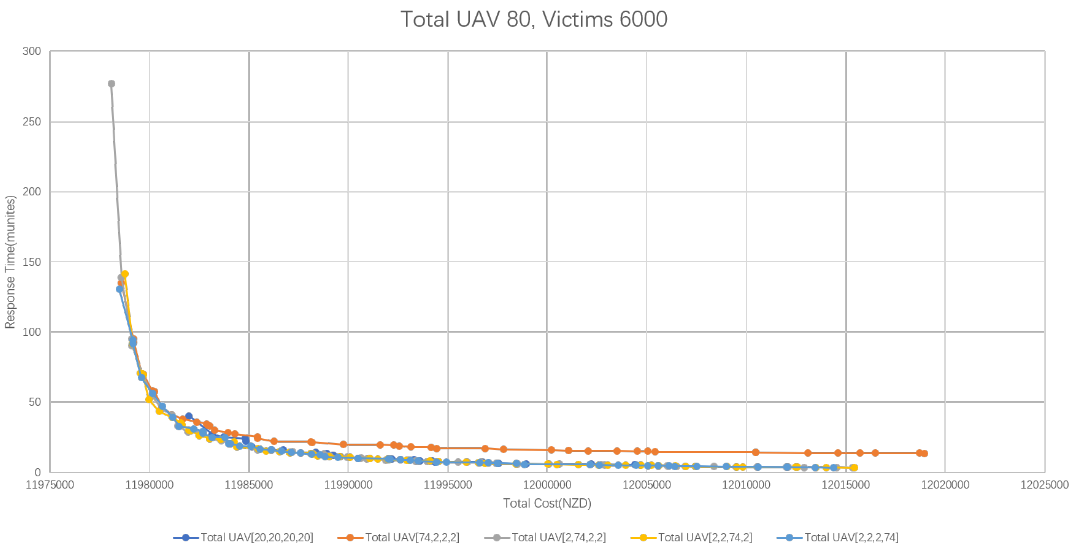

Figure 4.20: S2_RT_TC_UAV_80_Victims_6000

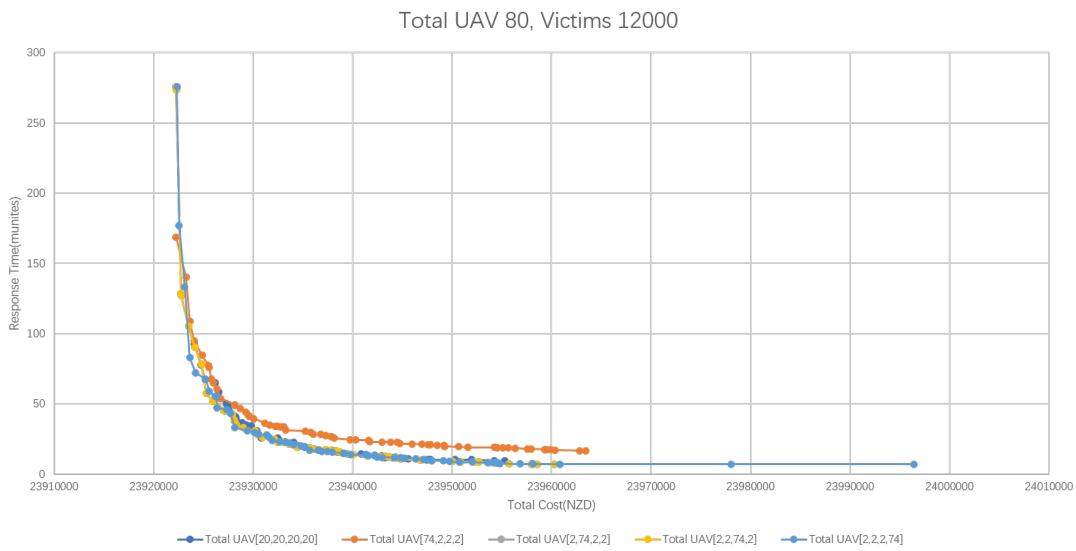

Figure 4.21: S3_RT_TC_UAV_80_Victims_12000

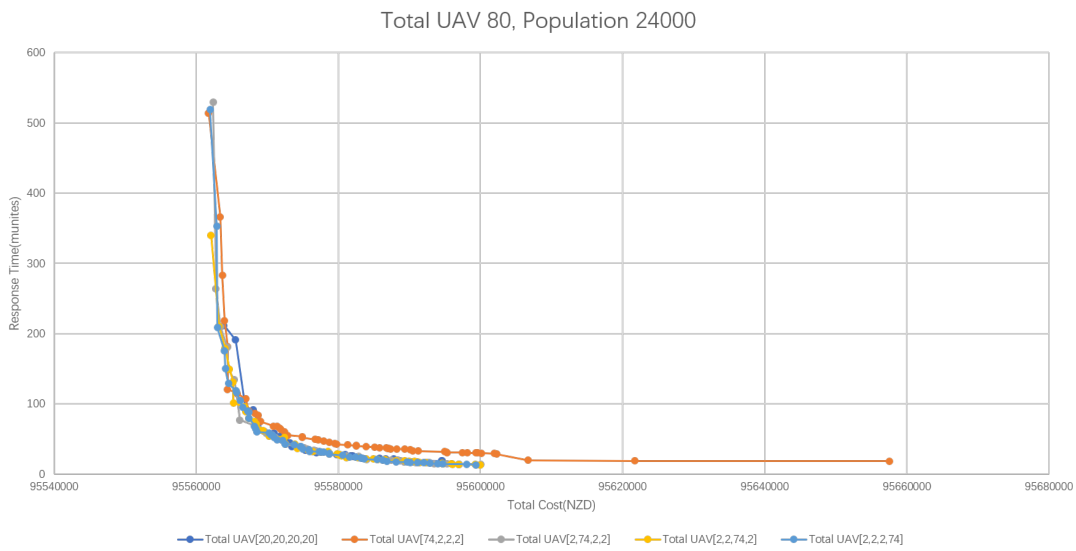

Figure 4.22: S4_RT_TC_UAV_80_Victims_24000

Figure 4.19 - 4.22 demonstrate that the minimum total cost increased while the number of victims increased. However, the correlation of response time and the total cost is similar to Study Case 2. There still are turning points on the curves. It means that whatever the number of victims increases, the optimal solution could be worked out by the algorithm. In addition, the optimal points move to the direction the total cost

ascended. Because as the number of victims increasing, more life resource is required and UAVs have to fly more distance to complete more tasks, e.g. delivering food, water and medicine. These factors would result in more cost. There is a longer curve in each figure. Compared with the other four curves in each figure, more cost is required and the response time is approximately the same. It depends on the location of TEU and the deployment of UAVs. If the location of TEU is farther from the section where UAVs are deployed more, more response time will be required to complete the tasks. For example, in Figure 4.19, the red curve is the longest and 74 UAVs were deployed in section 1, and the TEU is in section 12. It is much farther than the distance between section 12 and section 9, 11 and 14. In Figure 4.20 - 4.22, the same reason caused the longest curves.

4.5 Study Case 4: TEU Location Based on Different Distribution of EMS

4.5.1 Configuration

Before the simulation, in order to eliminate the negative effect caused by the number of UAV, the UAV quantity is set to the same. 20 UAVs are deployed in each EMS. The total number is 80. The affected victims were 6000 as shown in Table 4.2. Food is located in section 4 and water is deployed in section 10. TEU cannot be built in the section which is selected for EMS. The sections can be selected for TEU location in every scheme and the sections for EMS deployment will be listed in Table 4.27.

Table 4.26: EMS Distribution and Alternative TEU Location

Scheme	Sections where EMS located	Sections can be selected for TEU location
1	2,7,9,4	2,4,5,7,10,11,12,14
2	11,13,14,15	1,2,4,5,6,7,8,11
3	4,6,13,15	2,4,6,7,8,10,11,13
4	2,7,12,15	2,4,5,7,8,10,12,13
5	2,3,5,6	6,7,8,10,11,12,13,14
6	3,8,12,15	1,4,5,6,8,10,11,12,13
7	2,5,11,14	2,5,6,7,8,10,11,12,14

4.5.2 Simulation Result and Analysis

TEU is used as a temporary assisted medical service centre to provide medical service and life resource to victims who are delivered to the location from affected sections. TEU location depends on the locations of EMS, food, water and victim density in each section. The number of UAV in each EMS also counts. The changeable factor is only EMS location which resulted in the distribution of TEU.

Table 4.27: EMS Distribution and Optimal TEU Location

Solution	EMS Section	TEU Number	TEU Location
1	2,7,9,4	1	5 or 6
2	11,13,14,15	1	5 or 7
3	4,6,13,15	1	5
4	2,7,12,15	1	1 or 5 or 6
5	2,3,5,6	1	9 or 14
6	3,8,12,15	1	5
7	2,5,11,14	1	6

Table 4.28 demonstrates different TEU location based on various EMS location. Each solution presented one TEU. For example, the fourth solution has three possibilities of TEU location, 1 or 5 or 6. Any of these locations is optimal.

In order to explain Pareto optimal solutions better, another simulation has operated. In this simulation, total UAV is 65, and deployed in section 1, 9, 11, 14.

Table 4.28: Samples of Pareto solutions

Section	TC(NZD)	RT(minutes)	TEU	Total UAVs	EMS Location			
					1	9	11	14
1	180646.248	40.062	3	53	15	15	0	23
30	182458.711	35.048	3	56	14	15	0	24
83	205813.369	44.573	4	65	15	15	10	25
98	165703.059	34.744	3	53	15	13	0	25
161	130391.141	26.114	3	56	15	14	0	25
215	211133.196	52.353	3	44	0	11	10	23
732	171687.352	47.507	2	35	0	12	0	23

Interestingly, some solutions with more than one TEU came out in the Pareto group in the generations. However, these solutions not only were too expensive, but also were the response times too long. Consequently, after the optimization, new solutions with one TEU have replaced the old solutions with more than one TEU, as they cause lower costs and the same or even shorter response times.

This thesis took solution 1, 30, 83, 98, 161, 215 and 732 for example in Table 4.29. Each solution has more than one TEU. The total cost was more expensive and the response time was longer than those in the solutions with one TEU which have been listed in the appendix. For instance, solution 83 has a response time of 44.573 minutes, costs $205813.369, and utilizes a total of 65 emergency UAVs. Out of the 65 emergency

UAVs, 15 were from EMS in section 1, the other 15 were from EMS in section 9, 10 were from EMS in section 11, and 25 were from EMS in section 14.

4.6 Study Case 5: Simulation of UAV Path Planning

4.6.1 Simulation Results

The obstacles are generated randomly by using MATLAB. The current distribution of the obstacles is different from the last time. Various distribution has resulted in distinct planned path and path length. The experiments were carried out six times. The distribution and planned path of each experiment was displayed in Figure 4.23-4.28. The calculation and comparison of the distance, which was generated by Bezier Curves and optimal path, and the energy consumed by the UAV which travelled along the BezierCurve (km) and the optimalPath (km) and EnergyUse (kJ) will be displayed in Table 4.30-4.35.

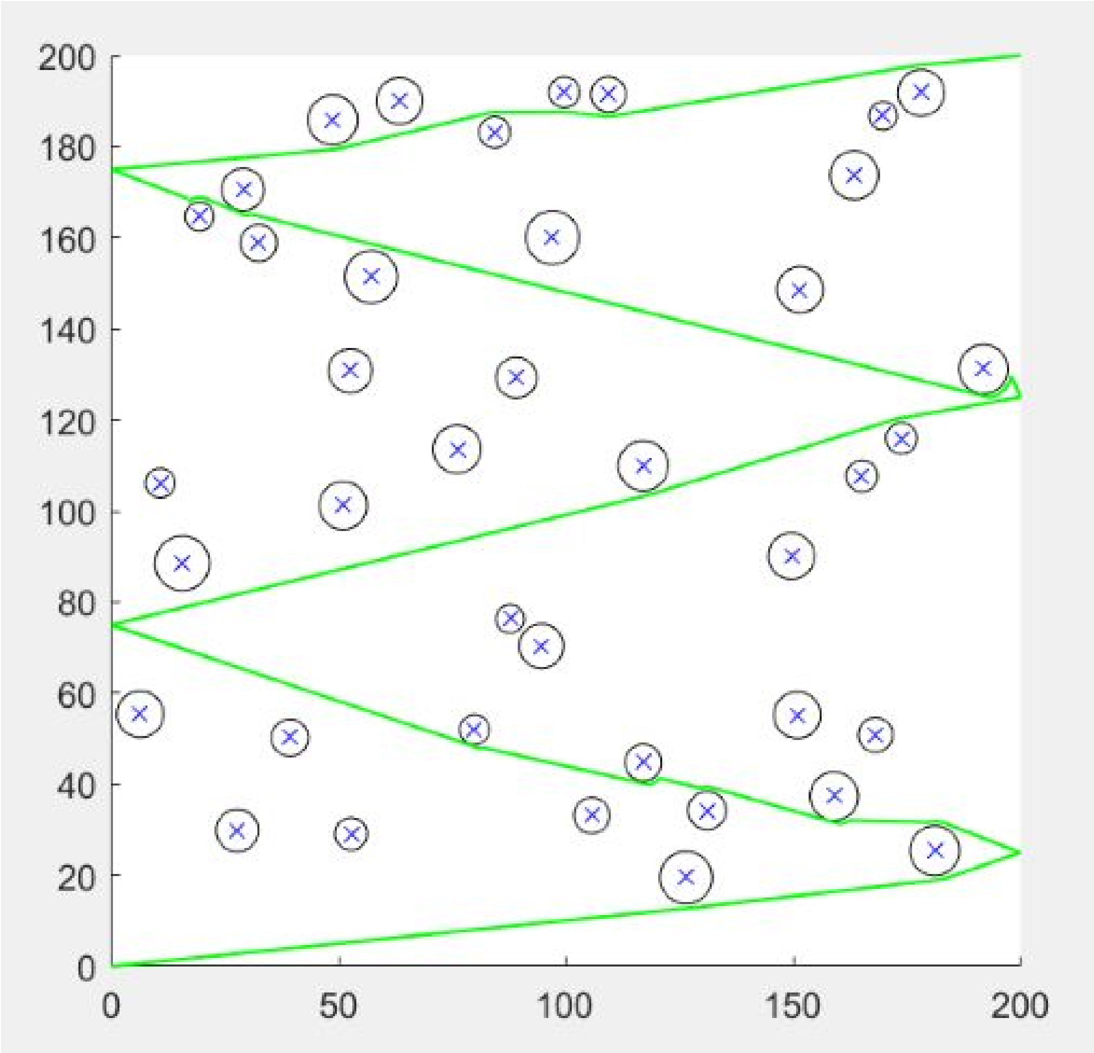

Figure 4.23: Path Planning (1)

Table 4.29: The Comparison of Length and Energy Consumption (1)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	2.103	12.385	0.672	13.611	3.046	31.817	3304
optimalPath	2.105	12.460	0.673	14.035	3.048	32.321	3298.6

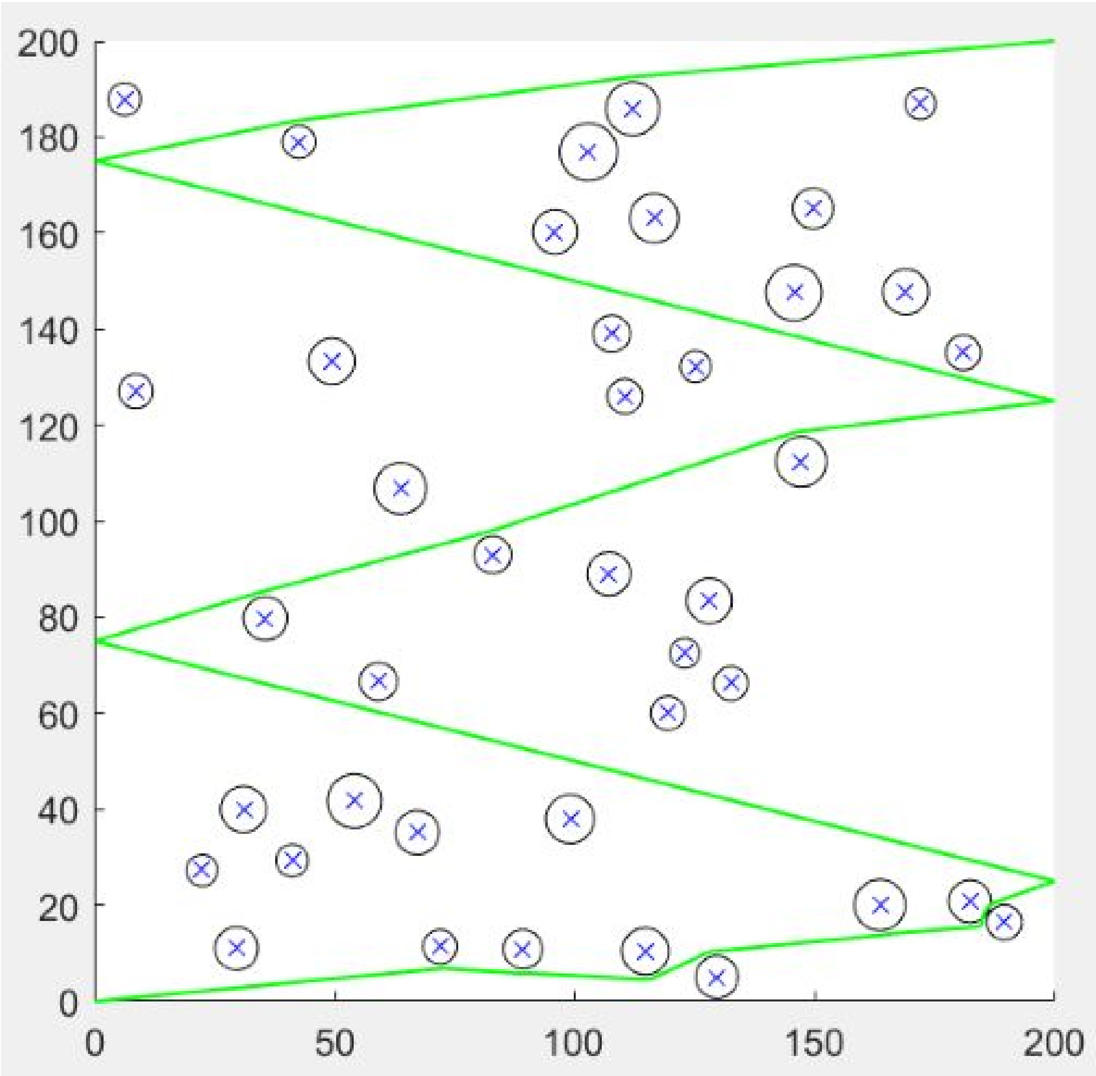

Figure 4.24: Path Planning (2)

Table 4.30: The Comparison of Length and Energy Consumption (2)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	15.745	26.791	5.416	25.516	6.834	80.302	8338.8
optimalPath	16.172	27.299	5.418	25.987	6.838	81.714	8339.6

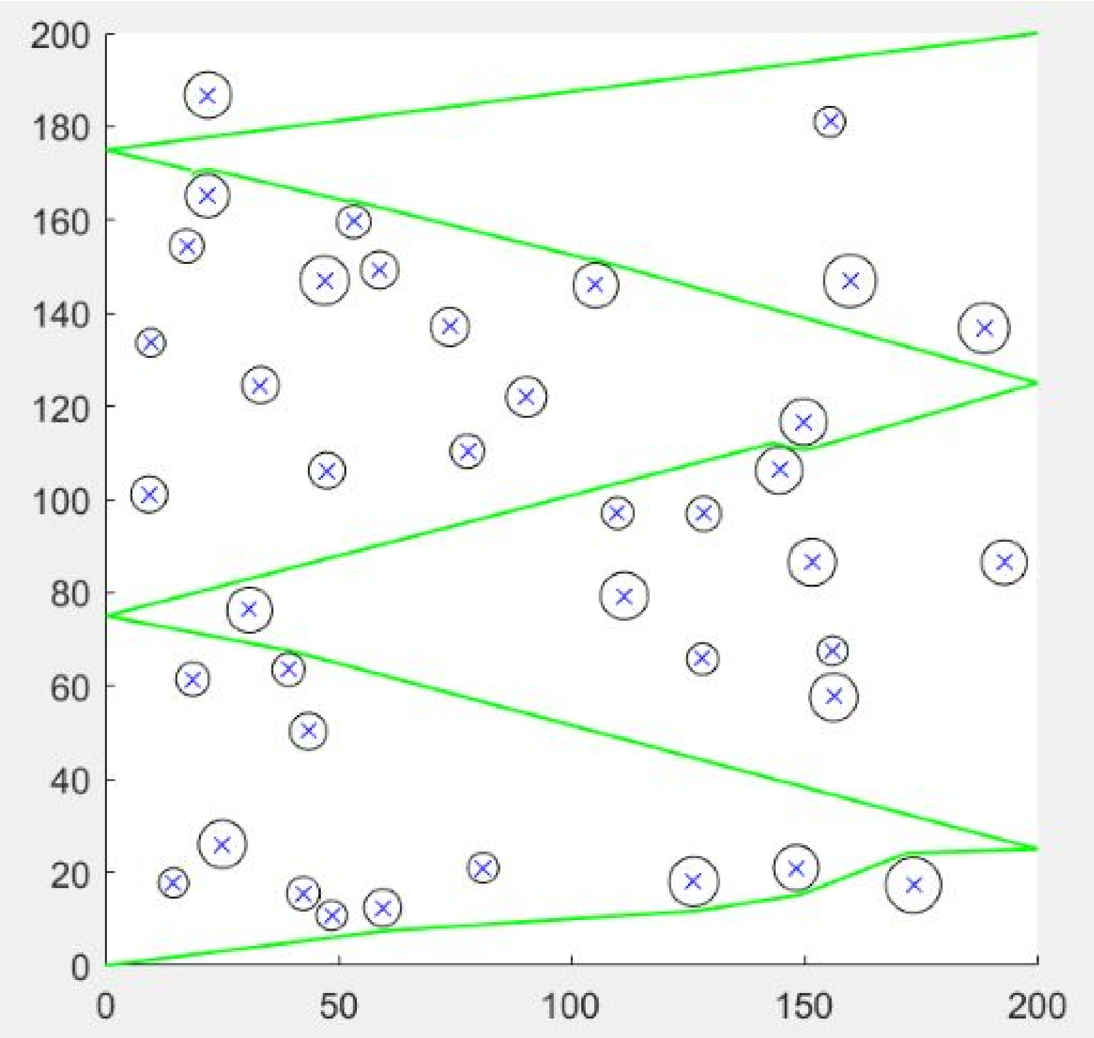

Figure 4.25: Path Planning (3)

Table 4.31: The Comparison of Length and Energy Consumption (3)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	19.050	27.637	8.651	32.370	6.834	94.542	10188
optimalPath	19.482	28.146	8.670	32.915	6.838	96.051	10135

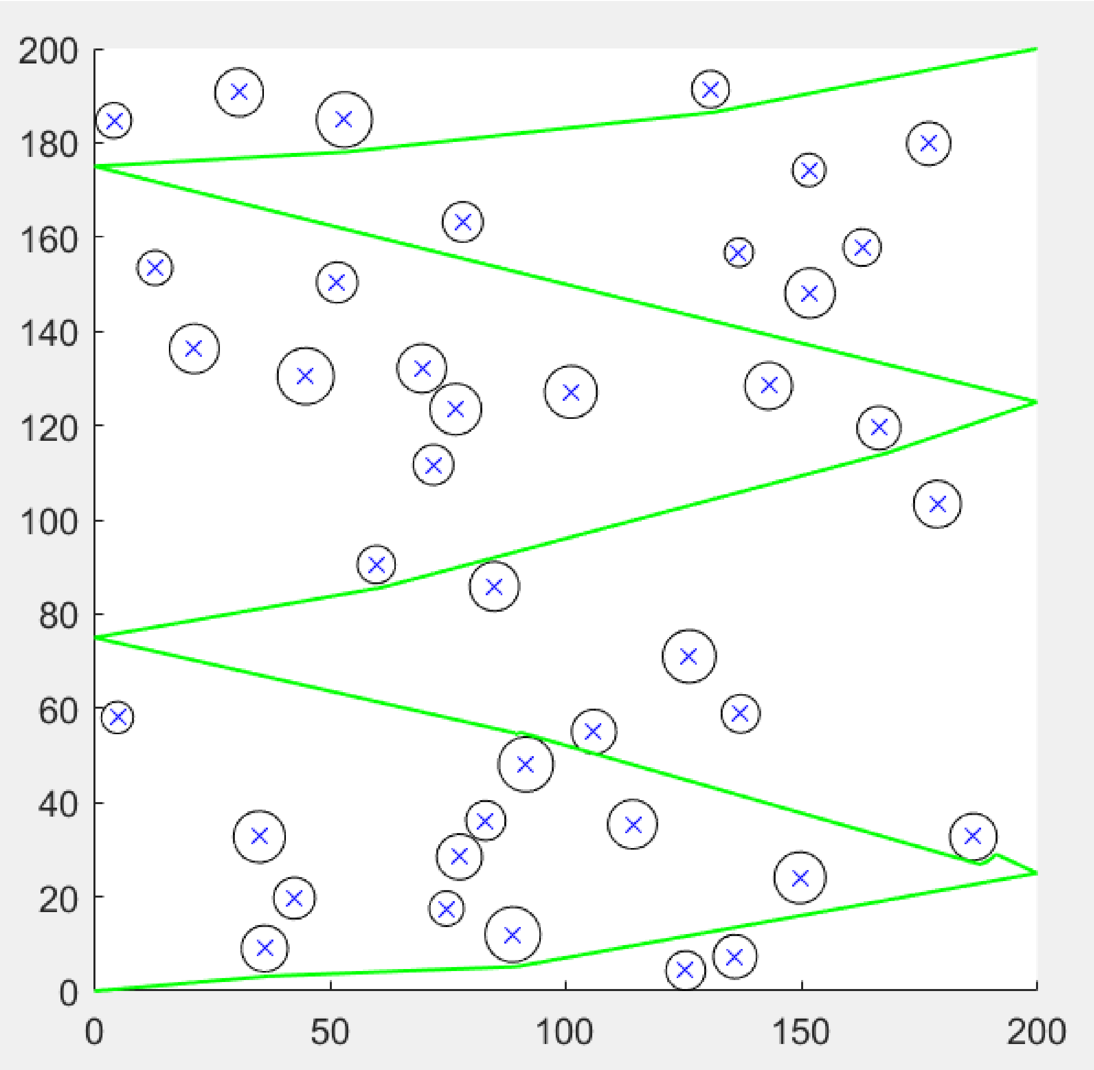

Figure 4.26: Path Planning (4)

Table 4.32: The Comparison of Length and Energy Consumption (4)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	20.289	33.361	9.548	32.37	7.900	103.468	12033
optimalPath	20.722	33.919	9.568	32.915	7.9	105.024	11976

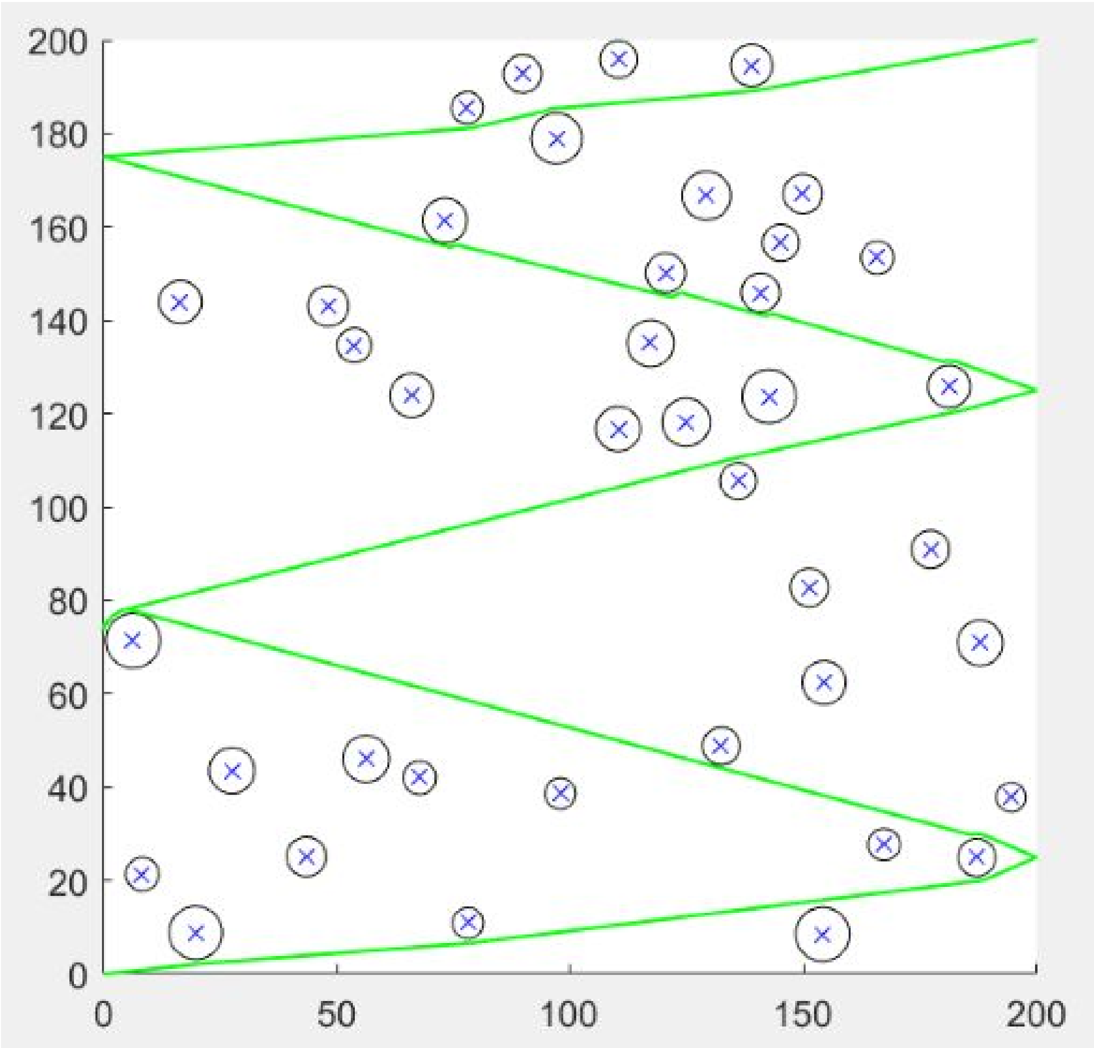

Figure 4.27: Path Planning (5)

Table 4.33: The Comparison of Length and Energy Consumption (5)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	22.183	45.222	18.471	41.478	10.868	138.222	13899
optimalPath	22.619	46.095	18.737	42.067	10.877	140.394	13822

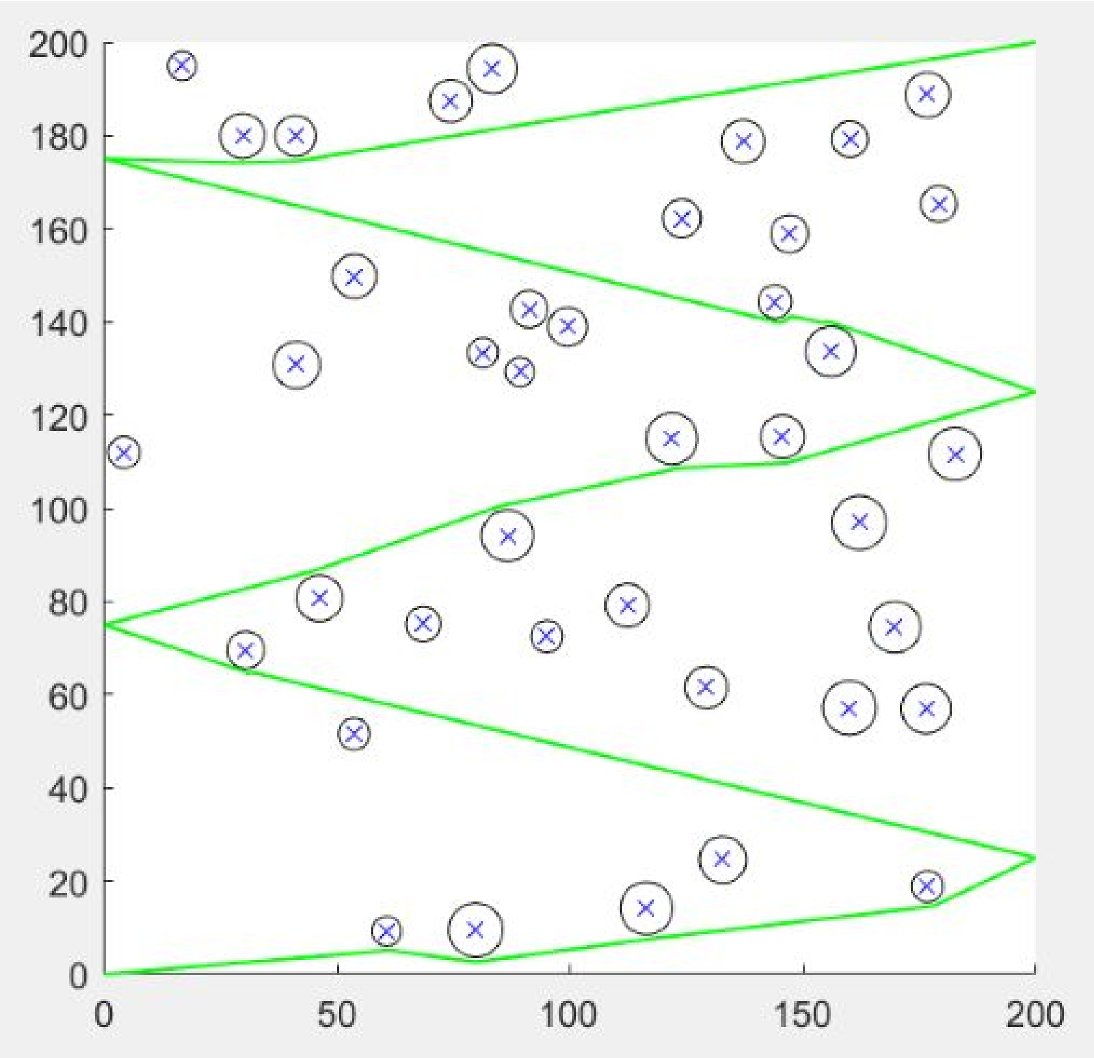

Figure 4.28: Path Planning (6)

Table 4.34: The Comparison of Length and Energy Consumption (6)

Type	Path1	Path2	Path3	Path4	Path5	Sum	EnergyUse
BezierCurve	26.536	46.583	20.622	46.063	12.576	152.380	15749
optimalPath	26.980	47.459	20.891	46.694	12.586	154.610	15665

4.6.2 Results and analysis of UAV Path Planning

According to the figures in Section 4.6.1. The paths have been planned. The green lines present the path along which the UAV travelled. The six points on the board consist of one start point and five destinations. Point (0, 0) is the start point. The planned paths bypassed the obstacles which are in the flight paths of the UAV to avoid collision.

As for the optimalDistance in the tables, they were calculated by Inverse Trigonometric Function. Obviously, the length of Bezier Curves is shorter. However, it is not suitable.

Firstly, the energy consumed by UAV which moved along Bezier Curves was more than the consumption along the optimalDistances.

Secondly, the length of Bezier Curve is still an approximate value. The distance generated by Inverse Trigonometric Function is closer to the real distance.

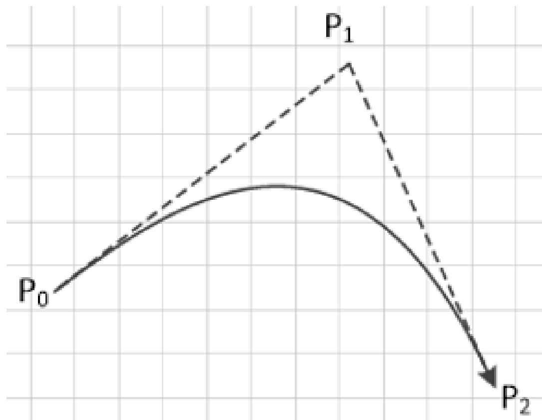

Figure 4.29: The Bezier Curve Constrained by the Three Points

Thirdly, the Bezier Curve cannot guarantee safety. These figures demonstrate the radius of the obstacle and the arcs around it. The minimum radius is ***(r + ws/2)***. The arc is the closest path to the obstacle. As shown in Figure 4.29, The Bezier Curve is tangent to the triangle formed by P_0, P_1 and P_2. The three points are on the arc which UAV travels along. The distance between the points on the Bezier Curve and the centre of the obstacle is shorter than the minimum radius. It means that the Bezier Curve is closer to the centre of the obstacle. In terms of the previous design, the radius of the arc around the obstacle has to be no shorter than the minimum radius. Obviously, if UAV is getting closer to the obstacle a bit, it will crash into the obstacle. Although the length of

Bezier curve is shorter, it is not safe.

And also, the planned path generated by the arc algorithm is used to navigate UAV flight close to obstacles without collision. Therefore, the arc algorithm is selected to plan the path and to calculate the length.

As for the calculation of energy consumption, in the simulation, a method is used to complete the calculation (Carson, 1982).The pseudocode will be shown below.

set constants:

air density:rho

equivalent parasite area:f

the weight of aircraft:w

the width of UAV:span

Oswald efficiency factor:eo

minimum velocity:10

maximum velocity:15

Coefficient: $A = rho * f/(2 * W), B = 2 * W/(rho * span^2 * pi * eo)$

Drag-Lift ratio: d_l

energy efficiency: eta_pos

Energy consumption: $d\_l * distance * eta\_pos.$

The file $optimization\_te.m$ is shown in GitHub:

https://github.com/diaoli-119/uav-path-optimization/tree/master/src/MultiDestinations

4.7 Summary

The precondition, which is the price of food, water and TEU, is assumed unchangeable to the five study cases. The price assumptions for the five study cases are the same.

Study Case 1 simulates that the response time is decided by the deployment and the number of UAVs. If more UAVs are deployed closer to the location of TEU, the response time will be shorter. And the response time is inversely proportional to the number of UAV. More UAVs can make the response time shorter.

Study Case 2 simulates that the response time is inversely proportional to the total cost. Each curve in every figure has a turning point. This is an optimal point which indicates the best solution.

Study Case 3 simulates that the correlation of response time and the total cost is similar to Study Case 2. The turning points still illustrate the best solutions. If the number of victims increasing, UAVs have to fly longer distance to deliver more life resource. The total cost will increase, otherwise, the total cost will be less.

Study Case 4 simulates that the optimal TEU locations are generated by different locations of EMS. Table 4.28 shows that every deployment of EMS decides distinct locations of TEU. Some scheme generates more than one optimal TEU. It gives decision makers more option.

Study Case 5 simulates the planned UAV path and calculates the energy consumption. Each path bypasses all of the obstacles on the path from the start location to the multiple destinations successfully. UAVs can be navigated to cover all the destinations by the planned path.

Chapter 5

Conclusion and Future Work

The object of this thesis was to provide an in-depth understanding and action of resource allocation. The purpose of resource allocation is to minimise response time and total cost, especially in the situation that the budget is limited. Due to the destroyed traffic on ground, terrestrial vehicles and people cannot reach some unpassable locations, e.g. lake, forest and debris caused by a disaster. UAV is considered to deliver life resource to these places with its high mobility.

5.1 Conclusion

This research presented an MO optimization method which helps to make the optimization of the combination of the response time, cost and emergency vehicles and to design the response tactics to a disastrous event. The model obtains the locations of emergency units in Auckland and dispatches emergency vehicles to evacuate injured victims, who have non-life-threatening injuries but need medical services. An evolutionary algorithm called PSDA was used to acquire the approximate Pareto set of optimal solutions where each solution represents an emergency response strategy. This method enables decision-makers to tradeoff response strategies based on values of the response time and cost of

TEU, emergency vehicles, water and food.

In addition, ***direct path planning algorithm*** and ***arc path planning algorithm*** are created to plan UAV path. The purpose is to navigate UAV to go through every affected sections to collect information of victims and deliver life resource efficiently and security. Efficient means that the path is the shortest on the precondition of security. Security means that UAV bypasses all the obstacles on the path, e.g. trees, building, telegragh poles, when it flies to multi-destinations without any collision.

5.2 Future Work

Because of the limited time period, some work will be investigated in future.

Firstly, the calculation of energy consumption and optimization. Although energy consumption is worked out in the study case 5 in chapter 4, it referred to an open source algorithm. The algorithm is used to calculate the moving energy consuming. The hovering energy consuming cannot be worked out by the algorithm. In addition, recharging energy is not presented. It is a key point for energy consumption and supplement. The whole energy usage circle is closed with consumption and supplement.

Secondly, the throughput of the network is not proposed. The bandwidth of the wireless network is important for victims to connect to medical servers out of the disastrous areas. If the bandwidth is capable of supporting video communication, it will increase the rescuing efficiency and the survival rate.

Thirdly, the path planning algorithm is not able to solve the events related to the dynamic obstacles. Swinging trees, moving UAVs, and even flying birds are fatal issues. If UAVs cannot avoid these obstacles, they will not able to complete the search and rescue tasks.

And this research will consider other aspects. Firstly, providing various services to victim categories based on the extent of injuries. Secondly, considering that multi-UAV operate multi-tasks, and the birds in the sky, they could be the dynamic obstacles on the flight path. Therefore, make sure UAV avoid dynamic obstacles on the flight path. Thirdly, UAV with a heavier payload and long-range is necessary. When the ambulance cannot arrive at the disastrous places to evacuate life-threatened victims, UAV is able to play a role in air taxi to carry the victims medical centres.

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