論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Model development for enhancing airport operation in immediate disaster response
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出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第10686号, 授与年月日:2017年9月20日, 学位の種別:課程博士, 審査員:花岡 伸也,髙田 潤一,髙木 泰士,朝倉 康夫,福田 大輔
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第10686号, Conferred date:2017/9/20, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Type(English)	Doctoral Thesis

Model development for enhancing airport operation in immediate disaster response

Submitted to the Department of International Development Engineering
in Partial Fulfillment of the Requirements of the Degree of
Doctor of Philosophy

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2017

ACKNOWLEDGEMENTS

The success of this thesis owes to the help, support, and inspiration of many people. Thanks God for supporting entirely through this wonderful journey all together. Foremost, I would like to express my sincere gratitude to my advisor Associate Professor Hanaoka Shinya for the continuous support for this dissertation for his endless patience, keen motivation, enthusiasm, and insightful suggestions.

Furthermore, I take this opportunity to express my gratitude to Professor Junichi Takada, Professor Yasuo Asakura, Associate Professor Hiroshi Takagi, and Associate Professor Daisuke Fukuda as my dissertation committees who have been spending time for examining dissertation with encouragement and valuable guidance on the thesis.

I would like to express my gratitude to Assistant Professor Nakamichi, Assistant Professor Kawasaki and all Hanaoka lab members for their greatest support. I owe my special thanks to my friend Seongnyeong who have been together since the start of my master's course in Tokyo Institute of Technology and who encouraged me fully for doctoral course from the start.

Lastly, I would like to thank my family who has supported me throughout entire process. I would really like to thank to Dr. Choi, mom, little-sister-Wonkyung, little-brother-Seokwon who brought me up entire life under their endless love and praying. I will be grateful forever for your love.

Model development for enhancing airport operation

in immediate disaster response

ABSTRACT

Natural disasters are in increase and they cause devastating impact on destroying nation's infrastructure widely so that sometimes requires involvement of not only national but also worldwide humanitarian relief assistance. When dealing with reducing impact of disasters, disaster management has gained noticeable attention. Among disaster management cycle, disaster response is closely related to humanitarian logistics operation. When road transportation is severely damaged due to earthquakes, tsunamis, hurricanes, and etc., air transportation usually serves as a main responding transportation mode in the region.

Lessons learned from 2011 Great East Japan Earthquake highlight again about airport operation in immediate disaster response. Immediate disaster response airport operation includes transporting personnel and evacuees, loading and unloading aid goods, fueling and refueling, information collection, emergency medical care, and so on. Since such roles are executed in and through airports, airports are regarded as disaster response base.

Regarding airport operation as disaster response base, Japanese government constructed a disaster management network in each region in order to prepare and respond to expected natural disasters such as earthquake and tsunamis after Great East Japan Earthquake. It is not only Japan that prepares disaster response planning with utilization existing airport infrastructures. Current practices such as Get Airports Ready for Disaster program provided by DHL, Southeast Airports Disaster Operations Group and Western Airports Disaster Operations Group (SEADOG/WESTDOG) in United States, regional logistics hub for humanitarian assistance in Panama are planned as a disaster preparedness and response planning. However, there is only limited number of research in this area with framework development to assist decision making of airport operators and related stakeholders.

Therefore, this study develops mathematical models to enhance airport operation in immediate disaster response. Current challenges of an airport in immediate disaster response are identified and conceptual framework to present three dimensional bases for assisting airport disaster response planning.

First, the first study focuses on a single airport operation dealing with limited space for sorting and staging relief goods and insufficient place for emergency worker's accommodation. It develops space planning methodology followed by calculation flow for base camp and staging area in a disaster response airport. The methodological procedure proposes a layout for a disaster response base within Shizuoka airport in Japan

The second focus of the study is to develop a model to estimate waiting time management of different airport operators with applying different queuing disciplines in an airport. The model is developed based on Jackson network queuing theory and considers various disaster response activities in an airport. The result suggests hybrid queuing discipline shows acceptable waiting time for higher priority operators. Also, the estimated data is compared with observed data regarding each airport's waiting time in Great East Japan Earthquake. Even though, there are some discrepancies in exactness of the model, tendency is found among three airports. We examined the same topology through comparing observed and estimated data and improved model accuracy by increase in transition probability from response activities to fueling.

Lastly, the study develops a model to estimate mean disaster response time of airports through cooperative plural airports operation scheme by an open Jackson network. The model is motivated by extension of previous chapter into plural airports network and the result reveals that cooperative role assignment among airport network in disaster response is effective in reducing mean waiting time of an aircraft in each airport.

The study concludes by summarizing its findings as in the last part. It is important to note that a single airport operation also affects the other neighboring airports operation so cooperative and collaborative operation framework should be built prior to large scale emergencies. The study also shows effect of how each airport can enhance its operation by reducing response time.

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1. Introduction

1.1 Background

Natural disasters are in increase these days throughout the world (ISDR, 2005). Japan suffered 2004 large Niigata earthquake and the December 2004 great Aceh-Sumatra earthquake and devastating tsunami in the Indian Ocean, the violent hurricanes followed by year by year such as August 2004 Charley, September 2004 Ivan, August 2005 Katrina , and September 2005 Rita in the Gulf Coast, and the October 2005 large earthquake in Pakistan. Such natural events come without notification and with great uncertainty. These natural disasters devastated infrastructure and made loss of lives and disruption in regional and national economy (Ismail-Zadeh,. and Takeuchi., 2007).

An extreme event such as earthquake, tsunami, flood, cyclone, and hurricanes allows need for research in disaster management. Nevertheless, disaster management planning is essential in society in order to mitigate risk, prepare, response and reconstruct well when disaster hits a region. Following the March 2011 Great East Japan Earthquake, there was a certain need to revisit disaster management planning regarding natural disasters. In order to build a sound disaster preparedness plans in many disaster prone cities and countries, academics and practitioners pay careful attention for disaster management planning.

Airports are often referred to as disaster response bases or humanitarian logistics bases in the immediate phase of disaster response. Especially, when responding to these disasters, airport infrastructures are critical since they are facilitated in immediate disaster response phase (first 72 hours after disaster strikes the region).They provide critical disaster response functions and facilities, such as staging areas, logistics centers, base camps, and medical treatment, which ensure the effective flow of commodities and personnel. However, the operation in airports for post-disaster activities faces limitations owing to insufficient parking space for aircraft, limited space for temporary storage of fuel in drums, lack of prepared space for temporary lighting facilities, lack of storerooms for storing relief goods, and lack of space for setting up staging care units (Hanaoka *et al*., 2013).

Regarding airport operation as disaster response base, Japanese government constructed a disaster management network in each region in order to prepare and respond to expected natural disasters such as earthquake and tsunamis after Great East Japan Earthquake. It attempts to assign several airports officially in each region as disaster response bases in Japan. Previous natural disasters such as in Haiti Earthquake 2010 as in Figure 1-1 provide lessons for measures to enhance airport disaster response operation. It is not only Japan that prepares disaster response planning with utilization existing airport infrastructures. Current practices such as Get Airports Ready for Disaster program provided by DHL, Southeast Airports Disaster Operations Group and Western Airports Disaster Operations Group (SEADOG/WESTDOG) in United States, regional logistics hub for humanitarian assistance in Panama are planned as a disaster preparedness and response planning.

Not having disaster response plans that, in detail, considered post disaster humanitarian logistics hampered public sector response as local officials had to confront the crisis without any guidance about how to proceed (Holguin-Veras *et al.*, 2012). Thus, it is important to develop specific and detailed disaster response plans for mid/large cities for the reasons discussed above. Little research has been conducted on providing guidance for disaster response operation of airports in microscopic and macroscopic viewpoint. The formulation of guidelines for the development of disaster preparedness plans related to large-scale catastrophes was hampered in the aftermath of the Great East Japan earthquake (Holguín-Veras *et al.*, 2012, Kapucu *et al.*, 2007).

Figure 1-1 Air side congestion in Port-au-Prince airport in Haiti

To the best of our knowledge, there has not been a study which develops, proposes and applies holistic approach for a single airport disaster response operation and plural airports as well under one research theme. Therefore, the study arises following questions to develop a methodological framework for airport operation: what is the core bottlenecks in airport operation in disasters? Why is the bottleneck occurred and what are some approaches in relieving bottlenecks for air transportation network in immediate disaster response?

1.2 Research Objectives

Therefore, the study develops framework for enhancing airport operation in disaster response planning while utilizing existing facilities and conditions of airports. In order to make use of lessons learned from past natural disasters, arising practical approaches for airport disaster response base and relevant government level plans, the study synthesizes relevant literature reviews to develop models to enhance airport operation based on three bases such as decision level, focus, and management.

There are three objectives achieved in the study:

1. To develop a method for diagramming a base camp or space for emergency workers and a staging area to be used during sorting, storing, loading, and unloading of relief goods in a humanitarian logistics base airport.
2. To develop a model for assessing waiting time of different operators' aircrafts in disaster response
3. To develop a model for cooperative response operation by assigning main disaster response roles to reduce mean and total disaster response time in plural airports

1.3 Focus and scope of the study

Airport operations is the effective and efficient planning, implementation, and control of the production of air service at an airport (Price and Forrest, 2016). It is functional area within airport management and it is committed to support safety management and emergency management within airport. In specific, airport operations in emergency management considers planning, implementing, and controlling actions to respond disasters in order to reduce risk in life saving and securing properties at airport.

In order to enhance overall operational effectiveness in emergency management, segmentation in management process is required to acquire valid elements and factors to realize the entire management by stages. This will enable managers and decision makers to concentrate on prioritization of tasks to improve the operation (Zhou *et al*., 2011). Here, we focus on airport operation regarding both operational and strategic decision level on managing time and space based on airside operation. Objective 1 covers strategic planning, objective 2 as operational planning, and objective 3 as both strategic and operational planning.

Decision level

Decision level is divided into strategic, operational, and tactic operation in disaster management. The mitigation phase usually considers strategic efforts to reduce impact of disasters. As in disaster preparedness, prepositioning of warehouses in facility location problems (Balcik and Beamon, 2008; Ahmadi, *et al.* 2015) is often considered as a strategic decision. On the other hand, operational level decisions (e.g. the work by Barbarosoglu and Arda, 2004 for vehicle routing, transporting personnel and equipment, last mile distribution of relief goods) and tactical initiatives (e.g. the work by Falasca and Zobel, 2011 for inventory management) are more relevant during disaster response. In disaster recovery phase, restoring communities back to prior-disaster is main concern and it usually is involved in long-term decision planning. Thus, there is a need to extend the analysis to the other decision levels (tactical and operational). Research on manpower management during emergencies, capacity planning, and casualty transportation is needed (Caunhye *et al*., 2012). This can be modeled as tactical and operational decisions. Similarly, we could consider decision level for disaster response operation of airports in to three level (Modified from Barbarosoglu *et al*, 2002). In airport operation disaster response planning consideration, three decision levels include the following components:

- Operational planning
  - The vehicle routing of aircrafts from the base to disaster points
  - Loading/unloading/delivery/rescue plan of each aircraft in every tour
  - The re-fueling schedule of aircrafts
- Tactical planning

- Determination of aircraft composition
- Assignment of parking spots in air side

➢ Strategic planning: imposing goals, targets, and constraints on tactical decisions, which are, in turn, implemented and supported via a number of operational execution functions
  - Establishment of prepositioning relief items
  - Assessment of equipment condition and preparation
  - Proposal of flexible space use in air and landside of airports

Framework for enhancing airport operation in disaster response

Based on our interviews to airport operators in Japan, literature reviews on academics and reports, we propose a framework to enhance airport operation in disaster response as in Figure 1-2. Normal airport operation itself is already highly related to management of time and space of an airport. Decision variables are that airport operator can take control as in the left side and performance index refers to result of disaster dynamics in an airport as in Figure 1-2. Here, we mainly develop mathematical models to improve performance index in airside of airports to achieve three research objectives in the study. In disaster response, both airside and landside space is occupied with aircraft, people (organizations) and goods. This model is the core of a

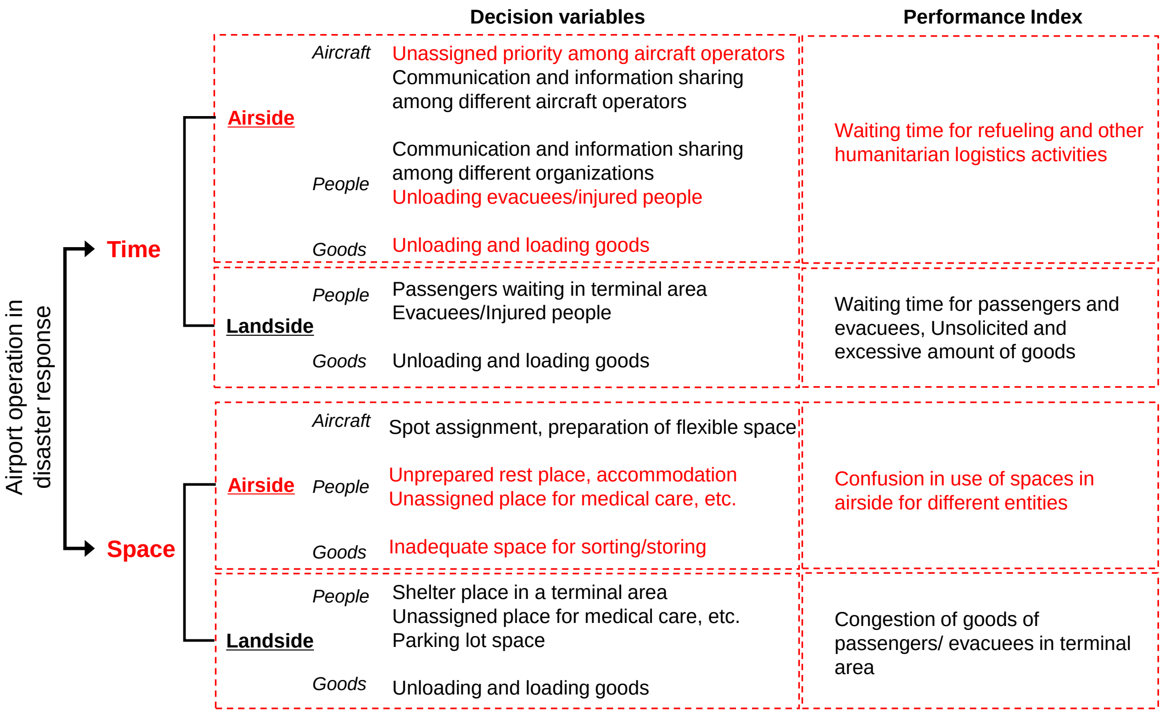

Figure 1-2 Framework for enhancing airport operation in disaster response

decision support system for airport operators, local and central government and other international organizations to assist organizations in charge of airport disaster response operation. (Vitoriano *et al*. 2011)

In addition, the study focuses on utilizing existing airports facilities and air transport network, while investigating possibilities in enhancing disaster response capacity of airports and the region and not on developing extra infrastructures significantly. Here, we mainly develop mathematical modeling and also conceptual framework to assist the theory and literature review is structured again to develop and propose a new approach for humanitarian response in airports and related stakeholders in immediate disaster response.

Proposed enhancement countermeasures are prioritizing differentiated aircrafts operation, assigning weight in major response roles in airports operation, and preparing a methodological framework for space planning in an airport as a response base. This could be useful in developing airport operators, local and central government, international humanitarian organizations and others to collaborate effectively. Especially, when there is competence against each other for sharing limited resources, we may find a balancing point for all to execute humanitarian logistics activities.

1.4 Dissertation outline

The thesis is consisted of six chapters as in Figure 1-4. Relations between each chapter are also depicted in the figure. Chapters were constructed in order to analyze each interconnected research objective. Management of a single airport operation was discussed in Chapter 3 and 4 and management of plural airports was discussed in Chapter 5. Chapter 3 developed a methodology for improvement in space and Chapter 4 and 5 for time. The details on each chapter of thesis are as the following:

Chapter 1 explains background, goal and objectives, scope and focus, outlines and approach of the study, and contribution of the study.

Chapter 2 includes relevant literature reviews on operation of airports in disasters and disaster management planning. Airports as disaster response base are defined and current relevant practices globally are discussed. In this section, we developed a three dimensional bases for disaster response operation of airports based on management, decision level and focus of operation. This section also reviews methodological literature review to support models in Chapter 3, 4, and 5.

Chapter 3 develops a methodology for a single airport operation on space management by developing a diagramming methodology used in architectural planning. The chapter investigates space allocation of a disaster response airport by developing a conceptual framework and estimation model. The model is applied to Shizuoka airport in Japan as a case study to examine feasibility since it has been selected as a disaster response airport with ongoing discussions on space planning.

Chapter 4 models waiting time of different aircraft operators with application of Jackson queuing network model to explain disaster response activities in a single airport. Each disaster response activity is modeled as a server and aircrafts are regarded as arriving customers in queue. The model is applied to three airports (Hanamaki, Yamagata, and Fukushima airport) in Great East Japan Earthquake as a case study. Validation was conducted with comparing observed data and estimated data, sensitivity analysis and parameter adjustment. On the basis of this section, extension to plural airports is discussed in Chapter 5.

Chapter 5 develops a model to estimate mean disaster response time of airports through cooperative plural airports operation scheme by an open Jackson network. Since waiting time in a single airport affects the overall connected air transport network, cooperative role assignment among plural airports is proposed and modeled in order to detect improvement chances of operation in reducing mean waiting time of an aircraft in all airports. The model is examined with numerical experiments.

Chapter 6 summarizes the new findings drawn from the research and suggestions for future research.

Figure 1-3 Dissertation framework

1.5 Contributions of the Study

One of possible outcomes is a model that can assist decision making in immediate disaster response also as well as preparedness planning. In disaster management planning, preparedness and response cannot be separated but rather closely related each other. It is valuable to understand interactions in a single airport and among airports in emergencies. Also, in practices, it is valuable to manage multiple stakeholders efficiently in airports.

Previous studies have been rather limited to qualitative approaches and a few existing relevant quantitative models consider management of link which identifies dispatching behavior, helicopter routing, delivery of aid goods, and so on. This study focuses on node management as airport is considered as a point of entry and first attempts to develop models to improve operational bottlenecks in airports in humanitarian logistics.

Firstly, this study clarifies space planning procedure for developing airport as a disaster response. It utilized conventional methodology used in architectural space planning with applying adjacency matrix and bubble diagram along with estimation flow for approximate size calculation. This will assist decision makers to assess current vacant and open space which may be used in flexible purpose in disaster response.

Secondly, proposed Jackson network model to describe airport disaster response operation establishes a base guidance for further mathematical model calibration. It examines the same topology through comparing observed and estimated data. Improved model accuracy is achieved by increase in transition probability from response activities to fueling. The model itself could be used as a reference for local and central government especially regarding airport operator and planner to guide disaster response policies.

Thirdly, this study explores the application of Jackson network model not only to a single airport operation but also plural airports operation in order to clarify optimal disaster response operation and cooperation among airports. The findings could assist national and international organizations for building robust disaster response planning while arguing necessity in collaboratively assigning main disaster response roles covering and assisting each airports.

2. Literature review

As this study addresses the issue of airport operation and disaster management planning, this section addresses detailed reviews on existing knowledge from academics and practices to confirm study goal and objectives. Chapter 2 discusses the following topics: Macroscopic viewpoint on disaster management and humanitarian logistics is first discussed in section 2.1. From section 2.2. to 2.5. covers airport operation specific viewpoint with determining roles of airports, challenges in operation, possibilities in coordination, and definition of disaster response base airport which the study focuses on. Especially, section 2.6. presents a holistic approach for building disaster response operation planning of an airport based on three dimensional bases such as management, decision level, and focus.

2.1 Disaster management and humanitarian logistics

2.1.1 Disaster management cycle

Disaster management can be defined as the discipline of avoiding and dealing with risks. Disaster management is a set of processes designed to be implemented before, during, and after disasters to prevent or mitigate their effects (Nikbakhsh E & Farahani R.Z., 2011). There are four stages in a disaster management as in Figure 2-1: mitigation, preparedness, response and rehabilitation. Disaster management involves different activities according to each stage. Mitigation involves barrier construction in order to minimize disaster impact, taxation, preventive measures and so on. Preparedness involves emergency planning, securing emergency supplies, construction of an emergency operations center, and so on. Response activities are to activate emergency plan, evacuation plan, fatality management, rescue activities, medical care and so on. Recovery deals with restoration activities, mass care for displaced population, cleanup activities (Altay and Green, 2006).

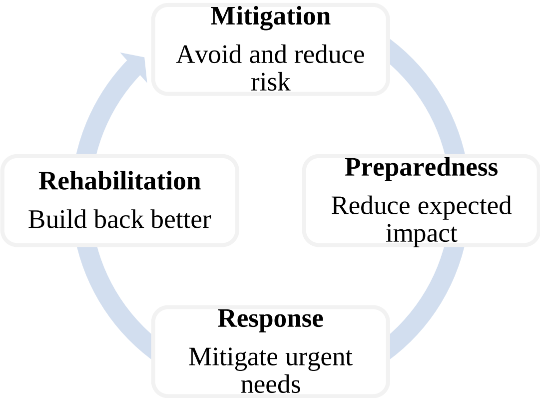

Figure 2-1 Disaster management cycle
Source: Modified from Tomasini *et al*, 2009.

2.1.2 Humanitarian logistics

Humanitarian logistics is defined as a logistics which deals logistical issues throughout a disaster management system, including various activities such as procuring, storing, and transporting food, water, medicine, and other supplies as well as human resources, necessary machinery and equipment, and the injured before and after disasters have struck (Nikbakhsh and Farahani, 2011). Precisely speaking, post-disaster humanitarian logistics is different from that of normal commercial logistics. Its demand is unknown and dynamic due to lack of information or access to the site. Supporting systems such as transportation may be changing along with circumstances of disasters. This could be regarded as a special operation of disaster response planning.

2.1.3 Bottlenecks in humanitarian logistics

Previous studies have identified what are critical success factors in post-disaster humanitarian logistics. Idea of critical success factors was first suggested by Daniel (1961). Certain factors are defined as factors that will be critical to the success of that organization, in the sense that, if objectives associated with the factors are not achieved, the organization will fail. (Huotari and Wilson, 2001)

Among critical success factor for humanitarian aid supply chain management as in Table 2-1, main consideration in dissertation discusses on capacity planning and transport planning of airport utilization. What affects capacity planning are warehousing, transport, material handling devices and human resources, and maximization of use of capacity. (Gunasekaran and Ngai, 2003). Capacity planning may be extended to include the ability of ports and airports to handle humanitarian relief goods under different disaster scenarios and assumptions.

As for airport capacity, the ability to take certain types of aircraft, cargo handling facilities, refueling, helicopter operational ability, and conflict with existing services will all impact on operational ability (Howard-Williams *et al.*, 2008). Airport capacity was considered as an important factor affecting relief operations in post-disaster especially in case of Haiti earthquake, Great East Japan Earthquake and Nepal Earthquake.

Table 2-1 Critical success factor for humanitarian aid supply chain management

Source: Adapted from Pettit and Beresfold, 2009

	Alternate descriptor	*Key aspects*
Transport planning	Transport availability and constraints	Transport mode, capacity, scheduling, maintenance and intermodality
Capacity planning	Storage, processing and transport capacity	Long- and short-term demand, number of warehouses/capacity, number of vehicles, and material handling equipment capacity

2.2 Roles of airports in immediate disaster response

Importance of air transport is especially critical in immediate disaster response phase. It is highlighted as an alternative transportation mode for road and rail transportation in earthquakes and tornadoes especially where road related modes are paralyzed. In immediate response phase within 72 hours, emergency medical care extremely depends upon on air. The airport (node) supports various humanitarian activities in emergencies and provides a base for impacted area. On the other hand, air route (link) enables delivering aid goods, transporting evacuees and so on.

Airports are often referred to as disaster response bases or disaster response bases in the immediate phase of disaster response. They provide critical disaster response functions and facilities, such as staging areas, logistics centers, base camps, and medical treatment, which ensure the effective flow of commodities and personnel. However, the use of available space in airports for post-disaster activities faces limitations owing to insufficient parking space for aircraft, limited space for temporary storage of fuel in drums, lack of prepared space for temporary lighting facilities, lack of storerooms for storing relief goods, and lack of space for setting up staging care units (Hanaoka *et al*., 2013).

The importance of airport disaster management has long been recognized, but the formulation of guidelines for the development of disaster preparedness plans related to large-scale catastrophes was hampered in the aftermath of the Great East Japan earthquake (Holguín-Veras *et al*., 2012). Kapucu *et al*. (2007) focused on the pre-selection and layout of a staging area and mentioned that there are no officially documented guidelines for emergency management planning that address selecting or planning a staging area.

The following paragraph explains about role of airport in post-disaster. Roles and impact of airports are different from that of normal cases (Perkins, 2013). Most activities are prioritized on humanitarian logistics activities involving rescue activities and aid goods management. Knowing the different role of airport in post-disaster, management of air transport during a catastrophe also changes from that of daily operation which is discussed by Smith (2010). He argues that airports are central to the critical national aviation infrastructure and essential to normal economic activities of their regions and even more important after regional disaster and catastrophes. He examined how the regional airports cooperate with the local, state, federal and non-governmental agencies to promote disaster preparedness, mitigation response and recovery.

- Airborne search and rescue
- Medical evacuation
- Moving emergency medical supplies and emergency personnel
- Firefighting and law enforcement
- Damage assessment and resource needs assessment, particularly related to other critical infrastructure and hazardous materials incidents
- Media and VIP transport

- Impact on public safety and health due to any expansion of their normal role
- Impact due to any reduction in that expected role due to damage to the airport structures, runways, or infrastructure
- Changes in passenger and cargo operations

Related on air transportation and disaster response, several relevant researches have been conducted. Kobayashi and Tanaka (2006) analyzed operation of helicopters in Niigata Chuetsu earthquake in 2004 and also compared it to Hanshin-Awaji earthquake. Mathematical model for helicopter operation in disaster relief is first developed by Barbarosoglu et al. (2002) and further by Ozdmar (2011). Barbarosoglu et al. (2002) modeled hierarchical decision making procedure for helicopter operation as in tactical and operational scheduling considerations. Ozdmar (2011) proposed an efficient system for coordinating helicopter operations during relief phase. It focused on last mile distribution in humanitarian logistics and two main purposes as medical care and injured evacuation.

2.3 Problems and challenges in airport operation

Congestion is a major cause of inefficiency in air transportation in usual (Gwignner *et al.*, 2006). Hanaoka *et al*. (2013) determined bottlenecks in the airport are found in both land side and air side caused by aircrafts from different organizations, unassigned priority among different operators and difficulty in spot assignment. Also, unsolicited aid goods flog in an airport and make it difficult to effectively operate as a point of entry in humanitarian logistics (Cassidy, 2003; Murray, 2005). In large scale emergencies, unexpected amount of people and goods gather in airports. Perkins (2013) mentions importance of airports and their operation in disaster. It is critical that the roles of airports in a disaster and the impact of those roles would be acknowledged by airports operators, local governments, and humanitarian logistics agencies in order to share information for effective disaster response plan. Unsolicited supplies in fact clog airports and warehouses (Cassidy, 2003; Murray, 2005) in post-disaster and create redundancies (Sowinski, 2003).

It can be considered simply as the traffic volume that demand was higher that the capacity of the airports. (Moline, J., Couping Humanitarian Air Transport and Storage: Lessons from Haiti Applied to Typhoon Haiyan Response in the Phillipines, Airport Planning and Design, 2013) Smaller airports with limited parking capacity were recognized as a main issue in disasters. Not only physical constraints but also loading/unloading equipment and human resources were problematic constraints as well.

Some other problems occurring at airport in post-disaster are congestion in runway, refueling issue, communication among players, and congestion in warehouse and apron area. The main focus of problems is congestion occurred by limited capacity. Because each airport has different capacity on its infrastructure, limited amount or capacity of airport's landside and airside infrastructure is difficult to change. Usually after disaster, many governments argue about expansion of airport or investment on facility. Some investment can be made in runway, apron, airport stands, lighting system, fueling tank, hangars and etc.

In summary, bottlenecks in airport operation in disaster response were identified recently (Hanaoka *et al.* 2013):

- Limited fueling system capacity
- Insufficient lighting facilities
- Insufficient lifting equipment
- Lack of aircraft parking space
- Undesignated space for medical emergency team
- Inadequate place to sort and store relief supplies
- Insufficient lodging spaces for emergency workers
- Lack of hardstand for helicopters

These operational bottlenecks also can be found in the next section regarding lessons learned from previous natural disasters.

2.4 Cooperation and disaster response in airports

The types of cooperation and coordination for resources utilization and information sharing need to be carefully studied, especially the perspective of multiple stakeholders, to promote the development and get better overall results in the chain without undermining deadlines and quality of disaster relief. Coordinating the activities of responders with different professional backgrounds, levels of expertise, priorities, and operating under different organizational structures is a highly complex task (Holguín-Veras, *et al*. 2007).

In the United States, coordination is decided by the National Response Plan (NRP), which provides a single, comprehensive and all-hazards approach for the management of high-impact domestic emergencies, i.e., Incidents of National Significance (INS) (Butts, *et al*. 2012). Regarding decision level and horizontal/vertical coordination is explained in Figure 2-3. Internal relationship is the main concern in horizontal coordination such as collaboration of an organization with other organizations in rivalry or not. Vertical coordination is found in connecting two or more organizations to share their responsibilities, resources and performance information to serve relatively similar end customers (Kaynak and Tuger, 2014).

- Cooperation – one of the partners in the strategic planning process, participating with others in resources, competencies and capabilities in order to achieve interests and optimum utilization of resources (Gulati, Wohlegezogen, Zhelyazkov, 2012, Elkatawneh, 2013.)

- Collaboration – allowing opportunities to share information, knowledge, skills and expertise among members in order to adjust their goals and contribute to the development (Elkatawneh, 2013)

Guideline of cooperation should be made to ensure the communication and operation among different departments, the military and local government. Besides, revising and updating emergency plan dramatically is very important for the full implement of emergency relief operation (Zhou et al. 2011).

Table 2-2 The coordination mix

Source: Adapted from Kaynak and Tuger, 2014

	horizontal		*vertical*
	Within cluster	**Among clusters**	
Operational	Organizations in a cluster cooperate in an operation	Cooperation among different clusters in an operation	Pipeline for an operation is coordinated among participants
Tactical	Organizations in a cluster cooperate at the regional level	Clusters cooperate at the regional level for storage, capacity	Storage and distribution from a regional level
Strategical	Global capacity planning, standards for a cluster	Global assessments, inter-cluster standards	Purchasing, global stockpiles and pipelines to affected regions

Airports cooperate closely with local emergency management agencies throughout the preparedness, response, and recovery phases of an emergency. Smith (2007, 2010) first discussed the cooperation, coordination, and communication roles of regional airports during disasters. He investigated the actual response activities and measures undertaken during previous disasters based on case studies to discover the essential elements of airports' collaborative practices (see also Smith, 2014). Likewise, a number of studies have examined various aspects of cooperative emergency management at airports (Barich *et al.*, 2013, Smith, 2012a, 2012b, IEM Inc. *et al.*, 2012).

Airport guidelines for preparing for emergencies and mutual aid agreements among nearby regional airports have been proposed in the United States (TRB, 2012). In particular, as part of disaster management planning, the Airport-to-Airport Mutual Aid Program, which was initiated with the voluntary assistance of airports in the aftermath of major natural disasters in the United States, was reviewed for this study. This program was developed to assist and provide aid during large-scale disasters and emergencies (TRB, 2012).

In one real-life example, Minato and Morimoto (2012) confirmed that regional airports in the Tohoku region were highly utilized in the wake of the Great East Japan Earthquake of 2011 compared with normal operations. Airports in the region responded by offering logistics services, transporting personnel and evacuees, collecting information, refueling helicopters, and providing immediate medical care. The aircraft operators involved included the fire department, disaster management agencies, medical helicopters, the Japan Self-Defense Forces, the Japan Coast Guard, and the Ministry of Land, Infrastructure and Transport in Japan (Hanaoka *et al.*, 2013).

Table 2-3 summarizes the aircraft takeoff frequencies following the Great East Japan Earthquake as well as the disaster response purposes and operators. This table shows the responses of the three major airports (Hanamaki Airport, Yamagata Airport, and Fukushima Airport) from March 11 to 14, 2011. For example, Hanamaki Airport's landing frequency was 124 and departing frequency was 94 on March 12, 2011, more than 10 times usual airport operations (Aratani *et al*., 2013).

Table 2-3 Aircraft takeoff frequencies following the Great East Japan Earthquake (adapted from Aratani *et al*., 2013)

			Fire/disaster management agencies	Medical helicopters	Police	Japan Coast Guard	Media helicopters	Japan Self-defenses	Foreign military	Airlines	Others	Total
Hanamaki Airport	Normal operation		5	–	–	–	–	–	–	3	1	9
Hanamaki Airport	Disaster response purpose	Ambulance transport	10	31	–	–	–	2	–	–	–	43
Hanamaki Airport	Disaster response purpose	Rescue operation	74	–	8	1	–	20	–	–	1	104
Hanamaki Airport	Disaster response purpose	Response operation	2	–	–	–	–	3	–	–	–	5
Hanamaki Airport	Disaster response purpose	Information collection	3	–	6	–	–	–	–	–	1	10
Hanamaki Airport	Disaster response purpose	Passenger transport	2	–	–	–	–	–	–	–	5	7
Hanamaki Airport	Disaster response purpose	Freight transport	14	1	3	–	–	5	–	–	–	23
Hanamaki Airport	Disaster response purpose	Extra flight	–	7	–	–	–	–	–	–	–	7
Hanamaki Airport		Others	5	1	7	–	1	78	1	–	–	93
Hanamaki Airport	Hanamaki Airport Total		115	40	24	1	1	108	1	3	8	301
Yamagata Airport	Normal operation		1	–	–	–	–	–	–	14	2	17
Yamagata Airport	Disaster response purpose	Ambulance transport	1	1	–	–	–	–	–	–	–	2
Yamagata Airport	Disaster response purpose	Rescue operation	50	–	3	–	–	–	–	–	3	56
Yamagata Airport	Disaster response purpose	Response operation	1	–	–	–	–	–	–	–	–	1
Yamagata Airport	Disaster response purpose	Information collection	3	–	8	–	–	–	–	–	5	16
Yamagata Airport	Disaster response purpose	Passenger transport	–	–	–	–	–	–	–	–	–	–
Yamagata Airport	Disaster response purpose	Freight transport	6	–	2	–	–	–	–	–	3	11
Yamagata Airport	Disaster response purpose	Extra flight	–	–	–	–	–	–	–	10	6	15
Yamagata Airport	Others		2	–	–	–	–	16	7	–	6	31
Yamagata Airport	Yamagata Airport Total		64	1	13	–	–	16	7	24	24	149
Fukushima Airport	Normal operation		3	–	–	2	–	–	–	12	3	20
Fukushima Airport	Disaster response purpose	Ambulance transport	2	4	–	–	–	–	–	–	–	6
Fukushima Airport	Disaster response purpose	Rescue operation	36	–	3	14	–	–	–	–	3	56
Fukushima Airport	Disaster response purpose	Response operation	1	–	2	–	–	–	–	–	–	3
Fukushima Airport	Disaster response purpose	Information collection	14	–	5	2	61	–	–	–	5	87
Fukushima Airport	Disaster response purpose	Passenger transport	–	–	–	–	–	–	–	–	–	–
Fukushima Airport	Disaster response purpose	Freight transport	15	–	1	4	3	–	–	–	19	42
Fukushima Airport	Disaster response purpose	Extra flight	1	1	–	–	–	–	–	28	5	35
Fukushima Airport	Others		10	–	8	–	1	38	3	1	16	76
Fukushima Airport	Fukushima Airport Total		82	5	19	22	65	38	3	40	51	325

In addition, Stambaugh *et al*. (2009) develops a guide for airport to respond chemical, biological, radiological, nuclear, or explosive materials targeted to airports and provide resource management such as fuel for vehicles, vehicle support, such as a shuttle bus service, cranes and truck, rehabilitation and/or break area, sanitary facilities as restrooms and showers, mass care supplies such as cots and blankets, lighting for 24-hour operations, bulk supplies such as sandbags or barricades, lodging and food. This is critical aspect of airport disaster response operation in immediate disaster response.

Cooperation among airport organizations as well as among organizations that operate aircraft is recommended (Hanaoka *et al.*, 2013). Yamagata Airport and Hanamaki Airport assigned major disaster response roles such as ambulance transport and rescue operations as high priorities among the different roles. However, Fukushima Airport only accepted the task of providing a landing point for the helicopters used by the media and the collection of that information thus focused on this airport. This balancing of the disaster response roles among airports in a real-life example of cooperative operation among airports in the immediate disaster response examined in the present study. Hanamaki Airport suffered few difficulties compared with the other two airports since it had previously cooperated with various aircraft operators in the response to the 2008 Iwate-Miyagi Nairiku Earthquake (Aratani *et al*., 2013).

2.5 Airport as a disaster response base

2.5.1 Definition

It is clear that airports play a significant role in post-disaster. Such roles are medical evacuation, transport of emergency medical supplies and emergency personnel, media, firefighting and etc. However, due to unexpected demand and unpredictable disaster impact, many airports suffer several problems due to their limited infrastructure.

In this research, *airport as a disaster response base* is defined as an airport that is planned ahead of disasters with satisfying critical disaster response roles including flexible management of facilities, equipment, personnel in order to support effective response activities (e.g. storing and sorting relief goods, securing medical care treatment, lodging spaces for human resources and evacuees, etc.). A conceptual diagram for understanding component of a disaster response base in order to support emergency workers and relief goods is drawn in Figure 2-4.

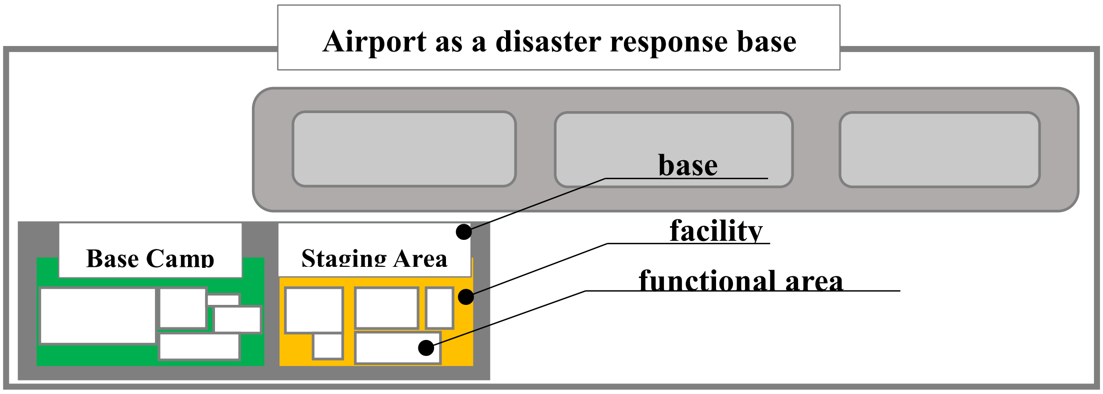

Figure 2-2 Disaster response base in an airport

Space for setting up medical care, space for emergency worker's accommodation area, space for handling excessive humanitarian aid goods is required in a disaster response base. In this study, since space for medical care need special requirement and facility design and sometimes can be set up at fire stations within an airport, the focus is on a base camp and staging area in a disaster response base. Among additional space requirement for an airport to have as a disaster response base, this study aims to support space for emergency workers and relief goods. Therefore, a disaster response base in this context would focus on base camp and staging area. A base camp would be constructed with planning functional areas to support activities and support for emergency workers. A staging area would assist for areas to sort and stack humanitarian aid goods and also accommodation place for workers.

With regarding space constraints problem, Aakil (2012) mentions suggested future research directions in post-disaster capacity planning for facility structures and resources. The author points out flexible use of space in emergency situations in order to improve handling of patients in a hospital by converting operating rooms, freeing up spaces for additional resources, and resource management. This kind of space planning concept can be used statically in pre-disaster and dynamically in post-disaster.

Previous practices often mention this approach as the air hub approach (World Food Programme, 2005): "*Strategic air deliveries of other foods and non-foods items were made. After some initial deliveries directly to airports in Indonesia, most relief supplies were channeled through Subang air base in Malaysia to shorten the line of supply and to relieve the extraordinary congestion in Medan and Banda Aceh. Long-rage deliveries from around the* *world were made into Subang, which was managed by a combination of the Malaysian Air Force, WFP and UNJLC. Cargoes from UN agencies and many other partners were then flown by smaller aircraft into Aceh Province. The decision to open the regional air hub at Subang was a key strategic decision. It was closed at the end of February having served its purpose."*

Here, we review practices and academic research on utilizing airports or air transport network as to enhance disaster response capacity of a region. In these disaster response airports, operation is more complex than normal operation so that flexibility is required upon operation. Veatch and Goentzel (2012) propose two operation approaches for enhancing airport disaster response operation based on queuing theoretical approach. The first is to prioritize cargo by type, always giving preference to critical items. The second approach is to prioritize by entity type, which can be done in a few different ways.

2.5.2 Expected requirement for a disaster response base

Requirements for air hub are listed as the following (Moline, 2013): slot availability for regular and emergency departures, physical capacity to handle a mix of aircraft including wide-body planes, physical space to handle unloading reloading of larger planes, ample parking space, sufficient personnel or surge capacity to enable large scale loading and unloading, equipment for loading, unloading, and transport, relatively low risk of significant damage from natural disasters, ample storage and/or proximity and accessibility to storage hub.

2.5.2.1 Base camp

Base camp is an area where emergency workers such as police, military, volunteer, etc. can be accommodated in case of disaster. Figure 2-5 indicates functional area for base camp.

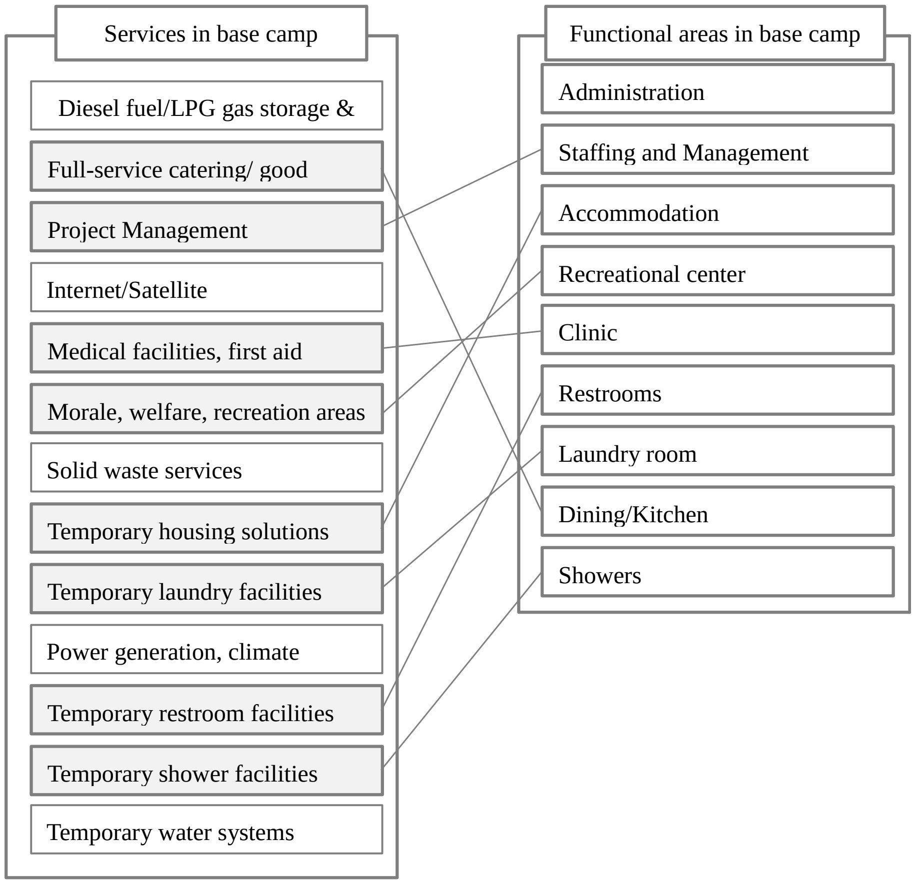

Figure 2-3 Functional area identification in base camp
Source: modified from State of Florida (2009a)

Left side in the figure explains services in a facility and right side explains area in order to assist those services. These functional areas will be allocated in each facility in planning process. For simplicity, colored boxes in services required for a base camp is considered in space planning. Identified functional areas in a base camp are administration area, staffing and management area, accommodation, recreational center, restrooms, laundry rooms, dining and kitchen area, and shower rooms.

2.5.2.2 Staging area

A staging area is a site selected by the appropriate federal, state, and county or city government for the purposes of pre-positioning and disbursement of disaster relief equipment and supplies.

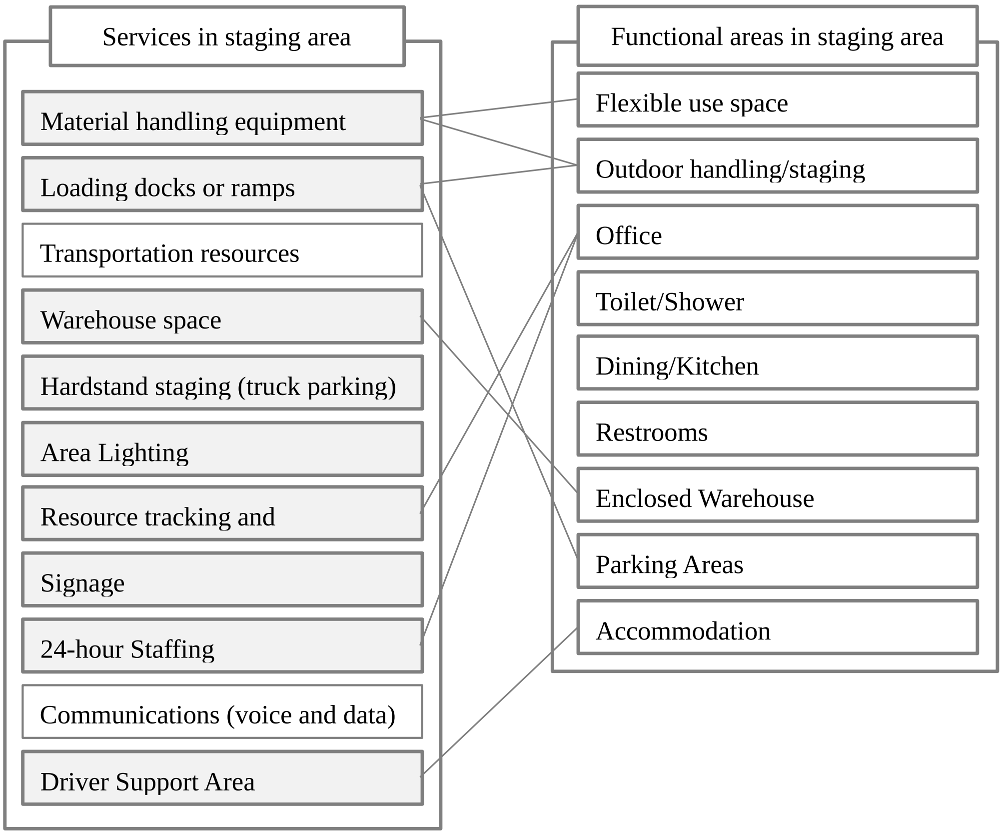

Figure 2-4 Functional area identification in staging area

Source: modified from State of Florida (2009a)

Staging area is a temporary site established in close to proximity to a disaster impact area where personnel, equipment and commodities are kept while awaiting tactical assignments. Proposed selection steps is: (1) identify the emergency resources needed at each secure location; (2) identify all critical cities within the supply chain; (3) set maximum response time goals for access to emergency resources and minimum distances secure site storage areas; and, (4) identify the number of approximate location of emergency resource facilities (Kapucu *et al.*, 2007).

General criteria for selecting staging area are: location/ operations center location/ access/ helicopter access/ safety and security/ demobilization/ hardstand/ equipment/ storage/ utilities. Figure 2-6 explains services to be provided in staging area and functional areas to serve the service. In order to assist services required in staging area, functional areas need to be set. Colored services in staging area are supported by space and uncolored services in staging area are assumed to be neglected in this study since it does not require physical space allocation. Identified functional areas in a staging area within a disaster response base in an airport are flexible use space, outdoor handling/staging area, office, dining/kitchen area, restrooms, enclosed warehouse, parking area, and accommodation.

The temporary local distribution centers are commonly located at airports, train stations, harbors or other sites adequate for handling large inflows and outflows of goods and personnel, and can serve as drop points (Rennemo, *et al*. 2014). Therefore, idea of assigning staging area inside of an airport is natural and more effective for disaster response planning.

2.5.2.3 Shelter

Sometimes, terminal area is used as a shelter area for passengers trying to fly out from the affected region and for evacuees who temporarily stay in an airport. Although guideline for developing shelter is not discussed in details, we argue that shelter is another component to consider when planning airport as a disaster response base.

2.5.2.4 Medical care

Particularly, in immediate disaster response, majority of helicopter missions focus on evacuation and transporting injured people in the region and rescue them on near airports and transport them again to near critical hospitals. Inside of airports, minimum requirement for setting up a temporary medical care should be assigned in advance.

2.5.3 Lessons learned from previous natural disasters

2.5.3.1 2005 Hurricane Katrina – USA

Hurricane Katrina, a category 4 storm, struck the U.S. Gulf states in late August, 2005, resulting in the most costly and second most deadly natural disaster in recent United States history. The storm and subsequent flooding due to levee failure necessitated the evacuation of

80% of the city of New Orleans' 484,674 residents (Klein, *et al.* 2007). The hurricane brought devastating impact on people, communities, infrastructure, and the nation. Even though evacuation plan was ordered in the region, 1,464 people lost their lives due to Katrina or while evacuating. City of New Orleans was severely damaged due to flooding and debris blocking. In Southern Mississippi, destruction of Highway 90 delayed recovery process and City of Biloxi also lost significant facilities (Perkins, 2013).

Figure 2-5 The path and strength of hurricane Katrian, by date

Source: Adpated from Klein, *et al.* 2007

The New Orleans Airport was closed before the storm but reported no flooding in airplane movement areas or inside the terminal building (Perkins, 2013). Even though there was little damage in airport's roof and hangars, New Orleans Airport responded to military, humanitarian and rescue operations actively. Since there were more than 27,000 patients in the airport, the terminal served as a staging area and a shelter place for over one week after the hurricane strikes the region.

2.5.3.2 2010 Haiti Earthquake – Haiti

The Haiti earthquake occurred at 4:53 pm Eastern Standart Time on January 12, 2010. With a moment magnitude of 7.0, it severely shook the entire country of Haiti. Haitian official government estimates note over 220,000 people were killed, and over 300,000 injured (Perkins, 2013). Damage was heaviest in the metropolitan Port-au-Prince metropolitan area and in much of southern Haiti.

The largest infrastructure problem impacting airport operations was the complete closure of the port, leaving the airport as the best means of getting supplies and relief workers into and out of the country. Haiti has one major international airport in Port-au-Prince which, before the earthquake, handled over 90% of the air traffic into the country, which amounted to approximately 35 flights per day.

The major cracks were obvious throughout the terminal building which could not be used for 6 to 12 months. The major bottleneck was at the airport. The job of coordinating the response in Haiti fell to two major groups: the United Nations, which created the humanitarian 'cluster system' for this purpose, and the U.S. military, which became a de facto coordinator through its control of the airport. The two failed to work together.

The airport had one single taxiway and this makes it a single aircraft operation for takeoff, landing and taxi because all arriving and departing aircraft must use the runway back to taxi. The max aircraft on the ground is 12, but only had enough material handling to offload 3 at a time. Sometimes, hand off load was required. It took about 8 hours to unload goods from a Chinese A330. Running out of fueling capacity and limited parking spots in a single runway airport, operation itself was overwhelming in Haiti. Furthermore, inoperative control tower made the situation even worse to allow aircraft movements. It is said that there were at least 4,000 metric tons of aid supplies at the airport. Proper procedure to allow landing aircrafts was not well maintained so it caused another chaos to the airport operation. Coordination among massive items, people, organizations, and others during disaster relief takes unexpected waiting time (Pasztor, *et al.* 2010). Every humanitarian logistics operation was concentrated drastically right after the earthquake.

2.5.3.3 2011 Great East Japan Earthquake – Japan

In Great East Japan Earthquake 2011, it aroused regional government, central government and researchers acknowledged importance of disaster management and especially planning about the worst scenario case. Especially it is said that Japanese regional airports in Tohoku region played a critical role in disaster response. Sendai airport which had been a hub airport in the region had to shut down its operation for examination for a while. Therefore, other regional airports such as Hanamaki, Yamagata, and Fukushima airports were highly used in the catastrophe. Minato (2012) says that Hanamaki airport among three airports didn't suffer much difficulties compared to other airports because they had already prepared for disaster management before this disaster. Three airports responded logistics roles, transporting personnel and evacuees, information collection, refueling base for helicopters, immediate medical care.

2.5.3.4 2013 Typhoon Haiyan – Philippines

Typhoon Haiyan impacted Philippines on November 8th, 2013 destroying homes of more than 200,000 people in Tacloban City. International assistance was called with voluntary organizations, militaries, international aid organizations and so on. The city was mainly served by Daniel Z. Romualdez airport (DZR) which has a single runway with a single-story terminal building.

DZR airport was destroyed by Typhoon Haiyan but reopened its operation from November 11th. Besides DZR, Mactan-Cebu International Airport (CEB) was also used as a primary response airport for receiving aid goods. This airport also has a single runway so it suffered significant congestion as well. Therefore, some flights were diverted to Francisco Bangoy International Airprot in Davao, Mindanao. Airports received mainly aid goods from international organizations and within the nation and transporting personnel was highly overloaded.

2.5.3.5 2015 Nepal Earthquake – Nepal

Relief activities were hampered from India to Nepal and national and international orgniazations simultaneously provided food, water, shelter, and medical help to survivors. The rescue and relief operations were struggling due to rains and the inability of Kathmandu airport to handle excessive air traffic up to 3 days after the earthquake. Uniqueness of geographical condition and disaster situation, neighboring countries responded quickly by assisting rescue teams to Nepal. However, most of the rescue operations as well as media attention were limited to the capital city—neighboring communities were deprived of water, food, tents, and medical supplies, and in remote villages, people were waiting for relief, and many still are (Neupane, 2015). The response in Nepal faced numerous logistical bottlenecks, from the lack of airport capacity to the damage done to roads and bridges inhibiting access to rural areas. Especially, airport capacity itself was constrained compared to other countries cases which aggravates stress on operation.

2.5.4 Current practices on airport operation and disaster response:

2.1. Airport as a humanitarian logistics base

Previous natural disasters highlighted the importance of utilizing airports in the immediate disaster response phase. In case of Hurricane Katrina in 2005, the roof and hangars of the New Orleans Airport experienced little damage. The airport was therefore actively used in military, humanitarian, and rescue operations. Because there were more than 27,000 patients in the airport, the terminal served as a staging area and a shelter for more than a week after the hurricane struck the region (Perkins, 2013). Conversely, there was a single runway in the Port-au-Prince airport at the time of the 2010 Haiti Earthquake, resulting in enormous congestion and hindering effective utilization of the airport (Pasztor *et al*., 2010). The airport failed to handle the overwhelming flow of items, people, and aircraft that concentrated there in the immediate disaster response phase. Still, response efforts continued to utilized the airport as a point of entry to the country. A similar situation occurred in the 2015 Nepal Earthquake when the World Food Program established a staging area for goods and medical evacuation in the Kathmandu Airport , using it as a disaster response base immediately after the quake.

Current practices related to the utilization of airports as humanitarian logistics bases are summarized in Table 1. Smith (2007, 2010) examined the role of airports and coordination among regional airports during disasters. He investigated actual response activities and measures undertaken during previous disasters based on case studies. In the United States, airport guidelines for preparing for emergencies and mutual aid agreements between nearby regional airports, such as WESTDOG and SEADOG (TRB, 2012), have been proposed. The

Regional Logistics Hub for Humanitarian Assistance in Panama is one of the practical plans initiated by the International Federation of the Red Cross (IFRC) and Red Crescent Societies. The IFRC placed its regional logistics unit in Panama to make it possible to respond to disasters quickly, especially during hurricane season. It is designated to cover the disasters in Latin America and the Caribbean (Martinez *et al.*, 2010). The hub incorporates an airport and several international humanitarian organizations that utilize the warehouses, open space, staging area, aprons, and helipads (UNOPS, 2012).

The logistics company DHL and the United Nations Development Programme (UNDP) developed a training program for airports in developing countries to help them prepare for emergencies. The program has been presented since 2009 (Deutsche Post DHL, 2010). A pilot program was initiated in two airports: Makassar and Palu in Indonesia. In Japan, a similar approach has been initiated by the Japanese government to assign airports for use as humanitarian logistics bases.

As part of disaster management planning, the Airport-to-Airport Mutual Aid Program, which was initiated with the voluntary assistance from airports in the aftermath of major natural disasters in the U.S.A., was reviewed for this study. The Airport-to-Airport Mutual Aid Program was developed to assist and provide aid during large-scale disasters and emergencies (TRB, 2012). The current practices of governments and international organizations reveal the need for preparedness and response planning in airports to meet the demands that arise during large-scale disasters. The involvement and collaboration of multiple airports are needed for an effective operational base for humanitarian logistics. Despite the current practices and academic research on preparedness planning in the context of airport utilization as a humanitarian logistics base, there have been few studies on specific guidelines and plans for the space layout of such a base. Airports need to acknowledge their current disaster preparedness and response planning in terms of flexibility of space.

Table 2-4 Current practices in humanitarian logistics bases and the utilization of airports

	Location	Coverage	Role	Features
Regional Logistics Hub for Humanitarian Assistance in Panama (2010)	Panama	International	• Supports humanitarian logistics activities • Warehouse • Staging area • Facilitates cooperation among international relief organizations	Humanitarian logistics hub is planned as part of the airport plan.
Get Airports Ready for Disaster (2009)	Pilot program: Indonesia (Makassar and Palu)	Domestic	• Prepare airports to review capabilities and capacities • Support humanitarian logistics activities • Train local people • Build a cooperative structure for disaster response	Training program for airports led by DHL and UNDP in 2009.
Airport to Airport Mutual Aid Program: SEADOG and WESTDOG (2012)	U.S.A.	Domestic	• Regional assistance between airports • Assist airport's functionality during disasters, emergencies, and non-disasters • Restoration of airport operations as quickly as possible	Airport-to-airport mutual aid approach is examined in other countries.
Chubu regional disaster management network: humanitarian logistics base (2012)	Japan	Domestic	• Support humanitarian logistics activities • Provide a base camp for emergency workers • Staging area and warehouse • Secure space for staging care unit	Utilization of airports is highly recommended. Shizuoka airport is under examination.

Additionally, the logistics company DHL and the United Nations Development Programme (UNDP) developed a training program for airports in developing countries to help them prepare ahead of emergencies; the program has been conducted since 2009 (DHL and UNDP, 2010). The pilot program was initiated in two airports (Makassar and Palu airports in Indonesia). A similar approach has been initiated by the Japanese government for assigning an airport as a disaster response base.

As part of disaster management planning, this study reviews the Airport to Airport Mutual Aid Program, which was initiated with voluntary assistance from airports in the aftermath of major natural disasters in the U.S. such as Hurricane Katrina. The Airport to Airport Mutual Aid Program aims to assist and provide aid during large-scale disasters and emergencies (TRB, 2012). The current practices of governments and international organizations reveal the need for preparedness and response planning in airports to meet the demands during large-scale disasters; the involvement and collaboration of multiple airports is needed for an effective operational base for humanitarian logistics.

2.5.5 Airport disaster response base and disaster management framework in Japan

As Japan is one of the most disaster-prone countries in the world, disaster management planning has been well established while recognizing lessons from previous disasters and updating latest arguments. Japanese local governments already have designated schools, community centers, or other public facilities as disaster prevention or response base. In addition, Ministry of Land, Infrastructure and Transport (MLIT) is under consideration about framing the national disaster management network. MLIT has developed principles and procedures about designating disaster management base in Japan. In order to enhance regional disaster response capability, Chubu Region Disaster Management Network was constructed after Great East Japan Earthquake in 2011. Its role is to corporate disaster management strategy throughout academics and practices from local and national government officials. Throughout continuous research and investigation, they constructed 10 tasks for disaster mitigation, preparedness, response and recovery. “Framework for disaster management network in Chubu region” is one of 10 tasks. This considers aligning a disaster management network within Chubu region and assigning current facilities to be a disaster response base in case of disaster. Some requirement to be fulfilled are open space for loading and unloading goods, extra parking spaces, base camp area, volunteer center for coordinating information and accommodation.

Disaster response base in disaster management network in Japan are selected under the following criteria: whether it is or is near a node of infrastructure network, having open space more than 15ha, whether it has lower-level disaster response base or not within prefecture, low possibility of flooding by tsunami, located outer border of Densely Inhabited District, and having optical fiber communication. Therefore, airports in Chubu region are detected as a disaster response base in case of Tonanakai disaster scenario. This issue is emergent ongoing topic regarding humanitarian logistics operation and its preparedness in regional and central government.

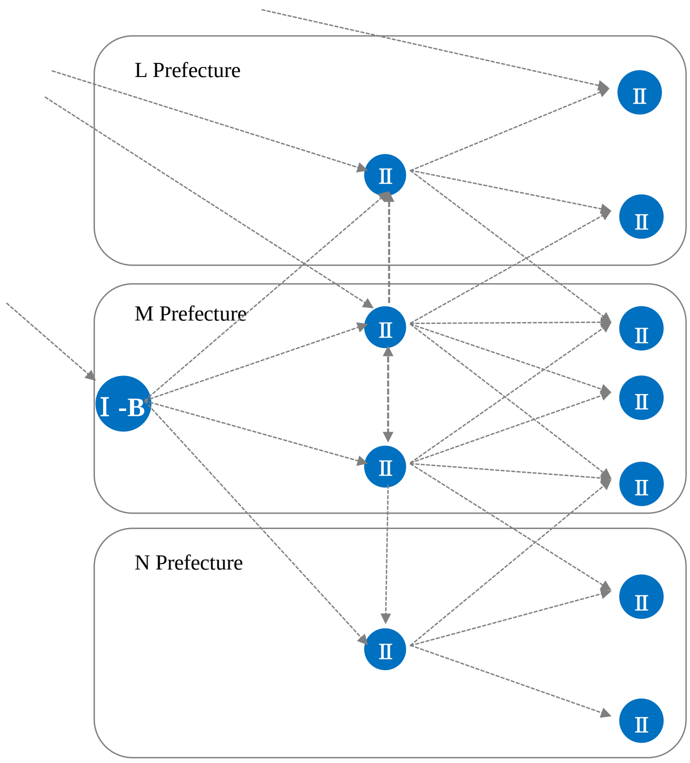

Figure 2-6 Disaster management network in Japan

Modified from MLIT, 2013

As in figure 2-8, basic strategy in disaster management network in Japan Chubu region is visualized. Ⅰ-A is considered as a disaster response base in this thesis, and second level of Ⅱ-A are region's distribution centers, and the last Ⅱ-B are considered as a point of distribution where humanitarian aid goods meet affected population directly.

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2.6 Methodological literature review

2.6.1 Space planning

Space planning is widely used when developing logical procedures to achieve space configurations. It is needed to address several design parameters such as a client's goals and priorities, an organizational structure and relationships, space allocation criteria, the constraints of fixed building elements and building system interfaces, and security and privacy issues (Addi and Lytle, 2000). In short, the aim of space planning is to find a solution for a space layout within the given constraints. It is a continuous process for achieving a designer's purposes and providing a solution for customers, even though the objectives, constraints, solution procedures, and results presentation methods may not be the same. In the case of office design, space planning is used to meet the clients' request to utilize their available office spaces more efficiently and effectively.

The planning consists of three processes as programming, diagramming, and results presentation (Do et al. 2000). Programming involves defining the requirements of the user and collecting information regarding the functional areas and allocation of each space. In programming, the first step is to determine the objective of the plan. Detailed strategies for finding the architectonic layout can vary (Coyne, 1988; Coyne and Gero, 1991). The planner identifies the objectives of space planning in the first step. Common objectives are minimizing dead space, minimizing cost, minimizing distances between spaces, and maximizing operating efficiency (Sutanthavibul et al., 1990; Shekhawat, 2015a; Liggett and Mitchell, 1981b). The objectives may be qualitative, quantitative, and/or based on multiple criteria defined by the planner (Rio-Cidoncha et al., 2007). In next step, the planner identifies the important parameters in the design process. The formulation of problems can be achieved by asking the following questions: (1) How much available area does the airport have?, (2) How many emergency workers are expected to be dispatched?, and (3) How should the cost function be specified? Asking these questions can be considered a single- or multi-stage process (Liggett and Mitchell, 1981b). Then, the necessary facilities are listed based upon the expected activities in each space or room. (Rio-Cidoncha et al., 2007; Hershberger, 2000). Information on lessons learned from past incidents and the current practices of government and humanitarian aid organizations is gathered. After listing the necessary facilities, categorization of the functional areas in each facility makes it possible to investigate the types of specific activities expected to occur in each functional area in a facility and to find similarities between functional areas.

Diagramming involves estimating the approximate area for each functional space and developing an illustration using adjacency or bubble diagrams. Space plans and furniture plans involve the placement of specific furniture, equipment, and interior furnishings (Addi and Lytle, 2000). The creation of adjacency and bubble diagrams is included in this part. According to Do and Gross (2001), the diagrams used in architectural planning help readers to recognize the spatial relations among elements and emergent patterns and configurations. Diagrams also represent the territorial boundaries of spaces in an abstract manner in the planning stage (Do et al., 2000). A strength of diagramming is that it enables planners to convert written information into a graphical format using a standardized design language (White, 1986). Despite the ease of use of the process, diagramming often requires an iterative process for implementation. Difficulties often arise during the thinking and analyzing process stage (Downing and Hubka, 1986).

In the results presentation stage, planners can develop a base schematic plan and enhance it with established preferences. Because space planning is a creative activity, understanding intuitive and arbitrary attributes is natural (Zawidzki et al., 2011). Selection of the most appropriate space plan requires continuous discussions with the planner, airport operator, government officials, and related stakeholders to reach an agreement.

2.6.2 Definition of queuing model

Queuing theory has been applied to transportation, manufacturing system, computer science, emergency medical care department in hospital, and so on. Queuing theory has been applied to these various systems in order to evaluate a wide range of performance measurements such as mean response time, resource utilization and throughput (Kaufman, 1984). The queuing approach also provides investigation of different network topologies in supply chain management and in humanitarian logistics as well. Nodes and links represent facilities and direct transportation connections respectively. Kerbache and Smith (2004) discuss further on transportation cost, capacities, resources, and processes regarding the facilities provide meaningful insight in operations.

In transport planning, application of queuing theory and its approach have been studied to propose a model for planning to assess the expected delays on landing or takeoff at an airport in runways, baggage claims, customs, customer service, taxi-in and out estimation, airline and airport network, and so on. Pyrgiots *et al*. (2013) examined congestion and delays of airports propagating across the network and spreading faster when weather conditions are not followed. The queuing model in airport congestion studies is rather simple and approximate than the other model since the model treats one airport as one queuing system within interconnected airport network. Fortunately, Hall (2003) concluded that modeling airport is unlike modeling of highway traffic, the number of customers (represented by aircraft) that may reside in a queue is relatively small, making it relatively easy to measure the system state as a discrete entity. However, here again, airport's operation applying a queuing network model was examined one to model situation of disaster response activities.

In usual operational situation, given the variability of airport operations, it is not a fixed quantity but depends on several operational factors, including weather conditions, the proportion of landings and takeoffs operated and the runway configuration in use (Gilbo, 1993; Neufville and Odoni, 2013; Simaiakis, 2012). On the other hand, as it reveals solution as analytical approaches, it has been used in humanitarian logistics and emergency medical department in order to answer allocation of limited resources in a given time and investigate level of service. An important challenge in this class of models involves the representation and estimation of airport capacity (Jacquillat and Odoni, 2015).

Distinctively, the mathematical queuing model addresses problems regarding hospital management and emergency department management in health care systems. As it reveals solution as analytical approaches, it has been used in an emergency medical department in order to answer allocation of limited resources in a given time and investigate level of service. Inefficiencies of the system and cost rise are the major concerns within limited resources in hospital. The model can also deliver the impact of priority disciplines among patients in order to minimize the time and cost. C and Appa Iyer (2013) claimed that simulation approaches to tackle the issue have been increasingly adapted in addition to traditional queuing theory. Peterson (1995) showed limitations in the transient and dynamic queuing behavior the field. Relevant studies on delays until the early 1990s were relatively small.

On the other hand, Cochran and Roche (2008) explained the reason for applying queuing theory compared to other operational research approaches enables minimal data and has ease of calculation with computational model. Especially in emergency medical systems, the minimization of response time directly relates to life savings of individuals so that design and modification of their layout are inevitable. In addition, Iannoni and Morabito (2007) analyzed the balance between investment and benefits from modified system layouts are necessarily addressed in emergency management system. Unlike many systems in which customers are served in the order of arrival, Pons *et al*. (2007) modeled patients with urgent needs are prioritized in many health care systems because their survival can be negatively influenced by long response times.

2.6.3 Queuing network model

Queuing network is a connected series of queuing systems. In many real world complex processing systems with limited resources, fast response times are demanded, Au-Yeung *et al*. (2006) pointed out that these are seldom delivered in queuing network theory. Despite the fact, Newell (1979) mentioned that key benefits of the queuing network approach is that it allows one to uncover those parameters which are critical in the exit process and to determine the overall impact of varying these parameter values on the exiting process. Among queuing theory, Jackson (1963) developed queuing network model called open Jackson network showing queuing characteristics as Poisson arrivals, first-come-first-served (FCFS) service disciplines, exponential service times, and probabilistic routing, the steady-state joint probability and a product-form solution.

In addition to open Jackson network, multiclass queuing network approaches have been studied in order to capture arriving, waiting and processing of customers in queuing network who have different behaviors. Such example is explained in Schönlein *et al*. (2013) by adapting multiclass queuing network on multiple product lines in dynamic supply chain. The research limitations lie in difficulty of depicting the real world system to uncertain parameters. Regarding multiclass approaches in open Jackson network, multiple priority disciplines are examined in waiting time management of emergency care center. Kim and Kim (2015), in particular, modeled an emergency care center by a general hybrid priority model which an FCFS discipline is applied in some processes and a priority discipline in others in the open Jackson network. Harchol-Balter and Osogami (2005) studies further techniques for analyzing multiclass priority queuing networks as to support calculation procedures.

2.6.4 Application of a queuing theory in a single airport operation

Airport departure modeling and queuing approach was developed by Balakrishnan and Chandran (2007). The runway system has been identified as the primary bottleneck in the departure process, primarily because of the different constraints imposed on runway operations (Idris, *et al*. 1998). The terminal-area is a dynamic and uncertain environment, with constant updated to aircraft stated being obtained from surveillance systems and airline reports (Atkins, *et al*. 2002). Simulation was conducted over First-come-first-served rule with applying different departure rates. Aircraft sequence was considered as Poisson process corresponding to different demand levels. Another model was developed by Carr *et al*. (2000) to model airport queuing dynamics considering spatial and temporal restrictions. Once the (unrestricted) aircraft completes its stochastic nominal taxi-out time, it enters a FCFS queue, which presents the departure queues typically observed near airport runways (Idris *et al*. 2000.) Here, runway service rate is estimated as high departure congestion service when runway operates at maximum throughput. Queuing model dynamics consider not only flow of taxiway but also runway as server. It is noteworthy to include the effect of finite parking space on airside since space can also severely constrain airport ground operation.

Input-output model and controlling departure process in congested airport was reviewed by Pujet *et al*. (1999) and model framework is shown as Figure 2-11. Here, the major bottleneck in U.S. National Airspace System is defined as airports so the model tries to reduce departure queues in an airport to enhance departure capacity. The paper focused modeling on current departure process of airports in order to investigate possible application of departure control policies. The airport terminal system and the runway system are modeled as queuing servers, and a stochastic distribution is derived for the travel time on the taxiway system from the terminal to the runway queue.

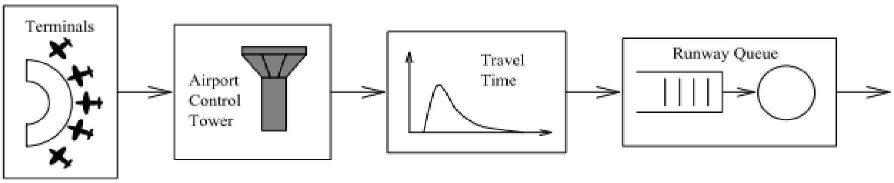


Figure 2-7 Proposed queuing model for the departure process

Adapted from: Anderson *et al*. 2000, Pujet *et al*, 1999

In the work by Anderson *et al*. (2000), three models are proposed to capture dynamics of busy hub airport operations including an arrival (taxi-in) model, a ground (aircraft-turn) model, and a departure (taxi-out) model as in Figure 2-12. Airport runway configuration is a major determinant of ground operations dynamics. This model also considers ground operations including: baggage unloading and loading, catering, cleaning, maintenance, passenger deplaning and boarding, and so forth. They argued that baggage handling process is one of the biggest bottlenecks in operation. The model could be used to evaluate the impact of congestion control at airside and to evaluate decision support tool enhancements. Also, further existing predictive capabilities to factor in delays may be considered.

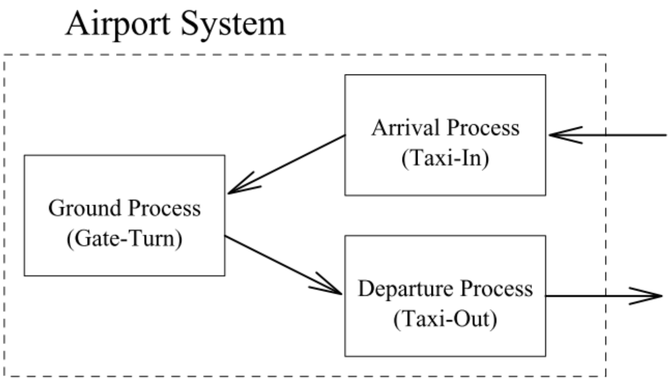


Figure 2-8 Developing an integrated ground-operations model

Source: Adapted from Anderson *et al*. 2000

2.6.5 Queuing model and emergency response

Altay (2000) believe that these queuing models can be used to estimate disaster losses and assist in mitigation and preparedness planning. Artalejo (2000) reviews application of queuing networks with catastrophes. In recent years, there has been significant amount of research focusing on planning for disaster response, Krishnamurthy *et al*. (2013) suggested future research direction for pre-positioning inventory at strategic locations, routing supplies to affected areas and relief centers in the region. They developed an analytical queuing model to quantify congestion of people in receiving aid goods at relief centers and investigate the impact of relief center layouts on the operational efficiency. This is one of the first papers dealt with applying queuing theory and humanitarian logistics area. Furthermore, understanding that emergency medical department and disaster response in an airport share similar features, queuing network has been discussed in order to demonstrate the situation and capture distinctive operational issues of an airport. In effect, a queuing model would determine the taxi-in and gate arrival times which requires as input the congestion levels of arriving aircraft, meaning the landing times would have to be given (Anderson *et al*. 2000).

2.7 Chapter conclusion

The complexities in disaster response operation of airports in immediate disaster response requires a structural planning approach. Airports as critical national infrastructures need to be secured in disasters as to assist effective response activities. Previous disasters give abundant information on operational bottleneck issues and also how to enhance airport operation. It also discusses importance of cooperation among airports and within airports to respond disasters effectively. Following recent practices and academic studies, there are various initiatives on utilization of airport as a disaster response base such as SEADOG/WESTDOG from USA, disaster management framework from Japan, Get Airports Ready for Disaster from DHL services, and so on.

Since airport operation in disasters is different from that of normal operation, in this study, we provide a three dimensional bases for enhancing airport disaster response operation based on decision level, management target and focus of operation. The study establishes conceptual framework for each base in the chapter.

Modeling airport operation in disaster response is quite challenging due to limited access to data collection. Previous studies on modeling airport ground operation and departure operation were modelled based on queuing theory. The study provides a broad range of queuing theory and its application to single airport operation and also relevant literature reviews on emergency operation. Motivated by Jackson network queuing approach, the study discusses further on modelling a single airport operation as well as plural airports operation in the following sections.

3. Diagramming development for a base camp and staging area in a humanitarian logistics base airport

3.1 Introduction

Air transport is critical in the immediate disaster response phase. It is highlighted as an alternative to road and rail transportation particularly when ground transportation has been paralyzed in the aftermath of events such as earthquakes or tornadoes. In the immediate response phase (the first 72 h after a disaster), emergency medical care is extremely dependent on air travel. An airport (node) in the impacted area will become a base supporting various humanitarian activities. Additionally, air routes (links) enable delivery and recovery from the affected zone, carrying evacuees, aid goods, and other cargo.

Airports are often referred to as disaster response bases or humanitarian logistics bases in the immediate phase of a disaster response. They provide critical disaster response functions as well as facilities such as staging areas, logistics centers, base camps, and medical treatment areas, ensuring the effective flow of commodities and personnel. However, the use of the available space in airports for post-disaster activities faces limitations due to insufficient parking space for aircraft, limited space for the temporary storage of fuel drums, and shortages in the prepared space for temporary lighting facilities, storerooms for storing relief goods, and space for setting up staging care units (Hanaoka et al., 2013).

The importance of disaster response management at the airport has long been recognized, but the formulation of guidelines for the development of disaster preparedness plans related to large-scale catastrophes was hampered after the Great East Japan earthquake (Holguín-Veras et al., 2012). Kapucu et al. (2007) focused on the pre-selection and layout of a staging area and mentioned that there are no officially documented guidelines for emergency management planning that address the selection or planning of a staging area. However, their study did not consider the internal configuration process and other critical facilities of a humanitarian logistics base. Current airport disaster management planning practice does not address the details of operating in the limited spaces in airports, such as how to assign the limited available space for various purposes. In this study, we argue that airports need to prepare for such space requirements and flexible operation in advance to ensure efficient and effective humanitarian logistics in airports. We recommend the use of space planning models for airports that can be employed in response to disasters and especially focus on diagramming in the planning models. The proposed method was devised to aid in making tactical decisions related to space utilization in airports in conjunction with specified logical procedures to be implemented in emergencies. The main contribution of this work is the development of an integrated framework that combines existing models and methodologies for application in immediate disaster response operations at airports.

The purpose of this study is to develop a method for diagramming a base camp and staging area as a humanitarian logistics base airport. The method enables the planner to estimate the required space and configure a layout for a humanitarian logistics base airport in an immediate disaster response situation. To achieve this objective, the space limitation issues in an airport were addressed in this study in the context of post-disaster relief activities and the need for effective decision making related to diagramming for use of an airport as a humanitarian logistics base. The diagramming method developed in this study is easy to comprehend and outlines the flow of goods and logistics for the benefit of airport operators, humanitarian aid organizations, government officials, and related stakeholders in responding to disasters.

The next section gives a summary the related literature on the operation of airports as disaster response bases. Section 3.2 summarizes scope of the framework on the operation of airports as disaster response bases. The proposed research method of this study is presented in Section 3.3. Section 3.4 presents the proposed layout for a humanitarian logistics base at the Shizuoka Airport in Japan, which is used as a case study; the results for the estimation of the required area, and the corresponding diagrams of a base camp and staging area. Finally, Section 3.5 presents the conclusions drawn from the research along with a discussion of the limitations of the study and the directions for future research.

3.2 Scope of the framework

This study focused on developing a diagramming process for airports as one of the components of disaster response planning. We incorporated several space layout strategies to address the space constraints related to relief goods and personnel in the first week of post-disaster relief activities. The methodological framework is expressed as in Figure 3-1 to follow three processes mentioned in Section 2.6.1. The step-by-step space planning procedure is formulated and integrated under one framework. The details on diagramming process are illustrated in upcoming sections. The framework is then applied to Shizuoka Airport as a confirmatory case study.

A humanitarian logistics base in an airport is not a permanent building structure; it usually involves temporary setups or tents needed in emergencies. Therefore, it does not have the constraints of a fixed building element. The setup must consider not only the approximate total size required but also the functional areas to be included. The selection criteria for such a type of base typically include the availability of open space for loading and unloading goods, the number of extra parking spaces, the base camp area, the presence of a volunteer center for coordinating information, and the accommodations. An airport can function as a humanitarian logistics base in the form of three critical types of facilities: a base camp, staging area, and medical care area. Because the study for a medical care area demands accurate knowledge of the medical system and its components, this study did not address the space layout for emergency medical care.

This study was inspired by the State of Florida (2009b), which has a unified emergency planning operation manual that includes the set-up of a base camp and staging area by erecting tents or managing trailers. This unified planning includes several layout plans to meet the requirements of different numbers of emergency workers.

The term "Phase 1 emergency relief" is used in this paper, following Wisetjindawat et al. (2014). Phase 1 emergency relief is defined as the period when victims have the minimum requirements for survival. This period is usually determined by the government and is usually from two to seven days. Short-term post-disaster planning (Caunhye and Pokharelb, 2011) becomes relevant after a disaster strikes a region and involves various activities such as delivering relief goods, evacuating displaced people, and providing transportation and medical care.

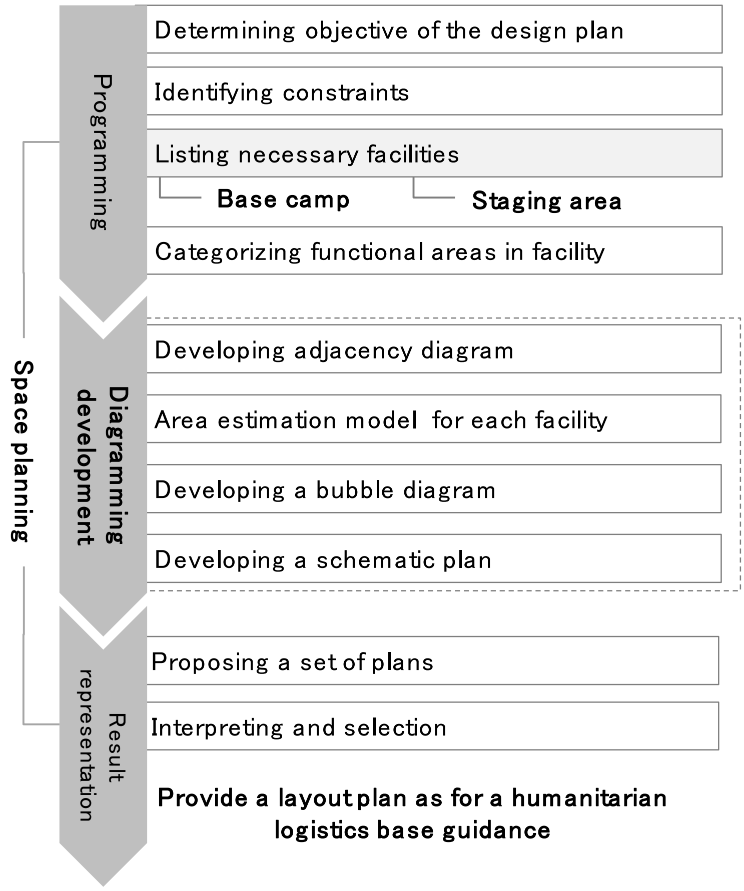


Figure 3-1 Space planning framework for a disaster response base airport

3.3 Methodological framework

3.3.1 Diagramming development

3.3.1.1 Developing an adjacency diagram

White (1986) proposed the use of an adjacency matrix diagram in diagramming. This type of matrix is used in architectural planning to visualize the relationships between the functional areas in a building. An adjacency diagram allows designers to identify and estimate proximity requirements. The adjacency diagram is flexible because the demands are able to meet the demands depending on the requirements of the client and designers. The diagram is composed of two-dimensional grids. The functional areas are listed in the top row and in the first column of the matrix. These areas are sometimes numbered so that they can be recognizable for drawing a bubble diagram in next steps. The relative relationships between areas can be marked as very important, desirable, or not critical. Another classification approach classifies the functional areas as mandatory, desirable, neutral, or negative. A third classification approach classifies the areas by immediate proximity and convenient proximity. In the approach proposed in this paper, immediate proximity and convenient proximity are used for the base camp design based on the practical designs of the State of Florida (2009a). Immediate proximity means that it is strongly recommended that the functional areas be located near each other, and convenient proximity means that it would be better that the functional areas were located near each other.

3.3.2 Area estimation for a facility

3.3.2.1 Calculation for a base camp

The calculation of the total size of the base camp area is shown in Figure 3-2. Cabinet Office of Japan and Ministry of Land Infrastructure, Transport and Tourism (MLIT) (2003) proposed a method to estimate the total number of emergency workers that are required for post-disaster activities (Cabinet Office of Japan and MLIT, 2003). This number can be calculated by dividing the total number of destroyed houses by 0.4. However, this is difficult to calculate because estimating the number of destroyed houses beforehand is quite challenging. This study presents several alternatives as standard guidelines. For instance, we set the required number of emergency workers m to 100, 250, 500, 750, or 1000 to propose standardized guidelines for base design.

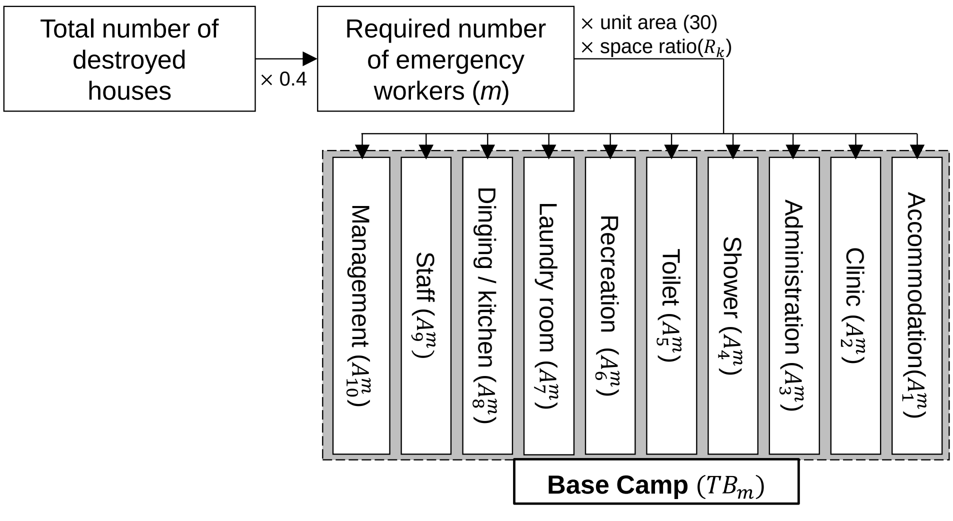


Figure 3-2 Estimation of the size of the base camp area

$$TB^m = \sum_{k=1}^{n} A_k^m \tag{1}$$

$$A_k^m = 30mR_k \tag{2}$$

$$\sum_{k=1}^{n} R_k = 1 \tag{3}$$

Equations (1) and (2) are used for the calculation of each functional area that is to be included in a base camp. The unit area required per emergency worker is set to 30 m^2 as a minimum and 50 m^2 as a maximum (Cabinet Office of Japan and MLIT, 2003). The minimum unit area is used in the estimation model, as shown in Equation (2). R_k is approximated based on the current practices for base camp design in *Florida State Emergency Planning in the U.S.* (State of Florida, 2009a). R_k is a constant and is equal to the ratio of each functional area to the total base camp area. However, if the planner decides to select other sets of functional areas instead of the proposed set, a different R_k would be determined based on the intentions of the planner and the restrictive conditions. Thus, R_k is set to 1 when the planner accounts for all functional areas (denoted as A_k^m) when considering the number of emergency workers *m*. The total area of the base camp is the sum of all functional areas within the base camp.

Where,

TB^m total area of base camp in meters squared required for the total number of emergency workers *m*

A_k^m area for the functional area *k* when there are *m* emergency workers

k identification of each functional area in the base camp

1: accommodation, 2: clinic, 3: administration, 4: shower, 5: toilet, 6: recreation, 7: laundry room, 8: dining and kitchen, 9: staff, 10: management

R_k relative space ratio of the functional area A_k^m to the entire base

m number of emergency workers required

n number of functional areas in the base camp

3.3.2.2 Calculation of the staging area

The total size of the staging area is calculated as shown in Figure 3-3. The estimation involves several stages based on four assumptions related to the role of the staging area of a humanitarian logistics base in immediate disaster response (Cabinet Office of Japan and MLIT, 2003):

1. The maximum capacity of the staging area has to support seven days' worth of items for the affected people.
2. Humanitarian aid items are stacked at a maximum height of 120 cm because this is considered a reachable height in storage and staging areas.
3. Humanitarian aid items are stored in different boxes according to item type.
4. The minimum required space considers the amount of goods on first day after the disaster

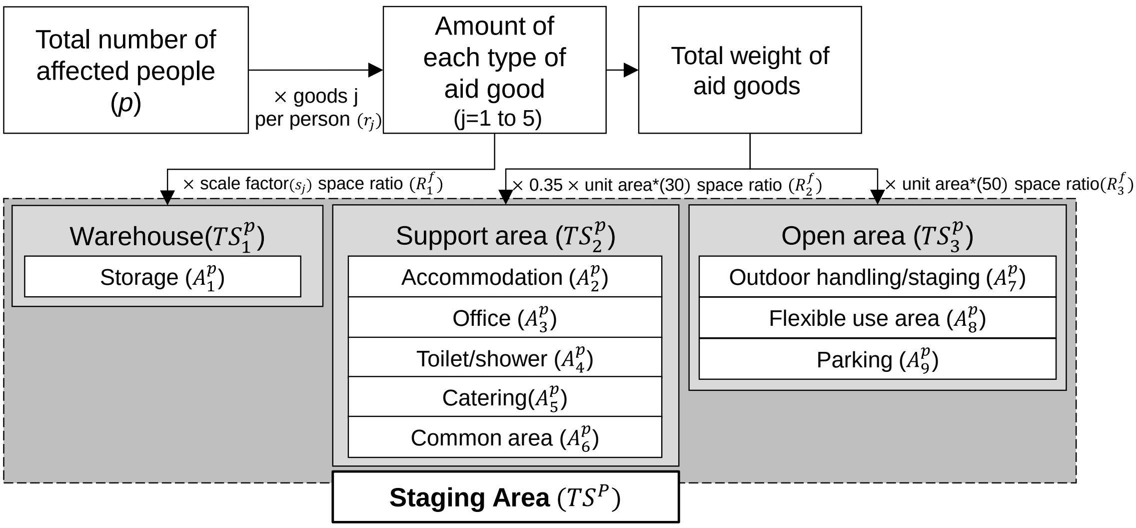


Figure 3-3 Estimation of the size of the staging area

Generally, staging area planning focuses on the selection of a site with the required operational capacity and on the availability of equipment such as loading docks, forklifts, and so on (Kapacu et al., 2007). Criteria for selecting staging area are the following such as location, operations center location, access, helicopter access, safety and security, demobilization, hardstand, equipment, storage, utilities and so on. (Kapucu et al., 2007; State of Florida, 2009a; Cabinet Office of Japan, 2012). Our proposed framework aims to estimate the approximate size of a staging area. Estimating this number (i.e., the area) enables the estimation of the amount of relief goods that can be stored or processed. The area is calculated using a scale factor that converts the weight of relief goods to the total staging area (MLIT, 2003). According to the regional humanitarian logistics hub in Panama, the total staging area consists of three components: the warehouse, the support area for workers, and the open area for loading and unloading goods (UNHRD, 2008).

$$TS^p = A_1^p = \sum_{v=1}^{3} TS_v^p \tag{4}$$

$$TS_1^p = (\sum_{j=1}^{5} r_j s_j p) R_1^f \tag{5}$$

$$TS_2^p = \sum_{f=2}^{6} A_f^p = 30\left(0.35 \sum_{j=1}^{5} r_j p\right) R_2^f \tag{6}$$

$$TS_3^p = \sum_{f=7}^{9} A_f^p = 50\left(\sum_{j=1}^{5} r_j p\right) R_3^f \tag{7}$$

$$\sum_{f=1}^{t} R_v^f = 1 \tag{8}$$

Where,

TS^p total area of the staging area (m^2)

TS_v^p area of the components of the staging area

v identification of the components of the staging area
1: warehouse, 2: support area, 3: open area

f identification of each functional area in the staging area
1: storage, 2: accommodation, 3: office, 4: toilet/shower,
5: catering, 6: common area, 7: outdoor handling/staging,
8: flexible use area, 9: parking

p total number of affected people

t number of functional areas in each TS_v^p

j identification of the items needed for the affected population
1: water, 2: food, 3: blankets, 4: mandatory kit, 5: temporary toilet

r_j required amount of item j per person (ton/person)

s_j scale factor of item j obtained by converting a weight to an area (m^2/ton)

R_v^f relative space ratio of the functional area A_f^p to the area TS_v^p

Equation (4) accounts for the required warehouse space. The warehouse is used for storing relief goods such as water, food, blankets, mandatory kits, and temporary toilets. The amount of each type of relief good is estimated according to the allotment presented in Table 2. The scale factor is estimated based on the method used in the MLIT report (MLIT, 2013b). Equation (5) is used to determine the size of the support area based on a unit area of 30 m2. Equation (6) computes for the size of the open area for staging. A factor of 0.35 is used for the manpower required to process 1 ton of relief goods in the staging area. The required unit area in the support area is 30 m2 per person, and that in an open area is 50 m^2/ton, as in MLIT (2013a). The relative ratio of each functional area in each component is 1 and is calculated and derived by practical means (UNHRD, 2008; UNOPS, 2012). In our proposed framework, the staging area also has three essential components according to UNHRD (2008), and the total area is calculated using Equation (8). The areas of the warehouse, the support area, and the space allocated to open areas are calculated, and the size of the individual functional areas in the facility is also determined.

Table 3-1 Goods allotment per person and scale factor

Source: Adapted from MLIT (2013b)

	Unit amount per person (ton/person)	**Scale factor (m^2/ton)**
Water	0.0210	1.63
Food	0.0105	3.78
Blanket	0.0030	4.44
Mandatory kit	0.0025	4.44
Toilet	0.0015	6.05
Total	0.0385	20.34

3.3.3 Developing a bubble diagram

After developing an adjacency diagram and estimating each functional area based on the estimation formulation in previous section for each facility, a bubble diagram is now developed. Ruch (1978) described the bubble diagram as an interactive approach for an architect to use to make a decision at every step of the space allocation process. The bubble diagram approach requires considerable experience; therefore, it is best suited for use by experts in presenting a concept than by beginners to study or explore (Lin, 2005). The design objectives of a space layout can be expressed in terms of two basic types of properties: topological and geometric (Arvin and House, 2002). Topological objectives consider the designer’s intentions concerning the relative positions and inner correlations of spaces, while geometric objectives consider the designer's intentions concerning the sizes and shapes of spaces.

Architectural bubble diagrams are used to consider the layout of functional areas in a floor plan. Bubble diagrams are used to explore the relationships among the sizes, adjacencies, and approximate shapes of the spaces needed for various activities. They can also be used to explore possible future changes in planning and show simple dimensions and relationships among adjacent spaces (Do and Gross, 2001). A bubble diagram is usually converted from an adjacency diagram to form a graphical representation, as shown in the center of Figure 3-4. Each functional area is expressed as a circle, and lines are drawn to show the relationships between functional areas. This process assists in creating a rough spatial configuration before an exact location and relative configuration are investigated (Glover and McMillan, 1985).

3.3.4 Developing a schematic plan

A schematic plan is a revised version of the bubble diagram that is used before planning the actual floor plan of a facility, as shown on the right side of Figure 3-4. When developing a schematic plan from a bubble diagram, a transient process is also required between the two. A schematic plan usually allows the planner to estimate the approximate space allocation and to understand the relationship between an area and its surrounding environment. The design process, from the abstract diagram to the diagram with additional details and finally to the diagram with alternative details, is expressed.

Multiple software programs and computerized tools such as EDGE (Jo, 1993), autoPLAN (Terzidis, 2008), and CPAD (Shekhawat, 2015b) have been developed for the automatic creation of schematic plans. For example, algorithms to assist in space allocation in the planning stage were developed approximately 50 years ago (Liggett and Mitchell, 1981b). Space allocation algorithms for schematic plans are based on the experience of designers. Sometimes, these algorithms involve the demanding task of formulating constraints and requirements (Liggett and Mitchell, 1981a). In addition, a schematic plan is normally restricted by the client's requests, shape constraints, budget constraints, structural requirements, and other constraints (Addi and Lytle, 2000; Liggett and Mitchell, 1981b). One of methods for developing a schematic plan from diagramming is by reducing the number of links between bubble diagrams (Hashimshony *et al.*, 1980). An approach for reaching dimensional plans from adjacency diagrams requires a step-by-step method and can be solved with the PERT algorithm (Roth *et al.*, 1982).

Using rough schematic plans is permissible in emergencies because urgent and tactical decisions are called for during emergencies if a plan is not provided in advance. The major constraint considered in the proposed framework is the amount of land to be utilized as a base at an airport. The following manual steps explain the rectangular formulation, which is taken to derive a schematic plan based on bubble diagrams to determine the approximate size of the base. This is a comprehensive process to incorporate information from bubble diagram about the proximity of a functional area and to acquire the dimensions of a functional area based on the estimation formulation. A systematic process of developing schematic plans from bubble diagrams is outlined below.

First, size estimates are assigned to all functional areas in each facility so that a common factor among these sizes can be derived (i.e. width can be assigned as a common factor that remains constant across all functional areas, and the length of each area will then vary according to their specifications). Second, all areas are laid side by side on a plane so that the planner can check if the total area exceeds the constraining dimensions of available land. If the area exceeds constraints, the planner can then select and reduce or change dimensions of functional areas that exceed the land constraint. This selection is at the discretion of the planner, and some planners prefer to manually develop the plan rather than use such a system (Ruch, 1978). The dimensions assigned in the first step to individual areas are then relaxed. New dimensions are given to keep the shape as similar to a square as possible while still meeting adjacency constraints. These iterative steps are conducted and completed until a layout is reached such that all functional areas are contained within the total disaster response base and vacant space is fully utilized in emergencies.

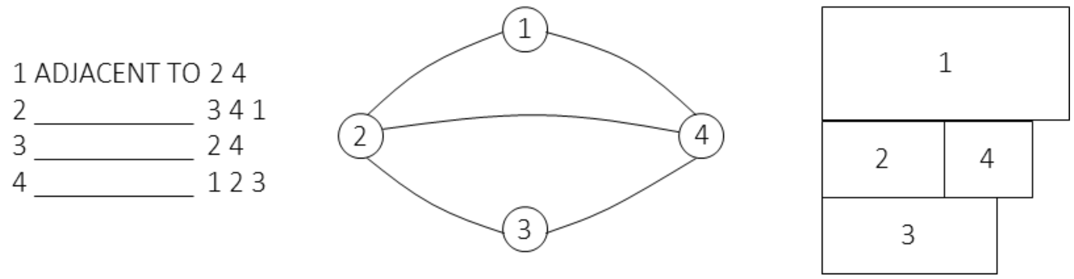


Figure 3-4 Graphical representation in an adjacency diagram, a bubble diagram, and a schematic plan

Source: Adapted from Ruch (1978)

3.4 Case study

3.4.1 Disaster management network and assigning airports as a humanitarian logistics base in Japan

As Japan is one of the most disaster-prone countries in the world, disaster management planning is established and is based on the lessons learned from previous disasters. The Chubu Region Disaster Management Network was set up after the Great East Japan Earthquake in 2011 to incorporate disaster management strategies from academia and the practices of local and national government agencies (MLIT, 2012). The Chubu region is a central region of Japan's mainland. The suggested "Framework for disaster management network in the Chubu region" considers the alignment of a disaster management network within the region and the assignment of current infrastructure such as community centers, schools, airports, and other public facilities as humanitarian logistics bases. Humanitarian logistics bases in the disaster management network in Japan are selected based on the following criteria: whether or not they are near a node of the infrastructure network with an open space of more than 15 ha and whether or not there is a low-level humanitarian logistics base within the prefecture that has a low probability of flooding by a tsunami, that is located outside the border of a densely inhabited district, and that has optical fiber communications.

Airports in and around the Tonankai region that are designated as humanitarian logistics airports (i.e., the Nagoya Airport and Shizuoka Airport) are highlighted in Figure 3-5. According to the disaster scenario proposed in MLIT (2013a), the Tonankai region faces the possibility of multiple natural disasters such as earthquakes and tsunamis. Shizuoka Airport is located on the eastern side of the Tonankai region. This airport can cover most of the areas in the Tonankai region along with the Nagoya Airport, which is designated as another humanitarian logistics hub in the region. Therefore, the airports in the Tonankai region are expected to be the region's humanitarian logistics base and usually serve as the prefecture's humanitarian logistics depots (MLIT, 2013a).

The current plan for the Shizuoka Airport, which is already assigned as a humanitarian logistics base in the region, includes only rough sketches for the facility and does not mention the logical procedures behind the humanitarian logistics base diagramming. The diagramming model proposed in this paper was applied to the space allocation of the required facilities within the airport. Space allocation is an ongoing issue in disaster management operations among regional and central government agencies in Japan.

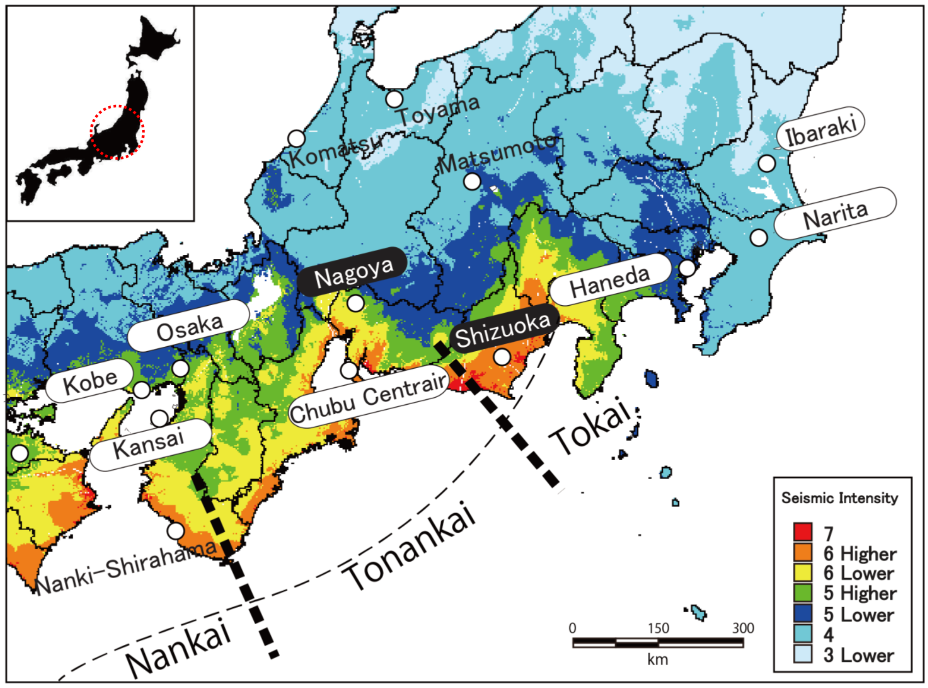


Figure 3-5 Location of airports in the Nankai Trough Earthquake scenario

Source: Modified from the Cabinet Office of Japan (2013)

3.4.2 Scenario building

In this study, the objective of the design plan of the Shizuoka Airport is set to cover the maximum number of estimated emergency workers and the affected population. The constraint within the case study is only the land constraint, which is 16 ha. The airport plans to develop a staging area and base camp within the land. The number of affected people and the number of emergency workers required in the Shizuoka Prefecture according to the Tonankai disaster scenario prepared by the Cabinet Office of Japan (2012) are listed in Table 3-2. The maximum coverage rate of the Shizuoka Airport under its current constraint of 16 ha of vacant land (MLIT, 2012) was examined in this case study along with the maximum coverage of the Shizuoka Airport based on the mean number of affected people in each scenario and the total number of emergency workers required in each scenario, as proposed by the Cabinet Office of Japan (2012).

Table 3-2 Number of emergency workers (left) and number of affected people (right)

Source: Adapted from the Cabinet Office of Japan (2012)

Organization	Workers
Ministry of Defense	11,600
National Policy Agency	2,540
Fire and Disaster Management Agency	2,860
Total	17,000

Scenario	People
Basic scenario: Winter/Midnight	54,000
Basic scenario: Summer/Noon	33,000
Basic Scenario: Winter/Night	42,000

3.4.3 Diagramming for Shizuoka airport

3.4.3.1 Base camp

In the diagramming process, the adjacency between a toilet and a shower, for example, is to be considered because these facilities share the water infrastructure line in a base camp. Figure 3-6 shows the proximity of the functional areas in a base camp as an adjacency diagram. For instance, the shower and toilet areas are assumed to have immediate proximity for the reason mentioned previously.

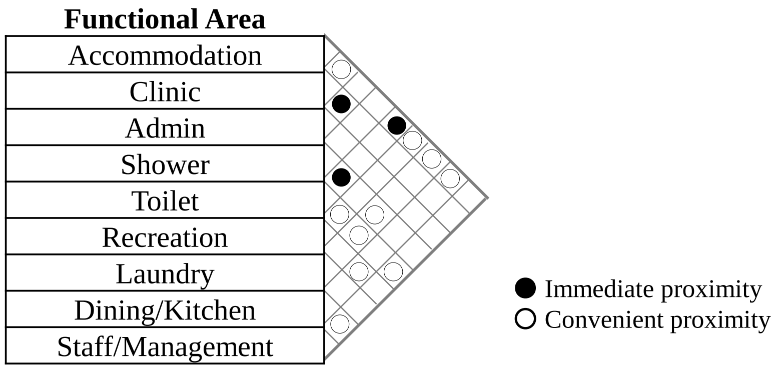


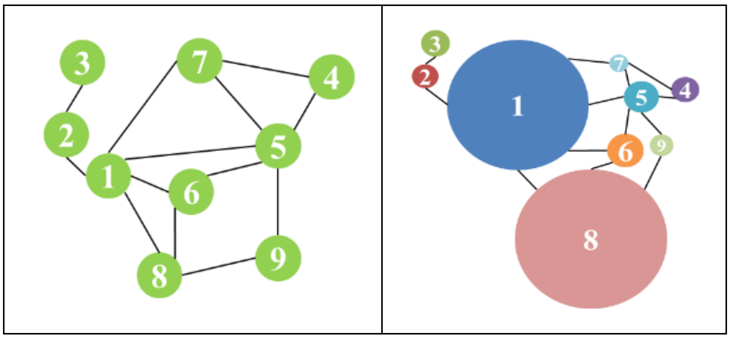
Figure 3-6 Adjacency diagram for a base camp

The approximate size of the base camp area is then calculated based on the estimation formulation. The result is summarized in Table 3-3. If 1,000 workers are needed to support the humanitarian logistics activities in a base camp in an airport that uses the minimum unit area, the accommodation area would be 9,009 m^2, and the total area of the base camp would be assumed to be 30,000 m^2. The dining and kitchen areas are larger than the accommodation area because more activity space is required between each worker in the first two spaces and because more aisle space is required than that of the sleeping area.

Table 3-3 Estimation of a base camp area

Functional area	**Size (m^2)**	R_k
Accommodation	9009.0	0.30
Clinic	1,126.1	0.04
Admin	1,126.1	0.04
Recreation area	2,252.2	0.08
Toilet	1,407.6	0.05
Shower	1,407.6	0.05
Laundry	563.0	0.02
Dining/Kitchen	12,263.5	0.41
Staff	563.0	0.02
Management	281.5	0.01
Total	30000.0	1

An initial bubble diagram without the size adjustment of each bubble is illustrated on the left side of Figure 3-7. An adjusted bubble diagram that considers each functional area's relative size according to Equation (2) is presented on the right side of Figure 3-7. It is clear from the adjusted bubble diagram that 1 and 8 (the accommodation area and the dining/kitchen area, respectively) constitute most of the base camp's gross area.



Functional Area	Number
Accommodation	1
Clinic	2
Admin	3
Shower	4
Toilet	5
Recreation	6
Laundry	7
Dining/Kitchen	8
Staff/Management	9

Figure 3-7 Bubble diagram for a base camp

Figure 3-8 illustrates the diagramming process of a base camp according to the proposed method. In calculating each functional area, the bubbles in the diagram were transformed into rectangular forms based on a common factor. In order to find the shapes that are as square as possible and as close as possible to the others, we tried several sets of numbers to derive the size.

These processes were followed manual iterative steps according to Section 3.2.4.

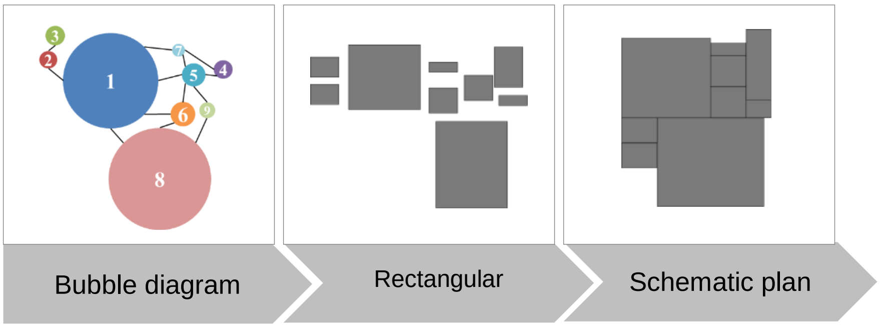


Figure 3-8 Diagramming process for a base camp

3.4.3.2 Staging area

An adjacency diagram is created to understand the space relationships within the facility, as shown in Figure 3-9. In terms of the proximity, all of the functional areas in the staging area are located close to one another. Basic architectural planning concepts are utilized in building the adjacency diagram.

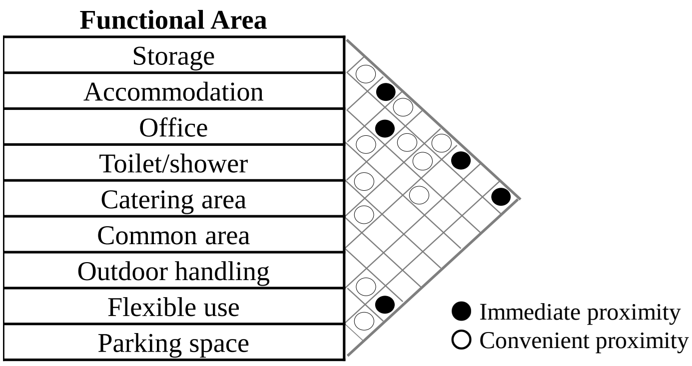


Figure 3-9 Adjacency diagram for a staging area

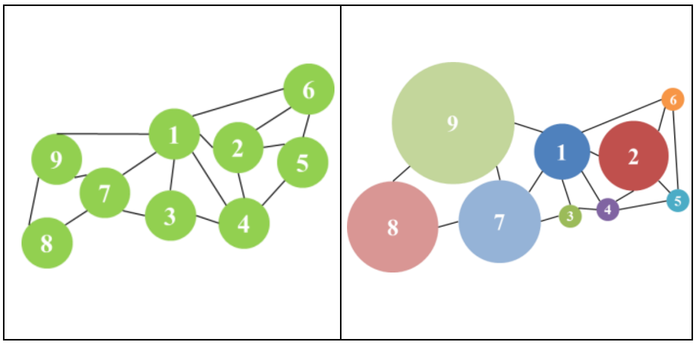
The number of affected people is assumed to be the total number at the prefecture level in Japan. The result of each staging area’s functional area is listed in Table 3-4. To support 10,000 people, the total area required for goods is 1,074.1 m^2. To ensure there will be sufficient space even after the utilization rate of the warehouse is accounted for, it is recommended that 20% of the total area is allocated for this use, yielding a total of 1,288.9 m^2 (UNOPS, 2012). Securing sufficient space is critical for responding to unexpected issues in immediate disaster response. We consider this extra 20% of the total area reserved flexibly for uses such as necessary aisle space, workspace, or space for the flow of goods.

The total support area required when assisting 10,000 people is 4,042.5 m^2. When supporting 10,000 people, the area required for flexible use and outdoor handling and staging would be 4,812.5 m^2, the required area for parking space would be 9,625.0 m^2, and the total open area would be 19,250.0 m^2. Because there are few guidelines regarding the size of an outdoor handling area within a staging area, the sizes of the outdoor handling area and the flexible-use open area are often assumed to be identical (UNOPS, 2012). The results show the approximate total size estimated for the staging area. To assist 10,000 affected people in an emergency, a staging area of 24,581 m^2 would be required for a humanitarian logistics base.

Table 3-4 Estimation of a staging area

	Functional area	**Size (m^2)**	R_v^f
Warehouse	Water	342.3	
	Food	396.9	
	Blanket	133.2	
	Mandatory kit	111.0	
	Toilet	90.7	
	Total area	1,074.1	1
	Total area (120%)	1,288.9	
Support area	Accommodation	3,234.0	0.80
	Office	202.1	0.05
	Toilet/shower	202.1	0.05
	Catering area	202.1	0.05
	Common area	202.1	0.05
	Total	4,042.5	1
Open area	Outdoor handling and staging	4,812.0	0.25
	Flexible use	4,812.0	0.25
	Parking space	9,625.0	0.50
	Total	19,250.0	1
Total Staging Area		**24,581.0**	

Figure 3-10 shows the relative size of the staging area and how the functional areas are related to one another. The open areas are correlated with one another to assist in the smooth flow of relief goods. In terms of proximity, the adjacency of the flexible-use space and the parking space would be convenient for quick response to unexpected events in an emergency. The parking space would occupy the largest part of the staging area because of the unpredictable number of vehicles and the amount of relief goods that may clog the area. Figure 3-11 illustrates the diagramming of a staging area. We follow our method presented in Section 3.4.4.



Functional Area	Number
Storage	1
Accommodation	2
Office	3
Toilet/shower	4
Catering area	5
Common area	6
Outdoor handling and staging	7
Flexible use	8
Parking space	9

Figure 3-10 Bubble diagram for a staging area

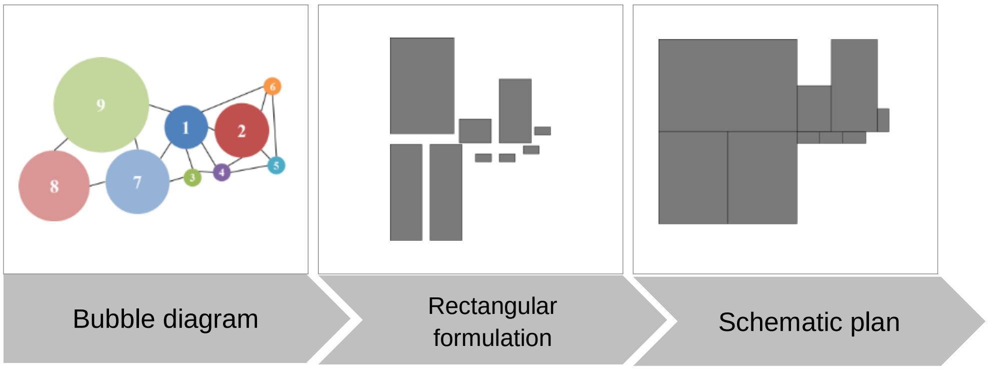


Figure 3-11 Diagramming process for a staging area

3.4.3.3 Humanitarian logistics base layout

The forms shown in Figures 3-8 and 3-11 are suggested in the layout. Figure 3-12 presents the suggested layout for a humanitarian logistics base within the current layout plan of the Shizuoka Airport. The airport has a total gross area of 500 ha, and the space available is assumed to be 16 ha. The approximate size of the current site is 280 × 580 m^2. In this case study, we examined the maximum acceptable number as 17,000 emergency workers and 43,000 affected people in a disaster scenario. These numbers were utilized as inputs for each estimation model. The results indicate that the Shizuoka Airport humanitarian logistics base covers 26.8%

of the total number of emergency workers and affected people, i.e., the base can provide assistance to 4,250 workers and 10,750 affected people as the maximum acceptable numbers in this proposed base layout within the land constraint.

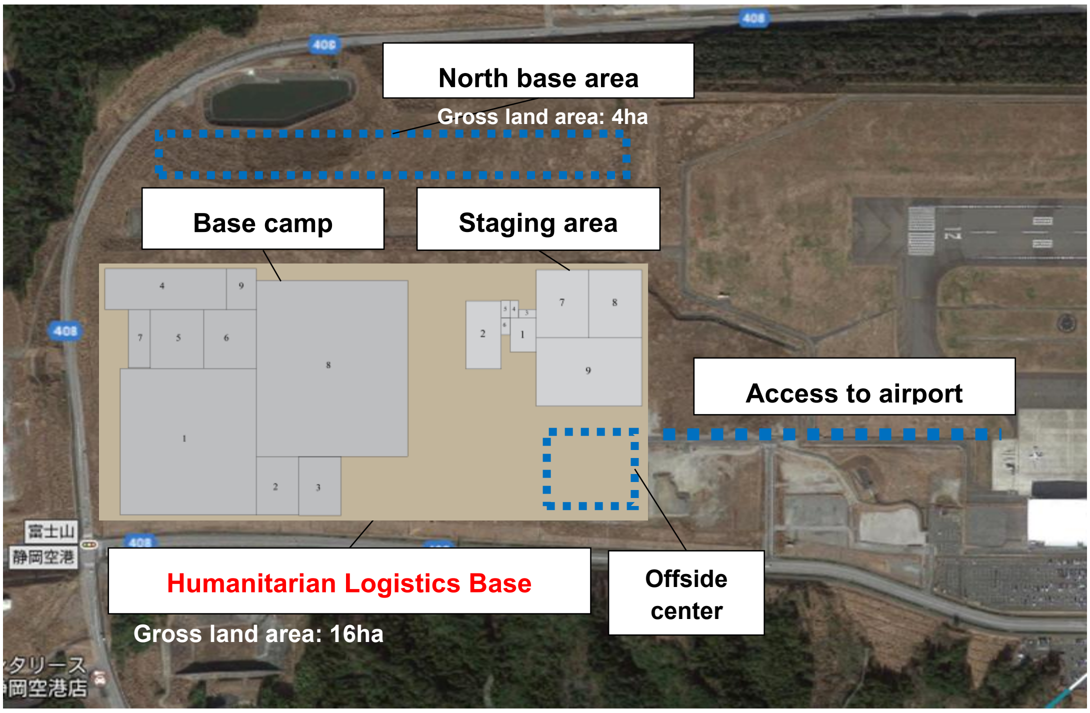


Figure 3-12 Layout plan for the Shizuoka Airport

3.5 Discussions

We applied a method to the Shizuoka Airport case and found that the Shizuoka Airport can cover 26.8% of the affected population and emergency workers in a disaster scenario. Applying the method to a case study is easy to replicate, however, an examination of the feasibility of the proposed layout plan is challenging. To investigate the feasibility of the proposed layout plan, as in Section 3.4.1, we interviewed officials of the Shizuoka Prefecture’s Transportation Infrastructure Department on December 6, 2013 about the applicability of the method. Based on the interview responses, we also confirmed that the feasibility of such disaster response planning in advance of a disaster is difficult. The study offers the following suggestions for developing a humanitarian logistics base in an airport.

First, the planning of a humanitarian logistics base should be treated as a flexible space guideline rather than a rigid plan. Because of the uncertainties associated with catastrophic events, it is not possible to divide an exact space with walls or with any permanent structures as in ordinary buildings; instead, the space must be divided using temporary structures such as tents, trailer units, partitions, and so on. In addition, we have to detect the available facilities or vacant space that can be converted for disaster response purposes. Second, the priorities of functional areas and facilities depend highly on the airport's existing capacity and the impact of the disaster. For instance, the Shizuoka Airport has sufficient space for use as a disaster base on the 16 ha of land on the left side of the terminal building. Therefore, airport officials believe that the Shizuoka Airport has the potential to be utilized in a disaster scenario. However, many regional airports in Japan may not have such vacant space as the Shizuoka airport. This calls for the development of a compact humanitarian logistics base by prioritizing the most likely functions in a post-disaster situation. This could be done by deciding the necessary functional areas during programming in the procedure.

3.6 Chapter conclusion

Despite the significant role of airports as a humanitarian logistics base in previous disasters, there is a need to study space planning guidelines for an airport in a disaster response more elaborately. This paper proposes a diagramming method for the utilization of an airport as a humanitarian logistics base. The outputs are obtained by integrating an estimation model and architectural planning processes. The method is used to estimate the approximate size of a base camp and staging area based on the number of emergency workers and the total amount of relief goods. In addition, the humanitarian logistics were visualized using diagramming from the output of a bubble diagram and a schematic plan. The Shizuoka Airport case study presents the internal configuration of the schematic plan developed using the proposed framework. Our study provides operational insights for the disaster response planning efforts of local and central governments and international humanitarian organizations. Thus, the model is a generic methodology, which the study can be applicable to vacant space in other critical nodes in the region such as ports, stadiums, schools, parks, and so on.

The study considered the available land space as a constraint and the maximum coverage rate of the affected population and emergency workers as the main objective. However, we find the following research directions very useful for further steps. First, as airports are critical infrastructure components in a region, an integrated approach to their utilization involving urban planning principles should be considered. For example, the relationship between the base and other facilities in an airports as well as road conditions, lifeline networks, etc. should be reflected in the planning. Second, legislation issues and engineering constraints for facilities within and around airports must be reflected. Third, the development of a mathematical model for the measurement of the space and the location of functional areas would allow decision makers to choose the best-fitting design from among different alternatives. Available open space may be affected by types of disasters and damage to the airport. Knowing these uncertainties as constraints, we may apply the methodology under given limited space. If there is not sufficient space, we should decide priorities among functional areas in each facility in the base. This calls for consideration of multiple constraints and objectives. In addition, decision criteria should be developed for use by nations and regions in enhancing airport operations as part of the immediate disaster response. Since our study provides a confirmatory case study, further case studies are recommended for validating the methodology.

4. Managing waiting time at an airport in immediate disaster response

4.1 Introduction

Airport operations have been of particular concern in the recent disaster responses to Hurricane Katrina in 2005, the Haiti earthquake in 2010, the Great East Japan Earthquake in 2011, and the Nepal Earthquake in 2015. The importance of air transport is especially critical in the immediate disaster response phase because air transport becomes an alternative to road and rail transportation, which is often disrupted by earthquakes, tornadoes, and other disasters. Within the first 72 hours of the immediate response phase, emergency medical care is particularly dependent upon air transport. The airport, considered as a node, supports various humanitarian activities and provides a base for the impacted area. Air routes, considered as links, enable the delivery of aid goods, transportation of evacuees, and so on.

For these reasons, preparing airports for disaster response has been a much discussed topic in the last decade. Smith (2007) first introduced the role of airports and their coordination during emergencies. Guidelines for airport disaster preparation have been proposed, and regional mutual aid agreements have been developed, such as Western Airports Disaster Operations Group (WESTDOG) and Southeast Airports Disaster Operations Group (SEADOG) (TRB, 2012). International organizations such as the International Federation of the Red Cross (IFRC), the United Nations Humanitarian Response Depot (UNHRD), and the United Nations Development Programme (UNDP) have developed airport plans for international responses to regional disasters (Martinez et al., 2010; UNHRD, 2008; UNOPS, 2012; DHL and UNDP, 2010).

However, as a point of entry, an airport is usually challenged to accommodate excessive demand within limited capacity constraints. Therefore, an aircraft usually has to wait in the airport for a long time before completing its disaster response mission. The organizational complexity inherent in the tactical assignment of various tasks in an airport definitely hinders humanitarian responses. In particular, multiple stakeholders such as medical helicopters, military, police, broadcasting and so on are involved in different disaster response missions.

Hanaoka et al. (2013) determined that bottlenecks in the airport originate both on land and in the air for several reasons. Aircrafts are operated by different organizations; different operators are not prioritized; and location assignment is also difficult. Considering these causes of congestion, this study focuses on how to reduce extreme waiting times and resolve operational bottlenecks at airports immediately after disasters.

In this paper, we claim that managing nodes within the network that are utilized as points of entry by many nations is critically important to coordinating effective disaster responses. The objective of the study is to find a solution for relieving congestion in airports during emergencies with the end result of enhancing overall humanitarian responses.

This paper develops a methodological framework for modeling airport operations during disaster responses and presents a model for estimating the waiting time of an aircraft in an airport during a disaster response based on queuing theory, considering the effects of current and other proposed queuing disciplines. An open Jackson network model is used, and different queuing disciplines are applied to a numerical example in order to investigate the effects of different policies such as first-come-first-served, priority, and a mixed of the two.

The rest of the chapter is constructed as the follows based on Figure 4-1. Section 4.2 discusses a methodological framework for assessing aircraft waiting times in an airport based on queuing theory. Section 4.3 details the model formulation, which applies an open Jackson network model, and a case study of the Great East Japan Earthquake is discussed in Section 4.4. and discusses further in Section 4.5. The results of the study suggest policy implications that are presented with the conclusions in Section 4.6.

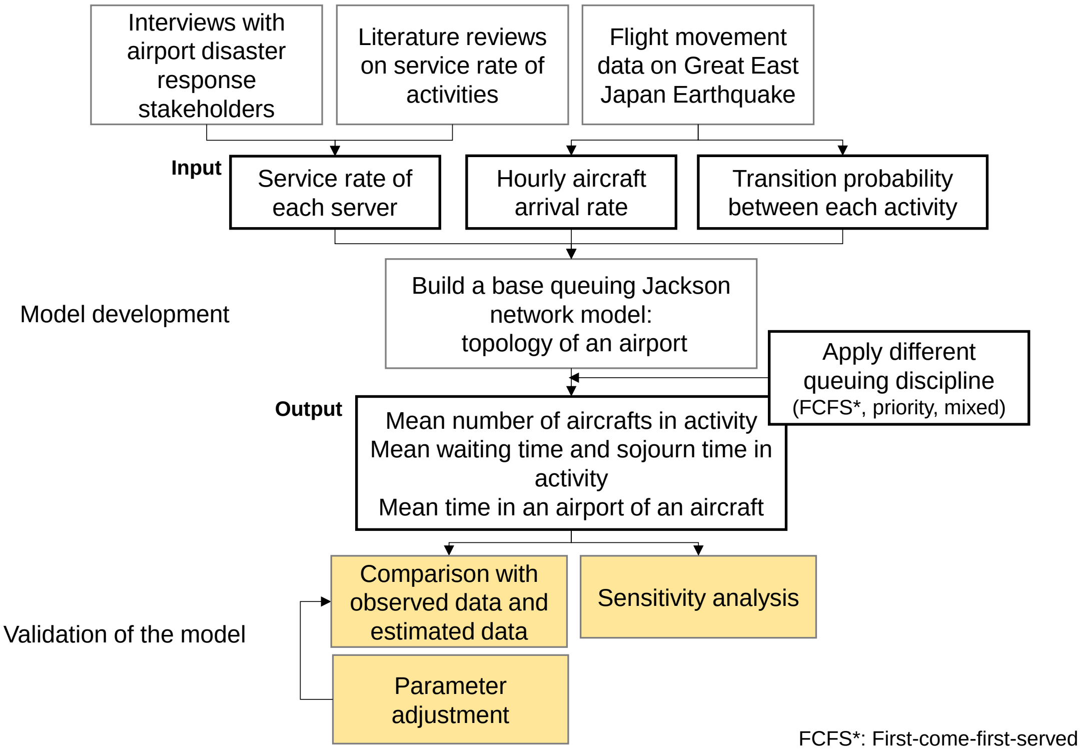


Figure 4-1 Estimation flow for the chapter

4.2. Methodological Framework

4.2.1. Modelling motivation

Despite the assistance that queuing theory provides to system performance evaluations, the theory's applicability to humanitarian logistics and disaster management has gained little attention. Moreover, the intersection between queuing theory and airport operations has been rarely discussed in the previous literature, even though a significant variety of research addresses the improvement of airport operations immediately following disasters, including both qualitative and quantitative determinations of bottleneck situations. Therefore, to begin this study, we compared certain features shared by airport operations during disaster responses and emergency department management in hospitals, as shown in Table 4-1.

The entities arriving at airports during emergencies are considered to be various aircrafts operated by different operators. These aircrafts have diverse operation purposes, and their degrees of urgency must be evaluated differently. In support of this methodology, Kim and Kim (2015) asserted that emergency departments in hospitals and airport operations during emergencies share these features; in particular, emergency departments in hospitals treat patients as arriving entities, and airports in emergencies treat aircrafts as arriving entities. Therefore, above mentioned background aroused research necessity in developing a framework for airports in immediate disaster response phase by queuing theory modeling to seek a possibility in operation enhancement.

Table 4-1 Features of airport in emergencies and emergency department

	Airport in emergencies	**Emergency department in hospital**
Arriving entities	Aircrafts	Patients
Entities feature	Poisson arrival	Poisson arrival
Place	Airport	Hospital
Configuration	Flexible	Fixed
Types of entities	Varying	Varying
Priority of entities	Undecided	Decided upon the severity

After the 2011 Great East Japan Earthquake, the Tohoku region of Japan was severely damaged, and various operators assisted with disaster response activities at targeted airports. Different operators; such as police and fire departments and disaster management agencies; the Japan Coast Guard (JCG); the Japanese Self-Defense Forces (JSDF); the Ministry of Land, Infrastructure, Transport and Tourism (MLIT); and medical helicopter units; fulfilled different functions during the immediate disaster response. The types of aircraft operators and their roles in the disaster response are listed in Table 4-2. The proposed model considers these main disaster response roles: ambulance transport, rescue operations, disaster response, information collection, personnel transport, and freight transport.

Time management is one of the most crucial factors influencing overall operations in humanitarian logistics, affecting multiple stakeholders involved in the disaster response activities, including airport operators, aircraft operators, emergency workers, and so on. Specific attention has been paid to aircraft operators because prompt and exact aircraft operation significantly impacts the population in the disaster area. Table 2 lists five aircraft operators and six operational tasks required for humanitarian logistics operations in airports. The data in the table is extracted from the flight movement data of the Great East Japan Earthquake in 2011; the total take-off and landing frequencies are summed over the first four days following the disaster.

Table 4-2 Helicopter operators and number of operations according to purposes in Hanamaki airport in 2011 Great East Japan Earthquake

Source: modified from Aratani *et al*. (2013), unit: frequency of taking off and landing

		Fire Disaster Management	Doctor Helicoptxer	Police	JCG	Broadcastin g helicopter	JSDF	Airline	Others	Total
Normal operation		5	-	-	-	-	-	3	1	9
Disaster response	Ambulance transport	10	31	-	-	-	2	-	-	43
	Rescue operation	74	-	8	1	-	20	-	1	104
	Disaster response	2	-	-	-	-	3	-	-	5
	Informatio n collection	3	-	6	-	-	-	-	1	10
	Personnel transport	2	-	-	-	-	-	-	5	7
	Freight transport	14	1	3	-	-	5	-	-	23
	Extra flight	-	7	-	-	-	-	-	-	7
Others		5	1	7	-	1	78	-	-	93
Total		115	40	24	1	1	108	3	8	301

The queuing system consists of three main components: arriving customers, the queue, and the service mechanism. This study defines the arriving customers as the aircrafts arriving at the airport. The queue and service mechanism refer to the Poisson processes of the two mechanisms in the study. Here, the queuing modeling is applied to an airport by considering different disaster response activities as services in the queuing system. In an airport, numerous operators and aircrafts gather, and all of their capabilities are valuable; however, medical treatment for critical patients is considered to demand more urgency than any other response.

4.2.2. Airport disaster response as an open Jackson network

For the queuing system components of the model, the arrival rate and service rate follow Poisson processes. The Jackson network of the model contains eight servers, and this study treats aircrafts as the sources of customers, following the infinite source case. This study also adopts FCFS, priority, and mixed disciplines as the queuing disciplines. The FCFS queuing discipline models real disaster response situations, in which no priority is assigned to different operators. In contrast, the priority discipline follows a non-preemptive priority discipline, in which priority is assigned to different operators by weighting their roles in life-saving operations. The term “non-preemptive” indicates that an aircraft being served cannot be ejected back into the queue if a higher priority aircraft enters the queuing system. Lastly, a mixed discipline is a combination of the FCFS and non-preemptive priority disciplines: priority is assigned to the top two operators, and the other operators are pooled together as the third priority, which follows the FCFS discipline.

The disaster response behaviors for different aircraft purposes are modeled as a single server in the network, as shown in Figure 1. In normal airport operations, aircraft behaviors follow conventional rules. The aircraft operator enters the airport by landing on a runway, taxis and parks at an apron area, refuels the aircraft’s tank, submits the aircraft to a maintenance review, and leaves the airport for the next destination. We found that aircrafts in emergencies also follow similar fixed processes.

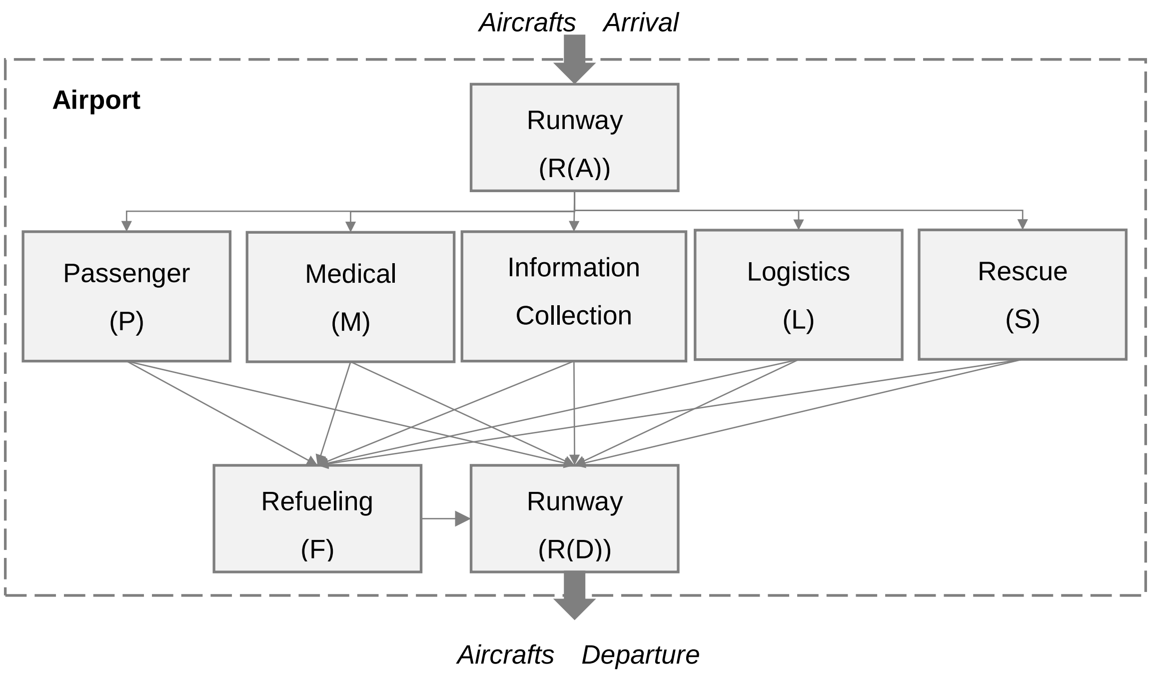


Figure 4-2 Open Jackson network model for an airport in disaster response

In general, one flight has one purpose and stops at a base airport after completing its mission, and the aircraft must be refueled before leaving for its next mission. Fueling is also critical for helicopters, especially to maximize their efficient response characteristics by reducing the number of times they must land at airports.

The M/M/s model of analyzing each service system and calculating performance measurements is achieved through Excel software from Hillier and Lieberman (2010). Since, an airport has different response activities according to servers inside, the behavior of arriving aircrafts follow M/M/1 model as in Figure 4-3. Figure 4-3 depicts differences between M/M/s model when s=3 and three M/M/1 models.

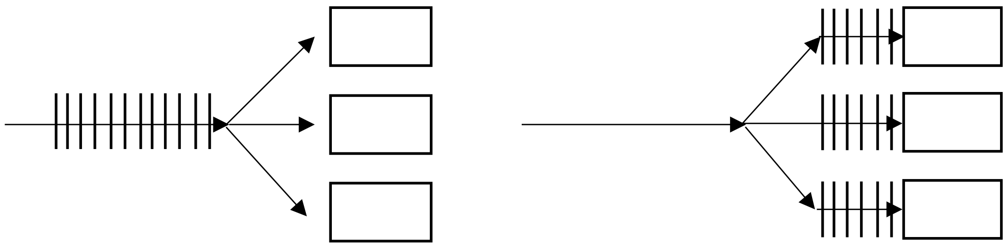


Figure 4-3 M/M/s model (left) and M/M/1 model (right): when s=3

This model specifies the following assumptions: the airport has one runway and is controlled by an air traffic controller; in the immediate response phase of three days after the disaster, all operations are conveyed by helicopters; to ease calculation, all helicopters have identical features (fueling capacity of 1,251 liters, and maximum loading is 2,313 kg, characteristic of the BELL412 helicopter model, which is often used for rescue and response activities); all helicopters have one purpose per flight mission; the airport operation hours are from 07:00 AM to 19:00 PM because aircrafts, especially rotary wing aircrafts, become significantly more dangerous to operate at night.

4.2.3. Estimating service rate

Data on the service rate of each activity are shown in Figure 4-4. One server is defined as an activity that the airport provides during disaster response such as medical care, personnel transport, unloading and loading logistics, rescue activities, refueling, and so on. It is not possible to determine the exact service rate for each individual activity in emergencies because of the lack of specific information and differences among emergencies. Therefore, this study collected service rate data from relevant researches as proxies for the service rate of each server.

There are seven service rates to be estimated in this study: runway, terminal, information collection, logistics, and refueling. The runway occupancy time was calculated from the number of rotary-wing and fixed-wing aircraft arrivals in an airport, using the mean runway occupancy time of the two different modes. The terminal area service rate refers to the loading and unloading of passengers from aircrafts, as suggested by Landeghem and Beuselinck (2002). Likewise, this study utilizes the medical treatment service rate data inferred from Cochran and

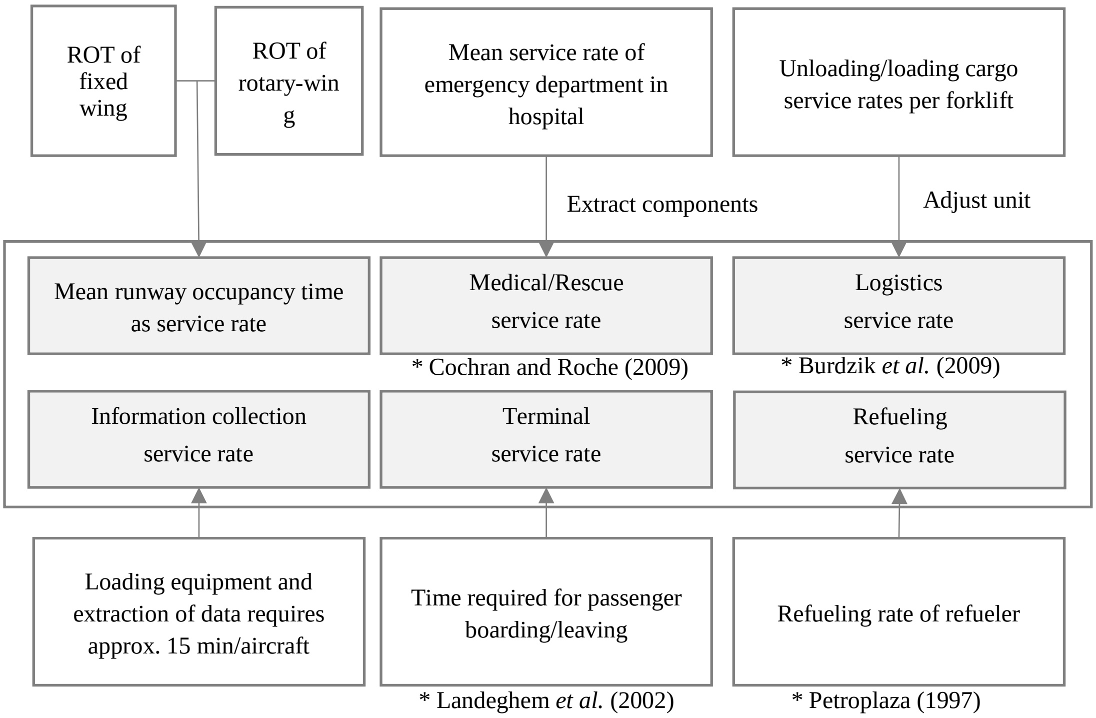


Figure 4-4 Data collection on service rate of each activity

Roche (2008), including different kinds of medical treatment in the literature, and extracting emergency medical treatment data on critical patients. Information collection is usually conducted with rotary-wing aircrafts operated by government or media agencies. From the interviews the authors conducted with airport operators involved in the Great East Japan Earthquake, approximately 10 to 15 min are required to unload and load broadcasting equipment and staff. The logistics service rate addresses the handling of humanitarian aid goods during disasters: in real-world situations, the process are treated manually, mechanically, and sometimes both depending on the airport's situation. Assuming that forklifts are widely used in an airport to lift goods, the forklift speed in Burdzik et al. (2014) was used to determine the logistics service rate. Gary (1997) states the flow rate of a fueling truck and hydrant dispenser that was used to determine the refueling service rate in this analysis.

4.2.4. Estimating arrival rate

Flight movement data from the Tohoku region in response to the Great East Japan Earthquake in 2011 was provided by MLIT. The dataset includes 20,243 movements, including arrivals and departures of both rotary-wing and fixed-wing aircrafts. Data was extracted for the period from

March 1st to March 31st, 2011, and the Hanamaki airport's operating hours were observed to extend from 07:00 A.M. to 19:00 P.M. Because this study focuses on the immediate disaster response phase, the mean hourly arrival rate over the time span within the first three days of the earthquake was derived, as shown in Figure 4-5. This process can be applied to other airports involved in the Great East Japan Earthquake to present more numerical examples.

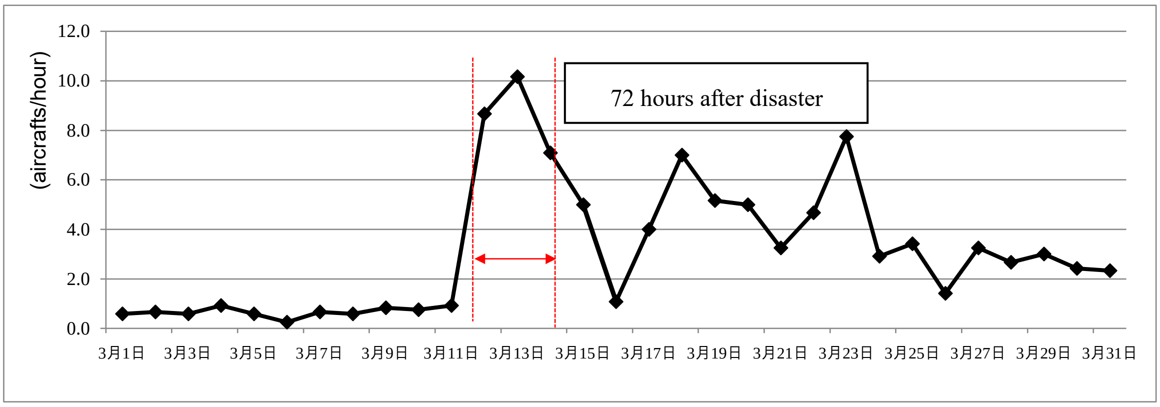


Figure 4-5 Mean hourly aircraft arrival rate at Hanamaki airport after the Great East Japan Earthquake

Modified from Aratani *et al.* (2013)

Figure 4-6 confirms that hourly arrival rate of Hanamaki Airport on March 12th, 2011 fits to Poisson distribution. All arrivals of aircrafts in the airport were counted every one hour from 6:00 AM to 20:00 PM.

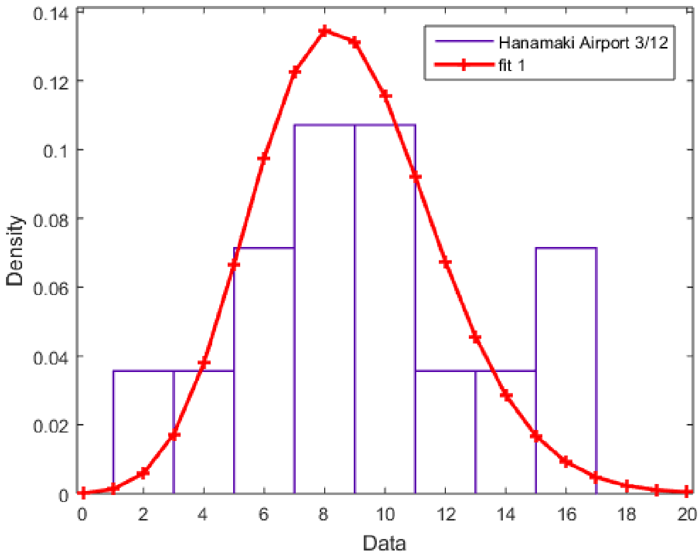


Figure 4-6 Hourly arrival rate of Hanamaki Airport on March 12th, 2011

Statistics summary is illustrated in Table 4-3. Mean arrival rate of Hanamaki Airport on March 12th, 2011 is 8.75 aircrafts per hour with standard deviation of 4.02.

Table 4-3 Statistics summary of hourly arrival rate of Hanamaki Airport on March 12th, 2011

Mean	8.785714286
Standard Error	1.075085335
Standard Deviation	4.022600985
Sample Variance	16.18131868
Confidence Level(95.0%)	2.32258066

4.2.5. Queuing discipline

The first queuing discipline, FCFS, is used in real-world disaster response situations, in which no priority is assigned to different operators upon arrival. The second queuing discipline is a non-preemptive priority discipline, in which priority is assigned to different operators by weighting their role in life-saving, although an aircraft being served cannot be ejected back into the queue if a higher priority aircraft enters the queuing system. The third queuing discipline is the mixed, which uses both FCFS and non-preemptive priority disciplines for different operators. In the mixed approach, priority is assigned to the top two operators, and the other operators are pooled together as the third priority, which follows the FCFS discipline. Table 4-4 shows the different priority assignments for each queuing discipline, where 1 represents the highest priority and 5 represents the lowest priority. The priorities were assigned based on how the degree to which each aircraft operator is involved in life-saving.

Table 4-4 Applying different queuing priority for each aircraft operator

(1 to 5: highest to lowest)

	Doctor Helicopter	***Fire/ Disaster management***	***JSDF***	***Police/ JCG***	***Broadcasting helicopter***
FCFS	1	1	1	1	1
Priority	1	2	3	4	5
Mixed	1	2	3	3	3

4.3. Problem formulations

A queuing network in an airport accommodates many different processes that are involve in disaster responses, starting from the runway and proceeding to the next process according to the given aircraft's purpose. Each aircraft's purpose is decided by the aircraft's operator, and the aircraft usually delivers a single mission with each flight. Because aircrafts are classified according to their purposes, the waiting time and the number of aircraft in each process can be calculated based on the Jackson network theorem.

The aircraft enters an airport with one or more operational purposes: runway, terminal, medical, information collection, logistics, rescue, and refuelling. The model proposed here assumes that all aircrafts need to refuel before leaving for the next flight mission, and that each aircraft must follow a runway procedure to complete its mission because both fixed-wing and rotary-wing aircrafts require runway access. Although rotary-wing aircrafts offer more flexibility in terms of landing sites, they are nonetheless directed by the air traffic controller.

4.3.1. Base case

Disaster response activities are defined by the server *i* (*i* =1, 2,…, m) within a multiclass open Jackson network. Airport performance in a Jackson network model with FCFS and priority rules can be predicted by models from Hillier and Lierberman (2010) and Kim and Kim (2015). Eq. (4-1) represents the business or utilization rate of the server *i* during the disaster response. λ_i is defined as the total arrival rate of all operators into server *i*, as given in Eq. (4-2) An open Jackson network model normally represents the external arrival rate from outside the network as $\lambda q_{s,i}$; however, it is assumed that because aircrafts strictly follow air traffic control rules, this external arrival rate is excluded from this calculation. Here, $q_{j,i}$ represents the fraction of aircrafts from server *j* to server *i*; the transition probability between servers is obtained, and the transition matrix is shown for all operators. Because each server follows *M/M/s* properties, the following performance measurements can be determined: expected waiting time in queue, expected waiting time in system (including service time), and expected number of aircrafts. The number of servers at each node *i*, represented as s_i, is defined as one in this case. Eq. (4-6) indicates mean waiting time in an airport which can be used for comparing waiting time with other airports.

$$\rho_i = \frac{\lambda_i}{\mu_i} (0 \le \rho_i \prec 1) \tag{4-1}$$

$$\lambda_i = \lambda q_{s,i} + \sum_{j=1}^{M} \lambda_i q_{j,i} (i = 1, \cdots, N) \tag{4-2}$$

$$E_i = \frac{\rho_i}{1-\rho_i} \tag{4-3}$$

$$W_i = \frac{\rho_i}{1-\rho_i} \frac{1}{\mu_i} \tag{4-4}$$

$$\overline{T}_i = \frac{\overline{N}_i}{\lambda_i} = \frac{1}{\mu_i - \lambda_i} \tag{4-5}$$

$$T = \frac{1}{\lambda} \sum_{i=1}^{M} E_i \tag{4-6}$$

μ_i mean service rate of response activity *i*

λ_i mean aircraft arrival rate through response activity *i*

ρ_i utilization rate for the response activity *i*

$q_{j,i}$ transition probability of aircrafts from response activity *i* to response activity *j*

E_i mean number of aircrafts in response activity *i*

W_i mean waiting time in response activity *i* excluding service time

$\overline{T}_i$ mean sojourn time in response activity *i* including service time

T mean waiting time in airport including service time for each aircraft

4.3.2. Priority case

To represent the priority discipline and mixed discipline, all of the performance measurements in the single server i follow the M/M/s spreadsheet template proposed by Hillier and Lierberman (2010). The expected sojourn time in processes with no pre-emptive priority is calculated based on the following model. The steady-state expected waiting time in the system, including the service time of an aircraft of priority class k, is defined in Eq. (4-7). Following the Jackson's network theorem for calculating the arrival rate and transition matrix for all operators, the total waiting time including service and queue waiting time can be derived.

$$W_i^k = \frac{1}{A_i B_i^{k-1} B_i^k} + \frac{1}{\mu_i}, \forall i \text{ and } k = 1, 2, \cdots, N \tag{4-7}$$

$$\text{where } A_i = s_i! \frac{s_i \mu_i - \lambda_i}{\rho_i^{s_i}} \sum_{k=0}^{s_i - 1} \frac{\rho_i^k}{k!} + s_i \mu_i,$$

$$B_i^k = \begin{cases} 1, k = 0 \\ 1 - \dfrac{\sum_{i=1}^{k} \lambda_i}{s_i \mu_i}, k = 1, 2, \cdots, N \end{cases}$$

W_i^k : expected waiting time in the node *i* including service time of priority class *k*

s_i : number of servers in node *i*

4.4. Case study

Data were collected following the data collection procedures mentioned in Section 4.3. We focused on three airports that were actively involved in the response to the Great East Japan Earthquake in 2011: Hanamaki, Fukushima, and Yamagata airports. In particular, Hanamaki airport was selected for investigation in the following section because its basic airport facilities sustained no severe damage after the earthquake. This airport had also prepared countermeasures for disasters based on experience from the 2008 Iwate-Miyagi Nairiku Earthquake to ensure cooperation among disaster response aircraft operators and prefectures (Hanaoka et al., 2013).

4.4.1. FCFS case: Hanamaki, Fukushima, Yamagata airport

The arrival rates for different helicopter operators in Hanamaki Airport and Yamagata Airport were estimated as shown in Table 4-6. The total mean arriavla rate of aricrafts during first 72 hours ins Hanamaki Airport is 8.62 airacrafts per hour and 3.92 aircrafts per hour in Yamagata airport. To maintain the necessary flow conservation in the queuing network, aircraft arrivals and departures through a single airport are assumed to be the same. The total arrival rate for each server is presented in the far right column of Table 4-6.

Table 4-5 Arrival rate of different helicopter operators: Hanamaki Airport

unit: aircrafts/hour

	Medical Helicopter	Fire/Disaster	JSDF	Police	Total arrival rate
Runway (A)	1.56	4.92	1.30	0.86	8.64
Terminal	0.00	0.10	0.00	0.00	0.10
Medical	1.51	0.48	0.10	0.00	2.08
Information collection	0.00	0.14	0.00	0.29	0.43
Logistics	0.05	0.67	0.24	0.14	1.10
Rescue	0.00	3.54	0.96	0.43	4.93
Refueling	0.78	2.46	0.65	0.43	4.32
Runway (D)	1.56	4.92	1.30	0.86	8.64

Table 4-6 Arrival rate of different helicopter operators: Yamagata airport

unit: aircrafts/hour

	Medical Helicopter	Fire/Disaster	Police	Total arrival rate
Runway (A)	0.04	3.17	0.71	3.92
Passenger	0.00	0.00	0.00	0.00
Medical	0.04	0.05	0.00	0.09
Information	0.00	0.16	0.43	0.59
Logistics	0.00	0.32	0.11	0.43
Rescue	0.00	2.64	0.16	2.81
Refueling	0.02	1.59	0.35	1.96
Runway (D)	0.04	3.17	0.71	3.92

Although an airport is treated as a connected open Jackson network, there is no external arrival rate from outside the network because an aircraft cannot land at a server without passing through the runway. The input data used to derive the performance measurements are estimated based on Section 4.3. Runway occupancy rate of Hanamaki airport in Great East Japan Earthquake 2011 was estimated for runway service rate as 15 aircrafts per hour. The following are the service rate for each activity within an airport: terminal as 4.8, medical as 7.24, information as 4, logistics as 4.5, rescue as 6.51 and refueling as 9.76 aircrafts per hour. Following the flow conservation law relating to the queuing network's input and output flows, the arrival rates determined by runway arrival and runway departure are the same.

The model assumes that the service rates are the same for all airports, except for the refueling service rate at Fukushima airport, which does not have as much capacity as the other two airports. It is challenging to set specific service rates for all of the different activities at each different airport. To consider the smaller refueling capacity, we consider that the fueling tank size is to be decreased to 60% of the normal refueling capacity.

First, the service rate was estimated, and the hourly aircraft arrival rate was calculated. The transition matrix of each operator was estimated based on the fraction of the total hourly arrivals occupied by the given operator. Because the particular transition probability for each different server is not known from the limited information available, this study assumes the following: each aircraft should proceed to refueling and the runway before leaving for its next mission, so that the refueling and runway transition probabilities are considered to be 0.5. In addition, all aircrafts that proceed from refueling must leave the airport, resulting in a transition probability of 1 from refueling to runway. Based on this approach, the transition matrix for a medical helicopter is shown in Table 4-5 as an example.

Table 4-7 Transition matrix for a medical helicopter: Hanamaki Airport

	Runway (R(A))	Medical (M)	Rescue (S)	Information collection (I)	Passenger transport (P)	Logistics (L)	Refueling (F)	Runway (R(D))
Runway (R(A))	0	0.97	0.00	0.00	0.00	0.03	0	0
Medical (M)	0	0	0	0	0	0	0.5	0.5
Rescue (R)	0	0	0	0	0	0	0.5	0.5
Information collection (I)	0	0	0	0	0	0	0.5	0.5
Passenger transport (P)	0	0	0	0	0	0	0.5	0.5
Logistics (L)	0	0	0	0	0	0	0.5	0.5
Refueling (F)	0	0	0	0	0	0	0	1
Runway (R(D))	0	0	0	0	0	0	0	0

Table 4-8 depicts number of aircrafts in each activity, expected waiting time including service time, and expected waiting time excluding waiting time and utilization rate of each activity in Hanamaki airport. Hanamaki airport primarily served as a base for search and rescue activities;

very few helicopters served the broadcasting purpose, and most of the aircraft's missions were focused on humanitarian logistics activities. The table shows the longest waiting time appearing in the rescue purpose; this is because many operators are first dedicated to search and rescue activities in the immediate disaster response phase.

The total waiting time including service time in the rescue purpose is the highest, at 37.97 min per aircraft, when applying the FCFS queuing discipline. This is because when operators are not weighted, every operator shares the same waiting time in the system. Runway congestion may not be the biggest bottleneck obstructing entry into an airport: the waiting time at the runway including service time is approximately 9.43 min in the network. In comparison, the waiting time including service time in the logistics system is 17.65 min, which is shorter than expected because the model considers only automatic assistance and does not consider the manual workforce.

In addition, the waiting time for refueling in queue is shown to be less than 5 minutes per aircraft. Although actual disaster response operations would ideally behave according to the model, this is not always the case. In the Great East Japan Earthquake, the findings from Hanaoka *et al*. (2013) revealed that refueling was one of the biggest bottlenecks in the airport because the airport sometimes lacked the necessary fueling capacity, so that aircrafts had to wait up to 60 min

Table 4-8 Performance measurement of FCFS case: Hanamaki Airport

	Runway (A)	Passenger	Medical	Information	Logistics	Rescue	Refueling	Runway (D)
E_i (number)	1.36	0.02	0.41	0.12	0.32	3.12	0.79	1.36
T_i (min)	9.43	12.76	11.65	16.81	17.65	37.97	11.03	9.43
W_i (min)	5.43	0.26	3.36	1.81	4.31	28.76	4.88	5.43
ρ_i	0.58	0.02	0.29	0.11	0.24	0.76	0.44	0.58

The data show that even under these conditions, the waiting time was almost less than 1 min for the terminal and information processes. This also implies that if unexpected operators add to the load on these two operations, the network system would suffer from further congestion and longer waiting times. The biggest waiting time including service time difference impacts the rescue operation: 28.54 min between the runway and rescue servers. Therefore, even if an aircraft enters the airport, it will not reduce the waiting time, indicating that the FCFS discipline is of limited support given the urgent demands of humanitarian logistics.

It is observed that the biggest number of aircrafts in the server is 1.6 which occurred in rescue in Figure 4-7. The other purposes are less than 1 aircraft in their waiting time. Because the operators convey most of their flight missions as to assist humanitarian logistics, most of the activities are highly related to life savings such as rescue. It is natural that waiting time of an aircraft in rescue is the longest when arrival rate is the highest after runway. We can conclude that the highest utilization of one activity in the server brings the biggest bottleneck among different priority groups. The total expected number of aircrafts is highest in rescue server in an airport and is about six aircrafts staying in the network. Be specific, different operators roles duplicate rescue activities in disaster response especially between JSDF and Fire/ Disaster management helicopter. There is comparably little waiting aircraft in terminal, medical and information collection system.

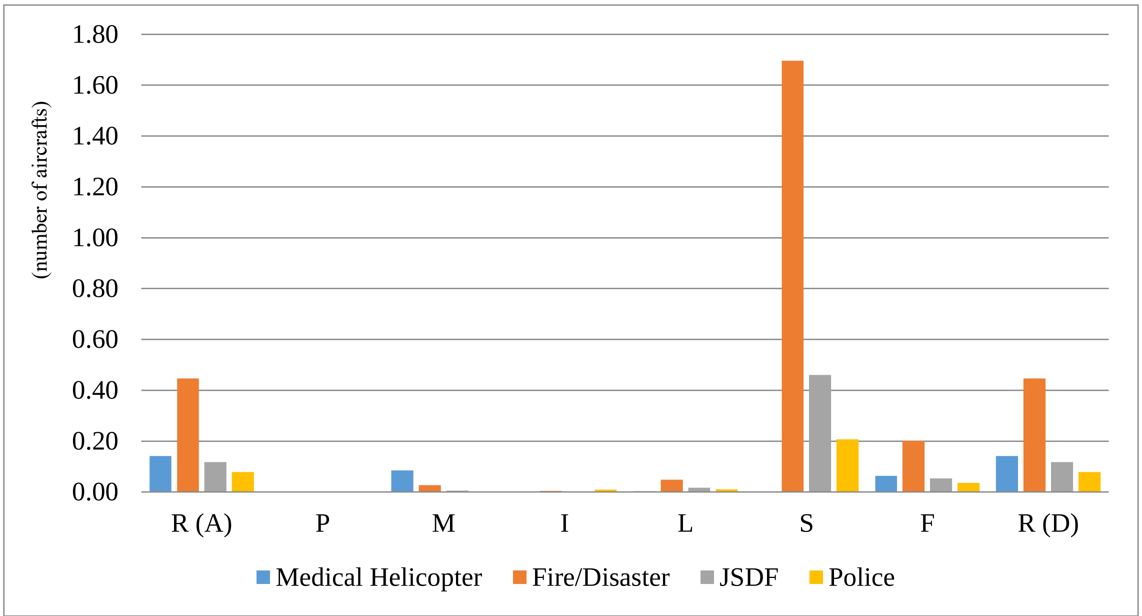


Figure 4-7 Expected number of each operator's aircraft waiting in the queue in system

Table 4-9 discusses number of aircrafts in each activity, expected waiting time including service time, and expected waiting time excluding waiting time and utilization rate of each activity in Yamagata airport. As inferred from Table 7, the number of aircrafts in the server is less than 1 aircraft for all servers. The longest waiting time which includes service time is occurred in rescue purpose. This shows similar tendency with Yamataga airport since many operators in immediate response are first dedicated to search and rescue activities. The total waiting time in the rescue purpose is 16.09 min when applying the FCFS queuing discipline. The shortest waiting time in Yamataga airport shows in runway and this means that runway itself was not bottleneck. The most congested server where utilization rate was the highest is refueling as 0.43. Utilization rate of other servers in Yamataga airport is less than 0.30 and the lowest utilization rate is 0.02 for medical purpose.

Table 4-9 Performance measurement of FCFS case: Yamataga Airport

	Runway (A)	Medical	Information	Logistics	Rescue	Refueling	Runway (D)
E_i (number)	0.35	0.02	0.17	0.11	0.75	0.25	0.35
T_i (min)	5.41	8.43	17.58	14.73	16.09	7.69	5.41
W_i (min)	1.41	0.14	2.58	1.41	6.87	1.54	1.41
ρ_i	0.26	0.02	0.15	0.10	0.43	0.43	0.26

Table 4-10 summarizes the result for Fukushima airport case with number of aircrafts in each server, waiting time in queue, waiting time including service time, and utilization rate. Number of aircrafts in Fukushima airport was less than 1 for all servers. Waiting time including service time shows highest in information purpose which is 17.58 minutes. The second highest was 16.09 minutes in rescue purpose. This is because the airport mainly served as an accepting role for media helicopter for information collection. When comparing waiting time in queue for each server, the shortest waiting time was in medical as 0.14 and highest in rescue as 6.87 minutes. On the other hand, utilization rate for rescue purpose and refueling purpose are both 0.43 which two servers had more congestion than other servers.

Table 4-10 Performance measurement of FCFS case: Fukushima airport

	Runway (A)	Medical	Information	Logistics	Rescue	Refueling	Runway (D)
E_i (number)	1.22	0.05	2.20	0.34	0.68	2.38	1.22
T_i (min)	8.89	8.69	32.00	17.91	15.50	34.66	8.89
W_i (min)	4.89	0.40	22.00	4.59	6.29	24.42	4.89
ρ_i	0.55	0.05	0.69	0.26	0.41	0.70	0.55

Therefore, this study investigated not only the FCFS rule, but also the priority rule and mixed rule; the results from these different disciplines are compared in Table 4-9. We evaluated the three discipline policies, and the following could be concluded. First, when comparing the FCFS and priority disciplines, a dramatic drop occurred in the waiting time for the medical helicopter and the fire/disaster management helicopter. In general, the priority rule reduces the waiting time in most servers for most operators. However, as mentioned in the previous section, because most disaster responses focus on rescue activities, the waiting time for police/JCG and broadcasting helicopters increases significantly when following the priority case compared to the FCFS case: by up to 360% for police/JCG activities and by up to 606% for broadcasting activities. These results are not acceptable in actual situations, and therefore the priority rule and mixed rule were also compared.

The mixed rule yields less waiting time for police/JCG and broadcasting helicopters, with a significant decrease compared to the priority case. However, the mixed rule yields a longer waiting time for the JSDF if we cannot apply the FCFS rule. When considering the urgency of activities that involve the medical helicopter and fire/disaster management, adopting the priority rule is recommended among the three alternatives. However, a trade-off occurs between lower-priority operators and higher-priority operators. We further examined another mixed discipline grouping of the medical helicopter, fire/disaster management, and JSDF as priorities 1, 2, and 3, respectively, and grouping the police/JCG and broadcasting activities as priority 4. However, the results showed an even longer waiting time for lower-priority groups.

Table 4-11 Aircraft waiting times in queue during disasters according to different queuing disciplines

unit: min

	Medical Helicopter			Fire/Disaster			JSDF			Police		
	FCFS	Priority	Mixed	FCFS	Priority	Mixed	FCFS	Priority	Mixed	FCFS	Priority	Mixed
Runway (A)	5.4	2.6	2.6	5.4	4.5	4.5	5.4	8.4	9.6	5.4	11.3	9.6
Passenger	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Medical	3.4	3.0	3.0	3.4	4.2	4.2	3.4	4.6	4.5	3.4	4.7	4.5
Information	1.8	1.6	1.6	1.8	1.7	1.7	1.8	1.7	1.9	1.8	1.9	1.9
Logistics	4.3	3.3	3.3	4.3	3.9	3.9	4.3	5.0	4.9	4.3	5.5	4.9
Rescue	28.8	7.0	7.0	28.8	15.3	15.0	28.8	49.6	63.0	28.8	93.1	63.0
Refueling	4.9	3.0	3.0	4.9	4.4	4.4	4.9	6.8	7.3	4.9	8.1	7.3
Runway (D)	5.4	2.6	2.6	5.4	4.5	4.5	5.4	8.4	9.6	5.4	11.3	9.6

4.4.2. Comparison of observed data and estimated data: Fukushima, Yamagata and Hanamaki airports

In Great East Japan Earthquake, three airports were mainly used and characteristics of airports are summarized as in Table 4-9. This section attempts to investigate feasibility of proposed Jackson network topology by simulating each airport's estimated waiting time.

		Hanamaki	Yamagata	Fukushima
Runway		2,500m	2,000m	2,500m
Taxiway		O	X	O
Apron		81,093m^2	26,770m^2	47,250m^2
Spot (before)	Large/medium	2	2	4
	Small	21	8	2
	Others	1	JSDF airfield	2 helipads
Spot (after)	Large/medium	2	2	more than 4
	Small	21	10	more than 2
	Others	more than 1	JSDF airfield	2 helipads or more
Logistics		Snow Removal Warehouse (1,000)	Not mentioned	Warehouse
Fueling	Available	12,000LX1 12,000LX1	20,000L X 2 12,000L X 1 3,700L 180,000/200,000L	One small refueling car for small sized aircraft
	Additional	+100,000L +10,000L	-	-
Medical care		Fire fighting warehouse	Not mentioned	Snow Removal Warehouse
Other features		Information sharing service rate: 15minutes/aircraft Maximum waiting time in fueling: 15minutes	-	Maximum waiting time in fueling: 60 minutes (Some priority was given in disaster response related)

Table 4-12 Airport characteristics in Great East Japan Earthquake

Optimizing parameters in the model means setting parameters to yield estimated result close to observed result. This is often challenging and difficult to adjust but Anderson *et al*. (2000) argues importance of parameter setting in simulation model. For each airport in each day case, we define the simulation error as the difference between average simulated and actual waiting time of an aircraft in the airport. There are still discrepancies in simulation error in Figure 4-6. We would like to discuss reasons and implications behind these discrepancies and relationship to parameter adjustment as well as data precision.

This section investigates the feasibility of applying the proposed Jackson network topology by simulating each airport's estimated waiting time. In this investigation, the model's parameters are considered optimized if they are set to yield estimated results that are close to the observed results. This optimization is often challenging, and the parameters can be difficult to adjust. A comparison of the aircraft waiting times on each date at each of the three airports is shown in Table 4-13.

The proposed model assumes that the probability that an aircraft is going either to refueling or to the runway is assumed to be the same, which is 0.5 as shown in Table 4-13. Based on our interview results, refueling was more actively supported in an airport that served as a base for helicopters. Therefore, we increased the transition probability by 10% to observe its effect on the waiting time. The least discrepancy was found in Hanamaki airport, for which the estimated waiting time was 95 min and the observed waiting time was 93 min when transition probability from each activity to refueling is 0.7. From these results, it can be concluded that a higher probability for refueling, such as 0.8 as shown in the right column in Table 4-13, produces less of a discrepancy between observed data and estimated data. However, Fukushima airport does not tend to show this since arrival rates sometimes exceed service rate of refueling system so that results are not estimated.

Table 4-13 Transition probability adjustment (each activity to refueling, each activity to runway)

		Estimated data				**Observed data**
		(0.5,0.5)	(0.6,0.4)	(0.7,0.3)	(0.8,0.2)	
March 12th	Hanamaki	52	55	58	64	76
	Yamagata	32	33	34	36	58
	Fukushima	170	-	-	-	93
March 13th	Hanamaki	86	89	95	109	93
	Yamagata	31	32	33	35	70
	Fukushima	49	59	89	893	72
March 14th	Hanamaki	40	41	43	46	72
	Yamagata	29	30	31	32	77
	Fukushima	44	51	66	114	59

These results can be attributed to the following three factors.

1. The estimated data set considers fewer aircraft movements than the observed data. When deriving the transition probability of each airport operator's movements inside an airport, there were sometimes missing and/or unknown data, and the information relevant to which operator managed each transition was incomplete.

2. The estimated data on service rate does not consider exact behavior during disasters. When gathering information on the service rate of each activity in the airport, some data such as

the information collection service rate, was based on actual interviews into the Great East Japan Earthquake case. However, because of the challenging data collection situation, other service rates were collected from previous literature reviews and reports. Even if we set specific numbers for the service rates, these do not include uncertainties associated with disasters or the impacts of disasters on the normal service rates.

3. Uncertainties associated with disasters are not included in the simulation. Airport operations are affected by wind, precipitation, temperature, control systems, and other factors. In addition, the impact of disasters was not considered on airport operations; for example, air traffic control was more burdened during the disaster compared to its normal operation.

4.5. Discussions

In every emergency, airport operation in disasters is not applicable in different cases but we can determine critical bottlenecks influenced widely on a common understanding. Especially, airport operations in emergencies depend highly upon the decisions of air traffic controller and management. These decisions are made based upon the conventional approaches such as FCFS rule. It is strongly recommended that stakeholders related to airport disaster response operation such as local government, military, airport operators and air traffic controller, medical team, and etc. discusses over optimal queuing rule, techniques enabling this operation, and also scenario planning in advance of disasters.

Since the model does not explicitly applies other constraints, validation of the result itself when comparing with real conditions is merely achieved in the study. Several future directions are suggested. Building scenario analysis to investigate sensitivity of the model is recommended to examine which parameter affects more in waiting time. Also, comparing different Jackson network topologies and following airports, and reflecting dynamics of disaster situation are necessary steps in achieving degree of effectiveness of the model. The other aspect is trade-off between benefit of waiting time reduction and cost for aircrafts waiting in nearby airports, helicopter bases, or sometimes in air. However, the findings here suggest as a simple and prompt analysis to enhance aircraft's operation in disaster response. It suggests that investigating queuing network as to represent airport disaster operation would be the first approach to evaluate waiting time of an aircraft and queuing disciplines until further developments on dynamics and uncertainties become available.

4.6. Conclusion

In the chapter, aircraft arrivals at an airport during a disaster response were modeled using an open Jackson network model. Considering different aircraft operators as multiclass, FCFS, priority, and mixed cases were investigated, and queuing theory was applied to the disaster response of an airport in order to estimate the mean waiting times for an aircraft entering the airport during an emergency.

The results showed that a priority rule significantly reduced the mean waiting time of an aircraft for those operators who were assigned a higher priority. However, the lower priority group showed excessive waiting times compared to the base FCFS case that would not be acceptable in an actual disaster situation. Therefore, the study suggested the favorable potential of a mixed queuing rule that assigns a higher priority to those operators involved in life-saving activities and no priority among lower priority groups. Several key points from the study are concluded in the following paragraphs.

There are three particularly significant implications related to the different queuing disciplines. First, current airport operations follow the FCFS rule on the runway, whereas the results of this study show that the mixed queuing discipline is recommended. Second, an operator's priority has to be assigned according to the aircraft's purpose, so that medical helicopters and fire/disaster management agencies experience the most reduced waiting times. Although the numerical example presented in this study did not precisely reflect the uncertain conditions of emergency situations, the analytical model intuitively evaluated which rule should be applied for aircrafts arriving at the airport. Finally, airport features and constraints can be considered as limited resources in humanitarian logistics, and extensive changes or additions to airport features require excessive investment costs. Therefore, it can be inferred that an airport's responsiveness can be enhanced when appropriate operations are supported.

The same topology was examined in each of three airports through comparisons between observed and estimated data. The estimated data was found to yield generally lower values than the observed data. The model's accuracy was improved by increasing the transition probability from response activities to fueling.

Airport operations during disasters are highly variable in response to the conditions of different emergency cases; nonetheless, we can determine common critical bottlenecks. In particular, airport operations during emergencies depend highly upon the decisions of air traffic controllers and management. These decisions are made based on conventional approaches, such as the FCFS rule. The results of this study indicate that stakeholders involved in airport disaster response operations, such as local government, military, airport operators, air traffic controllers, medical teams, and others should discuss optimal queuing rules, techniques that could enable optimal operations, and also scenario planning in advance of disasters.

Because the proposed model does not explicitly apply any other constraints, the results are validated in comparison with actual conditions. Several future research directions are suggested. Developing the scenario analysis to investigate the sensitivity of the model is recommended to examine which parameters most affect the waiting time. In addition, exploring different Jackson network topologies, different airports, and the unique dynamics of disaster situations is also necessary to achieve an effective model. However, the findings here suggest that a simple and prompt analysis can enhance airport operations during a disaster response. This suggests that further investigations of the queuing network as a method of representing airport disaster operations would be an effective approach to evaluating aircraft waiting times and queuing disciplines until further developments on disaster dynamics and uncertainties become available.

5. Estimating the mean waiting time in airports through cooperative disaster response operations

5.1. Introduction

In air transport networks, effective disaster preparedness and response planning can decrease the impact of large-scale emergencies. The management of these catastrophes typically requires the involvement of multiple airports as well as different operators, agencies, and international and local humanitarian aid organizations, and this can lead to bottlenecks in airports since aircraft are operated by different organizations, different operators are not prioritized, and location assignment is also difficult (Hanaoka et al., 2013). Findings from Chapter 4 confirm the effect of changing queuing discipline and significance of runway service rate. From these, we understand that disaster response role assignment among airports is necessary. Cooperation among airports and aircraft operators is thus essential to achieve an effective disaster response because one entity cannot manage it solely within its own capacity (Sampey, 2013).

In addition, excessive demand on an air transport network provides additional scope for bottlenecks in airport operation. This congestion in airports raises the waiting time incurred when transporting people and goods. Indeed, the unassigned priorities of aircraft operators raise the waiting time for aircraft operators involved in saving lives to unacceptable levels (Hanaoka et al., 2013). Therefore, airport managers are often the ones to decide which types of aircraft can land at the airport during an immediate disaster response.

Regarding the prioritization of aircraft operators, Choi and Hanaoka (2016) confirmed the effect of changing queuing discipline and the significance of the runway service rate for reducing waiting time in an airport. They asserted that airport disaster response operations in the region play a vital role in reducing waiting time in airports. However, the need for cooperation (i.e., helping each other and overcoming problems jointly) among airports is also hampered, especially during emergency responses when assigning disaster response roles. This assignment of disaster response role can refer to accepting which kind of aircraft operator and type that airports should handle preponderantly.

Planning for cooperative disaster response operations in airports is therefore worthy of study. The present study is motivated by this issue, and it thus introduces assigning the main disaster response roles in an airport based on the network as well as serving other response roles through cooperative disaster response operations. We set the hypothesis of the study as the following: assigning major disaster response role for airports in disaster response would reduce overall mean waiting time of an aircraft in an airport. The conceptual approach for examining this hypothesis is illustrated as in Figure 5-1. Not having coordinated guidance on plural airports operation makes hindrance for humanitarian logistics network and this is why the study focuses on point of entry in the network. We should investigate how to enhance operation through collaboration among plural airports. The term ‘collaboration and cooperation’ are slightly different each other and details are explained in Section 2.4.

Here, we define ‘cooperative disaster response operation among airports’ as assigning main disaster response roles for an airport accordingly in the network as well as serving other response roles. Research question is “What are possible *cooperative operational scheme* for relieving operational bottlenecks of airports in disaster response?” We investigate how to enhance operations through cooperation among multiple airports in order to relieve operational bottlenecks during disaster responses. In this regard, this study develops a model that can estimate the mean waiting time in airports through cooperative disaster response operations by using an open Jackson network.

The remainder of the paper is organized as follows. The next section summarizes the relevant literature on airport cooperation during disasters and the open Jackson network model. Section 5.2 presents the proposed research method and Section 5.4 describes the numerical experiments and their results. Finally, Section 5.5 provides the conclusions from the research as well as the limitations of the study and future research directions.

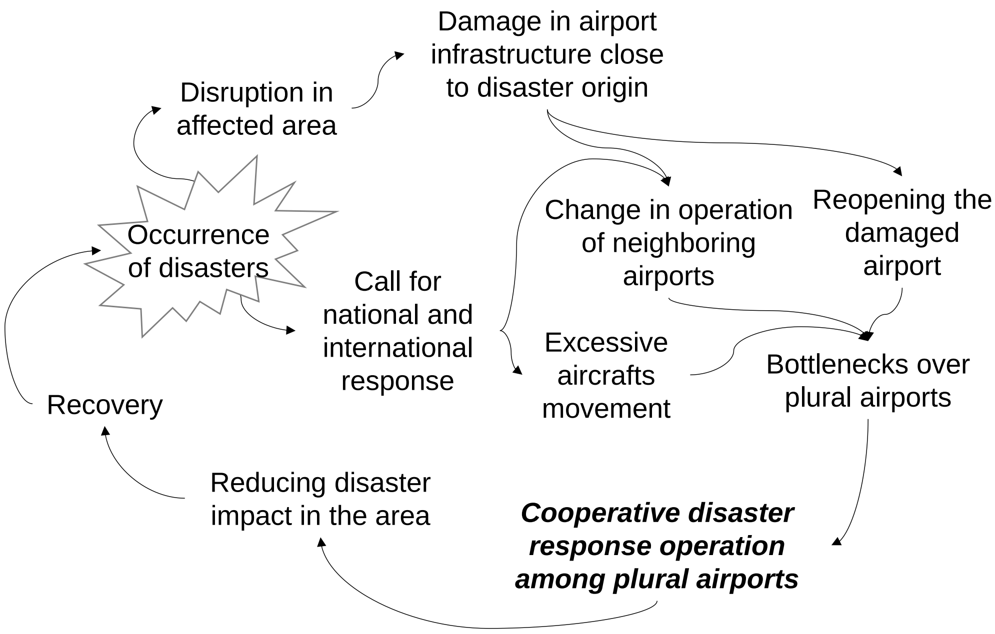


Figure 5-1 Cooperative disaster response operation among plural airports

5.2. Problem formulation

5.2.1. Study focus

As mentioned above, multiple airports cooperate with each other to mitigate the impact of a disaster in a region. The roles and operators of aircraft in each airport naturally differ, however. Although there are numerous ways for airports to cooperate, this study provides cooperative operational schemes that have not thus far been suggested in the literature. Such schemes aim to balance operations at airports assigned responsibility to conduct specific disaster response roles. An example of this operation, as the initial stage in humanitarian logistics in a disaster response scenario, is modeled in Figure 5-2. The stage presented in this figure is the initial flow from aircraft departing to their stay in airports until the next flight mission. Since airports are the points of entry to many nations, bottlenecks always hinder the effective operation of the whole humanitarian logistics network. Therefore, we highlight the importance of cooperative airport operations in the initial stage.

Our proposed cooperative operation scheme considers the following:

- Roles include the transport of personnel and transport of aid
- The main disaster response airport is the closest one to the disaster
- The supporting disaster response airport is determined based on the service rate

• The transition probability of all arriving aircraft in the region is adjusted according to the airport's operational capability

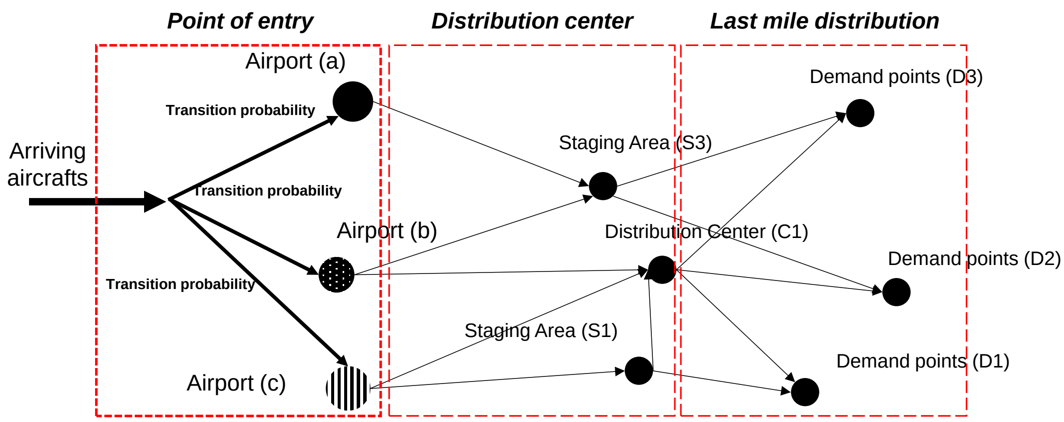


Figure 5-2 Study focus in humanitarian logistics stage

5.2.2. Model assumptions

We consider that all arriving aircraft depart for the next disaster response mission through airports. Each airport in the network is modeled as M/M/1 queuing, where aircraft are treated as waiting customers. Each service system is analyzed and performance measurement is calculated based on the model of Hillier and Lieberman (2010). Table 5-1 summarizes the details of the queuing system.

Table 5-1 Queuing system components

Queuing system components	*Characteristics*
Arrival rate	Poisson process
Service rate	Poisson process
Number of servers	N (according to model scenario)
Source of customers	Infinite
Queue discipline	FCFS
Queue length	Infinite

A queuing network in an airport consists of different airports. The various supply points as well as demand points to be served are unknown. We thus regard all aircraft flying into the region as an arriving aircraft in the network. The purpose of disaster response activities is typically decided by an aircraft's operator and the aircraft often finishes its flight mission by delivering a single purpose. Therefore, aircraft are considered to be arriving customers and each airport is treated as a server in the network. The mean waiting time and number of aircraft in each airport can then be calculated based on the open Jackson network theorem.

The aircraft proceeds to one or more processes when entering an airport: runway, terminal, medical, information collection, logistics, rescue, and refueling. Here, we treat an airport as one service rate since the main objective of the model is to understand how the transition probability is adjusted and its relation to the decrease in waiting time. The model assumes that all aircraft need to refuel before leaving for the next flight mission. Hence, aircraft cannot ignore runway procedures to complete their mission.[1] The following assumptions are made to develop the model.

Airport features

- The airport has one runway and is controlled by an air traffic controller
- Airport operations run from 07:00 am to 7:00 pm (12 hours)
- The airport control system is in operation and is not disturbed significantly during the disaster response

Aircraft features

- In the immediate response phase, all operations are conducted by identical aircraft
- The disaster response missions of helicopters are assigned as single purpose in one operation

Transition probability

- The transition probability is regarded as proportion of the disaster response roles assigned

5.3. Open Jackson network model

We model the disaster response operation of multiple airports by using open Jackson network modeling. Since the airport disaster response operation is different from the usual situation in terms of the spontaneous operations of multiple airports, various disaster response activities

[1] It is natural for all fixed-wing and rotary-wing aircraft to follow runway procedures. Although rotary-wing aircraft can land at the airport, they should also follow the air traffic controller’s rule when being assigned a spot.

delivered, multiple operators, and allocation of space for response activity on the airside and landside of airports. This requires a description of the complex network topology. Therefore, the Jackson network model can address this issue because of its flexible topology. In addition, we adopted an open Jackson network where arriving entities exit the network. Kim and Kim (2015) also asserted that an open Jackson network model is formulated as a tangled network, which can be efficient for jointly considering multi-class operators as well as FCFS and other disciplines. An extension of the Jackson network model is the Gordon and Newell (1967) theorem, a closed queuing network model that cannot be applied to airport disaster response operations since aircraft need to leave after completing their operation missions. Choi and Hanaoka (2016) modeled a disaster response operation at an airport by using open Jackson network modeling focused on a single airport operation. The below model is similarly formulated and extended to multiple airport operations in a disaster response, meaning that calculating the transition probability is different from the processes shown in previous work.

We assume that responding airports are server *i* (*i* =1, 2,…, m) within an open Jackson network with multi-class consideration. The performance of an airport in this model with FCFS is then estimated. Eq. (1) indicates the business or utilization rate of airport *i* in the disaster response. λ_i is defined as the arrival rate of all aircraft into airport *i* (see Eq. (2)). An open Jackson network model normally treats the external arrival rate (i.e., that outside the network) as $\lambda q_{s,i}$; however, it is assumed that since aircraft follow air traffic control strictly, this external arrival rate is excluded from the calculation. Here, $q_{j,i}$ the proportion of aircraft from airport *j* to airport *i*, is defined as the transition probability. Since we focus on the initial stage of humanitarian logistics, $q_{j,i}$ in Eq. (2) is considered the transition probability of aircraft arriving outside affected region *j* to disaster response airport *i*. A cooperative scheme is achieved by balancing the transition probability of disaster response airports through assigning disaster response roles according to the strengths of airports. Eq. (3) determines the expected number of aircraft in queuing airport *i*. Eq. (4) indicates the expected waiting time in airport *i* excluding the service time. Eq. (5) is the mean waiting time in airport *i* including the service time. Eq. (6) determines the mean waiting time in airports among the network including the service time for each aircraft:

$$\rho_i = \frac{\lambda_i}{\mu_i} (0 \le \rho_i \prec 1) \tag{1}$$

$$\lambda_i = \lambda q_{s,i} + \sum_{j=1}^{M} \lambda_i q_{j,i} (i = 1, \cdots, N) \tag{2}$$

$$E_i = \frac{\rho_i}{1 - \rho_i} \tag{3}$$

$$W_i = \frac{\rho_i}{1 - \rho_i} \frac{1}{\mu_i} \tag{4}$$

$$\overline{T}_i = \frac{\overline{N}_i}{\lambda_i} = \frac{1}{\mu_i - \lambda_i} \tag{5}$$

$$T = \frac{1}{\lambda} \sum_{i=1}^{M} E_i \tag{6}$$

μ_i	mean service rate of airport *i*
λ_i	mean aircraft arrival rate to airport *i*
ρ_i	utilization rate for airport *i*
$q_{j,i}$	transition probability of aircraft from input flow *i* to airport *j*
E_i	mean number of aircraft in airport *i*
W_i	mean waiting time in response airport *i* excluding service time
$\overline{T}_i$	mean waiting time in response airport *i* including service time
T	mean waiting time in airports including service time for each aircraft

5.4. Numerical experiment

Table 5-2 presents the structure of the three numerical experiments according to their purposes. Numerical experiment (1) shows the effect of increasing responding airports in the network. Numerical experiment (2) shows the change in the transition probability when two airports respond in the network. Numerical experiment (3) attempts to find the optimal transition probability case when the two responding airports are in the affected region, while we distinguish between two roles: the transport of personnel and of goods.

Table 5-2 Structure of the numerical experiment

Numerical experiment	***Number of airports***	***Airport service rate***	***Role assignment***	***Purpose of experiment***
1	1–5	Different	No specific	Number of responding airports increases
2	2	Different	No specific	Change in transition probability
3	2	different	People, Logistics	Change is transition probability set for two different roles for both airports

5.4.1. Numerical experiment (1): increasing responding airports with different service rates

Experiment (1) discusses multiple responding airports with different service rates and the same transition probability given in the input parameter in Table 5-3. Here, we use the same transition probability as in the first experiment since we consider the distance to each airport from the origin of the disaster and set the same transition probability. Airports (a) to (e) have different service rates. Hence, the one-airport case means that the disaster response operation is solely served by airport (a). An increase in the number of airports in the network indicates that airports (b) to (e) are utilized accordingly. The transition probability when multiple airports are in operation is the same for n airports in the network with 1/n.

Table 5-3 Input data for numerical experiment (1)

	Arrival rate	**Airport (a)**		**Airport (b)**		**Airport (c)**		**Airport (d)**		**Airport (e)**		**Transition probability**
		arrival rate	service rate	arrival rate	service rate	arrival rate	service rate	arrival rate	service rate	arrival rate	service rate	
1 airport	14.00	14.00	15.00									
2 airports	14.00	7.00	15.00	7.00	12.00							0.50
3 airports	14.00	4.67	15.00	4.67	12.00	4.67	8.00					0.33
4 airports	14.00	3.50	15.00	3.50	12.00	3.50	8.00	3.50	5.00			0.25
5 airports	14.00	2.80	15.00	2.80	12.00	2.80	8.00	2.80	5.00	2.80	5.00	0.20

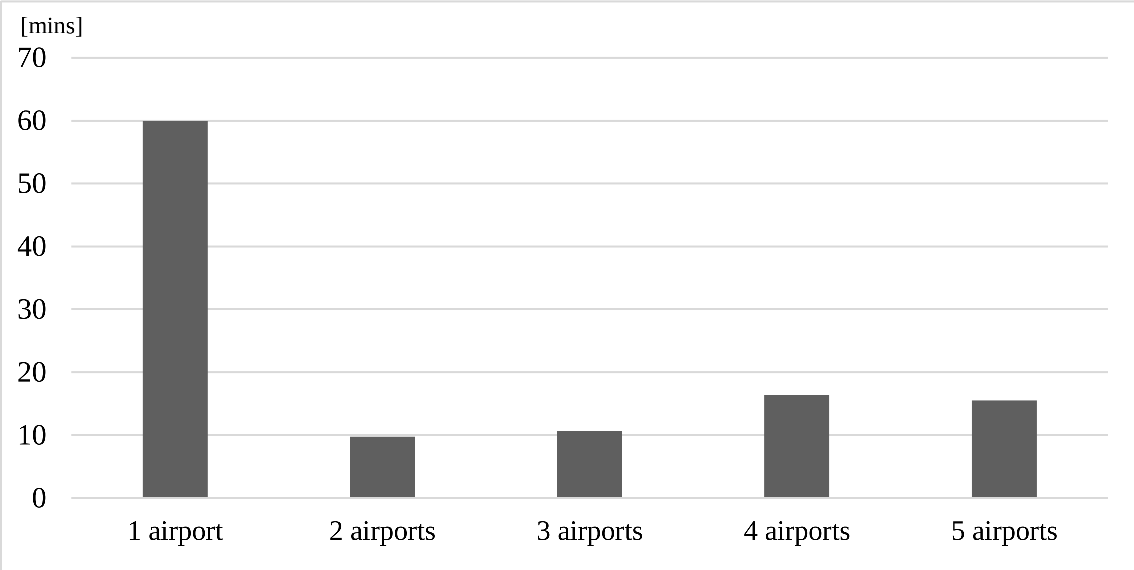


Figure 5-3 Mean waiting time of an airport in numerical experiment (1)

When more airports respond simultaneously during a disaster response, the waiting time does not always decrease as in experiment (1) (see Figure 5-3). The waiting time is the shortest when two airports are operating. Here, the longest mean waiting time for an aircraft in the network is 60 minutes with only one airport responding. The four-airport case is 16.5 minutes, five-airport case is 15.5 minutes, three-airport case is 10.7 minutes, and two-airport case is 9.8 minutes. Therefore, the shortest waiting time occurs when two airports respond in this scenario.

5.4.2. Numerical experiment (2): two airports with different service rate and changing transition probability

Experiment (2) features two airports in the responding network, each with different service rates. Here, we change the transition probability to investigate the optimal point of the disaster response operation for reducing the mean waiting time in the network. Table 5-4 summarizes the arrival rate, service rate, and transition probability for each airport. The (0.54, 0.46) case is selected and investigated by setting the transition probability proportional to the service rates of Airport 1 and Airport 2.

Table 5-4 Input data for numerical experiment (2)

Arrival rate	Airport 1		Airport 2		Transition probability
	arrival rate	service rate	arrival rate	service rate	(A1, A2)
14.00	4.20	15.00	9.80	13.00	(0.3, 0.7)
14.00	5.60	15.00	8.40	13.00	(0.4, 0.6)
14.00	7.00	15.00	7.00	13.00	(0.5, 0.5)
14.00	7.00	15.00	7.00	13.00	(0.54,0.46)
14.00	8.40	15.00	5.60	13.00	(0.6, 0.4)
14.00	9.80	15.00	4.20	13.00	(0.7, 0.3)

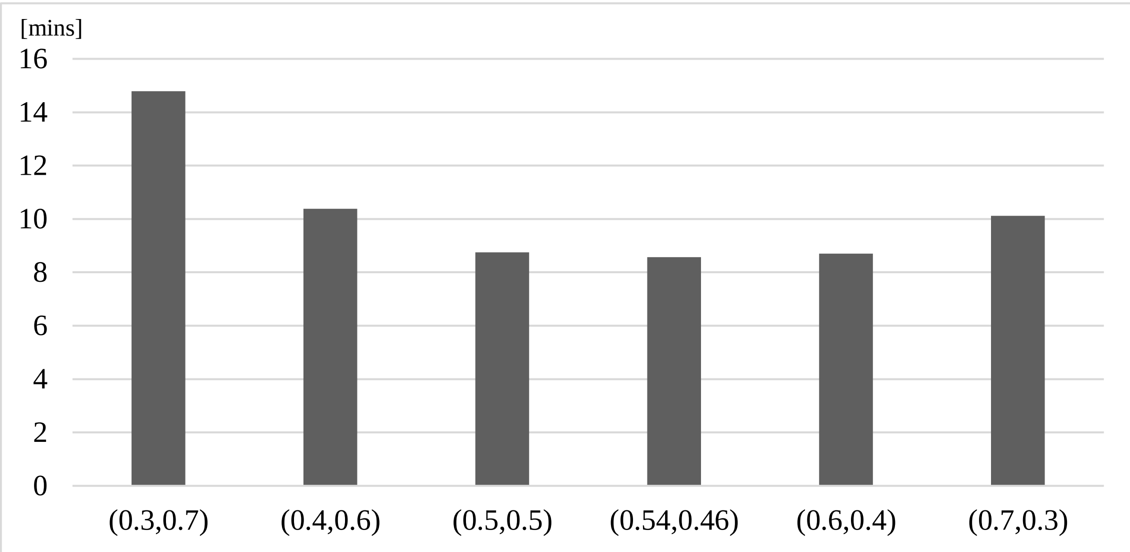


Figure 5-4 Mean waiting time of an airport in numerical experiment (2)

In reality, airports have different service rates. When the features are identical, the same transition probability as 0.5 and 0.5 would show the shortest waiting time in the network. In Figure 5-4, case (0.54, 0.46) shows the minimum waiting time (8.5 minutes) followed by the (0.6, 0.4) case (8.7 minutes). The longest waiting times are 14.8 minutes in case (0.3, 0.7), 10.4 minutes in case (0.4, 0.6), 10.1 minutes in case (0.7, 0.3), and 8.8 minutes in case (0.5, 0.5).

5.4.3. Numerical experiment (3): two airports with different service rate

Here, we develop a cooperative airport operation for this experiment by assigning different transition probabilities for the transport of people and goods (see Tables 5-5 and 5-6). Altogether, 25 cases need to be estimated in this experiment.

Table 5-5 Transition probability for people

	P1	*P2*	*P3*	*P4*	*P5*
$q_{i,a}$, $q_{i,b}$	0.7,0.3	0.6,0.4	0.5,0.5	0.4,0.6	0.3,0.7

Table 5-6 Transition probability for logistics

	L1	*L2*	*L3*	*L4*	*L5*
$q_{i,a}$, $q_{i,b}$	0.7,0.3	0.6,0.4	0.5,0.5	0.4,0.6	0.3,0.7

Table 5-7 summarizes the service rates for Airports a and b, which serve people and goods as their expected roles, respectively (Table 5-8). In our cooperation scheme, we assume that the role assigned is decided on its service rate.

Table 5-7 Cooperation scheme for two airports: 25 operation cases

	P1	*P2*	*P3*	*P4*	*P5*
L1	L1,P1	L1,P2	L1,P3	L1,P4	L1,P5
L2	L2,P1	L2,P2	L2,P3	L2,P4	L2,P5
L3	L3,P1	L3,P2	L3,P3	L3,P4	L3,P5
L4	L4,P1	L4,P2	L4,P3	L4,P5	L4,P5
L5	L5,P1	L5,P2	L5,P3	L5,P4	L5,P5

Table 5-8 Input data for Airport a and Airport b

			Airport a				Airport b			
CASE	Incoming flow		Logistics		People		Logistics		People	
	L	P	Arrival rate	Service rate	Arrival rate	Service rate	Arrival rate	Service rate	Arrival rate	Service rate
L1,P1	13	20	9.1	11	14	20	3.9	14	6	15
L1,P2	13	20	9.1	11	12	20	3.9	14	8	15
L1,P3	13	20	9.1	11	10	20	3.9	14	10	15
L1,P4	13	20	9.1	11	8	20	3.9	14	12	15
L1,P5	13	20	9.1	11	6	20	3.9	14	14	15
L2,P1	13	20	7.8	11	14	20	5.2	14	6	15
L2,P2	13	20	7.8	11	12	20	5.2	14	8	15
L2,P3	13	20	7.8	11	10	20	5.2	14	10	15
L2,P4	13	20	7.8	11	8	20	5.2	14	12	15
L2,P5	13	20	7.8	11	6	20	5.2	14	14	15
L3, P1	13	20	6.5	11	14	20	6.5	14	6	15
L3, P2	13	20	6.5	11	12	20	6.5	14	8	15
L3, P3	13	20	6.5	11	10	20	6.5	14	10	15
L3, P4	13	20	6.5	11	8	20	6.5	14	12	15
L3, P5	13	20	6.5	11	6	20	6.5	14	14	15
L4, P1	13	20	5.2	11	14	20	7.8	14	6	15
L4, P2	13	20	5.2	11	12	20	7.8	14	8	15
L4, P3	13	20	5.2	11	10	20	7.8	14	10	15
L4, P4	13	20	5.2	11	8	20	7.8	14	12	15
L4, P5	13	20	5.2	11	6	20	7.8	14	14	15
L5, P1	13	20	3.9	11	14	20	9.1	14	6	15
L5, P2	13	20	3.9	11	12	20	9.1	14	8	15
L5, P3	13	20	3.9	11	10	20	9.1	14	10	15
L5, P4	13	20	3.9	11	8	20	9.1	14	12	15
L5, P5	13	20	3.9	11	6	20	9.1	14	14	15

Table 5-9 Mean disaster response time of all airports

	P1 (0.7, 0.3)	P2 (0.6, 0.4)	P3 (0.5, 0.5)	P4 (0.4, 0.6)	P5 (0.3, 0.7)
L1 (0.7, 0.3)	24.88	19.87	18.42	18.46	19.69
L2 (0.6, 0.4)	25.59	17.08	17.86	17.48	18.26
L3 (0.5, 0.5)	28.49	21.81	19.31	18.47	18.80
L4 (0.4, 0.6)	35.70	27.80	24.52	23.04	22.79
L5 (0.3, 0.7)	68.96	58.06	52.50	49.09	38.73

Numerical experiment (3) shows that the optimal operation case of the 25 cases is L2, P2 (17 minutes; Table 5-9). Adopting a balanced role assignment to match the service rate of the response activity is thus found to be preferable to drastic role assignment. Further, the operation based upon on L2 tends to produce a short waiting time. Except for the 25 cooperation schemes, we also analyzed the mean waiting times of airports. We set the transition probability of each airport as proportional to its service rate for the transport of people and goods. The mean waiting time is 11.8 minutes, which is lower than that for the 25 cooperation schemes.

5.5. Chapter conclusion

In this chapter, we investigated the possible reduction in the mean waiting time at an airport when the transition probability is controlled as a cooperative operation according to an airport's characteristics. Cooperation among multiple airports was modeled by assigning specific disaster response roles as well as other serving roles. In particular, the study focused on the point of entry in the humanitarian logistics network since most bottlenecks in past natural disasters have been concentrated in this initial stage. We then developed an open Jackson queuing network model to estimate the mean disaster response time of an aircraft from each airport in the affected region.

When reacting to disasters, an increase in the number of responding airports does not always lead to the minimum response time. Therefore, we provided several numerical examples to investigate the balance between utilizing airport resources and enhancing operations. Adjusting the transition probability to meet an airport's service rate was found to be the optimal case in cooperative operations.

The policy implications for airport operators are thus that airports must be prepared to handle a balanced role assignment during a disaster response episode. In detail, during the preparedness planning stage, airport managers, the government, and related stakeholders should discuss the strengths and weaknesses of each airport to help determine the roles each airport can play in immediate disaster responses. In particular, this could assist airport managers decide which types of aircraft and operators to land at the airport during the immediate disaster response phase.

Future research should aim to include the features and facilities of airports (e.g., runways, logistics/lighting/fueling facilities, parking spots) in the model. Since the model provides static answers for certain input settings, the dynamics of demand or time could also be considered as an extension. Motivating local and central governments to adopt this proposed policy would be another research direction suggested from the results presented herein.

6. Conclusion

6.1 Summary of findings

In this dissertation, several model developments and analysis were conducted to answer achieve research objectives mentioned in Section 1.2 regarding airport operation in immediate disaster response.

In chapter 2, we developed conceptual framework for enhancing airport operation in terms of decision levels, what to manage and where the management takes place. In this section, we reviewed relevant literature reviews to build understanding on lessons learned from past natural disasters, current practices in airport operation, and cooperation issues.

In chapter 3, space planning procedure for a disaster response facility in an airport was firstly mentioned and developed in this area. By adopting conventional architectural approaches, we examined Shizuoka airport as a case study which is currently under discussions in Japan.

In chapter 4, we developed an open Jackson network model of disaster response activities in an airport to estimate waiting time in each activity and within an airport. We adopted first-come-first-served, priority, and mixed queuing discipline to understand how waiting time can significantly be reduced for those aircraft operators with higher priority in terms of life savings in real situation. Then, we examined estimated result with observed result in Great East Japan Earthquake based on first-come-first-served queuing discipline which is normally used in current airport traffic management.

In chapter 5, understanding cooperation between airports was defined as assigning main disaster response role in each airport accordingly. We developed a queuing network approach and reduction of waiting time in an airport was examined. Findings indicate that assignment by adjusting transition probability to meet airport's service rate shows optimal case in cooperative operation.

6.2 Conclusions based on objectives

The first objective of the study was to develop a model for space planning procedure of a disaster response base facilities in an airport. Facility planning for an airport was focused on normal operation and emergency operation was not research mainstream. We looked into practices of UNHRD, IFRC, Chubu network framework in Japan, and others to understand space constraint issues in immediate disaster response. Therefore, we firstly investigated conventional space planning approach used in architectural planning and modified its process in order to integrate humanitarian logistics context such as necessary goods, people, equipment and so on. We included estimation model for each facility in a disaster response model in the planning procedure and explained sequence to reach a schematic plan. The methodology was applied to Shizuoka airport as a case study and interviews were followed to investigate feasibility of the model.

The second objective was to develop a model for assessing waiting time of different aircraft operators at airports during disaster response. In order to model disaster response activities of an airport, we conducted several interviews with airport operators in Japan and Japanese Self Defences. Based on interview results and literature reviews, we modelled an airport as a connected open queuing network and applied Jackson's theorem to examine performance of each airport. We applied conventional first-come-first-served rule, priority rule for weighing higher priority for life saving related operators, and mixed rule with grouping priority operators. We examined that priority rule gives drastic decrease in doctor helicopter but gives unacceptable waiting time for lowest group Also, we examined the same topology through comparing observed and estimated data. Improved model accuracy is achieved by increase in transition probability from response activities to fueling.

The third objective is to model cooperative operation by assigning main disaster response roles to reduce mean and total disaster response time of each airport. Cooperative operation among plural airports is defined and it was controlled by adjusting transition probability from all arriving aircrafts to each airport. The model was developed based on M/M/s queuing network model and numerical experiment was given to investigate impact of service rate adjustment, capacity increase in the network and adjusting transition probability. The results show that optimal operational point can be achieved by utilizing existing airports resources with adjusting transition probability.

6.3 Future scope

Findings of the study are found as useful contributions in disaster management and airport operation. However, there are also remaining areas to be answered in the future.

- Improving model accuracy regarding data collection

The most challenging factor in this dissertation is considered as data collection. During disaster response, it is not possible to record all activities and issues due to complexities of disasters. Hence, this area is quite new compared to other transport planning research areas. Unavailability of detailed data makes the model development sensitive to input data. Accuracy of model in terms of fitness to the observed data can be improved significantly if data collection is reachable.

- Developing optimization modelling considering dynamics

We understand that this dissertation is the first attempt to develop models on space planning issues in airports, waiting time management of a single airport and plural airports role assignment. Therefore, we developed analytical models focusing on 72 hours of immediate disaster response phase without considering dynamics in demand, supply, and natural disaster itself. These models give various policy implications on different scenario setting easily accessible and operational by government officials as well. One of dynamics to consider is change of available fuelling capacity with decrease of service rate. Therefore, to enhance modelling methodology, essential future directions are to build optimization modelling with reflecting dynamic issues in real disaster response operation.

- Validating the model with application to another case studies

Three different models are developed in this dissertation to discuss time and space management in disaster response operation at airports. These proposed methodology is examined and applied in either scenario analysis or case studies in Chapter 3, 4, and 5. It is needed to validate further on model applicability with recent natural disasters such as Nepal Earthquake in 2015 and Kumamoto Earthquake in 2016.

- Extension of the model scope

Since main concern in our study is operation of point of entry in humanitarian logistics network, we can extend the network until last mile distribution. Relationship between space constraint and its effect on time can be considered in the further developments. The current queuing network model in Chapter 4 and 5 can be further developed including next stages. Assumptions in Chapter 4 regarding refuelling capacity can be considered as finite in further steps.

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