DISASTER RELIEF SUPPLY MODEL FOR LOGISTIC SURVIVABILITY

by

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Dedicated to God and Family who always be there for me and lead me through the journey

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LIST OF ABBREVIATIONS

LDC	Local Distribution Center
t	ton
ICRC	International Committee of the Red Cross
WVI	World Vision International
WFP	World Food Programme
IFRC	International Federation of Red cross and Red Crescent Societies

GLOSSARY

Local Distribution Center – Warehouse where the stock of items are stored and distributed from.

Last mile distribution – The last stage of supply which transporting items from hub to the final destination.

Survivability – A capability of achieving its original and fundamental goal while the activities originally required to reach the goal are experiencing hardship from environments.

Logistic Agent – An entity involved in operation regarding logistics such as transportation vehicle, driver, and pilots.

ABSTRACT

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Disasters especially from natural phenomena are inevitable. The affected areas recover from the aftermath of a natural disaster with the support from various agents participating in humanitarian operations. There are several domains of the operation, and distributing relief aids is one. For distribution, satisfying the demand for relief aid is important since the condition of the environment is unfavorable to affected people and resources needed for the victim's life are scarce. However, it becomes problematic when the logistic agents believed to be work properly fail to deliver the emergency goods because of the capacity loss induced from the environment after disasters. This study was proposed to address the problem of logistic agents' unexpected incapacity which hinders scheduled distribution. The decrease in a logistic agent's supply capability delays achieving the goal of supplying required relief goods to the affected people which further endangers them. Regarding the stated problem, this study explored the importance of setting the profile of logistic agents that can survive for certain duration of times. Therefore, this research defines the "survivability" and the profile of logistic agents for surviving the last mile distribution through agent based modeling and simulation. Through simulations, this study uncovered that the logistic exercise could gain survivability with the certain number and organization of logistic agents. Proper formation of organization establish the logistics' survivability, but excessive size can threaten the survivability.

CHAPTER 1. INTRODUCTION

This study inquires into the question of last mile distribution's survivability gained from the number of allocated logistic agents for achieving the humanitarian logistic agents' goal of delivering relief goods. This happens over a specific duration in the situation where logistic agents survivability is in question are not survivable due to vulnerabilities acting in the dynamic environment. It introduces this research by presenting a background on humanitarian logistic agents' vulnerability on dynamic situations from a disaster. It also covers the research significance, assumptions, limitation and delimitations which define the extent of this study.

1.1 Background

There is no universally accepted single definition of disaster. Many studies and organizations define disasters differently [1]. The United Nations Office for Disaster Risk Reduction(UNISDR)'s a definition of disasters as follows [2]:

> A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

There are various types of disasters which occur in the world, and the most frequently occurring natural disaster is flooding which represents 43.4% of the total number of reported disasters from 1998 to 2017 [3]. After flooding, storms were the second most frequent disaster type, and earthquakes are third. Regardless of their sizes, location, and types, natural disasters bring destructive impacts to individuals and overall society. According to the report, disasters killed 1.3 million people killed and damaged two trillion dollars(USD) of assets from 1992 to 2012 [4].

Against the catastrophic result that disasters cause, disaster management is trying to mitigate the damage by covering the preparedness, response, and recovery. Although there are efforts on optimizing disaster management, they still face challenges since the uncertainty in environments is magnified due to the circumstances in reality. The humanitarian logistic which regards supplying the essential relief aids to affected people's survival is one of the operations which are largely troubled by the dynamic and dangerous environment. In humanitarian operations, even though the relief aids are successfully procured, the affected people's lives are put into danger as the essential goods could not be reached them. The circumstances which are unfavorable to maintaining the good condition of logistic agents may reduce the lifespan of logistic agents such as vehicle malfunction and battery drain, and it challenges the survivability of disaster relief logistics. Survivability, in this case, means that the original goal of agents is reached even in the situation where agents cannot do the scheduled task which is fundamentally required for reaching the goal. Survivability is critically vital in regards to humanitarian operations because if last mile distribution cannot take place, due to the failure of logistic agents, it will adversely affect people.

1.2 Problem Statement

The problem addressed by this study is the logistic agents' unexpected incapacity to perform the delivery operation at the last mile distribution stage which hinders ultimate disaster recovery but is rarely considered. Last mile distribution is the final stage which concerns the delivery from the Local Distribution Centers(LDC) where large amounts of relief goods to affected areas where demands exist, are stored [5].

For response and recovery after disasters, supplying the relief goods continuously to the location where the demand exists is critically important. In the situation where the essentials for living such as water, food, and medicine are scarce, delivering those to the affected people is crucial for their survival. In the typhoon Haiyan, which hit the Philippines in 2013, people suffered more from the shortage of relief aids such as food, water, and medicine because of delayed delivery [7]. Therefore, they did not have a choice

Figure 1.1. Phillippines sign for requesting water after typoon Haiyan [6]

other than drinking unclean water from polluted wells which put them into more danger. The primary reason for this delay was that the logistic agents involved in delivering relief goods were not available in scheduled operation [8]. The destruction of logistic infrastructures such as bridges and roads is what makes the transportation agent unavailable, and this was pointed out for the last mile failure from studies [5] [9] [10].

On top of infrastructure problems, the availability of logistic agents which are essential for moving relief aids to areas such as trucks and helicopters, are significantly influential to the success of last mile distribution. If logistic agents are unavailable, the last mile distribution can fail even with reliable infrastructure. The problem is the logistic agents who take a significant role in last mile distribution but are susceptible to the dynamic environment the disaster made at the same time. The harsh environment from a natural disaster can make the vehicle break down such as punctured tires and engine failure. Previous research on disaster relief supply rarely considered the possibility of those agents' inability to perform their role [5] in the future even though logistic agents cannot survive infinitely. Since the incapacity of expected agents can result in the delay in supply [11], the last mile distribution should acknowledge the problem of the situation where the logistic agents could not deliver the goods at some point and address the problem with the logistic agent's assignment with the proper consideration on their vulnerability. Allocating excessive logistic agents into demands where supply should survive only for a few months will be a waste of resources or capital, since excessive logistic agents could have been used for other things such as procuring relief aids and shelters. On the other hand, assigning small numbers of logistic agents to the last mile distribution operation which should survive, for the long term, will create problems in the future with unexpected incapacity endangering affected people, like the case of Haiyan [8].

1.3 Scope

Several things are required for successful humanitarian logistic such as donation, procurement, inventory checking, and route decision. This study focuses on the logistic agents' last mile distribution for the humanitarian logistic. The agent is the entity that perceives the environment through the sensors and affects the environment through the actuators [12]. Various agents can be involved in this operation such as donor agent, government agent, NGO agent, and logistic agent [13]. Since the problem this study identifies is on the site where actual logistics occur, the study focuses only on agents that directly contribute to allocating relief aids to the affected area such as demand agent, allocation agent, and logistic agent. Also, the relief aids that will be delivered during the operation for this study are also scoped to be water and canned food which do not get contaminated from the weather condition and consumed daily for survival.

1.4 Research Question

This research contributes answers for following questions:

- Which organization of logistic agents is required for optimizing the last mile distribution after a disaster for duration of time and the survival?

1.5 Significance

As have seen from the previous events such as earthquakes that happened in Haiti and Japan, disasters bring out the chaos in local society and sometimes globally [14]. For society to stabilize, not only relief items that are required for people's wellness, but also further resources to reconstruct the destroyed infrastructure. The duration that the relief aids should be delivered for affected people depends on the severity and magnitude of damage inflicted from disasters. As the last mile distribution's logistic takes the second largest portion of the expense for the humanitarian aids organizations next to the staff cost [15], it is important for them to take a wise decision on logistic agents which can survive logistics for the specific duration needed to served for areas and at the same time efficient. As the expense it takes for assigning logistic agents can be instead allocated to procuring the items that needed to recover, profiling of logistic agents organization that can survive the last mile distribution is essential. Therefore, this study that tries to establish the model on distributing resources to affected areas and get the profile of logistic agents that makes the specific duration of last mile distribution survives with the consideration on logistic agent's incapacity to supply in the future is significantly important. Especially, this study puts the focus on the survivability of last mile distribution. Last mile distribution is the stage that takes the crucial roles in finally meeting the demand from affected people by directly supplying items, but has significant uncertainty.

In 2017, Puerto Rico severely suffered from Hurricane Maria. Even though support had arrived, the relief aids loaded container could not be distributed to the affected area. According to Crowley, who shipped the 3400 containers at one port in the island, they unloaded the shipment quickly, but the shipment stayed at the port without quickly moving to the affected area [16]. Although the support gathered quickly and procurement was effectively done, the eventual delay at the last mile distribution stage of the humanitarian supply threatened people's lives. Studies regard on last mile distribution

Figure 1.2. Relief aids for Hurricane Maria stacked at the port [16]

lack of consideration on logistic agents incapacity which can endanger whole humanitarian operation [17]. This study is significant in causes by getting the profile of logistic agents and survivability of last mile distribution which can helpful for managing the unexpected putting risk on a humanitarian operation

Therefore identifying the reasons that block the last mile distribution and making the survivable agent model for last mile distribution is important in disaster operation. However, the resilient supply model for a disaster situation was not actively investigated. This study contributes to the modeling of the survivable agent's organization to insure progress on their task and accomplish their goal in dynamic situations where the aftermath of a disaster will deprive agents of capacity and capability.

1.6 Assumptions

The assumptions for this study include:

- The operation time for every logistic agents are assumed to be 24 hours.
- The communication between logistic agents and the allocation agent is assumed to be always secured.

- The agents’ loading capacity for the operation can be less than maximum.
- Once a logistic agent is assigned to the demand areas, an allocation agent believes that the logistic agent will deliver the relief aids.
- The route from LDC to each demand area is one unit.
- The decision is made by the allocation agent alone, therefore it is assumed that the logistic agents always follow the allocation agent’s assignment on the delivery.
- It is assumed that the multiple logistic agents go at the same time using one road is possible.
- When the agent fails to deliver the goods on the operation for a known or unknown reason, the situation will be conveyed to allocation agents to decide further action.
- This study assumes that the logistic agents employed at the operation will be new.
- This study assumes that the environment the logistic agents are working can damage logistic agent but not to the extent of immediate removal.
- Logistic agent’s capacity is expected to decrease gradually because of continuous operations.

1.7 Limitations

The limitations for this study include:

- The survey data from the previous studies that this study takes into account for designing agents can be restricted to certain disaster circumstance.
- The study does not take into account the situation where the road is completely disconnected or can not accommodate the logistic agents for routing.
- Maintenance on logistic agents is not considered in this study.

- Logistic agents entails a set of vehicles and one driver or one pilot.

1.8 Delimitations

The delimitations for this study include:

- This study focuses only on the last mile distribution problem among the supply chain problems in humanitarian operations.
- The study focuses on the last mile distribution, therefore the logistic operation prior to the Local Distribution Center will not be dealt in the study.
- The study focus on solving the problem with the existing route, therefore, a new routine decision will not be discussed in this study.

1.9 Summary

This chapter provided the scope, significance, assumptions, limitations, and delimitations that this study has for the research question asking “Which organization of logistic agents is required for optimizing the last mile distribution after a disaster for duration of time and the survival?”. The next chapter provides a review of the literature relevant to “Disaster Relief Supply Model against Agents Unexpected Incapacity” including disaster supply, survivability, and agent-based model.

CHAPTER 2. REVIEW OF LITERATURE

This chapter provides a review of the literature relevant to the problem of Humanitarian logistics, the agent based model, and survivability.

2.1 Humanitarian Logistics

For managing disasters, human, capital, and physical resources are put into many phases such as rescue, evacuation, shelter and restore. Since those resources are limited but in high demand, managing resources is important for successful disaster management. Consequently, there is great emphasis on humanitarian logistics. Humanitarian logistics is the process of planning and controlling the flow and storage of relief aid efficiently from the support origin to the affected area to alleviate the suffering of victims [18]. This process covers preparedness, planning, procurement, warehousing, and transport. Wassenhove claimed that about 80% of disaster relief is about logistics so that the management on supply should be productive, transparent and precise [19].

Humanitarian relief aid organizations from various sectors provide the general humanitarian logistic operation once the disaster occurs. When stakeholders on disaster management acknowledge the disaster, the assessment on the damaged area is initiated to procure relief aid. In the situation where the limited resources should be efficiently supplied to many areas, the accurate assessment on the damage is important. Sheu [20] also said that the task of identifying the right amount of relief goods required for the affected people is challenging. As Sheu pointed out, the predicted amount of demand for relief aid might be accelerated due to the circumstance in which people want to secure more resources for their safety. It can jeopardize overall logistics and put hazard on other areas suffering from disasters. Regarding this problem, Bendea et al. proposed using UAVs for gathering the data to support humanitarian operations [21]. They claimed that satellite images have a limitation because of their instant availability. Instead, they expect the availability of the relevant data, such as affected areas and the estimated number of victims from images taken by the camera loaded on autonomously navigating UAVs.

Once the assessment on demand is finalized, procuring relief aid based on assessed needs follows. For this, humanitarian organizations need financial support which can be established by funding from donors. Donors include government agencies who traditionally supply the substantial portion of funds, and private donors such as individuals, trusts, and corporations [22]. Private sectors have come to play a significant role as donors as their portion of assistance continuously increase. In 2015, it reached the value of 6.9 billion US dollars approximately. Also, combined support from both sectors steadily has grown and stretched to 27.3 billion US dollars in 2017 [23]. As the donors and their influence for humanitarian relief expanded, the need for humanitarian agents to actually deliver the relief aid by using the funds efficiently and transparently became important.

About $50 billion US dollars are used on procurement of services and goods for humanitarian operations. Especially, about 60 percent of the relief aid fund is used on procuring the relief goods [24]. Even though the primary goods for the relief purpose are relatively simple, price and availability become the concern when it comes to humanitarian logistics. Therefore, the procurement process for relief goods should be considered both locally and internationally depends on situations. The local procurement has its advantage on transportation time and cost, but international procurement stands out from the perspective of a large quantity, and low price [25]. Falasca et al. suggested a two-stage decision model to improve the effective procurement [25]. The model aims to secure the goods at the first stage despite the uncertainty in need assessment since the act of supplying upon the disaster is essential. At the second stage in which demand and donation become relatively sure, the humanitarian organization makes up the gap between the first stage procurement and the second stage's assessment so that overall procurement covers actual demands.

After procuring the relief aid locally and globally, relief goods from various locations arrive at the primary hub in which large transportation such as airplane and the large ship can be accommodated. Then the supplies go to consecutive warehouses for the storage and sorting [5]. Those warehouses should be able to cover affected areas because the number, location, and capacity of warehouses have a significant role in the effective time and cost management for disaster response [26].

From the warehouse, where a large number of relief aid is stocked, to affected areas, logistic agents take on a significant role in last mile distribution which is the final stage of humanitarian logistics [5]. Regarding the operation, the decision for relief aid allocation, delivery schedule, and routing should be made. However, the problem arises in reality from the perspectives of limited available transportation, emergency supplies, damaged road, and coordination problem within humanitarian agents. For this matter, Balcik et al. proposed the two-phase model on inventory allocation and vehicle schedule decision in last mile distribution with the consideration of delivery time, vehicle capacity, and supplying relief aid [5].

Battini et al. got motivation from Balcik et al. [5] and applied the two models to the Haitian case [15]. This study aims to see the potential of using different transportation methods such as helicopters, trucks, and a combination of those. From the study, it was revealed that the costs occurring during the last mile distribution have a higher level of effectiveness when the different relief aid delivered using the co-transportation.

Ferrer et al. suggested a multi-criteria model for the last mile distribution that considered not only the traditional criteria such as cost, time, coverage, and equity but also the security such as the possibility of the ransack happening in the middle of delivery operation [27].

Majima et al. identified the problem in the logistics' low robustness in disaster situation reflecting the previous disaster operations that collapsed due to the damaged road. The study tries to solve the frail logistics in a disaster environment by using small ships as alternative [28]. Through the various simulations, the study found the ships' ideal number, a place to be located. This simulation result can contribute for professionals to find the place that should be recovered first in case one of the ports used for logistics are damaged by the disaster. The study shows the survivability feature that the model can have against the disaster situation which motivates the proposed study.

As Balcik et al. pointed out, the last mile distribution was not fully explored compared to the other relief logistic problems were studied. Although studies after Balcik et al's model modified and applied it to various disaster data, those are more focused on changing demand in areas. The last mile distribution's survivability in uncertain environments after disasters with the organization of logistic agents needs to be studied

2.2 Agent Based Model and Simulation

Agent-based model and simulation is an approach for modeling the dynamic system of the agents which act autonomously and interact with each other [29]. An agent is an entity that detects the environment with sensors and changes the environment using their component [12]. The agents behave upon their rules, interact with other agents, and cause an impact through those interactions. Based on that, Macal et al. organized the elements of agent-based model as follows:

- A set of agents, their attributes and behaviors: Agents' attributes can be static and dynamic. The static attributes like agent name do not change. On the other hand, dynamic attributes in the agent such as resource, and capacity can change as they progress.

- A set of agent relationships and methods of interaction: Agents have dynamic relationships with other agents and relations further influence agents themselves and future interactions.

- The agents' environment: agents also have interaction with the environment. The interaction entails that agents gather the information from the environment through the sensor and that they affect the environment.

Through the agent-based model, the result that emerged from agents' dynamic interactions can be observed and further analyzed. Therefore, it is used for various research areas such as urban planning, consumer behavior, industrial network, electricity market and supply chain management [30] [31] [32]. Also, it excels at capturing the complexity that results from the various interactions between components of society [33] and this motivates this study to employ agent-based model as humanitarian logistics especially requires involvement of many agents.

There are studies regards logistics problems and uses agent-based modeling to solve them. Chen et al. suggested that the crowdsourced delivery would work as the solution against the challenge they face on last-mile delivery [34]. They modeled crowdsourcing last mile delivery using an agent-based model to research significant factors that affect crucial performance in crowdsourcing delivery. They defined three types of agents; distribution center, package, and crowd carrier. They behave with defined rules such as crowd carrier identifying the packages that matched to specifications, picking, and delivering the packages. According to the result from agent-based model simulations, invaluable findings could be drawn such as that the number of crowd carriers grows, the detour distance shortens which again increases the benefits of the crowd. For the problem of delivery capacity shortages in last-mile deliveries, the strategy of giving incentives to crowds, so they give up the detour time can be drawn. From the simulation, not only can we gain insight into the phenomenon, the strategy to prevent the problem can also be experimented.

Chatterjee et al. proposed the public transportation delivery model to prevent urban areas' pollution from worsening because of excessive use of private logistic companies' transportation [35]. The agents modeled in the proposed system are delivery agents, bus agents, tram agents, and transport scheduling agents. The delivery agents are carriers that deliver the package to the designated place. Bus and tram agents are public transportation agents which carry the delivery agents on each delivery plan. The idea of agents having the same purpose and function, but different impacts on environment motivate this study as the logistics could show different results depends on different types of agents are organized and employed.

Fiedrich et al. [36] stressed the potential that the agent technology could be applied to support disaster management. In terms of the disaster management that should be executed in a timely and resource-efficient manner, the agent technology can be useful since it supports intelligent agents to collaborate in a distributed system. The technology presents the coordination that should be established in the real emergency. In the circumstance where complex tasks exist and should be executed by different organizations, using agent technology is expected to help to make decisions about the coordination problem.

2.3 Survivability

Survivability is the feature that has come to take an essential part in studies because the purpose should be achieved even though the system is vulnerable and the nature of the environment is against its purpose. The definition of survivability varies upon each study.

However, there is consensus on the definition of survivability; it entails the feature which delivers the essential services that are needed for achieving the system's goal, even in situations in which there are attacks on the system and system failure. The common clarification of survivability that was first defined by Ellison et al. follows

> ”Survivability is the capability of a system to fulfill its mission, in a timely manner, in the presence of attacks, failures or accident” [37]

This study stressed that it is the mission that should be survived ultimately, not the part of the system. Therefore, the most important feature for the survivability is not keeping the current system; if modifying and reorganizing the system enables the sustaining of the fundamental mission, it leads to the survivability.

Ellison et al. also depicted the four main keys which are expected to possess for the survivability [37]. Firstly, the system should be resistant to the attacks. Warding off the potential attacks beforehand using the user authentication can be one of the examples. Also, they should recognize that they are getting attack and how much damage they suffered. Against the attack and damage they got, the system should recover fully or to the extent of at least delivering the essential services for the mission. For recovering or maintaining the essential services, the system should alter its behavior and functions. Even though the self-healing may not be appropriate in this study, changing the behavior so that essential service can be still carried out can be motivation for the survivability in our study. Lastly, they suggested that the system should be able to evolve to increase its resistance against the future attack.

There are studies that brought out the vulnerability problem in the system and tried to increase the survivable feature in fields. Zuo pointed out the lack of survivability features in the RFID and suggested the potential survivable RFID system [38]. He also defined the requirements for a survivable system in three aspects as follows :

- Survivable system has the property which services against the damage exist in the system
- Survivable system accomplishes the original mission even though there are interruptions against its function
- Survivable system should provide acceptable functions even though it has damaged

Regarding the requirement suggested by Zuo, our study can be motivated to define the acceptable degree of a function for logistics to be declared as ‘survived status’.

Cardoso et al. expressed the concern on the vulnerability of the workflow management system and asserted the need for survivability features in the system since the system could not fully support its role in the sensitive environment. The study proposed the way of improving the survivability of the METEOR workflow management system from four level architectures which are instance, schema, workflow, and infrastructure level [39]. Those are categorical elements that function in the runtime environment of the system. The study suggested the solutions for each category and implemented two modules which are dynamic change and adaption. Each module allows the change of instances in workflow level and handles the generated exception based on the previous experiences the system dealt with. The feature suggested in this study can not be applied to our study, but changing the instances can motivate how the logistics in our study can survive.

Gomez et al. tried to put the survivability feature in a multi-agent system where the mission of the system is on assisting living [40]. Regarding the challenges that the system can encounter, three strategies based on social interaction are suggested. The first is finding the agents that have the same capability as the failed agents' one. The second strategy is generating a solution based on the different capabilities from agents. The last one is a more sophisticated strategy which seeks the solutions that previously generated from the other agents' experiences. The first strategy can be considered for increasing the survivability in our study's problem. Finding the agents which have the same capability as the deceased agent can be put into prior consideration for survivability in the situation where the agent loses its capability.

Vincent et al. asserted that the distributed system can be powerful but at the same time vulnerable to the deliberate attack from outside and system failure [41]. Therefore, the study suggests that the distributed system should be flexible, and survivable through the agent coordination scheme which in this case generalized partial global planning(GPGP).

Agents in environments share their view for problem-solving and negotiate which agents will take which task. This can be applied to our study since agents can share the local information they gathered and central agent can allocate the other agents based on collected information so that the goal of the model can be achieved regarding the problem that the agent could not carry the expected task.

Tan et al. said that the complexity from global business environment increased the vulnerability in the supply chain and proposed two strategies creating resilient supply chain network [42]. Supply chain network is consist of different types of the node which are retailer, distribution center, and supplier. For the supply chain network to be survivable, the supply from the supplier should reach to the retailer. Traditional single supplier supply chain network was very vulnerable, because when the one supplier goes down, then the whole supply chain network encounter crisis of survival. Therefore, the suggested survivable supply chain network employ network growth models which retailer chooses the supplier to be linked. The first strategy, 'Hierarchical Preferential Attachment', suggests determining the type of node which should be decided on the ratio of existing nodes type and attached to nodes with relative importance. The second strategy, 'Hierarchical Random Attachment' expect the hub of nodes that has high connectivity would increase the vulnerability of the overall supply chain network. Therefore, the strategy makes the nodes to be attached to the upper node randomly and at the same time distributed uniformly. This does not make the one nodes to become heavy with lots of connection to retailers. Through the simulation analysis, suggested strategies are revealed to be much resilient compared to the traditional single supplier supply chain. From this study, the importance of survivable model for the supply chain could be once again acknowledged. Also, the models that applied to the situation and the evaluation could also be applied to our study that aims to increase the survivability of last mile distribution even though the nodes in the problem would be different.

For the problem this study put significance on, the essential function of agent organization which carries the task of delivering the relief aid to the final destination should be maintained for the goal of supply relief aid to be survivable. Therefore, for the sake of the survival of the ultimate goal, organization transition can happen such as agent task change, and transfer of task.

2.4 Summary

This chapter provided reviews of the literature to humanitarian logistics, agent-based model, and survivability which are relevant to "Disaster Relief Supply Model survivable to Agents Unexpected Incapacity". Those provide the background knowledge on humanitarian logistics' various decision making and its issues. For the proposed study, the literature on agent-based modeling and survivability suggest the fundamental concept needed for defining the survivability in the problem of this study and motivations that could be considered on modeling the survivable last mile distribution in humanitarian logistics.

CHAPTER 3. HUMANITARIAN LOGISTIC MODEL AND SURVIVABILITY

This study aims to solve the problem of humanitarian logistic last mile distribution endangered by logistic agents' capacity loss shortening the agent's survival period. Agents and their behavior are described in this chapter. Also, the definition of 'Survivability' in the humanitarian logistics' last mile distribution will be defined.

3.1 Survivability

The definitions on 'survivability' depends on the studies, but has the general agreement on the significance of accomplishing its original and ultimate goal. Even though threatened by the attack and its error, survivability puts the priority on fulfilling the overall system's goal even though sustaining the original behavior is sacrificed. From the perspective on 'agent' concept, therefore, survivability is defined as agents accomplishing their ultimate goal in the situation where their capability is threatened to be decreased or lost.

Humanitarian logistic agents in this study have the ultimate goal of satisfying the affected area's demand by supplying relief aid. When the end goal of humanitarian logistic agents is considered, whether the last mile distributions survive or not against the damages depends on if the requested relief aids can be covered by the logistic agents' total capacity. Even though the humanitarian logistic agents lost its capacity or capability because of the environmental factors, if the loading capacity the logistic agents can deliver to the affected area exceeds area's demand, then humanitarian logistic agents' ultimate goal is achieved, in other words, survives.

Suppose there are two humanitarian logistic agents work on delivering the relief aids to one affected area $P1$ daily. The logistic agents, however, lose their capacity to deliver a certain amount of essential goods to the affected area day by day because of the harsh environment, after a disaster like the situation shown at the figure 3.1.

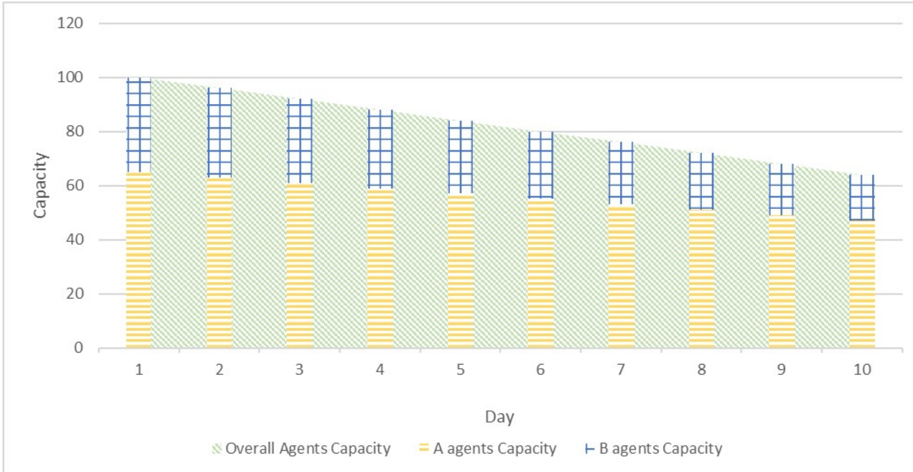


Figure 3.1. Humanitarian Logistic Agent's Capacity Loss

Even though their total capacity decreases, last mile distribution survives because a logistic agents' capacity is not zero. However, the last mile distribution fails to achieve its goal from day 7 since humanitarian logistic agent's supply becomes insufficient to satisfy the demand which means failure to the goal and at the same time to survival as can be seen from Figure 3.2.

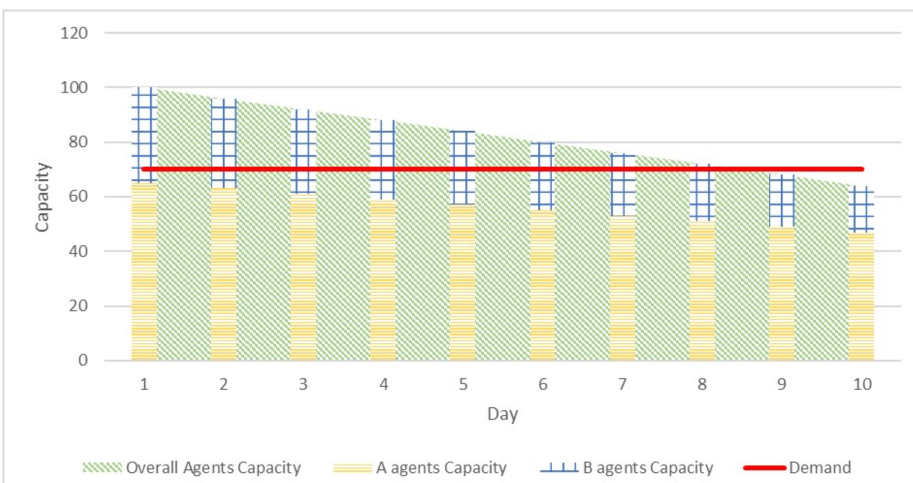


Figure 3.2. Threshold for Survivability

Therefore, the logistic agents' last mile distribution goal to be achieved and survive, the logistic agents' capacity should be adjusted at least until the point of the affected area's demand.

In an open environment, the logistic agents which, were not participating in the operation, can join and participate in last mile distribution. Figure 3.3 shows the survivability in an open environment. If the entered logistic agents' capacity is sufficient to cover the gap between the demand and overall agents' capacity, humanitarian logistic agents could deliver the demanded amount of relief aids to the affected area. Therefore, the ultimate goal of logistic agents can be achieved, so last mile distribution survives, with the additional capacity.

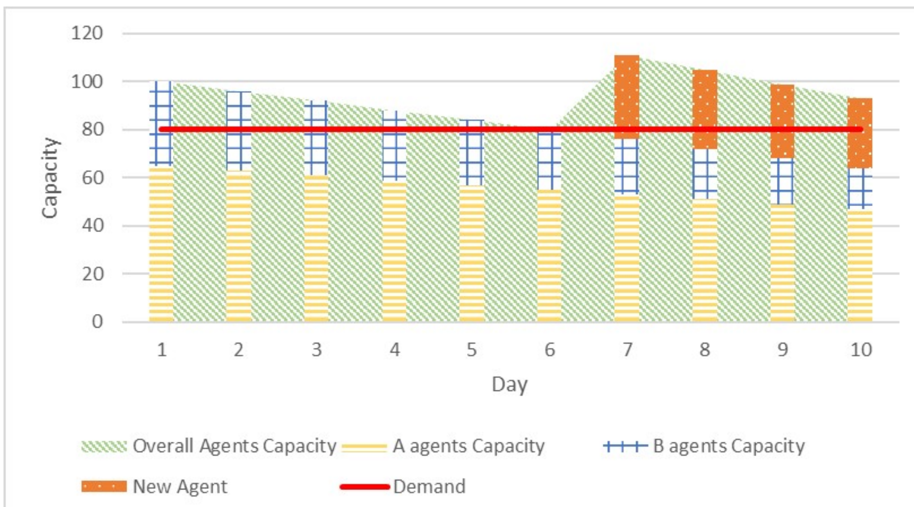


Figure 3.3. Survivability in Open environment

On the other hand, in a closed environment, the additional agents from the outside of the environment where the current logistic agents are working cannot enter. Figure 3.4 shows the survivability in a closed environment. Therefore, for the humanitarian logistics' last mile distribution to survive, the allocation agent should coordinate the remaining logistic agents' capacity and their assignment to the area, so the adapted capacity from allocation agent's coordination can satisfy unmet demand. As the adjusted capacity from the cooperation is above the minimum level of demand, the logistic agents' goal comes to achieved and last mile distribution survives.

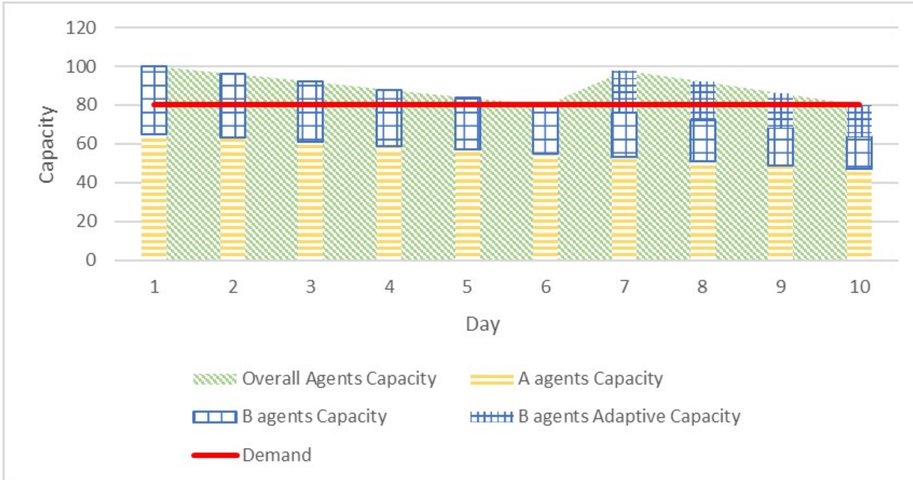


Figure 3.4. Survivability in Closed environment

Consequently, in the situation where the logistic agents lose their capacity, the humanitarian logistic's last mile distribution survives when every area's demands are satisfied with the supply that was enabled from the allocation agents' coordination decision on logistic agents. Employing logistic agents which survives the last mile distribution for the duration of time which is needed for the affected areas to recover is important.

3.2 Humanitarian Logistics's Agents

The humanitarian logistic's last mile distribution model has three agents, demand agents, allocation agents, and logistic agents.

Demand agents are situated at the affected areas, and they put the request for relief aid to the allocation agent so that the affected area's victim can be relieved with the relief aids supply. Demand agents have 'Need' and 'Need' means the quantity of relief aids that demand area requires from the local distribution center. The quantity of 'Need' is renewed every day until the end of the operation. The 'Need's from demand agents are significantly important as they are the criteria deciding the success and failure of humanitarian logistic, and also their survivability.

An allocation agent is a central agent located at the LDC which gets the request of relief aids from the demand agents. This agent pursues the humanitarian logistics' ultimate goal of satisfying the demand of the affected area's victim by supplying relief aids so that the suffering of affected people can be alleviated. Therefore, they get the request from the demand agent, assesses the reported availability of logistic agents to satisfy the needs. Then, the allocation agent allocates the specific amount of relief aids to logistic agents and assign them the area where they have to deliver the items based on the assessment.

Logistic agents execute the tasks given by the allocation agents which, are delivering the allocated relief aids to the assigned areas. They load the specific amount of relief aids and move with the allowed speed at maximum. It takes time to load and unload the goods depend on the quantity they deliver. After logistic agents arrive and unload the carried items at the assigned demand area, they return to the LDC to for the further deliveries or the end of the daily delivery.

Under logistic agents, there are four logistic agent types which reflected the real logistic transportation used in humanitarian logistics such as the Haitian humanitarian logistic [43]. There are two ground vehicles which are off-road trucks and two aircraft for the last mile distribution. Table 3.1 is the description of logistic agents that will be modeled in this scenario.

They show the difference in their capacity regarding the loading and speed by logistic agents' types.

Table 3.1. Last mile Logistic Agent's Capacity

	Ground Vehicle		Aircraft	
Agent	Truck A	Truck B	Helicopter A	Helicopter B
Loading Capacity(tonne)	7.5	14	2.5	2
Operational Speed(km/h)	85	85	180	160

Other than loading capacity and speed, the logistic agents have other attributes such as status, destination, history, sequence, and LDC. Status shows the state where the logistic agents, are such as located at the LDC, moving to the destination, delivery, and returning to the LDC. Destination differs by the agent, and it tells where the logistic agent will deliver its capacity until the needs of the destination are satisfied. Each logistic agent remembers which demand they visited and its sequence. Then, they repeat it daily until the end of the operation.

Agents in humanitarian logistics' last mile distribution model only pursue their goals of supplying relief goods to the affected areas. Figure 3.5 is the agent interaction diagram for humanitarian logistics' last mile distribution models to achieve the goal of satisfying the requested demand by supplying with relief aids.

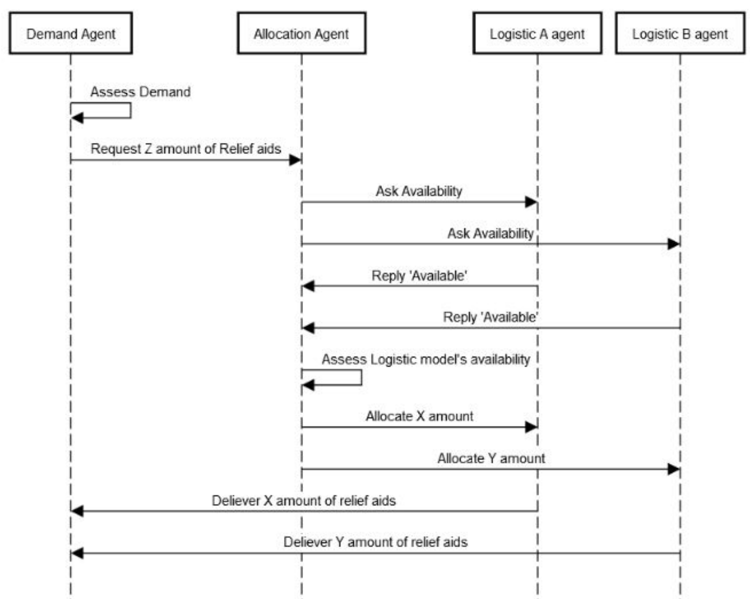


Figure 3.5. Agent Interaction in Last mile distribution model for Humanitarian Logistic

Figure 3.6 shows the fundamental attribute the logistic agents have to deliver the task for last mile distribution. When the logistic agent who moves the relief items stored at the allocation place to demand A is a_1, a_1 have the capacity of loading, speeding and operating. The loading capacity, C_{a1} is how much weight of relief items a_1 can load. The overall speed, S_{a1} shows the how fast a_1 can move from allocation place to demand area A. Finally, general operation time means that the working hour the logistic agent, a_1 will do the task of delivering.

Based on the defined agents above in the humanitarian logistics' last mile distribution model, suppose the situation where the agent $a1$ should deliver a certain amount of relief aids to the affected area $p1$ in the last mile for humanitarian logistic.

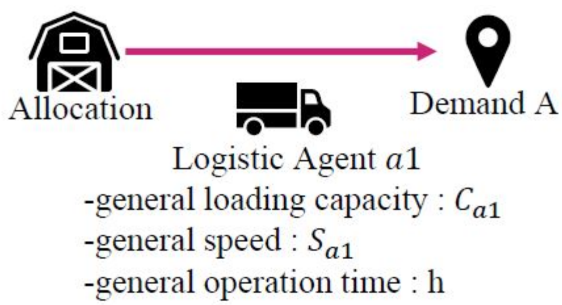


Figure 3.6. Logistic Agent Description for Humanitarian Logistic

Where the distance from Local Distribution Center(LDC) to the affected area $p1$ is d_{p1}, and the agent $a1$'s speed capacity is s_{a1}, the time taking for agent a1 to arrive at the affected area $p1$ is t_{a1p1}.

$$t_{a1p1} = \frac{d_{p1}}{s_{a1}} \tag{3.1}$$

For the logistic agent $a1$ to complete the task of delivering relief aids to the affected area, the agent $a1$ should depart from the LDC and arrive at the affected area $p1$, then come back to the LDC. Therefore, it takes $2t_{a1p1}$ time for agent $a1$ to complete one round of distribution task to $p1$.

Suppose the agent $a1$ has a certain amount of time h hours that can be operated for a day. Then, r_{a1p1} defines how many rounds the agent $a1$ can transport to the affected area $p1$ which can be calculated as below.

$$r_{a1p1} = \left\lfloor \frac{h}{2\ t_{a1p1}} \right\rfloor \tag{3.2}$$

When the loading capacity the logistic agent $a1$ can perform at one round is c_{a1}, the entire amount of relief aids that logistic agent $a1$ carry and distribute to the $p1$ area can be expressed as C_{a1p1} and calculation follows.

$$C_{a1p1} = r_{a1p1} * C_{a1} \tag{3.3}$$

For logistic agent $a1$ to accomplish its ultimate goal in the last mile distribution, its total loading capacity, C_{a1p1} should be always equal to or greater than the $p1$ area's demands on relief aids as shown in equation 3.4.

$$C_{a1p1} \geq N_{p1} \tag{3.4}$$

If there are x number of logistic agents and y number of affected areas where the last mile distribution model has to serve, how many number of agent types are assigned to where can be expressed with the matrix. When the number of agent $a1$ assigned to area $p1$ can be expressed as N_{a1p1}, following matrix can be created.

$$N = \begin{bmatrix} N_{a1p1} & N_{a2p1} & \dots & N_{axp1} \\ N_{a1p2} & N_{a2p2} & \dots & N_{axp2} \\ \dots & \dots & \dots & \dots \\ N_{a1py} & N_{a2py} & \dots & N_{axpy} \end{bmatrix}$$

Also, the capacity of agent type depends on the area which is expressed with the matrix P. As defined above, the total quantity of relief aids that logistic agent $a1$ can carry and deliver to the $p1$ area can be expressed as C_{a1p1}. If so, the total capacity each agent have for the area can be normalized like below matrix.

$$P = \begin{bmatrix} C_{a1p1} & C_{a1p2} & \dots & C_{a1py} \\ C_{a2p1} & C_{a2p2} & \dots & C_{a2py} \\ \dots & \dots & \dots & \dots \\ C_{aXp1} & C_{aXp2} & \dots & C_{axpy} \end{bmatrix}$$

When both matrices multiplied, the total loading capacity that would be delivered to a specific area with the N configuration can be calculated like below.

$$C = \begin{bmatrix} N_{a1p1} & N_{a2p1} & \dots & N_{axp1} \\ N_{a1p2} & N_{a2p2} & \dots & N_{axp2} \\ \dots & \dots & \dots & \dots \\ N_{a1py} & N_{a2py} & \dots & N_{axpy} \end{bmatrix} \begin{bmatrix} C_{a1p1} & C_{a1p2} & \dots & C_{a1py} \\ C_{a2p1} & C_{a2p2} & \dots & C_{a2py} \\ \dots & \dots & \dots & \dots \\ C_{aXp1} & C_{aXp2} & \dots & C_{axpy} \end{bmatrix} = \begin{bmatrix} C_{p1} & \dots & \dots & \dots \\ \dots & C_{p2} & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & C_{py} \end{bmatrix}$$

From a diagonal line in the matrix C, the total loading capacity that can be deliverable to each area with the certain configuration of agent types' number and capacity can be known. For example, the C_{p1} would be the total loading capacity transferred to area $p1$ with the agent's number and capacity assignment from matrix N and P. When each capacity can cover the demand from each area, the goal of humanitarian logistic is achieved.

3.3 Agent Rule

Following is the behavior rule of logistic agents in last mile distribution model. Based on the behavior completion, logistic agents change their status.

Check-destination The logistic agent checks its destination to decide if it will continue its delivery or not. Logistic agents check the status of destination if it is fulfilled with the demand. When the need of destination is left unsatisfied and the logistic agent finished supplying needs posted from demand agent they were initially assigned, they set up the unsatisfied demand area as new destination randomly.

Load Before departing from LDC, the logistic agent should load the relief aids. The quantity of items that will be loaded depends on allocation agent's decision. For loading the items for operation, there are tasks to be done such as reporting, and preparation equipment to load items. Burdzik et al. studied the time taken for the task of loading the items [44] and time was reflected to the model. Following equation shows the time taken for loading task based on the work of Burdizik et al [44].

$$T_L = 67 + (LoadingAmount * 2357) * 0.0000027903(min) \tag{3.5}$$

Move The logistic agents head to the destination with the speed with which the allocation agent suggest them to move. The tough environments which are assumed to be the environment where the logistic agents are working in this study are unfavorable to a logistic agent's capability. In this model, logistic agents have their capacity reduced such as payload and speed. As the damage logistic agents received influences from continuous operations, logistic agents are limited on their speed and capacity for further delivery.

Unload The actual delivery of relief aid happens once the loaded items are unloaded from the logistic agents arriving at the destination. Also, unloading items is necessary as the logistic agents can return to the LDC when they go through the unloading process. Like loading the item, unloading relief items takes time, so logistic agents should stay at the destination for a specific duration for the unloading process to be done. The tasks required for unloading items differ with tasks for loading item, so the time they stay for unloading can be estimated as below [44].

$$T_{UL} = 59 + (LoadingAmount * 1861) * 0.0000027903(min) \tag{3.6}$$

Return The logistic agent returns to LDC after they finish unloading the relief aid to the destination. Return behavior is needed for agents because the relief aid are stacked at the LDC, the logistic agent can do further distribution when it comes back the LDC and load the new relief aid that matched to the needs from destinations.

3.4 Initial Simulation and Result

Agent's rule and behavior were modeled with NetLogo which is well known multi-agent modeling program [45]. In order to get the optimal profile of a logistic agent that survive humanitarian logistics, the humanitarian logistic agent model is also simulated by varying the logistic agents' capacity initially.

3.5 Scenario

Four cases where different types of logistic agents are delivering relief aids to a demand area were simulated to get the baseline profile of capacity needed for achieving the survivability to survive logistic for the duration of time.

As the logistic agent types have different maximum loading capacities or operational speed, it is expected that capacity loss on agent differs by agent types which influence each logistic agent type's survivability for the operation to the demand area.

One demand in this simulation is 79km away from the LDC where the allocation agent and logistic agents are located. Also where the environment where the last mile distribution is done from LDC to demand area in below four cases are assumed to be hazardous to ground vehicle, rather than aircraft. The demand agent at an affected area requests water containers weighing 6,737kg and needs to supply the water every day as the water is needed for daily living.

3.5.1 Case 1. Truck A(T_a) supplying Demand

In this case, the baseline is that one truck A being assigned for supplying the waters to the Demand A speeding at 85km/h when departed and loading 7.5t per one operation.

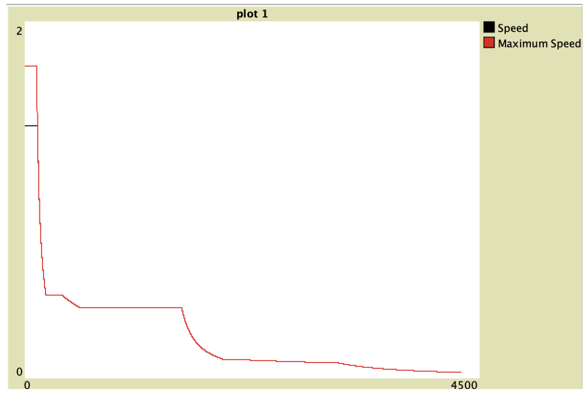
3.5.1.1 Result

Table 3.2. Truck A(T_a)'s last mile distribution to Demand

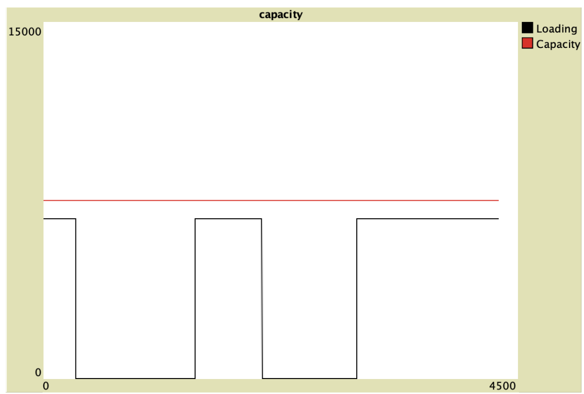
Truck A			
Number	Loading(t)	Speed(km/h)	Logistic Survival Days
1	7.5	85	2

From the result, the truck A could deliver the required amount of relief aids for two days with baseline capacity. With baseline capacity, Truck A could finish the distribution in one round of travel until the end of day 1. However, the damage because of speed and capacity during continuous operation hinders the truck A to survive after the second day of operation. Figure 3.7(a) shows the great damage the logistic agent got from the first travel to the demand. To increase the survivability of truck A's last mile distribution, an adjustment on Truck A's loading and speeding capacity were simulated further. To make this logistic survivable, truck A's speed and loading capacity is adjusted with 836 runs of the simulation. Figure 3.8 is showing the survival days change by adjustment on capacity and speed.

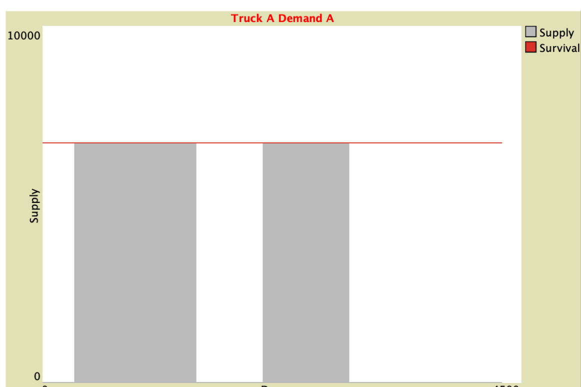
At the maximum speed which Truck A can move, survival days vary by the capacity they load. When truck A load items weighing from 6.8t to 7.5t, the logistics can survive for 2 days. However, when Truck A loads from 2.3t to 6.7t, the truck can survive for 1 day. The worst case is loading under 2.2t as they need to do 8 rounds of travel to complete the delivery task. Even though the capacity is less per operation, they need to do four times more round trips than when they load the maximum amount per each operation, and it eventually lowers the logistics ' survivability with Truck A. Survivability with Truck A can be maximized to 3 days when Truck A moves at 45km/h loading 7.5t of relief aids per operation.



(a) Speeding Capacity Loss



(b) Loading Capacity Loss



(c) Survival Days

Figure 3.7. Truck A(T_a) assigned to Demand

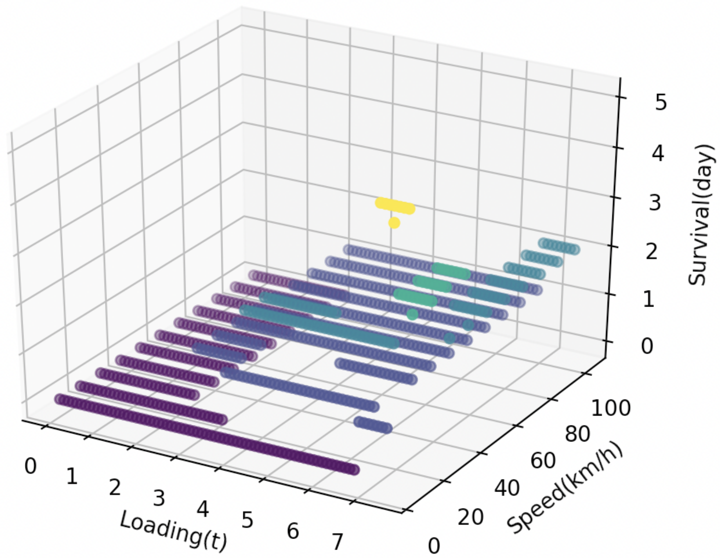


Figure 3.8. Distribution Survivability with Truck A(T_a)'s adjusted capacity

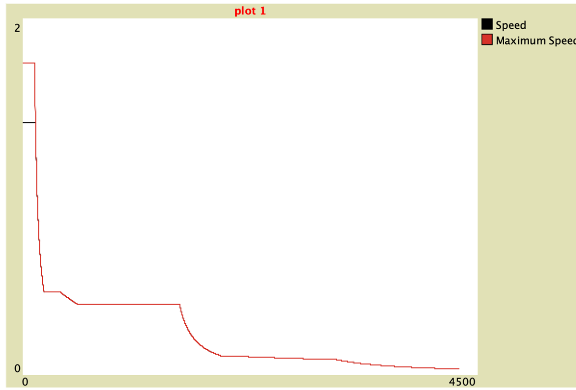
3.5.2 Case 2. Truck B(T_b) supplying Demand

In this case, Truck B is assigned for supplying the relief aids to the demand area. This truck exhibits baseline speeding capacity by moving at 85km/h. Contrary to truck A, truck B is capable of loading 14 tons of items per one operation. Table 3.3 shows last mile distribution survivability when truck B distribute with baseline capacity.

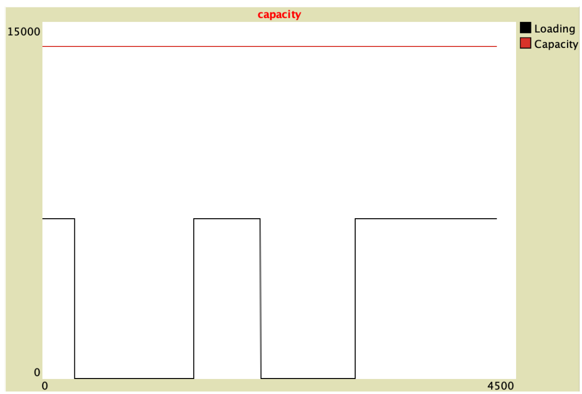
3.5.2.1 Result

Table 3.3. Truck B(T_b)'s last mile distribution to Demand

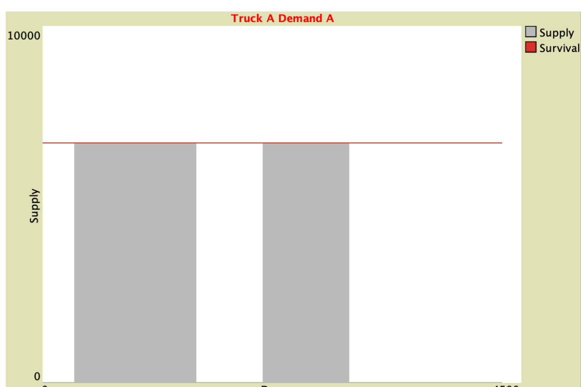
Truck B			
Number	Loading(t)	Speed(km/h)	Logistic Survival Days
1	14	85	2



(a) Speeding Capacity Loss



(b) Loading Capacity Loss



(c) Survival Days

Figure 3.9. Truck B(T_b) assigned to Demand

The round trips Truck B should make for satisfying the demand is one. As baseline capacity per operation already covers the needs from the Demand A, Truck B can survive at least one day, but shows dramatic decrease in speed capacity as the operation goes by.

As the loading capacity and speed adjusted for Truck B, the survival days showed the change. Figure 3.10 is graph showing survival results with the modified capacity .

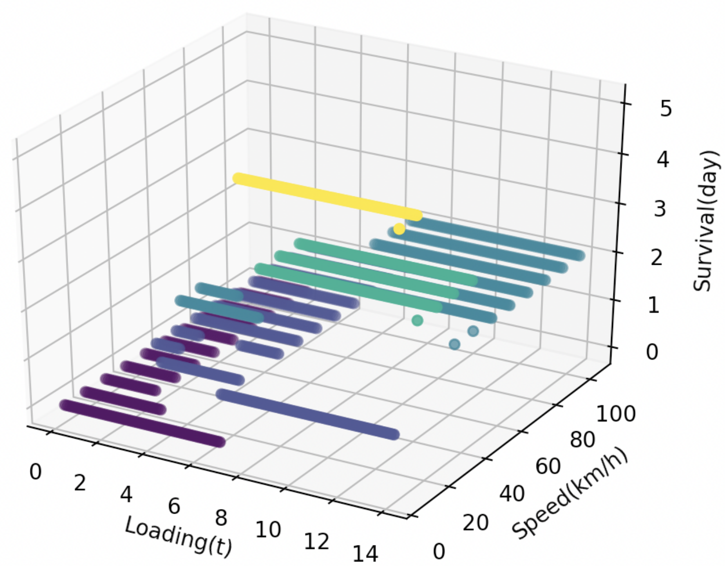


Figure 3.10. Distribution Survivability with Truck B(T_b)'s adjusted capacity

From the Figure 3.10, loading capacity plays a major role in deciding survival days can be seen. As the amount of relief aids that Truck B loads get bigger, the survival days are also shown to be increased. The best case was B type trucks surviving logistics for three days when its speed is decreased to 45km/h and it loads 13.9 tons of items. On the other hand, the logistic shows the worst case of non-survival when it loads items under 2.2 tons per operation even truck moved with maximum speed. As the quantity of loaded items per travel becomes smaller, the round of travel that Truck B should do to deliver all requested relief items increases and it shortens the time when Truck B can keep its delivering capability which results in an adverse effect on logistics' survivability.

3.5.3 Case 3. Helicopter A(H_a) supplying Demand

The third case is employing one Helicopter A for last mile distribution. The baseline of this case is that helicopter deliver items to the destination with the speed of 180km/hour which is considerably faster than two trucks in previous cases. However, the maximum loading capacity of Helicopter A is only 2.5 ton which is lower than trucks.

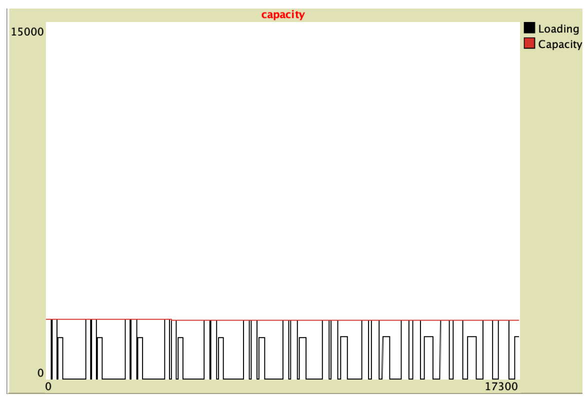
3.5.3.1 Result

Table 3.4. Helicopter A(H_a)'s last mile distribution to Demand

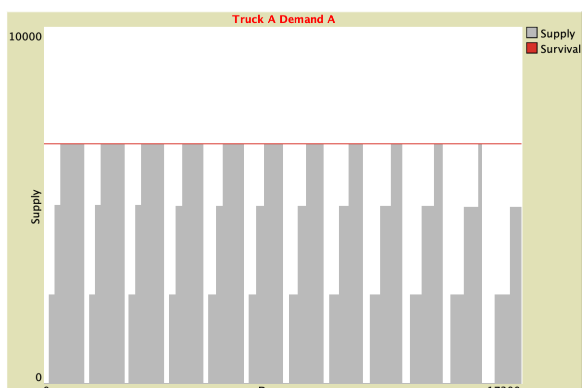
Helicopter A			
Number	Loading(t)	Speed(km/h)	Logistic Survival Days
1	2.5	180	11

As can be seen from the result presented at Table 3.4, Helicopter A can survive for 11 days with the baseline capacity. Contrary to trucks which show sharp decrease in speeding capacity after first operation, Helicopter A shows a smooth decrease which makes supply continue more days. As the environment where distribution tasks are done is less difficult for helicopters compared to ground vehicles, supplement with helicopter shows longer survival days. For the survivability, Helicopter A's capacity on speed and loading were adjusted and Figure 3.12 shows logistics survivability. As the loading capacity decreases from the maximum, the survival days decrease regularly from 11 days to non-survivable, or 0 days. When A Helicopter loads 0.9 ton of items per operation, the logistic can not survive even though helicopter A moves with the highest speed. The helicopter A shows the best case of making logistic survival for 12 days when it starts delivery with 140km/h speed and 2.4 ton loading capacity. As can be seen from the adjustment result from simulation, how much a logistic agent's load and environment's toughness has a influence on logistic's survival period.

(a) Speeding Capacity Loss



(b) Loading Capacity Loss



(c) Survival Days

Figure 3.11. Helicopter A(H_a) assigned to Demand

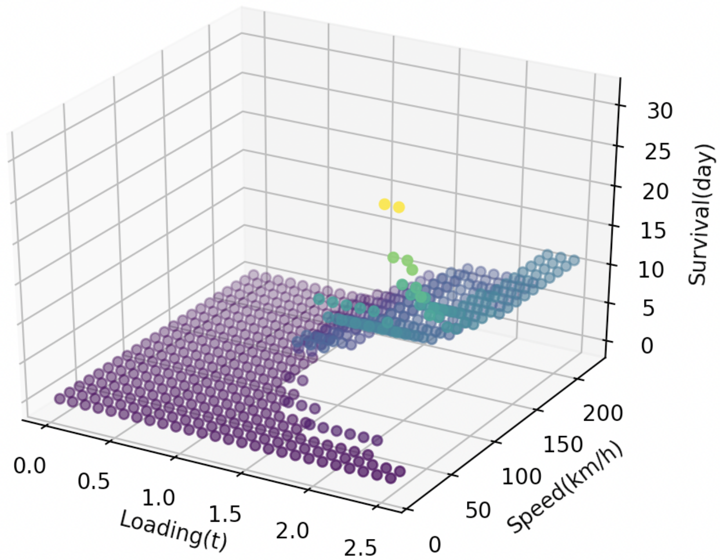


Figure 3.12. Distribution Survivability with Helicopter A(H_a)'s adjusted capacity

3.5.4 Case 4. Helicopter B(H_b) supplying Demand

The last case is when the B type helicopter is assigned to an affected area. B type helicopter's baseline capacity in speed is 160km/hour, which is slower than Helicopter A, but is faster than the trucks. Also, base loading capacity is only 2 tons, and this is less than A helicopter's base loading capacity.

3.5.4.1 Result

Table 3.5. Helicopter B(H_b)'s last mile distribution to Demand

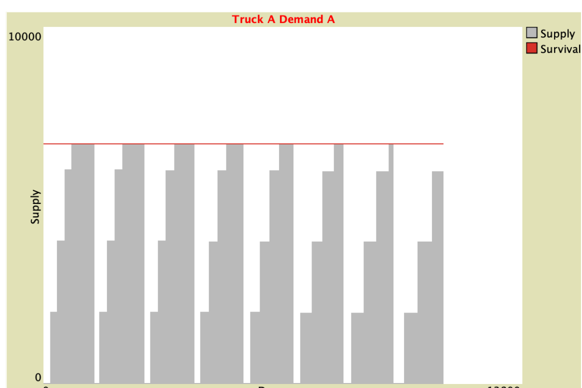
Helicopter B			
Number	Loading(t)	Speed(km/h)	Logistic Survival Days
1	2	160	7

From the baseline simulation, Helicopter B is reported to survive for seven days in a row. As the loading and speed capacity is lower than A helicopter, B helicopter is shown to survive logistics less than A helicopters. To increase the survivability of Helicopter B's distribution, the loading and speed capacity adjustment were simulated, and survivability is on following Figure 3.14.

According to the simulation result presented at Figure 3.14, logistic survival days with Helicopter B shows a decreasing trend as they load less amount of relief aids per round. This trend accords with results from the cases that employed a different kind of logistic agents. The logistics with Helicopter B shows the worst survival days when it loads less than 0.9 tons of items. Even with the maximum speed of 200km/h, the logistic could not survive when helicopter B loads less than 0.9 ton items per operation. Regardless of the time that B helicopter can finish the one round of travel, the logistic agents cannot deliver the total requested items if the time of travel is too large. Helicopter B shows the best case by keeping logistic alive for 8 days with 130km/h speed and 1.9 ton loading. Even with the lower than operational speed, helicopter B can make last mile distribution survivable when loading capacity is big enough.

(a) Speeding Capacity Loss

(b) Loading Capacity Loss



(c) Survival Days Loss

Figure 3.13. Helicopter B(H_b) assigned to Demand

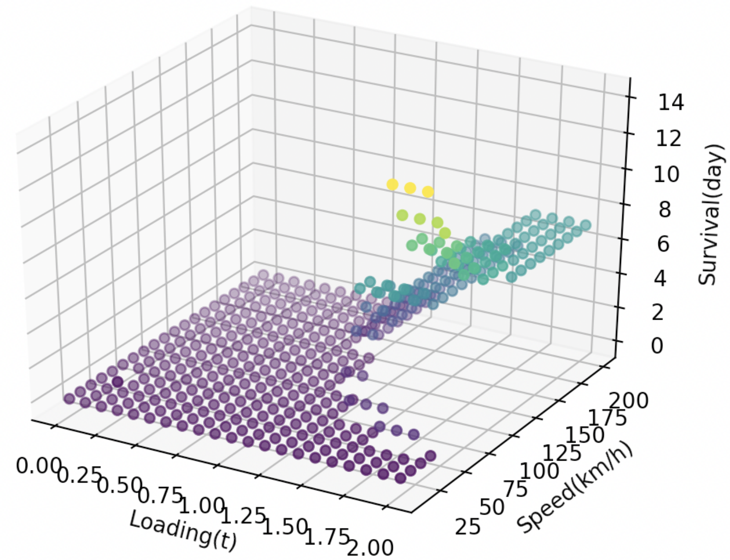


Figure 3.14. Distribution Survivability with Helicopter B(H_b)'s adjusted capacity

CHAPTER 4. MODIFIED LAST MILE DISTRIBUTION

From the simulation with the approach inflicting damage on speed and capacity every minute, it was found that the approach inflicting damage on logistic agents is unrealistic as it resulted in 11 days of last mile distribution survival, at most, when logistic agents move with the reasonable speed and loading specification. Survival longer than 30 days is also found to be with helicopters traveling with 90km/h which is also unreasonable for the helicopters.

As damage is inflicted on logistic agents, in the model, was deemed to be inappropriate, the approach how the logistic agents were damaged from the last mile distribution in this study was adjusted with the new attribute which is the lifespan of logistic agents. Lifespan means the average age of trucks and helicopters. According to [46], the truck is revealed to be operable for about 12 years. The helicopter's average age was also researched but could not be founded from sources, therefore it was also set to 12 years. Therefore, the model is modified that the logistic agents which travel in an organized environment such as the even road condition and stable landing space can be operable for 12 years.

However, the logistic agents in this study do rough operations compared to vehicles which are used for a daily commute. As can be seen from the simulation results, the logistic agents acquire damage as they complete more rounds of last mile distribution.

Martinez et al. [47] provided the information on the average age of vehicles employed on humanitarian logistic. Among four international humanitarian organizations, ICRC(International Committee of the Red Cross) and WVI(World Vision International) mobilized vehicles very frequently with the purpose of transporting relief items and materials for the recovery, which is matched to the goal of last mile distribution. Since their usage aligns with the last mile distribution, which is the environment and tasks this study focus on, the average age of vehicles from those organization motivated the damage on logistic agents by decreasing the lifespan, as they continue operation for the last mile distribution on disaster environment.

Contrary to the damage on logistic agents which is very frequently used for the last mile distribution, WFP and IFRC used the vehicles rarely or occasionally for last mile distribution. Therefore, the damage on the lifespan of logistic agents which are used infrequently for last mile distribution was motivated from fleet age of vehicles belongs to WFP(World Food Programme) and IFRC(International Federation of Red cross and Red Crescent Societies).

Apart from the occasion or substantial assignment to last-mile distribution, the logistic agents also have the danger of sudden incapability when they are idle for the duration, such as 30 days, with battery drain [48].

4.1 Logistic agent

The specification of the logistic agent in this study take a significant role in this study as their speed and loading capacity change how many rounds of travel is required to survive the last mile distribution, and it affects the logistic agent's non-operation status thus affecting the survivability of last mile distribution.

Table 4.1 shows the specification of four logistic agents that were used for modified last mile distribution in this study and this is motivated by the logistic agents used for operation at Haiti [43].

Table 4.1. Modified Last mile Logistic Agent's Capacity

	Ground Vehicle		Aircraft	
Agent	Truck A	Truck B	Helicopter A	Helicopter B
Loading Capacity(t)	7.5	14	3	2
Maximum Speed(km/h)	105	105	217	205

A type truck(T_a) is the Renault truck and it can load 7.5 tons of items [43, 49]. B type truck(T_b) can load 14 tons, and it is produced by the DAF [43, 50]. For both types of trucks, the maximum speed is motivated from Hawaii's driving speed regulation on state highway [51] as the Haitian's driving regulation for trucks could not be found and Hawaii as an island have a similar environment. Helicopter A(H_a) is motivated from Bell 205 which can load 3-4 tons of items from the report, but defined to load 3 tons in this study. According to the information presented from [43, 52], the maximum speed is set at 217 km/h. A Helicopter B(H_b) is referenced from Bell 212 which is presented to do the task of last mile distribution by loading 2 tons of items according to the report on the logistic operation after Haitian hurricane, and its maximum speed is 205 km/h [43, 53].

4.2 Last mile distribution agent interaction

Every day, the allocation agent which is located at the distribution center assesses the capability of logistic agents employed. In a previous model, the allocation also assesses the logistic agents but did not consider the logistics' survivability. Rather than the overall last mile distribution's survivability, the availability of logistic agents was assessed. For last-mile distribution's survivability, the important aspect is if the logistic agents are capable of surviving overall logistics. Therefore, allocation agents assessing each logistic agents' supplement can satisfy the need from each demand. If there are multiple demands where the logistic agents expect to be able to satisfy and survive, the allocation agents assign the demand which logistic agents can finish with the minimum round of travel since the round of travel has a great influence on logistic agent's life span and further logistic's survivability. This process repeats every day before the initial travel and logistic agents which did not perform the last mile distribution previously are subject to the assignment. Once the demand area where the logistic agents should attend is decided, the logistic agents deliver the relief aids until the requested need for the destined area is finished.

4.3 Modified Agent Rule

Check-destination For the purpose of this study, the survivability should consider the worst case. Therefore the logistic agent's behavior of checking destination is modified to not setting a new destination even though there is a destination left unsatisfied after they finish their assignment. The logistic agents will check the status of the destined demand area once they are at the local distribution center. If the requested needs from destination area are fully satisfied, the logistic agents no longer operate, but waits for the new assignment tomorrow.

Logging work-hour Logistic agents log their working hours as working hours are the criteria for deciding assignment priority. The Federal Motor Carrier Safety Administration states that truck drivers have 11 hours daily driving limit [54]. The 11 hour driving limits entail that the drivers should rest after driving consecutive 11 hours. This 11 hours driving limit might not be available in humanitarian logistic considering the urgency of the task for last mile distribution. However, the logistic agents will consider declining after operating past 11 hours if there are substitute logistic agents who were not assigned previous days.

Helicopters also have the regulation on flight hours according to the Federal Aviation Administration [55]. If one pilot is flying a helicopter, flight time is limited to 9 hours. As in the case of trucks, the helicopters type of logistic agents is a low priority when it has records of operations previously.

CHAPTER 5. SIMULATION RESULT

The following chapter shows the result from the simulation on last mile distribution that is conducted after a disaster situation to satisfy the demand from affected area with its supplement.

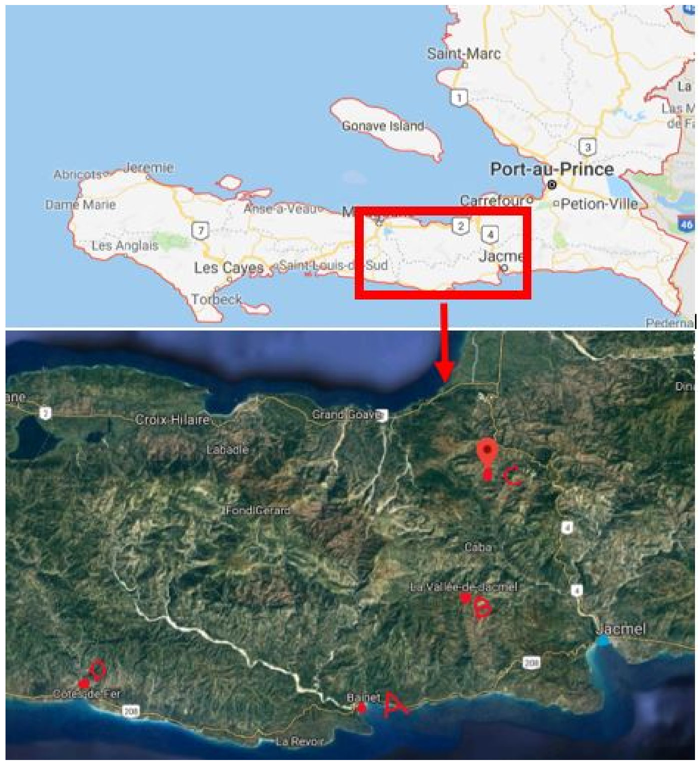


Figure 5.1. Last mile distribution situation

The data of the demand location and requested needs is motivated from the last mile distribution conducted in Haiti after 2010 earthquake [15]. Figure 5.1 shows the geographic image of demand areas from google maps and detailed information is presented at Table 5.1. The model is simulated on NetLogo and results shows the last mile distribution's survival days by the number of demand areas and organizations of logistic agent serve.

Table 5.1. Last mile distribution situation

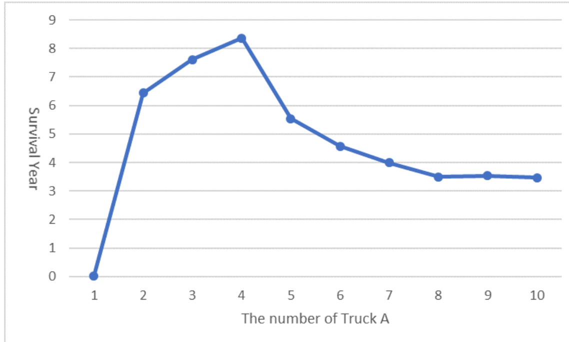
	Demand Areas			
	Baniet(D_a)	La Vallee(D_b)	Trouin(D_c)	Cotes-de-Fer(D_d)
Distance(km)	45	16	41	79
Needs(kg)	24243	13701	10183	6737

5.1 last mile distribution

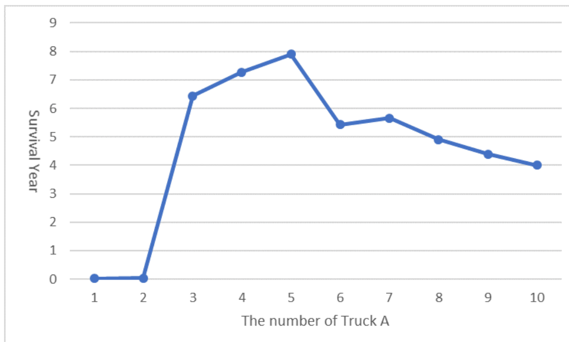
The result presented in this section shows the survival years of last mile distribution where the allocation agent assigns the logistic agent for the humanitarian logistic. The allocation agent evaluates an adequate demand area where logistic agents are deemed to fit for delivering the relief items. An assignment is given to logistic agents who have high priority, and it is decided based on the number of trips that logistic agents have done for last mile distribution previously. As the logistic agents have exerted themselves with the more logistic task, logistic agents are given lower priority for assignment. Once a demand area is assigned to logistic agents, the area will not be changed until the end of the day. From the result presented below, the last mile distribution's survival years can be found and its relation with the number of logistic agents in operation.

5.1.1 Allocating with Truck A(T_a)

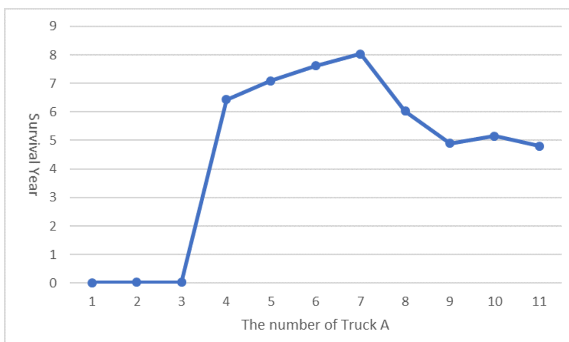
As can be seen from Figure 5.2(a), assigning one Truck A can satisfy the needs of the demand area A, Baniet for about 10 days. Instead, putting two A Trucks into operation survives the last mile distribution for at least 6 years from the simulation result. From the result, the survival year shows the trend of increasing as the number of the logistic agent assigned into operation increased to the point of total 4 logistic agents. When the number of A-type trucks placed in this last mile distribution is four, the supplement can survive for



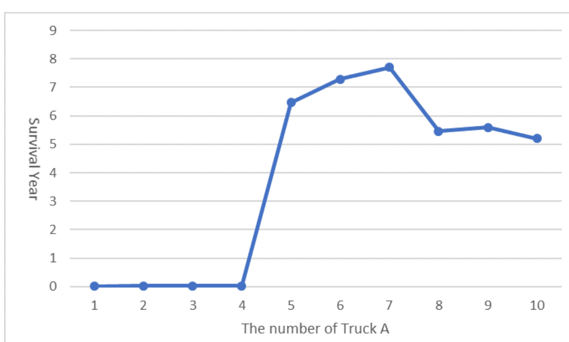
(a) One Demand Area - Baniet



(b) Two Demand Areas - Baniet, La Vallee



(c) Three Demand Areas - Baniet, La Vallee, Trouin



(d) Four Demand Areas - Baniet, La Vallee, Trouin, Cotes-de-Fer

Figure 5.2. Truck A(T_a) Organization's last mile distribution

8 years. However, the survival time will decrease when the A-type truck is over four. When five trucks are placed in the last mile distribution and follow the assignment from allocation agent, the logistics will survive only for 5 years which is shorter than four trucks' last mile distribution survival year. From the result, the A-type truck placement on last mile distribution for one demand area is advised to be between two and four trucks.

When the last mile distribution includes the other area which is La-Valle, the relief organization should serve two demand areas. Figure 5.2(b) shows that the number of truck A to be placed at the local distribution center is different. Two trucks are not enough to satisfy the need from two demand area simultaneously, for even a day. However, three A trucks can survive the logistics for more than 6 years. Even surviving for seven years is possible with the five A trucks allocated at Local Distribution Center.

In the third case, the relief aids should be delivered to three areas which are Baniet, La Vallee, and Trouin. As can be seen from Figure 5.2(c), four A trucks are needed for successful logistics for six years. The survival year can be increased when more than four logistic agents are placed to the local distribution center, and 7 A-type trucks show the most extended survival year with 8 years. If more logistic agents than 7 A trucks are placed, However, the survival year of last mile distribution is shown to be decreased.

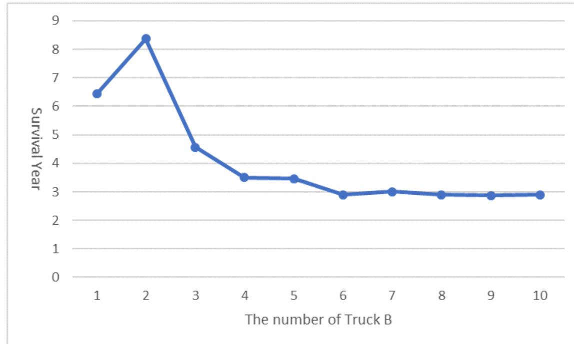
The last Figure 5.2(d) shows how many years the logistic can survive when one local distribution center should conduct last mile distribution for four demand areas which are Baniet, La Vallee, Trouin, and Cotes-de-Fer. Needs from four areas to be fulfilled for a day, five A truck should be placed for the operation, minimally. If a fewer number than five A trucks are put into the operation, they can not deliver a sufficient amount of relief items that are needed for areas even they continuously work all the time. When more than five A type trucks are allocated to the operation, the last mile can survive for 6 years. With 7 trucks, the last mile distribution shows the best performance from the perspective of survival years as they can continue the operation for nearly 8 years. However, the survival year can be decreased when more than 8 A trucks are placed in the last mile distribution.

5.1.2 Allocating with Truck B(T_b)

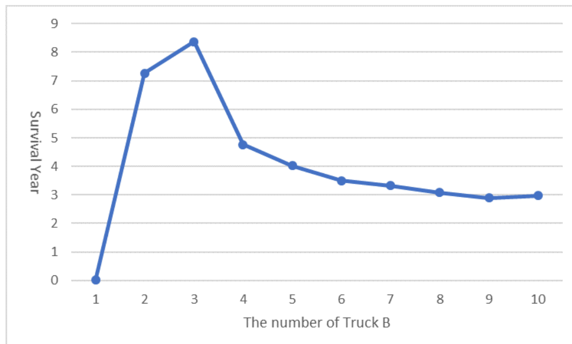
Compared to Truck A, Truck B can survive the logistics to the one demand, Baniet with only one truck for 6 years. As the loading capacity of the B truck is more prominent than the Truck A, a Truck B can supply the amount of relief aid that two A trucks can do. As presented in Figure 5.3(a), distribution can survive for 8 years With the organization formed with two B trucks. However, putting more than 3 B trucks show shorter survival years than survival years with one or two trucks. From the perspective of finance and survivability, therefore, putting one or two B trucks is beneficial for relief aids organization.

When it comes to serving two demand areas, Baniet, and La Vallee, the survival years are shown in Figure 5.3(b). As the number of demand areas served increases, one truck B is not enough for satisfying the need for both areas. Therefore, at least two B trucks are needed to deliver the amount of relief aids that needed to demand areas. Allocating three B trucks show the most extended survival years in this case by surviving more than 8 years. However, putting more than 3 trucks decrease the survival years to the point where they can satisfy the demand by 4 years.

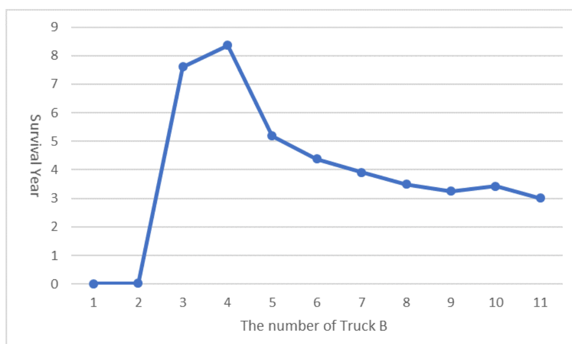
The third case presents the situation where LDC should serve the last mile distribution to three areas and the survival years can be found from Figure 5.3(c). For distributing relief items to three areas, the number of B trucks that should be put into operation is three. The distribution can survive for more than 7 years when the three trucks continuously deliver items to the designated areas as their total loading capacity become over than 48,127kg which is total need from three demand areas. With four B trucks, the affected people can get a steady supply from LDC for 8 years. However, more than five B trucks' last mile distribution show fewer survival years even though it can serve more than three years.



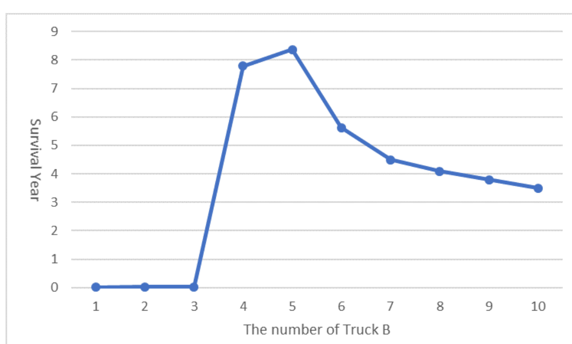
(a) One Demand Area - Baniet



(b) Two Demand Areas - Baniet, La Vallee



(c) Three Demand Areas - Baniet, La Vallee, Trouin



(d) Four Demand Areas - Baniet, La Vallee, Trouin, Cotes-de-Fer

Figure 5.3. Truck B(T_b) Organization's last mile distribution

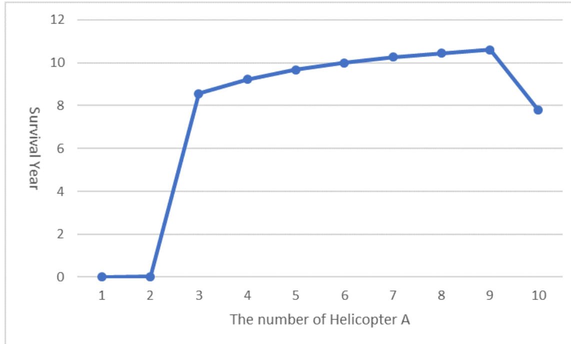
When four areas need the relief aids and only B trucks can be placed to the areas, the LDC requires four B trucks as the number of areas where they can be distributed to is four. According to the result presented from Figure 5.3(d), assigning 5 B trucks into operation will survive the distribution for 8 years. However, placing a bigger number of B trucks than 5 rather decrease the survival years.

5.1.3 Allocating with Helicopter A(H_a)

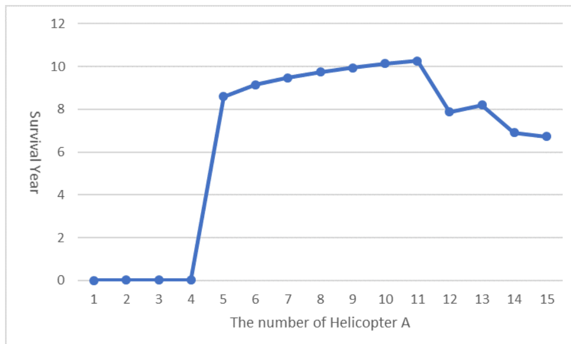
Compared to trucks, helicopters' loading capacity is much smaller. Therefore, the helicopters require many trips from LDC to demand areas to deliver the amount requested from these areas. However, helicopters are much faster than trucks which compensate for the weakness. Specifically, Helicopter A defined in this study can carry 2 tons of items at a time and fly with a speed of 217km/h.

The first Figure 5.4(a) shows the case where the allocation agent needs Helicopter A for last mile distribution to one area, Baniet which requires 24,243 kg of items per day. As the size of needs are enormous for one A helicopter to carry, A helicopters require many trips. However, the round of trips they can do is limited which results in non-survival even with two A helicopters on the operation. As the number of Helicopters comes to three, the logistics can survive for 8 years. Also, survival years presented from the result shows an increasing trend from three to nine A helicopters placement. Having more than 10 A helicopters for the distribution increase the possibility where logistic agents can encounter the immediate danger of inoperable status from insufficient uses.

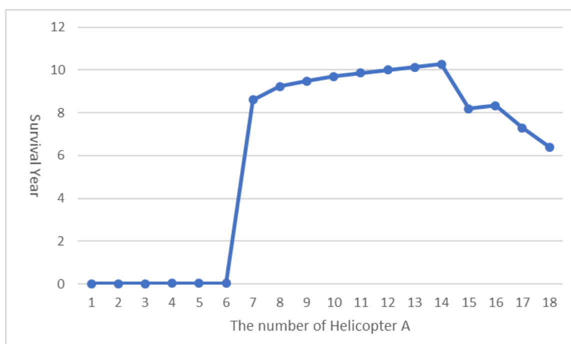
The second case of serving two demand areas, the allocation agents require at least five A type helicopters to deliver relief items matched to request. As the second area, La Vallee requires 13,701 kg of items which is significant for A helicopters to finish delivering in a day alone. Figure 5.4(b) shows that organizations consisting of more than five A helicopters survive logistics for at least 8 survival year. Especially, logistics can survive for 10 years when 11 A helicopters are placed to the organization. However, putting more than 12 helicopters instead decrease the burden on other helicopters but put them into the danger of sudden incapacity from improper uses.



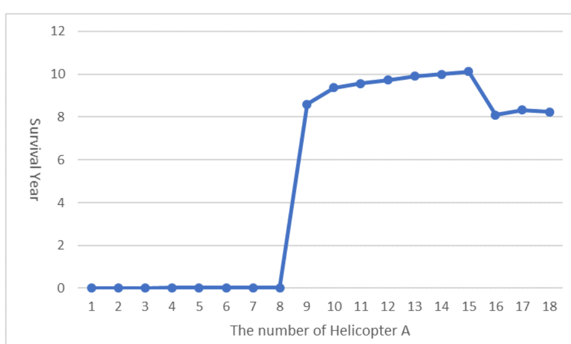
(a) One Demand Area - Baniet



(b) Two Demand Areas - Baniet, La Vallee



(c) Three Demand Areas - Baniet, La Vallee, Trouin



(d) Four Demand Areas - Baniet, La Vallee, Trouin, Cotes-de-Fer

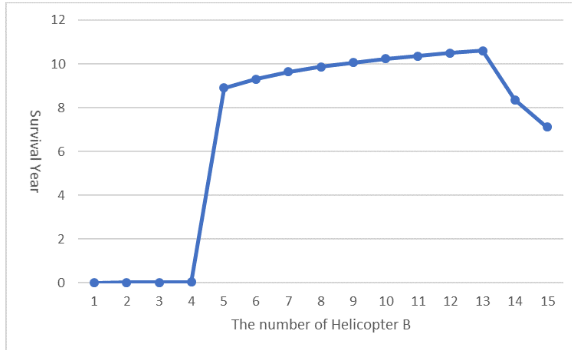
Figure 5.4. Helicopter A(H_a) Organization's last mile distribution

The third case presents the case where three demand areas request relief items from LDC. From the result shown from Figure 5.4(c), the logistic cannot satisfy the demand posted from four demand areas when the number of A helicopters participating in the operation is under 8. As the need which each of demand area wants are large for one helicopter to carry out, at least two A helicopters are needed for each demand area. Therefore, having more than 8 A helicopters have shown a dramatic increase in survival years to the point of 8 years. If the 15 A helicopters are employed for the last mile distribution, the logistic can even continue for 10 years. However, more than 16 helicopters are shown to continue operation for 8 years which is less than survival year presented from 15 helicopters.

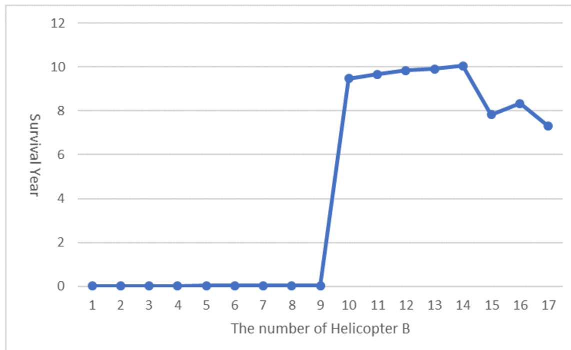
The last Figure 5.4(d) shows how many years the logistic can survive when one local distribution center should conduct last mile distribution for four demand areas which are Baniet, La Vallee, Trouin, and Cotes-de-Fer with A-type helicopters. For needs from areas to be fulfilled for a day, five A truck should be placed for the operation at least. If less than five A trucks are put into the operation, they can not deliver a sufficient amount of relief items that are needed for areas even they continuously work all the times. When the more than five A type trucks are allocated to the operation, the last mile can survive for 6 years. With 7 trucks, the last mile distribution shows the best case from the perspective of survival years as logistics survive for nearly 8 years. However, the survival year can be decreased when more than 8 A trucks are placed in the last mile distribution.

5.1.4 Allocating with Helicopter B(H_b)

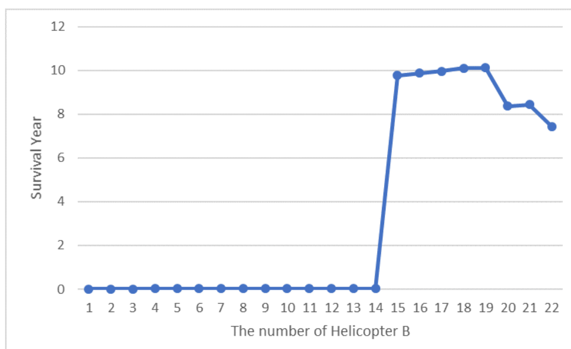
Compared to A type Helicopter, Helicopter B can load 2 tons of items which is lower than Helicopter A's loading capacity. Also, the maximum speed is 205 km/h which is also slower than Helicopter's A. Following results shows the last mile distribution's survival year when these B type helicopters were employed for logistics.



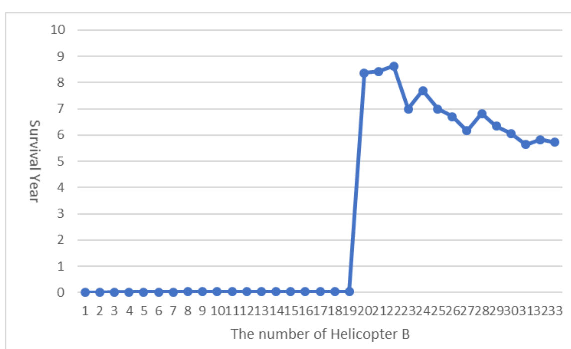
(a) One Demand Area - Baniet



(b) Two Demand Areas - Baniet, La Vallee



(c) Three Demand Areas - Baniet, La Vallee, Trouin



(d) Four Demand Areas - Baniet, La Vallee, Trouin, Cotes-de-Fer

Figure 5.5. Helicopter B(H_b) Organization's last mile distribution

The first Figure 5.5(a) shows the result for the case where Baniet is the only area which demanded resources for recovery from LDC. Like the case results which used only A type helicopters, one B type helicopter is insufficient to deliver the requested amount of how many times they travel in a day. Because of the limitation that B type helicopters have, the distribution to one demand area can survive more than a day when at least 5 B helicopters are employed. The last mile distribution can survive at least 8 years when the number of helicopters employed is between 5 and 13. When more than 14 B helicopters participate in the operation, However, last mile distribution still survives but less than 10 years.

The second case is on two areas request the relief aids to the LDC. As the number of demand increased compared to the first case of one demand, the B helicopters can satisfy the overall demand from two regions with at least 10 B helicopters. According to results from simulation, last mile distribution can continue at least for 8 years if the distributed B trucks number is between 5 and 13. Especially, affected people from two areas can get the beneficiary of resources supply from LDC for more than 10 years when 13 number of B helicopters are working on last mile distribution. Survive

The third Figure 5.5(c) describes the case when three affected areas, Baniet, Vallee, and Trouin call for help getting essential items. Simulation results show that 15 number of helicopters are needed to satisfy the demand from 3 areas when only B types of helicopters can be employed for the operation. Compared to the simulation results for the cases where trucks are used, the number of helicopters that should be put into the last mile distribution to satisfy needs is significantly high. The simulation result present that the supply can continue 10 years in minimum when more than 15 and less than 19 number of B helicopters are used for the operation. However, more than 20 B helicopters make the overall supply survival day less than the 10 years.

The last Figure 5.5(d) shows the simulation result on cases supplying relief items to four areas which are Baniet, Vallee, Trouin, and Cotes-de-Fer. Overall requests from four areas are large for B type of helicopters to carry out with 2 tons of loading capacity which makes supply can only satisfy with 20 B helicopters. If less than 20 B helicopters are placed to LDC, the logistic cannot meet the need from areas unless they are going to the multiple demands a day. Placing 20, 21 and 22 number of B helicopters to the operation survived supply for 8 years, but placing more number of B helicopters is shown to have fewer survival years which is not ideal.

As can be seen from above simulation results, the number of logistic agents have a significant effect on last mile distribution's survival years since how many years the last mile distribution can continue heavily depends on the type and number of logistic agents placed on logistic. Therefore, the result can be the source for deciding how many logistic agents should be placed for the cases. As presented from the result, the large number of logistic agents does not guarantee long survival years. It is because the excessive number of logistics agent placed on the distribution rather put agents into the danger of unexpected incapacity such as battery drain for long term idle status. Therefore, placing the appropriate number of logistic agents that can survive through the scheduled operation is important.

5.2 Multiple kinds of logistic agents

This section presents the cases where multiple kinds of logistic agents are needed for last mile distribution. Each logistic agents type has different advantages and disadvantages on its speeding and loading capacity. Therefore, it is also important to see the logistics' survivability when there are multiple kinds of logistic agents do the task for the last mile distribution. Following results show the last mile distribution's survival days when a number of different types of logistic agents which shown the longest survival days individually work together for last mile distribution to four different demand areas.

5.2.1 Allocating Truck A(T_a) and Truck B(T_b)

According to the survivability result when A-type trucks are individually simulated, the last mile distribution reveals to have the longest survival days when 7 number of A-type trucks are allocated to the LDC. On the other hand, allocating 5 trucks shows the long survival duration when it comes to B type trucks. Therefore, allocating both of 7 A type trucks and 5 B type trucks to last mile distribution are simulated to see the survival days and results show that they can survive the last mile distribution only for 3.8 years which is significantly short survival years compared to the survivability they made individually. It is because the total number of logistic agents are excessive in this last mile distribution. Therefore, additional cases under the number that individually shown the best survivability were simulated. Following Table 5.2 presents the extreme cases of logistic survivability with a combination of Truck A and Truck B. As can be seen, the survivability can be obtained to the extent of more than 8 years when two Truck A and 5 Truck B are allocated. The cases showing the high survivability have a trend of having 6 logistic agents in total and more B type Trucks, rather than A trucks. Contrary to cases having high survivability, the cases show weak survivability when the total logistic agents employed to the operation comes to under four, especially shows non-survival when logistic agents are under three.

Table 5.2. Extreme Logistic Survivability cases with Truck A(T_a) and Truck B(T_b)

A Truck(T_a)	**B Truck(T_b)**	**Survival Year**
2	5	8.347436322
1	5	8.342675272
1	4	8.061967775
..	..	..
1	2	0.002392558
2	1	0.002357258
1	1	0.00185934

5.2.2 Allocating Truck A(T_a) and Helicopter A(H_a)

In this case, allocating A trucks and A helicopters on distribution was simulated. A type of helicopters showed the best survivability when 15 A helicopters were allocated. Therefore, 15 A helicopters are employed together with 7 A trucks to last mile distribution and results show that last mile distribution continues for 4.1 years. This is also short survival years compared to individual survivability shown at previous simulation. As employing total of 22 numbers of logistic agents is deemed to be ineffective for logistics survivability, further logistic agents combinations under 22 total logistic agents are simulated and the extreme cases are shown in Table 5.3. The table shows that the survivability can be gained to the extent of more than 10 years when a total of 15 logistic agents are employed, and helicopter A takes the most in the organization. Even though one Truck A would be not sufficient to satisfy the needs from four demand areas, the survivability can be achieved in the extreme when it is allocated with the proper number of helicopter A.

Table 5.3. Extreme Logistic Survivability cases with Truck A(T_a) and Helicopter A(H_a)

A Truck(T_a)	**A Helicopter(H_a)**	**Survival Year**
1	14	10.16220992
2	13	10.14809998
..	..	..
2	6	0.006780251
1	7	0.005391362
1	6	0.005391362
..	..	..

5.2.3 Allocating Truck A(T_a) and Helicopter B(H_b)

B helicopters show the extensive survivability when 22 of them are allocated. When B type helicopters are employed to logistic with A truck, the logistic survives for 4.6 years with 29 logistic agents in total. Considering the survivability each of logistic agents shown individually such as more than 8 years with 22 number of B helicopters and at least 7 years with 7 number of A trucks, 4.6 survival years with the combination of A trucks and B helicopters are rather ineffective in terms of survivability. Therefore, additional Truck A and Helicopter B combinations were simulated and Table 5.4 shows that combination of Truck A and Helicopter B can maintain last mile distribution for more than 8 years. The strong survivability that logistics carry on for 8 years is established with Helicopter B taking the majority of total logistic agents and one A trucks. On the other hand, Truck A and Helicopter B combinations with the total number under 7 shows the weak survivability as non-survival.

Table 5.4. Extreme Logistic Survivability cases with Truck A(T_a) and Helicopter B(H_b)

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
1	19	8.366654364
1	21	8.273598808
1	20	8.091654364
..	..	..
4	3	0.002740463
3	4	0.002740463
1	7	0.002691656
4	2	0.002689529
..	..	..

5.2.4 Allocating Truck B(T_b) and Helicopter A(H_a)

When 5 B type trucks and 15 A type helicopters cooperate for the last mile distribution, the survival days is shown to be 4.2 years. This result showed a similar trend when the logistic was simulated for the case where both of A trucks and A helicopters were employed together at last mile.

74 more cases are simulated to find the logistics survivability with the combination of Truck B and Helicopter A. From the part of results presented in Table 5.5, logistics could survive more than 10 years when more than 8 Helicopter A are placed to the last mile distribution with 1 Truck B. When the number of Truck B employed for the operation is one or two, and the total number of logistic agents in organizations is under 6, the last mile distribution could not satisfy the needs from four different areas.

Table 5.5. Extreme Logistic Survivability Cases with Truck B(T_b) and Helicopter A(H_a)

B Truck(T_b)	**A Helicopter(H_a)**	**Survival Year**
1	14	10.26109881
1	13	10.13609881
..	..	..
2	3	0.002717882
2	2	0.002717882
1	4	0.002479869
2	4	0.002461693
..	..	..

5.2.5 Allocating Truck B(T_b) and Helicopter B(H_b)

When solely B type trucks were assigned to the task of delivering relief aids to four demand areas, 5 trucks could continue logistics for more than 8 years. Also, B type helicopters survived distribution for almost 8 years with 22 helicopters. However, when the distribution is conducted with a total of 27 logistic agents, last mile distribution only survived for 4.5 years. From the extensive simulations, the last mile distribution with the union of Truck B and Helicopter B is revealed to be survivable for about 8 years. As can be seen from Table 5.6 presenting extreme cases of logistic survivability, the logistics have strong survivability when one Truck B is employed with 15 to 21 Helicopter B. Also, the cases where 5 B Trucks are employed could keep its operation continuously more than 8 years when those cooperates with under 15 B Helicopters.

Table 5.6. Extreme Logistic Survivability Cases with Truck B(T_b) and Helicopter B(H_b)

B Truck(T_b)	**B Helicopter(H_b)**	**Survival Year**
1	21	8.63332103
1	20	8.544432141
1	19	8.513876586
..	..	..
4	3	0.001107379
4	2	0.001107379
4	1	0.001107379
3	4	0.0011073797
..	..	..

5.2.6 Allocating Helicopter A(H_a) and Helicopter B(H_b)

This case presents when helicopters A and B participate in a logistic task together, and Table 5.7 shows its extreme cases. Even though the operation is immense including overall 37 logistic agents, last mile distribution only survives for about 4.7 years which shows not much increase in survivability compared to the case where 5 A trucks and 15 A helicopters are cooperating. However, the additional simulations where both kinds of helicopters are delivering together were conducted, it is founded that survivability can be achieved for more than 10 years. Especially, delivering with helicopters are shown to have strong survivability in many cases compared to other situations where the combination of truck and helicopter, or only trucks are operating. 7.2% of cases are shown to have more than 9 years survivability which is higher than other cases' proportion.

Table 5.7. Extreme Logistic Survivability Cases with Helicopter A(H_a) and Helicopter B(H_b)

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
7	12	10.12736043
8	11	10.11347154
5	14	10.08486151
..	..	..
8	4	0.002765475
7	5	0.002765475
7	4	0.002765475
6	6	0.002765475
..	..	..

5.2.7 Expanding logistic agents types

For employing more than three types of logistic agents, the cases where the total number of logistic agents are restricted to be 10 was simulated. The entire survivability when three types of logistic agents are employed at last mile can be seen from Table G.1. The cases where humanitarian organization got three types of logistic agents show different survivability trends based on types of logistic agents like the cases which employed two logistic types. When Truck A was excluded and Truck B, Helicopter A, and B were allocated to LDC, the supply shows about 4.4 years of survivability in average. The longest survivability shown from the cases are about 8.3 years as can be seen from the table 5.8. Those cases have mostly Helicopter A more than rest kinds of logistic agents like Truck B and Helicopter B. contrast to those cases, the cases where less number of Helicopter A is assigned to LDC shows about 3 years survivability.

Table 5.8. Extreme Logistic Survivability with Truck B(T_b), Helicopter A(H_a) and Helicopter B(H_b)

B Truck(T_b)	**A Helicopter(H_a)**	**B Helicopter(H_b)**	**Survival Year**
1	8	1	8.361098808
1	6	3	8.269154364
..	..	..	..
6	1	3	3.244413104
3	2	5	3.150821031

The extreme cases in which Truck B is excluded for last mile distribution, but Truck A, Helicopter A, and Helicopter B were employed are presented at Table 5.9. In general, the supply with this type of organization continues logistics about 6.16 years. Among cases, the survivability can be up to more than 7 years when the number of helicopters employed is more than 7. However, the survivability is shown to be rather short by continuing for about 3 years when less than 3 helicopters are employed.

Table 5.9. Extreme Logistic Survivability with Truck A(T_a), Helicopter A(H_a) and Helicopter B(H_b)

A Truck(T_a)	**A Helicopter(H_a)**	**B Helicopter(H_b)**	**Survival Year**
3	6	1	7.591654364
3	5	2	7.591654364
..	..	..	..
6	2	2	3.691151099
6	1	3	3.388802767

The third case for employing three kinds of logistic agents is assigning two kinds of trucks and Helicopter B. These cases are presented to survive logistics for 4.4 years on average. Contrast to other cases which employed Helicopter A, cases which exclude Helicopter A show 6 survival years at most as can be found from extreme cases presented at Table 5.10. Even, the case indicates that logistics can survive only 2 years which is never seen from other cases employing Helicopter A.

Table 5.10. Extreme Logistic Survivability with Truck A(T_a), Truck B(T_b) and Helicopter B(H_b)

A Truck(T_a)	**B Truck(T_b)**	**B Helicopter(H_b)**	**Survival Year**
2	1	7	6.018851575
3	1	6	5.975770886
..	..	..	..
2	3	5	3.086171493
1	5	4	2.969576073

The last case in employing three different types of logistic agents is having Truck A, Truck B, and Helicopter A. In average, the operation having those logistic agents continued achieving the goal of last mile distribution for 4.4 years. Also, the cases showing the survivability living more than 8 years allocated 7 or 8 Helicopter A out of all logistic agents according to the Table 5.11. On the other hand, cases showing half of the logistic survivability than cases living more than 8 years mostly assigned more trucks than helicopters.

Table 5.11. Extreme Logistic Survivability with Truck A(T_a), Truck B(T_b) and Helicopter A(H_a)

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**Survival Year**
1	1	8	8.361098808
2	1	7	8.360977295
..	..	..	..
2	2	6	3.244413104
1	3	6	3.150821031

Following table 5.9 shows the part of simulation results where LDC can accommodate all types of logistic agents and restricted in space to have 10 in total. Entire results can be seen at the table H.1. Even though the same number of 10 logistic agents are allocated, the survival years significantly become various from 2 years to 8 years depends on the organization of logistic agents. When trucks are two, and totally 8 helicopters are allocated, the logistics can keep its operation for about 8 years which is the strong survivability shown from the result. On the other hand, the logistic show 4 years survivability at most when majority agents of the organization are trucks.

Table 5.12. Extreme Cases of last mile distribution to Demand with all logistic agents

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_b)**	**Survival Year**
1	1	7	1	8.361098808
1	1	6	2	8.133866764
1	1	5	3	8.8.35042174
1	1	4	4	8.301274637
..	..	..	..	..
1	5	1	3	4.385886029
1	7	1	1	4.373147885
4	3	2	1	4.348341657
4	2	3	1	4.305407614

CHAPTER 6. CONCLUSION AND FUTURE WORK

6.1 Conclusion

Through simulations, the emergent situations where logistic agents have unexpected incapability to deliver relief aid to destined demand areas are shown. In a real situation where the continuous supply is essential as the case of Typhoon Haiyan, the sudden stop on distribution puts significant strain on the recovery process. This study inquires the last mile distribution's survivability after the disaster with organization of logistic agents. By simulating multiple logistic agents which can be employed in last-mile distribution, this study shows that the logistic survivability depends on the number of logistic agents employed to the distribution. Assigning as many logistic agents as possible is revealed to be not ideal for logistic survivability as could be seen from the simulation result that increased the agent number employed in the same environment. Consistently, logistic agents experience the downtrend in the survival at a certain size of the organization. For the last mile distribution to four different areas, following logistics' survivability is observed when different kinds of logistic agents were used solely.

- Employing Truck A showed the uptrend until the total number of Truck A is 7, but assigning more than 8 A trucks showed rather decreased survival compared to a smaller organization.

- Employing Truck B survives the logistics at most 8 years when the size of the organization is up to 5, but bigger organizations formed with more than 6 B trucks show a decreasing trend in survivability.

- Employing Helicopter A shows the uptrend when the organization formed with from 9 to 15 A helicopters, but the survival reduces when bigger organizations formed with more than 16 A helicopters are employed.

- Employing Helicopter B survives logistics when organizations are established with more than 20 B Helicopters. Organizations with more than 23 Helicopter B display shorter survivability than the smaller organization.

If an excessive number of logistic agents are employed at the last mile distribution, the logistics chance to survive is reduced because the possibility of unexpected agent failure is increased. Because logistic agents are idle and not utilized, negative impacts are produced on lifespan, as much as, the ones which are frequently used for the last mile distribution.

Also, logistics' survivability depends not only on the size of the organization but also which type of logistic agents formed logistic organizations.

- When A Truck and B Truck are assigned to the distribution, the logistics survive for 8 years with logistic agent organization formed with 2 A trucks and 5 B trucks.
- When A Truck and A Helicopter are employed, the organization consisted of 1 A truck and 14 A helicopter survives logistic for 10 years.
- When A Truck and B Helicopter are assigned to the distribution, the organization formed with 1 A truck and 19 B Helicopters continues last mile distribution for 8 years.
- When B Truck and A Helicopter are assigned, the distribution survivability shows a similar trend with the one employed the organization of A truck and A Helicopter. The organization consisted of 1 B truck and 14 A trucks survives logistics for 10 years.
- When B Truck and B Helicopter are employed together, the logistics organized with 1 B truck and 21 Helicopters survive for 8 years.
- When A Helicopter and B Helicopter are employed, the organization formed with 7 A Helicopters and 12 B Helicopters distribute resources for 10 years at most.

Table 6.1. Summary of Logistics Survivability Bast Cases - Two Logistic Agent Type Organization

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_b)**	**Survival Year**
2	5	-	-	8
1	-	14	-	10
1	-	-	19	8
-	1	14	-	10
-	1	-	21	8
-	-	7	12	10

Following Table 6.1 shows the summary of best logistics survivability cases when the organization formed with two kinds of logistic agents. Except for the organization that two kinds of trucks are involved in, the cases that the helicopter takes the significant part in organization showed the best survivability.

When LDC restricted the logistics organization's size to be 10 and allow more than three types of logistic agents to be organized for last mile distribution, following survivability can be observed.

- When three types of the logistic agent which are B Truck, A Helicopter, and B Helicopter are to be assigned, the organization formed with 1 B Truck, 8 A Helicopters, and 1 B Helicopter survives the distribution for 8 years.

- When three types of the logistic agent which are A Truck, A Helicopter, and B Helicopter are to be assigned, the organization formed with 3 A Trucks, 6 A Helicopters, and 1 B Helicopter survives the distribution for 7 years.

- When three types of the logistic agent which are A Truck, B Truck, and A Helicopter are to be assigned, the organization formed with 2 A Trucks, 1 B Truck, and 7 A Helicopter survives the distribution for 6 years.

- When three types of the logistic agent which are A Truck, B Truck, and A Helicopter are to be assigned, the organization formed with 1 A Trucks, 1 B Trucks, and 8 B Helicopter survives the distribution for 8 years.
- When all logistic types of agents can be assigned, the organization formed with 1 A Truck, 1 B Truck, 7 A Helicopter, and 1 B Helicopter survives the distribution for 8 years.

Table 6.2. Summary of Logistics Survivability Bast Cases - Organization with 10 logistic agents

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_b)**	**Survival Year**
-	1	8	1	8
3	-	6	1	10
2	1	-	7	6
1	1	8	-	8
1	1	7	1	8

Following Table 6.2 shows the best survivability cases when LDC restricted the size of logistic organizations to be 10 and more than three kinds of logistic agents are assigned. As can be seen from the Table 6.2, each case showing the like the best survivability have organizations taken majority of occupants with helicopters like the trend shown from cases having organization formed with two kinds of logistic agents.

Depends on type of logistic agents consisting organization, the survival showed different trend. Even though the total number of logistic agents assigned to local distribution center is same, how long last mile distribution survives vary by which type of logistic agents are the major of organization. Consistently, helicopters are shown to be beneficiary for strong survivability as organizations that helicopters occupy significant parts display long survivability.

For humanitarian logistic, it is significantly important to make logistics survivable for the duration of time. Unexpected stop on continuous supply prevents affected areas to recover and prolongs the suffering. However, those risks increase as logistic agents which have critical role in delivering items suffer from harsh operation. Therefore, this study researched logistic survivability with the consideration on logistic agents' susceptibility to humanitarian operations. Eventually, this research found different trends in logistic survivability depends on sizes and arrangements of logistic agent organizations and optimal organization having strong survivability by situations.

6.2 Future Work

This study assumes that logistic agents are a set of one transportation vehicle and one driver or pilot. Also, drivers will be always available when the vehicle should be operated is assumed. However, there are chances that drivers are not available for the operation which would be critical considering professionalism required for vehicles to be operated. Therefore, logistics' survivability when human logistic agents are susceptible to the environment can be further studied. For last mile distribution especially for the humanitarian logistic, the role of human logistic agents are important as vehicles because various things can affect them in ways. Therefore, the professional human logistic agents and human agents organizations to survive last mile distribution can be further researched.

Also, this study assumes that the demand from each areas are consistent, but it can become vary by the stage of recovery. As the later stage of recovery involves in infrastructure, the requested items and its size would grow. Accords to stages of recovery, the logistic transport agent and human agent organization that can survive the change in stage can be more studied.

For humanitarian logistic, it is also important not to make excessive waste on budget and survive at the same time. Last mile distribution requires a notable budget for overall management by taking the second largest proportion of the total expense that humanitarian aid organizations spend for overall aid operation [15]. As the expense is secured from the donation, the properly managing the expense in logistic will enhance the credibility and effectiveness in providing aids with allocating much expense on procuring relevant resources for recovery. From the result, the excessive allocation of logistic agents is revealed to not increase the survivability at a certain point and different survivability depends on the composition of organizations. Allocating more logistic agents than needed can not only decrease the survivability of logistic and chance that the budget could be used for a more needed part in the humanitarian operation. Therefore, logistic agent organizations that could give credibility by surviving logistics and reducing excessive cost can be further studied.

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APPENDIX A. 2 TYPES OF LOGISTIC AGENT : TRUCK A AND TRUCK B

Table A.1. Logistics Survivability with Truck A and Truck B

A Truck(T_a)	**B Truck(T_b)**	**Survival Year**
2	5	8.347436322
1	5	8.342675272
1	4	8.061967775
2	3	7.822199955
6	1	7.42630064
3	2	7.256516113
5	1	7.24993976
4	1	6.952002588
7	2	5.894033499
6	3	5.599218775
5	4	5.275748274
4	5	5.270453049
4	3	5.157689529
5	2	5.116704488
6	4	4.701712234
7	3	4.599356196
5	5	4.496138877
3	3	4.458849083
7	1	4.392133974
4	2	4.308998665
6	2	4.221856196
5	3	4.213245085
7	4	4.180674937
6	5	4.111719976

Table A.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**Survival Year**
2	4	4.043053814
4	4	4.025189529
3	5	3.918800641
3	4	3.858042807
7	5	3.847133974
2	2	0.004078418
3	1	0.00380064
1	3	0.00380064
1	2	0.002392558
2	1	0.002357258
1	1	0.00185934

APPENDIX B. 2 TYPES OF LOGISTIC AGENT : TRUCK A AND HELICOPTER A

Table B.1. Logistics Survivability with Truck A and Helicopter A

A Truck(T_a)	**A Helicopter(H_a)**	**Survival Year**
1	14	10.16220992
2	13	10.14809998
1	13	9.973305841
2	12	9.909432141
1	12	9.361038052
2	11	9.360497685
2	15	8.247863019
1	15	8.074304948
2	14	7.747145315
3	10	7.642639223
3	7	7.591654364
6	1	7.40631949
3	11	7.26663397
2	9	7.259709919
2	8	7.259709919
2	10	7.25832103
3	6	6.95545713
4	3	6.810529876
3	8	6.692840883
1	11	6.675265475
3	9	6.624911751
5	2	6.574911751
1	10	6.466654364
5	1	6.422133974

Table B.1 – continued from previous page

A Truck(T_a)	**A Helicopter(H_a)**	**Survival Year**
1	9	6.418043252
1	8	6.416654364
2	7	6.416574393
4	1	6.412679636
3	12	6.053724786
4	6	5.899785328
3	14	5.764790421
7	6	5.554935689
3	13	5.545752679
7	10	5.479380134
7	2	5.466046801
4	5	5.237158904
3	15	5.158987466
4	4	5.090189529
4	7	4.849911751
7	14	4.811918107
5	9	4.789961693
6	3	4.762487697
5	12	4.699965551
6	2	4.577689529
5	5	4.548270015
5	13	4.525181935
5	6	4.509633974
6	15	4.503451717
5	4	4.47635279
5	10	4.47186379
6	12	4.46622753
6	7	4.465265475

Table B.1 – continued from previous page

A Truck(T_a)	**A Helicopter(H_a)**	**Survival Year**
4	14	4.413477295
4	15	4.35542174
4	13	4.338013725
4	11	4.329253103
5	14	4.326015481
6	11	4.293839676
4	10	4.289448221
4	9	4.229987839
7	11	4.215752679
6	13	4.212373779
7	1	4.198522863
4	8	4.188876586
5	3	4.187411751
5	7	4.15832103
5	15	4.138260274
7	15	4.129861871
7	12	4.087141568
6	5	4.076338613
6	14	4.059348601
5	11	4.03292174
7	13	4.01436379
6	10	4.004687348
7	3	3.997133974
7	4	3.959671946
5	8	3.949432283
7	7	3.944356196
4	12	3.936298058
6	9	3.924911751

Table B.1 – continued from previous page

A Truck(T_a)	**A Helicopter(H_a)**	**Survival Year**
6	4	3.886098808
7	5	3.84300528
6	6	3.813876586
7	8	3.604116391
6	8	3.579154364
7	9	3.576338613
3	4	3.211061899
4	2	3.210993978
3	5	3.20813223
3	3	2.977394836
3	2	2.977091054
2	5	2.883055221
2	6	0.006780251
1	7	0.005391362
1	6	0.005391362
2	4	0.002717882
2	3	0.002598876
1	5	0.00255984
1	4	0.002479869
3	1	0.002347775
2	2	0.002198821
1	3	0.002049867
2	1	0.001976731
1	2	0.001738719
1	1	0.001149357

APPENDIX C. 2 TYPES OF LOGISTIC AGENT : TRUCK A AND HELICOPTER B

Table C.1. Logistics Survivability with Truck A and Helicopter B

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
1	19	8.366654364
1	21	8.273598808
1	20	8.091654364
1	22	7.760997547
3	10	7.591249322
3	9	7.591249322
6	1	7.591088165
7	10	7.507639648
2	18	7.502765475
3	13	7.46940713
6	11	7.419356196
3	11	7.391629352
1	18	7.349987697
2	20	7.313600246
2	17	7.310643136
2	16	7.310643136
2	15	7.259709919
2	14	7.259709919
2	13	7.257915988
2	11	7.257915988
2	10	7.257915988
2	12	7.255555556
3	12	7.205555556
2	19	7.191467082

Table C.1 – continued from previous page

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
1	17	6.955543252
1	16	6.955543252
3	8	6.955492622
3	7	6.954733168
3	6	6.952335118
3	14	6.840165429
2	21	6.501049616
2	22	6.466556141
1	15	6.418043252
1	14	6.416654364
5	2	6.416578418
5	1	6.416578418
2	9	6.416224006
2	8	6.41584428
1	13	6.413851271
1	11	6.413851271
3	5	6.41348972
2	7	6.413066502
1	12	6.411111111
3	15	6.278878024
7	11	6.157817766
7	12	6.152777778
6	12	6.152777778
6	13	5.988689304
7	8	5.982639648
3	19	5.94554469
3	17	5.883133749
3	16	5.883133749

Table C.1 – continued from previous page

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
4	13	5.863638674
4	22	5.772111696
2	6	5.744381511
3	18	5.737389474
1	10	5.682915988
3	20	5.663650876
4	14	5.656655801
7	9	5.649711357
7	6	5.627084093
7	7	5.624711357
6	14	5.587389474
5	17	5.533020287
5	16	5.533020287
7	4	5.522111696
7	14	5.519016113
4	19	5.476326107
4	20	5.462211357
6	21	5.461964712
5	20	5.446972008
1	9	5.432890673
6	8	5.427489135
6	15	5.413371498
5	18	5.402489135
5	21	5.385745611
5	4	5.374484432
6	17	5.333018464
6	16	5.333018464
4	6	5.324711357

Table C.1 – continued from previous page

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
5	19	5.30804469
4	7	5.302489135
5	13	5.256706432
6	7	5.238373321
6	10	5.23304469
4	12	5.225
6	19	5.216175503
5	12	5.213888889
5	15	5.204056141
1	8	5.202335118
5	11	5.174711357
7	19	5.161984432
5	22	5.146933579
6	18	5.114875672
7	20	5.081729772
6	20	5.074395374
5	10	5.052489135
3	21	5.041503688
7	5	5.024484432
4	10	5.005518241
6	9	5.005266913
5	8	4.997111696
7	13	4.94554469
4	15	4.897022638
5	9	4.894333919
7	1	4.847133974
4	18	4.824811554
4	17	4.797111696

Table C.1 – continued from previous page

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
4	16	4.797111696
4	4	4.786073797
4	9	4.76940713
7	22	4.768750759
5	14	4.752590395
7	15	4.752436682
5	3	4.741151099
3	22	4.708296019
7	21	4.70383914
4	5	4.691151099
4	11	4.686022863
7	18	4.679861871
7	17	4.661806315
7	16	4.661806315
6	22	4.649889474
6	5	4.641556141
5	6	4.635822468
4	8	4.605266913
5	7	4.552436682
5	5	4.538600246
6	4	4.341378024
6	6	4.219155801
6	2	3.796528537
7	3	3.777489135
6	3	3.674306315
7	2	3.48304469
4	21	2.866567279
4	3	0.002740463

Table C.1 – continued from previous page

A Truck(T_a)	**B Helicopter(H_b)**	**Survival Year**
3	4	0.002740463
1	7	0.002691656
4	2	0.002689529
4	1	0.002689529
2	5	0.002689529
3	3	0.002652215
3	2	0.002652215
3	1	0.002652215
2	4	0.002652215
1	6	0.002603407
1	5	0.002566093
2	3	0.002440428
2	2	0.002440428
1	4	0.002354306
2	1	0.002136647
1	3	0.002050525
1	2	0.001746743
1	1	0.001442962

APPENDIX D. 2 TYPES OF LOGISTIC AGENT : TRUCK B AND HELICOPTER A

Table D.1. Logistics Survivability with Truck B and Helicopter A

B Truck(T_b)	**A Helicopter(H_a)**	**Survival Year**
1	14	10.26109881
1	13	10.13609881
1	12	9.891654364
1	11	8.361098808
1	10	8.361098808
1	9	8.361098808
1	8	8.361098808
5	8	8.358333333
5	4	8.358333333
1	15	8.308247211
4	1	7.768824578
3	2	7.591046801
3	1	7.590439238
5	7	7.309883682
5	3	7.290972982
5	5	6.976550349
1	6	6.416046801
4	13	6.371881126
4	14	6.259883682
5	9	6.132817766
5	10	6.13021446
5	6	6.10832103
5	1	5.78766146
2	10	5.716606771

Table D.1 – continued from previous page

B Truck(T_b)	**A Helicopter(H_a)**	**Survival Year**
2	11	5.50549566
2	9	5.397033017
2	13	5.291046801
2	6	5.269384549
2	12	5.247162327
3	14	5.169358322
2	15	5.113828993
2	8	5.097162327
2	7	5.097162327
5	13	5.082105904
2	5	5.011051216
5	12	4.993928877
3	15	4.949987697
4	11	4.849380134
4	10	4.749987697
2	14	4.741654364
4	9	4.73332103
5	15	4.527777778
4	15	4.463269023
5	2	4.341046801
3	3	4.335770015
3	13	4.313876586
5	14	4.213547793
5	11	4.077765475
3	6	4.055039988
3	7	3.763547793
3	5	3.6971361
3	11	3.605543252

Table D.1 – continued from previous page

B Truck(T_b)	**A Helicopter(H_a)**	**Survival Year**
4	12	3.53332103
3	10	3.530543252
3	8	3.491325571
3	9	3.488876586
3	4	3.441325571
4	2	3.432992237
3	12	3.391654364
4	7	3.174987697
4	8	3.13332103
4	6	3.13332103
4	5	3.13332103
4	4	3.099913878
4	3	3.080469434
2	3	0.002717882
2	2	0.002717882
1	4	0.002479869
2	4	0.002461693
1	7	0.002461693
1	5	0.002401798
2	1	0.002376786
1	3	0.001708113
1	2	0.001426912
1	1	0.001149357

APPENDIX E. 2 TYPES OF LOGISTIC AGENT : TRUCK B AND HELICOPTER B

Table E.1. Logistics Survivability with Truck B and Helicopter B

B Truck(T_b)	B Helicopter(H_b)	Survival Year
1	21	8.63332103
1	20	8.544432141
1	19	8.513876586
1	17	8.361098808
1	16	8.361098808
1	15	8.361098808
5	14	8.358333333
5	13	8.358333333
5	12	8.358333333
5	11	8.358333333
5	10	8.358333333
5	9	8.358333333
5	8	8.358333333
5	7	8.358333333
5	6	8.358333333
5	5	8.358333333
5	4	8.358333333
5	3	8.358333333
5	2	8.358333333
5	1	8.358333333
1	18	8.35832103
1	22	7.738778363
1	14	6.635693766
5	15	6.552436682

Table E.1 – continued from previous page

B Truck(T_b)	**B Helicopter(H_b)**	**Survival Year**
1	13	6.446804877
5	16	6.419444444
1	12	6.416249322
1	11	6.416249322
1	10	6.413775325
1	9	6.413775325
1	8	6.413775325
5	17	6.258333333
5	20	5.866666667
2	13	5.752667252
2	22	5.538600246
2	14	5.352667252
3	22	5.322111696
2	12	5.274711357
3	21	5.216276763
2	16	5.213851574
3	20	5.20544503
3	19	5.174711357
2	21	5.158222808
2	20	5.063778363
4	20	5.058222808
4	16	5.041378024
2	15	5.016556141
2	11	4.92726221
3	18	4.916556141
4	17	4.894333919
4	21	4.872212957
4	19	4.846933579

Table E.1 – continued from previous page

B Truck(T_b)	**B Helicopter(H_b)**	**Survival Year**
4	15	4.841629352
2	18	4.838778363
4	22	4.830266913
2	17	4.824889474
4	18	4.822184908
2	9	4.811000585
2	8	4.7717706
2	10	4.766556141
5	18	4.704861871
4	14	4.65804469
2	19	4.633222808
5	19	4.627667252
2	7	4.547111696
5	21	4.507992237
3	17	4.502667252
5	22	4.360417426
3	12	4.358296019
2	6	4.333222808
2	5	4.327667252
4	12	4.277489135
4	13	4.233222808
3	16	4.18304469
4	11	4.163498985
3	15	4.088600246
3	14	4.027667252
4	10	4.016629352
3	11	4.011101846
3	13	3.830266913

Table E.1 – continued from previous page

B Truck(T_b)	**B Helicopter(H_b)**	**Survival Year**
3	8	3.80794343
3	9	3.75804469
3	10	3.70544503
4	9	3.561000585
3	7	3.546933579
4	8	3.355266913
4	7	3.221832319
4	5	3.094155801
3	5	3.05544503
3	6	3.019333919
4	6	2.969054541
4	4	2.861000585
4	3	0.011073797
4	2	0.011073797
4	1	0.011073797
3	4	0.011073797
3	3	0.002740463
3	2	0.002740463
3	1	0.002740463
2	4	0.002740463
1	7	0.002691656
1	6	0.002691656
1	5	0.002654341
2	3	0.002528677
2	2	0.002528677
1	4	0.002442555
2	1	0.002224895
1	3	0.002138773

Table E.1 – continued from previous page

B Truck(T_b)	**B Helicopter(H_b)**	**Survival Year**
1	2	0.001834992
1	1	0.001531211

APPENDIX F. 2 TYPES OF LOGISTIC AGENT : HELICOPTER A AND HELICOPTER B

Table F.1. Logistics Survivability with Helicopter A and Helicopter B

A Helicopter(H_a)	B Helicopter(H_b)	Survival Year
7	12	10.12736043
8	11	10.11347154
5	14	10.08486151
14	1	10.07222222
6	13	10.06380277
7	11	10.04639984
13	2	10.04197045
4	15	9.994330881
12	3	9.992817847
3	16	9.991654364
2	17	9.991654364
1	18	9.980543252
11	4	9.979935689
5	13	9.974889474
10	5	9.969596335
13	1	9.948133567
9	6	9.936111111
4	14	9.936000585
12	2	9.9
8	7	9.9
1	17	9.877765475
11	3	9.866654364
3	14	9.85513821
7	8	9.85207179

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
10	4	9.846681441
12	1	9.833333333
9	5	9.831365639
3	15	9.811098808
2	16	9.811098808
6	9	9.802777778
8	6	9.797222222
4	13	9.78332103
11	2	9.778385341
7	7	9.766666667
5	10	9.759383253
10	3	9.731706735
6	12	9.710896287
4	11	9.7
3	13	9.697007398
6	8	9.687262291
9	4	9.667928372
8	5	9.663361018
11	1	9.647981676
5	9	9.626970529
7	6	9.626261706
3	12	9.610693766
6	7	9.582222303
10	2	9.579296685
4	10	9.565040069
5	8	9.5582704
5	12	9.541451843
4	9	9.482501681

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
10	1	9.475
1	16	9.469432141
2	15	9.463876586
2	14	9.463876586
9	3	9.463572804
2	13	9.463572804
3	11	9.463319653
3	10	9.374582655
9	2	9.353587862
8	3	9.340040069
2	12	9.269027099
6	11	9.235946917
7	10	9.135896287
7	3	9.002765475
9	1	8.991654364
8	2	8.991654364
2	11	8.988623435
8	10	8.857814728
6	16	8.744381511
4	18	8.73332103
1	22	8.694358322
4	19	8.644358322
3	20	8.594155801
3	19	8.563778363
8	1	8.561098808
7	2	8.561098808
6	3	8.561098808
1	15	8.561098808

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
1	14	8.561098808
1	13	8.561098808
1	12	8.560693766
2	20	8.555469434
2	21	8.544358322
1	21	8.511024989
2	19	8.446933579
1	20	8.446933579
6	15	8.416580545
1	19	8.341603733
5	17	8.311098808
5	18	8.310693766
5	16	8.297159289
9	8	8.105340731
15	2	8.099835806
15	3	8.074987697
4	12	8.013674065
8	9	8.00832103
4	17	8.005543252
10	8	7.969432141
12	7	7.96912836
9	10	7.949785176
14	4	7.938876586
14	3	7.938876586
11	7	7.938876586
11	8	7.927765475
8	13	7.927691656
11	6	7.919432141

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
12	5	7.90832103
7	14	7.880492622
9	12	7.880469434
13	6	7.861098808
10	7	7.861098808
10	11	7.860822468
9	9	7.855340731
15	1	7.755543252
13	5	7.749785176
3	22	7.744330881
12	6	7.741654364
13	4	7.716654364
14	5	7.688876586
4	21	7.610896287
10	9	7.555543252
11	11	7.547007398
3	18	7.511098808
9	13	7.488876586
13	8	7.461098808
8	14	7.452765475
2	22	7.452765475
12	9	7.430543252
10	12	7.40832103
12	10	7.399987697
7	15	7.391603733
3	21	7.363876586
5	20	7.361048178
14	2	7.352765475

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
4	20	7.311098808
5	21	7.288522174
13	9	7.272209919
4	22	7.260896287
13	3	7.236098808
7	16	7.227765475
6	17	7.224987697
14	8	7.180543252
6	19	7.177714844
14	7	7.130391362
11	10	7.080340731
5	11	7.049785176
15	6	7.03332103
10	10	7.024987697
8	15	7.013876586
12	8	6.997209919
7	18	6.971832319
15	7	6.95832103
13	7	6.927765475
12	4	6.927765475
11	9	6.924987697
8	12	6.905340731
6	20	6.894432141
9	11	6.888674065
15	4	6.874987697
9	17	6.844333919
5	22	6.844155801
8	17	6.833222808

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
7	19	6.824785176
9	16	6.741654364
7	13	6.724785176
6	14	6.702664214
11	12	6.686048178
6	21	6.655492622
11	5	6.613876586
12	11	6.585896287
7	20	6.5832704
15	8	6.569432141
15	5	6.561098808
6	10	6.547007398
10	13	6.53332103
8	18	6.53332103
10	15	6.533118509
13	10	6.527765475
14	6	6.505543252
7	22	6.496832319
14	9	6.480340731
11	14	6.472007398
10	16	6.449633285
9	14	6.413674065
13	12	6.405391362
12	13	6.394432141
10	6	6.380543252
5	19	6.366654364
8	21	6.346832319
15	10	6.33332103

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
14	11	6.302765475
11	15	6.302562954
7	17	6.299987697
6	22	6.2832704
9	20	6.269045276
6	18	6.236098808
12	12	6.199785176
8	19	6.197209919
8	16	6.194432141
7	21	6.19422962
9	7	6.191654364
13	11	6.149785176
12	14	6.127740463
9	18	6.116451843
13	13	6.105543252
10	19	6.105266913
8	20	6.102489135
15	9	6.088876586
14	12	6.080543252
7	9	6.055340731
8	22	6.035899325
14	10	6.027765475
15	11	6.019432141
9	15	6.00832103
11	18	5.994155801
10	17	5.985896287
10	14	5.952765475
9	21	5.910744396

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
11	13	5.885845657
11	16	5.872058028
12	15	5.866654364
12	17	5.861024989
13	14	5.847209919
8	8	5.841654364
14	13	5.774987697
15	12	5.752765475
9	19	5.722209919
10	20	5.713876586
15	14	5.699987697
11	17	5.64422962
9	22	5.627562954
13	16	5.616556141
10	18	5.613876586
11	19	5.605340731
14	15	5.549987697
12	18	5.488825955
14	16	5.449582655
13	15	5.447007398
15	13	5.436098808
5	15	5.411098808
10	21	5.399987697
12	16	5.396804877
14	14	5.38054629
11	22	5.366378024
13	17	5.349532025
12	19	5.341350582

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
4	16	5.280543252
12	21	5.25794343
15	15	5.252411063
13	20	5.177489135
13	18	5.174582655
3	17	5.169432141
14	17	5.138825955
11	21	5.1332704
2	18	5.130543252
14	19	5.130156387
11	20	5.119432141
10	22	5.074987697
12	22	5.074076352
15	18	5.024686953
15	16	4.972159289
13	21	4.969330881
15	19	4.936000585
14	20	4.922007398
12	20	4.894432141
14	18	4.844027099
13	19	4.833118509
15	17	4.822007398
13	22	4.797209919
14	21	4.758296019
15	20	4.724987697
14	22	4.586098808
15	22	4.557225341
15	21	4.547209919

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
8	4	0.002765475
7	5	0.002765475
7	4	0.002765475
6	6	0.002765475
6	5	0.002765475
6	4	0.002765475
5	7	0.002765475
5	6	0.002765475
5	5	0.002765475
5	4	0.002765475
4	7	0.002765475
4	6	0.002765475
3	7	0.002765475
4	5	0.002679353
3	6	0.002679353
2	7	0.002679353
4	8	0.002613584
3	9	0.002613584
3	8	0.002613584
2	10	0.002613584
2	9	0.002613584
2	8	0.002613584
1	11	0.002613584
1	10	0.002613584
1	9	0.002613584
1	8	0.002527462
7	1	0.002461693
6	2	0.002461693

Table F.1 – continued from previous page

A Helicopter(H_a)	**B Helicopter(H_b)**	**Survival Year**
6	1	0.002461693
5	3	0.002461693
5	2	0.002461693
4	3	0.002424379
5	1	0.002401798
4	4	0.002309802
3	4	0.002272488
3	5	0.00222368
2	6	0.00222368
1	7	0.00222368
3	3	0.002212592
2	5	0.002186366
1	6	0.002186366
2	4	0.002060702
4	1	0.002011894
4	2	0.002006021
1	5	0.00197458
3	2	0.001860003
2	3	0.001822689
1	4	0.001670798
3	1	0.001556222
2	2	0.001404331
1	3	0.001367017
2	1	0.001215126
1	2	0.001063235
1	1	0.000759

APPENDIX G. 3 TYPES OF LOGISTIC AGENT

Table G.1. 3 Types of Logistic agent combinations when LDC allows 10 agents

A Truck(T_a)	B Truck(T_b)	A Helicopter(H_a)	B Helicopter(H_b)	Survival Year
1	1	8	0	8.361098808
2	1	7	0	8.360977295
1	5	4	0	7.309414886
3	1	6	0	6.561366531
4	1	5	0	5.730770015
2	5	3	0	5.528586981
3	2	5	0	5.221308124
3	5	2	0	4.9960186
5	4	1	0	4.943569954
1	2	7	0	4.84271446
4	5	1	0	4.804612264
6	3	1	0	4.747091242
2	6	2	0	4.725451774
7	2	1	0	4.553992954
1	6	3	0	4.506291957
3	6	1	0	4.478981127
1	7	2	0	4.328910032
2	7	1	0	4.150641951
4	4	2	0	4.117967307
3	4	3	0	4.052712313
5	3	2	0	3.95880064
4	3	3	0	3.898283057
1	4	5	0	3.896376586
6	1	3	0	3.886586013
4	2	4	0	3.883035658

Table G.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
3	3	4	0	3.879641568
7	1	2	0	3.831022863
2	4	4	0	3.825265475
6	2	2	0	3.793522863
1	8	1	0	3.759465527
5	2	3	0	3.691623985
5	1	4	0	3.654709919
2	3	5	0	3.34082103
2	2	6	0	3.244413104
1	3	6	0	3.150821031
0	1	8	1	8.361098808
0	1	6	3	8.269154364
0	1	7	2	8.209633974
0	5	2	3	8.125992059
0	5	1	4	7.468110601
0	1	1	8	6.413775325
0	1	5	4	6.344588406
0	1	4	5	5.152280113
0	1	3	6	4.824653537
0	7	1	2	4.542613108
0	7	2	1	4.5147281
0	1	2	7	4.491910512
0	2	6	2	4.306879486
0	2	7	1	4.242440105
0	6	3	1	4.05094154
0	2	5	3	4.043515774
0	2	1	7	4.032909285
0	8	1	1	3.993750759

Table G.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
0	3	5	2	3.925522616
0	5	3	2	3.880680425
0	3	6	1	3.720244838
0	2	3	5	3.710404222
0	2	4	4	3.593747681
0	2	2	6	3.465989852
0	4	3	3	3.337610708
0	4	2	4	3.337032399
0	3	4	3	3.220358412
0	5	4	1	3.167058261
0	4	5	1	3.146033718
0	6	2	2	3.133222808
0	4	1	5	3.09039367
0	4	4	2	3.039252242
0	3	1	6	3.029333919
0	3	3	4	2.942572766
0	6	1	3	2.89098485
0	3	2	5	2.690171465
3	0	6	1	7.591654364
3	0	5	2	7.591654364
3	0	4	3	7.591654364
3	0	3	4	7.591654364
3	0	2	5	7.591654364
3	0	1	6	7.588674065
2	0	7	1	7.25832103
2	0	5	3	7.25832103
2	0	4	4	7.252765475
2	0	3	5	7.144432141

Table G.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
2	0	2	6	7.097209919
2	0	6	2	7.074380134
2	0	1	7	7.052461693
1	0	8	1	6.416654364
1	0	7	2	6.402765475
1	0	6	3	6.361098808
1	0	5	4	6.277157912
1	0	4	5	6.241654364
1	0	3	6	6.169432141
1	0	2	7	6.060491245
4	0	3	3	5.888373321
4	0	4	2	5.885770015
7	0	1	2	5.708247211
5	0	2	3	5.577436682
5	0	1	4	5.577436682
4	0	2	4	5.536073797
1	0	1	8	5.513446229
4	0	1	5	5.371706654
4	0	5	1	5.130469434
7	0	2	1	5.122133974
6	0	3	1	4.816580545
5	0	3	2	4.430266913
5	0	4	1	4.3971361
6	0	2	2	3.691151099
6	0	1	3	3.388802767
2	1	0	7	6.018851575
3	1	0	6	5.975770886
6	1	0	3	5.915228029

Table G.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
2	5	0	3	5.580975184
5	4	0	1	5.422903229
7	1	0	2	5.382663424
4	4	0	2	5.296754146
6	3	0	1	5.161535686
5	3	0	2	5.159523225
4	5	0	1	5.144955688
7	2	0	1	5.091813464
3	5	0	2	5.055630438
2	4	0	4	4.982140981
6	2	0	2	4.892894405
4	1	0	5	4.796207116
2	6	0	2	4.689206654
3	6	0	1	4.621763664
3	4	0	3	4.566752728
1	7	0	2	4.279484432
2	7	0	1	4.164401996
5	1	0	4	4.053437034
2	2	0	6	4.027725821
1	2	0	7	3.918700777
4	2	0	4	3.632223924
5	2	0	3	3.556072673
3	2	0	5	3.515601295
1	6	0	3	3.404808466
4	3	0	3	3.401798295
3	3	0	4	3.360284724
1	4	0	5	3.175641435
1	3	0	6	3.133375903

Table G.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
2	3	0	5	3.086171493
1	5	0	4	2.969576073

APPENDIX H. 4 TYPES OF LOGISTIC AGENT

Table H.1. 4 Types of Logistic agent combinations when LDC allows 10 agents

A Truck(T_a)	B Truck(T_b)	A Helicopter(H_a)	B Helicopter(H_b)	Survival Year
1	1	7	1	8.361098808
2	1	6	1	8.360451799
2	1	5	2	8.356256881
2	1	4	3	8.355722808
2	1	3	4	8.351833919
1	1	5	3	8.35042174
2	1	2	5	8.344611696
1	1	4	4	8.301274637
1	5	3	1	8.186158729
1	1	6	2	8.133866764
3	1	4	2	6.354658904
1	1	2	6	6.28044503
1	1	3	5	6.261267933
3	1	3	3	6.248425663
1	1	1	7	6.08044503
3	1	5	1	5.848790676
2	4	1	3	5.535039401
4	1	4	1	5.534936682
6	1	2	1	5.388748755
2	1	1	6	5.381073797
7	1	1	1	5.305781751
2	5	2	1	5.301984432
2	4	2	2	5.289081537
3	2	4	1	5.188512899
4	4	1	1	5.130876855

Table H.1 – continued from previous page

A Truck(T_a)	**B Truck(T_b)**	**A Helicopter(H_a)**	**B Helicopter(H_a)**	**Survival Year**
5	3	1	1	4.967689529
3	5	1	1	4.95820213
4	1	2	3	4.91314752
4	1	3	2	4.8405342
1	2	6	1	4.836881126
1	6	2	1	4.819797104
2	6	1	1	4.813107477
1	6	1	2	4.787119838
6	2	1	1	4.747881479
3	1	2	4	4.618188754
2	3	3	2	4.608252679
5	2	2	1	4.53451395
1	5	2	2	4.530709451
1	2	5	2	4.520773438
1	4	1	4	4.481499537
3	4	1	2	4.448160897
2	5	1	2	4.428577553
5	1	3	1	4.4096361
1	5	1	3	4.385886029
1	7	1	1	4.373147885
4	3	2	1	4.348341657
4	2	3	1	4.305407614