

Investigation on the Area of Using Hubs in Humanitarian Logistics

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ABSTRACT

Natural disasters such as earthquake, flooding and pandemic diseases can cause millions of deaths, economic loss, and a lot of displaced people. In order to save the lives of humans, pre-disaster and post-disaster operations and humanitarian logistics are very important. Optimal locations of the hubs such as evacuation hubs, warehouses hubs and production hubs should be defined in preparedness stage. Distribution of relief items, transportation of casualties to hospitals and evacuation of victims to temporary hubs are post-disaster operations that should be decided in the planning horizon and they will be ready to use in response stage. Operations research and optimization modelling are important disciplines to solve the problems related to humanitarian logistics. This thesis proposed two mathematical models to tackle these problems. Furthermore, a literature survey was conducted in the context of hubs related to humanitarian logistics. The aim of the first model is to find the optimal locations of the production hubs to produce face masks in case of pandemic diseases such as COVID 19. The model used was simple and used the concept of covering location problem. This model can be solved within few seconds. Lingo 12 was used to solve the mathematical model. The model is examined using a case study of EUROPEAN UNION area. The second model used simple mathematical model with introducing the concept of covering location problem to find the optimal locations of the hubs along a river. Two cases were considered: with dam and without dam. A case study was used to illustrate the usage of the mathematical model for the two cases. The model was solved using Lingo 12 software. The model was feasible and took seconds to solve it. The survey study was conducted using 58 papers in contact with hubs in the area of humanitarian logistics. Several new and unique tools was

used. The results of this study were very useful for the research area. Finally, future directions and recommendations were suggested.

Keywords: humanitarian logistics, pre-disaster operations, post-disaster operations, hub location problem, optimization modeling, flooding, covid 19, coverage location problem.

ÖZ

Deprem, sel ve salgın hastalıklar gibi doğal afetler milyonlarca ölüme, ekonomik kayba ve çok sayıda insanın yerinden olmasına neden olabilir. İnsan hayatını kurtarmak için afet öncesi ve sonrası operasyonlar ve insani yardım lojistiği çok önemlidir. Tahliye merkezleri, depo merkezleri ve üretim merkezleri gibi merkezlerin optimum konumları hazırlık aşamasında tanımlanmalıdır. Yardım malzemelerinin dağıtımı, yaralıların hastanelere taşınması ve mağdurların geçici merkezlere tahliyesi, planlama ufkunda kararlaştırılması gereken afet sonrası operasyonlardır ve müdahale aşamasında kullanıma hazır olacaktır. Yöneylem araştırması ve optimizasyon modellemesi, insani yardım lojistiği ile ilgili sorunları çözmek için önemli disiplinlerdir. Bu tez, bu problemlerin üstesinden gelmek için iki matematiksel model önerdi. Ayrıca, insani lojistiği ile ilgili merkezler bağlamında bir literatür taraması yapılmıştır. İlk modelin amacı, COVID 19 gibi pandemik hastalıklar durumunda yüz maskeleri üretmek için üretim merkezlerinin en uygun yerlerini bulmaktır. Kullanılan model basitti ve kaplama yeri sorunu kavramını kullanıyordu. Bu model birkaç saniye içinde çözülebilir. Matematiksel modeli çözmek için Lingo 12 kullanılmıştır. Model, AVRUPA BİRLİĞİ bölgesindeki bir vaka çalışması kullanılarak incelenmiştir. İkinci model, bir nehir boyunca göbeklerin en uygun yerlerini bulmak için kaplama yeri problemi kavramını tanıtan basit matematiksel modeli kullandı. İki durum ele alındı: barajlı ve barajsız. İki durum için matematiksel modelin kullanımını göstermek için bir durum çalışması kullanıldı. Model, Lingo 12 yazılımı kullanılarak çözülmüştür. Model uygulanabilirdi ve çözmesi birkaç saniye sürdü. Anket çalışması, insani yardım lojistiği alanındaki merkezlerle temas halinde olan 58 kağıt kullanılarak gerçekleştirildi. Birkaç yeni ve benzersiz araç kullanıldı.

Bu alıřmanın sonuçları araştırma alanı için ok faydalı olmuřtur. Son olarak, gelecekteki yönergeler ve tavsiyeler önerildi.

Anahtar Kelimeler: insani lojistik, afet öncesi operasyonlar, afet sonrası operasyonlar, merkez yerleşim sorunu, optimizasyon modellemesi, sel, covid 19, kapsama alanı sorunu.

To my family

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LIST OF ABBREVIATIONS

BPVC	Bio-Macromolecules Polymerized Polyvinyl Chloride
DCC	Disaster Command Center
DMF	N, N-Dimethyl-Formamide
DOPs	Demand of Points
ECC	Emergency Command Center
EU	European Union
FFR	Filtering Facepiece Respirators
FMCLP	Fuzzy Maximal Coverage Location Problem
GA	Greedy Adding Algorithm
GAS	Greedy Adding with Substitution Algorithm
GPS	Global Positioning System
LP	Linear Programing
MCLP	Maximal Coverage Location Problem
Min CLP	Minimal Coverage Location Problem
MINLP	Mixed Integer Non-Linear Program
MLHs	Mobile Logistic Hubs
μm	Micrometer
NIOSH	National Institute of Occupational Safety and Health
nm	Nanometers
PCL	Polycaprolactone
PEO	Poly Ethylene Oxide
PLLA	Poly-L-Lactic Acid
PP	Poly Propylene

PSOM	Particle Swarm Optimization Method
PVA	Poly Vinyl Alcohol
SA	Simulated Annealing
SCLP	Set Covering Location Problem
SMS	Spunbond Meltblown Spunbond
TCMC	Thermoplastic Carboxymethyl Cellulose
TLHs	Temporary Logistic Hubs
UAVs	Unmanned Autonomous Vehicles
WHO	World Health Organization

Chapter 1

INTRODUCTION

A disaster is a huge damage and disruption that happens during a short or long period of time. The most general definition of disaster given by (Papp, 2019) is as follows. It is an event such that it has at least two out of the three properties (i) it is a sudden event, (ii) it causes large damages in lives and economy, and (iii) the local community has not enough resources to overcome the effects of the event. Disaster can be natural like flood, hurricane and earthquake, or man-made disaster like chemical leakage and terrorist attacks (Caunhye, Nie, Pokharel, & 2012). Disaster can cause loss of human beings, ecological disruptions, suffering of inhabitants and health deterioration. The most important occurrences that cause vast damage properties and huge number of injuries and casualties is an earthquake (Najafi, Eshghi, & Dullaert, 2013).

Natural extreme events can strike human suddenly without any warning causing a lot of victims and society damage. For instance, in 2014, 324 natural disasters were registered that have left 140.8 million victims, 7832 casualties and over 99 billion dollars of assets loss. These events have raised the growing awareness on scientific methods to mitigate the bad consequences of the disasters. One of the most important methods is facility location problem. This method is widely used in humanitarian logistics such as relief items and emergency medical service. The facilities used to store relief item to be used in response phase. However, some of relief items can be

pre-positioned in pre-disaster stage. This method determines the location of facilities to be ready before disaster happening since high demand of relief items, medical supplies and large number of injured people will show up in a short time period at the affected area (Mohamadi & Yaghoubi, 2017).

Natural disasters are always existing in our life and despite of developments that happened in technology and science, human beings cannot prevent these catastrophic events. Several natural disasters and catastrophes such as earthquakes, tsunamis and flood have happened in the last decades. About 450000 people have lost their lives due to the following fatal disasters: (Haiti, 2010), (Sichuan in China, 2008), (Kashmir in Pakistan, 2004), (Bam in Iran, 2003), (Gujarat in India, 2001), (Chichi in Taiwan, 1999) and (Izmir in Turkey, 1999). (Tavana, Abtahi, Di Caprio, Reza Hashemi, & Yousefi-Zenouz, 2018a).

Pandemic diseases such as Corona Virus, Sars, Cholera cause catastrophic effects, millions of deaths and infected people who need emergency and special medical treatments and quarantine to prevent the spread of the pandemic in the whole country and in other countries. Pandemic disease case needs proper and enough personal protective items and special procedures and rules to be used to protect the inhabitants from death and infection. In this context, robust emergency operation management and logistic planning are very important to save more lives.

(Caunhye et al., 2012) mentioned that emergency logistic planning faces the following key challenges: 1) Limited resources such as relief items and supply, transportation capacity, fuel and people. 2) Difficulties to achieve timely and efficient delivery of relief items for demand points. 3) Uncertainties that come from

several issues such as safety, changing of facility capacity, unusable routes and demand uncertainties. 4) Coordination and communication channels become more complex due to damage to communication lines, inaccessibility to accurate real time demand information and involvement of government, civilians and many third parties in emergency logistics.

These challenges are addressed by using several methods such as: decision theory, fuzzy methods, probabilistic models, stochastic models and the most popular optimization models.

After the disaster strikes any place, immediate need for emergency responses to save lives and transport the casualties to hospitals as fast as possible, furthermore, transfer the relief items to victims or demand points from warehouses. Several types of transportation modes can be used such as: roads like trucks and railways, water way like boats and ships, air mode like helicopters and nowadays the usage of unmanned arial vehicles (drones).

1.1 Humanitarian Emergency Operations

(Caunhye et al., 2012; Jiang & Yuan, 2019) described the emergency operations stages in different ways. (Jiang & Yuan, 2019) discussed the four stages of disaster that are: mitigation stage, preparedness stage, response stage and recovery stage. The first stage is mitigation stage: during this stage the decision makers apply the important measures that may prevent the onset of the disaster or moderate the bad impacts and the consequences aftermath of the disaster. Preparedness stage that includes activities to prepare population for responding after disaster strikes. The activities-related activities reduce the response time by the advanced procurement and pre-positioning of required supplies and relief items. Response stage is the

allocation of resources and procedures to save life, environment, properties, economic and social structure of the community. Recovery stage concludes actions that will be carried out in long period of time such as rebuilding the infrastructure, retrieving the victims and mitigation the damage in the disaster zones in order to settle the community and restore normal life and it starts after finishing the immediate impact of disaster.

(Caunhye et al., 2012) described the disaster operations according to the time of disaster happening. Two disaster operations are considered: Pre-disaster operations that are carried out prior to occurrence of the disaster and post-disaster operations that are carried out after disaster strikes. Figure 1 shows different disaster operations.

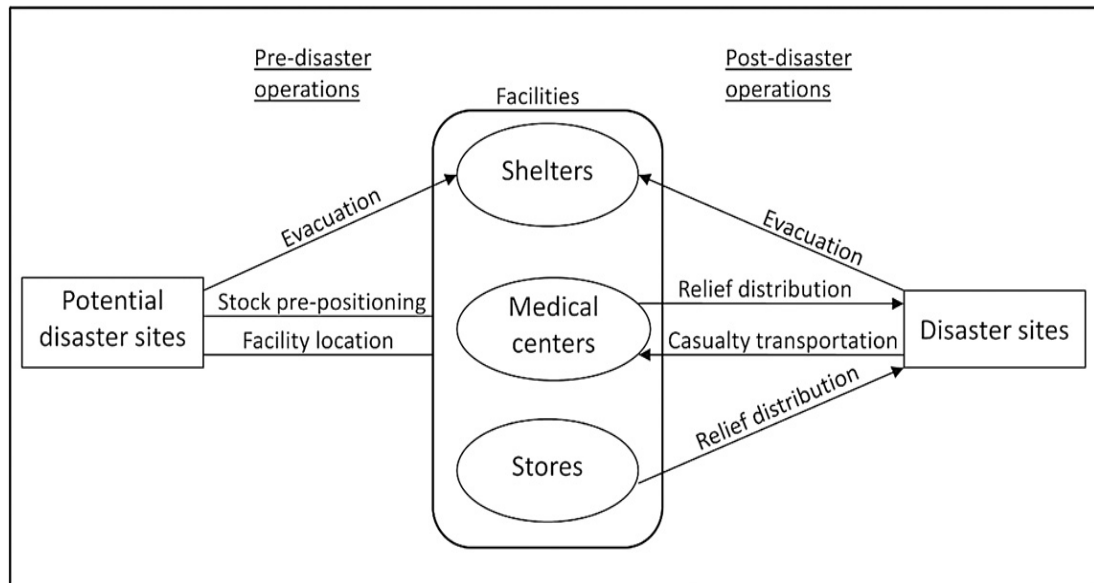


Figure 1: Disaster operations (Caunhye et al., 2012)

According to figure 1, the pre-disaster operations include evacuation of the population from potential disaster sites to shelters or temporary hubs if the time and place of disaster happening are known. Facility location is the central problem that should be solved and prepared, it includes the places of permanent and temporary

hubs such as evacuation shelters, temporary tents, warehouses or stores to store the stock of relief items. Also, stock pre-positioning is essential to save more lives and it is necessary to determine the stock levels according to the available quantity and the risks of demand points. It consists procurement of the stock and store them in warehouses that they considered as global or central hubs. The relief items should be defined such as water, food, blankets and medicines, etc. Post-disaster operations conclude the following operations: a) evacuation of the affected people to closed shelters or temporary hubs by using several types of transportation modes such as road, air and water modes, b) relief items distribution for the victims. These items are different according to the time of distribution for example the most important item is water and food that should be distributed in the first 24 hours, then medicine and sanitizer, c) casualty transportation to general permanent hospitals or mobile hospitals according to the nature and the type of the injuries and the priority of treatment and this is called triage system in which the injured victims are classified into categories according to the severity of their condition. The triage classification of the injuries is based on using colors including red, orange, yellow and green colors. Each color has definite response time. The injured people are transferred using equipped vehicles at increased speed (Mohamadi & Yaghoubi, 2017).

1.2 Humanitarian Logistics and Relief Centers

Humanitarian logistics is a branch of engineering that study and analyze the problems related with the storage and distribution of relief items that required by the affected people aftermath of the disaster. These items need efficient and effective distribution to the affected areas and also rapid transferring casualties to hospitals in order to avoid death from starvation and disease (Camacho-Vallejo, González-Rodríguez, Almaguer, & González-Ramírez, 2015a). The relief items are partially

pre-positioned in the warehouses in preparedness stage. The location of the warehouses and temporary hubs are defined in planning horizon to be ready aftermath of the disaster.

1.3 Hub Utilization in Humanitarian Logistics

Hubs is a type of facility that are using to serve the people in certain geographic location. It can be shelters for evacuation the affected people and warehouses to store the relief items. Hubs in general can be used for emergency operations and for service sector.

(Moreno, Alem, Ferreira, & Clark, 2018) mentioned two types of hubs that are used to store the relief items: 1) permanent hubs that are located in non-vulnerable areas since these kinds of warehouses are usually based on long-term decisions, 2) temporary hubs having two types. The first one is the facility that exists in the country. These facilities may be public schools, offices and churches. These facilities do not have proper infrastructure and areas to store and accommodate supplies in long term. For this reason, the storage capacity of relief items can be considered as the available volume in the facility. These facilities also may not suitable to store some items such as refrigerated food and medicines and can be located in vulnerable areas. The second type of temporary hubs that can be prepared technically like tents and dry storage with simple constructions can be used to store perishable relief items.

Types of hubs according to the function of the hubs: Production hubs that are producing some items such as personal protective items production units (face mask production hubs), another example for temporary production hub is a type of production hubs filling textile sacks with sand for building temporary dams to

prevent the river from flooding (extension dams) citing. Warehouses hubs that are used in storing the stock of relief items such as: canned food, water, blankets, hygienic materials and medicine. Medical hubs such as mobile medical clinics like some kinds of medical equipped tents and temporary hospitals. Evacuation hubs that are used for evacuation the affected people after happening the disaster, they can be both temporary and permanent hubs. Temporary hubs can be prepared technically inside the country or can be obtained from production factory or specific companies, it can be as tents that may use as evacuation shelter, medical mobile clinic buses, dry storage and quarantine tent for medical staff (See Appendix A).

1.4 Hub Using in Service Sector

Several types of hubs are used in service sectors to serve all the population in each geographical area of the country. Pharmacies, medical centers, banks, markets, malls and hospitals are common examples of service hubs. Service sector hubs are used in clever or smart cities and new capitals in some countries such as Indonesia and Saudi Arabia that are planned to establish brand new cities.

1.5 Data Sources in Disaster Area

Sufficient and accurate data is a challenge in disaster relief operations. In order to obtain the real data from affected areas aftermath of disaster, we can use many sources such as: news media, police officers, traffic cameras, sensors and phone calls. Common data also may appear in a disaster including reports of traffic flow, casualties, structural damage, road conditions. Emergency management centers receive data and these data may be incomplete, inaccurate and duplicate due to chaotic situations, so it is very difficult to obtain useful information in order to facilitate disaster response. Data fusion is one of the technologies that is used to efficiently organize and interpret huge amount of data related to disaster-affected

areas to emergency response centers when data is varied (Lin, Batta, Rogerson, Blatt, & Flanigan, 2011).

In order to provide real time data, we can use drones that can hold cameras and other sensors and connect with Emergency Command Center (ECC) of the country. Furthermore, these drones can use global positioning system (GPS) to reach the isolated area. There are two types of drones according to the kind of wing as follows. a) fixed wing, b) rotor wing. Drones can be used in different sectors such as: medical, agriculture, military and commercial, deliver different packages such as: medicine, vaccine, medical supply and blood to remote areas, transport test kits, disease test samples and aid packaging (Ayamga, Akaba, & Nyaaba, 2021).

1.6 Problem Description and the Methodology

Disaster response is a challenge due to insufficient resources that are offered in the immediate aftermath, the demand is always greater than the supply in case of disasters. Furthermore, lack of information, weak infrastructure, risk of facilities, damage of road channels and buildings and poor governance. Hence, to be prepared for disasters is critical to the success of the response humanitarian efforts (Maharjan et al., 2020b). High demand of relief items and emergency supplies are offered suddenly in the first hours of disaster. The affected people need evacuation to shelters, medical treatment and relief items distribution as fast as possible. In case of pandemic diseases, the population need special protective items such as masks, gowns, gloves, vaccines, respiratory devices and sanitizers. The infected people should be treated in isolated and separate area in the existed hospitals or utilization of temporary hubs to be used as mobile medical centers to treat all the infected people. It is better to create a proper system to protect the healthy people from infection such

as comprehensive quarantine, specify permanent hospitals to treat them far from the infected people and distribute protective personal equipment such as masks, gowns and hygienic solutions. In order to save human life, loss in property and infrastructure in case of natural disasters, strategic actions are needed on the level of the country and the following important actions should be implemented:

- 1) Effective and efficient emergency and humanitarian logistics to reach all effected people in both reachable and isolated areas.
- 2) Improve disaster management operations and focus on preparedness and response operations.
- 3) Define the number and the location of the logistic facilities in the planning horizon.
- 4) Disaster response facilities can be warehouses to store the relief items, shelters to evacuate the victims and medical centers for treat the casualties and injuries. The response facilities can be both temporary and permanent.
- 5) Pre-positioning some of the existed relief items in the warehouses or hubs and determine the stock level to be provided by approved suppliers or international donators to be ready for distribution in response stage of the disaster operations.
- 6) Disaster response facilities must be established quickly in the planning horizon.
- 7) Transportation is a vital factor that can save lives, it includes transferring the relief items to affected people and transport the casualties to the hospitals and medical centers according to the severity of the injured people.

- 8) The most important factors in transportation that can save more lives are the distance or the time of travelling and provide the transportation vehicles in the suitable time.
- 9) Road transportation like trucks and ambulances could be used to serve the reachable areas, however, the isolated areas need aerial transportation like drones to transfer the relief items in isolated areas.
- 10) The location and number of disaster response facilities are based on: a) The amount and quality of information, b) The method used to define location and the number of response facilities.
- 11) Each type of disaster needs special emergency logistics and operations. They are different in many ways such as: types of relief items, time and place of happening and the consequences of happening.
- 12) Small drones can be used to collect real-time information aftermath of the disaster, these small drones are holding cameras and connecting with emergency management system of the country.
- 13) In case of pandemic diseases, personal protective items should be provided continuously and distributed in proper way. Each country should produce its own masks using its own facilities and also, they can import them from other countries.

To enhance the disaster preparedness and response and to achieve the safety of the population, this research aims to determine the number and the location of temporary hubs that are necessary for saving the lives of the victims. In this study, one stage mathematical model was used and the concept of coverage introduced to the study in two sections: the first one is defining the number and the location of face mask production hubs in the European Union. The second part is defining the number and

the location of the warehouse's hubs along a river. The third section is a survey study associated with the hub concept that is used in humanitarian logistics and explain the results using new tools.

Despite of the research on facility location problem is abundant in the context of humanitarian operations, facility location models used in this thesis are unique, they are simple and not complex, most of mathematical models in the literature are complex and large-scale needing a lot of information that could be difficult to obtain accurately in real life. Many mathematical models used 5 or 6 indices and this take a lot of time to collect the data and information to solve the problem and this will affect the efficiency and effectiveness of emergency response operations. The aim of the humanitarian operations is saving as many lives as possible in a short time. The proposed models are simple and can be solved in few seconds, and this is the contribution of this research. The limitation of this research is that the proposed problem does not discuss the uncertain nature of location problem and the distribution of relief items and transportation of casualties in response stage. Location and distribution problem can be solved together using the same mathematical model but in two stages or levels. (Mete & Zabinsky, 2010) proposed a new method to solve the location-distribution problem considering uncertainty nature by using two stage stochastic problem model for the medical supply. The first stage of the problem was solved to find the optimal locations of the warehouses and inventory decisions. In the second stage of the problem, resource decisions collection defining transportation plan was solved depending on the solution of the first stage.

The research is structured as follows. chapter 2 reviews the related literature and is divided in two sections: a) optimization modeling in humanitarian logistics and

disaster management related to hubs, b) coverage location optimization models, chapter 3 discusses the survey study related to the humanitarian logistics hubs, chapter 4 discusses the first mathematical model that solves the facility location problem of face mask production hubs in EU, chapter 5 discusses the second mathematical model that solves the facility location problem of warehouses hubs along a river, chapter 6 describes the conclusion and the future directions.

Chapter 2

LITERATURE REVIEW

2.1 Optimization Modeling in Humanitarian Logistics and Disaster Management Related to Hubs

Optimization models became a powerful tool to tackle the problems of emergency logistics in both preparedness and response stage. The most popular models are decision theory, stochastic models, probabilistic models and fuzzy methods. Optimization modeling is used to solve the problems in both pre-disaster and post-disaster operations. The problems that are solved by optimization models are related to facility location, stock level and pre-positioning, transportation of casualties and relief items distribution. Furthermore, rehabilitation of lifeline and traffic control. Few models solve location-alone problem, on contrary, most of the models of optimization modeling combine more than one problem (Caunhye et al., 2012).

The first optimization models in emergency logistic planning were created in the late 1970s following several maritime disasters that happened between late of 1960s and 1970s. Most of early optimization models concentrated on maritime disasters and oil spills. From 1980 up to now, other field of research has explored since other large-scale emergencies are developed such as earthquakes, hurricanes and floods (Rivera-Royero, Galindo, & Yie-Pinedo, 2016).

The facilities that are used to serve the affected people aftermath of the disaster should be located as fast as possible. The location and the number of these facilities should be determined in the pre-disaster planning horizon for upgrading the effectiveness and the efficiency of the disaster operations. The facilities that are used in disaster operations are temporary hubs and permanent hubs. Network structure of humanitarian relief distribution can contain multi-layers. Figure 2 illustrates the supply relief chain of humanitarian relief which contains the following different layers of relief supply chain: 1) supply points that represent the permanent warehouses and all points of entry to the impacted country by using different transportation modes such as: land, sea and air, 2) temporary logistic hubs (TLHs) that receive the relief item from global permanent hubs and then they are transferred to the points of demand (PODs), 3) PODs that represent the aggregate demands in a single district of disaster areas (Maharjan & Hanaoka, 2020). TLHs can be considered as distributed centers that could be located in public places such as hospitals, schools and mosques. However, some of the existing public places can be used also as global or central warehouses (Tavana, Abtahi, Di Caprio, Hashemi, & Yousefi-Zenouz, 2018b).

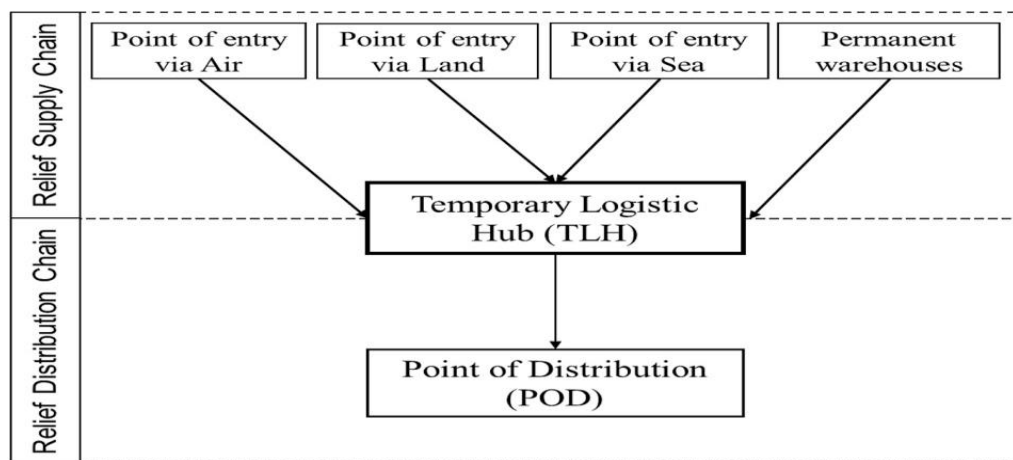


Figure 2: Network of humanitarian relief distribution (Maharjan & Hanaoka, 2020)

(Hezam & Nayeem, 2020) discussed the classifications of the facility location problems. Facility location problems are classified according to the nature of the parameters into two types: Deterministic models and non-deterministic models. In deterministic models, input parameters are known and constant over time such as transportation cost, number of victims, shelter capacity, facility establishment costs and the location. These parameters are used in facility location problem to determine the locations of facilities such as warehouses to store the relief items and safe shelters for evacuation the affected people. Deterministic models can be classified into categories: median, center and coverage problems. Deterministic models can be called as network facility location problems because the demand can be considered at the node. Some other categories of non-deterministic models are: capacitated, non-capacitated and dynamic facility location models. Non-deterministic models consider uncertainty in input parameters due to randomness. Stochastic and robust models are used to solve facility location problem with uncertainty nature of parameters. In stochastic models, the uncertain parameters dispense through probabilistic distributions or scenarios with known probabilities. Chance-constrained method can be used in probabilistic problems. It is difficult to find out the exact value of uncertain parameters and the probability distribution as well, in this case robust models are proper to solve facility location problems. Interval uncertainty and discrete scenarios are handled in robust models. (Liu, Lei, Wu, & Zhang, 2019) proposed robust optimization model combined with model predictive control-based rolling horizon framework approach for response stage distribution considering injured victims and relief items. The objective of this model is minimization the total weighted unmet demand by considering multi-period multi-commodity distribution model. Mixed integer linear programming used to solve this problem. Three important

aspects were addressed in this model: dynamic issue in which the parameters such as number of supplies and demand quantities are vary in post-disaster period. Multi-period-based approach is used to handle this challenge. The response stage is divided into several periods and suppose that the environment is static within each period. The second aspect is uncertainty since collecting the real-time information in post-disaster period is very difficult due to power disruption and communication channels damage aftermath of the disaster. Robust approach is used to manage this issue. The third aspect is evolution, it means that the information develops during response stage and distribution operation due to uncertainty and secondary disasters. This plan needs to be adjusted promptly according to real-time information. A case study of great Wenchuan earthquake that happened in China in 2008 was used to illustrate the applicability of the model.

The response operations of disaster management should be taken place in the first 72 hours aftermath of large-scale disasters. The first 12 hours period known as standard relief time is crucial to prevent the death of the affected people. In this context, pre and post-disaster operations models are proposed with multi objective models to provide the optimal locations of the warehouses and at the same time stock pre-positioning and transportation operations. (Tavana et al., 2018b) suggested deterministic multi objective optimization modeling for both pre-disaster and post-disaster operations. In pre-disaster stage, inventory of the perishable relief items (products such as food, milk and medicine that should be consumed in certain period of time) and the locations of the central warehouses were determined. In the post-disaster stage, the distribution plan designed by formulation of multi-echelon vehicle routing with multiple depots problem. MILP problem was designed. To solve small

size problems, epsilon-constraint method was used. On contrary, complex problems were solved using two types of meta-heuristic algorithms (genetic algorithms). Bi-level or two-phase methods used in solving the facility location problems with multi-objective approach. The first level or phase solution is used to solve the second level objective. (Lin, Batta, Rogerson, Blatt, & Flanigan, 2012) proposed two phase heuristic approach to improve the humanitarian logistics efficiency. This strategy named a distributed-supply delivery strategy is formulated as integer programming model. This problem is decomposed into four sub-models. The first sub-model is solved in the first phase to locate the temporary depots and allocation of the demand points to an open depot. The solution of the first phase is used to solve the other three sub-models in the second phase. A case study of an earthquake scenario in Los Angeles is performed to investigate the applicability and feasibility of the problem. The computational results shows that the overall humanitarian logistics performance is improved. (Cavdur, Kose-Kucuk, & Sebatli, 2016) suggested two stage stochastic integer programming for allocation of temporary facilities considering demand uncertainty to represent the decisions in preparedness and response stages. In this model, 5 scenarios with its associated probability of occurrence were solved using deterministic model and then the corresponding stochastic program solved. The objectives of the model are to minimize the total number of the facilities, unmet demand and total distance travelled. The model considered the difficulties to access the facilities but the risk of facilities is not considered. A case study of the earthquake in Turkey is utilized to illustrate the proposed model. Risk of facilities is important in disaster operations. Many articles investigated this concept. (Boonmee, Asada, & Arimura, 2017) proposed multi-objective linear mixed integer stochastic programming to find the optimal locations of the shelters. It considers two criteria as

objective functions: risk index of the shelter and the average travel distance. Epsilon constraint approach was utilized to solve the problem using real case study of Thailand flood.

Post-disaster operations specifically relief distribution and casualty transportation need proper transportation modes. Road transportation such as vehicles, railway, air modes such as helicopter and water modes such as boats are used in disaster area. The wireless network is famous nowadays and they play a very important role in disaster environment. Survivors who need evacuation in isolated areas require communication with the outside world. Furthermore, the authorities need to collect real-life information about the extent of the disaster and the number of the evacuees and injured people for rescue operations. Social media like Twitter and Facebook were used to request rescue and evacuation in several disasters' situations such as Haiti 2010 earthquake and hurricane Harvey in Texas. The unmanned autonomous vehicles (UAVs) and the related temporary wireless network have been developed to help in disaster environment. UAVs routing system can transport the relief items to the isolated affected areas. Furthermore, UAVs can be used as a monitoring system and visual surveillance based on holding cameras by some kinds of small UAVs (Park, Nielsen, & Moon, 2020). (Vizvári, Golabi, Nedjati, Gümüşbuğa, & Izbirak, 2019) proposed top-down approach to design the relief system for the main city exposed to earthquake specifically using UAVs in the first 48 hours aftermath of the disaster. Different long-term and short-term decisions are investigated such as relief items network, transportation, fundraising, debris removing and re-building infrastructure. In this model, UAVs are utilizing for monitoring tasks and transportation of the relief items because it is safer and faster than the ground

transportation. This system is controlled by disaster command center (DCC). A combination of truck and drone routing problem called tandems is used nowadays in humanitarian logistics but in small cases. Using UAVs faces several restrictions and aspects that did not appear in recent routing problems, most notably, limited power life to the batteries (endurance) and the location of the meeting points where they are replaced by fully-charged new batteries. (Gonzalez-R, Canca, Andrade-Pineda, Calle, & Leon-Blanco, 2020) proposed a greedy heuristic method to overcome these limitations. This process is hatched by global optimization scheme using simulated annealing (SA) algorithm. This hybrid truck-drone system determines the best routes for both a single truck that equipped with a single drone.

2.2 Coverage Location Optimization Models

A coverage optimization problem can be considered as set covering location problem (SCLP) and maximal coverage location problem (MCLP). Coverage problems are utilized for solving facility location problems in which the maximum demand points are satisfied by a required amount of stock that are assigned in each facility. Coverage is a concept that signifies if a location of the demand is within a pre-specified radius which can be measured by using different metrics such as: travel time and distance. The PODs are considered “covered” if they are located within a specified radius “coverage distance” from the hub. It means that it is close to at least one facility. On the contrary, the uncovered PODs are located outside of the coverage distance. MCLP is more proper for planning the relief chain networks. In the MCLP models, the total demand that are covered within a maximal service distance are maximized due to limited number of resources and facilities constraints. On the contrary, the SCLP models minimize the number of facilities in which all PODs are

covered. It means that the PODs must be within the specified response time of the hubs (Maharjan et al., 2020a).

(Drakulić, Takači, & Marić, 2016) added minimal coverage location problem (MinCLP) as a third type of location problem. The objective of MinCLP is to cover maximal number of locations with pre-defined number of facilities and minimal distance among locations or demand points facilities. Furthermore, this paper mentioned other fields such that coverage location problems can be used to find the optimal location of various facilities such as: emergency units, pharmacies, shops, schools, pollution sources and antennas. This paper proposed a new model of fuzzy maximal coverage location problem (FMCLP) with two types of fuzzy numbers for modeling uncertainty. The fuzzy numbers describe the distance between locations and coverage radius (travel time). To solve this problem, particle swarm optimization metaheuristic method (PSOM) was used.

(Maharjan et al., 2020a) proposed a methodology which combine quantitative and qualitative approaches to identify the optimal location of mobile-logistic hubs (MLHs) in different parts of Nepal area. This study utilized a modified version of MCLP and focus group discussion (knowledge of experts) to select the first-five priority locations of the MLHs in preparedness stage. Disaster risk, level of human development and transportation accessibility concepts were used and added as constraints. Integer programming method was used to solve the mathematical model. The objective function is maximization of the number of the served demand points. The original model developed by (Church & ReVelle, 1974) that used MCLP to maximize the total number of the population that are served within a pre-defined distance with fixed number of facilities. They used heuristic algorithms to solve the

mathematical model. Greedy adding algorithm (GA) was used to identify the first facility which can serve the maximum number of the population. For the second facility, GA also selects the location that covers the most of the population that are not covered by the first facility and so on. Also, this paper used the greedy adding with substitution (GAS) algorithm to test the mathematical model that improves the solution at each iteration by replacing any facility in the solution set of facilities if the coverage area increased. Linear programming (LP) was also used with minimization of the uncovered population objective function. Branch and bound method and the method of inspection were used to solve the problem when the linear program terminates fractional, it means there is no feasible solution. As a result, the all-integer optimal solutions are determined. A proper comparison between the results of all the methods has been proposed.

The quality and the preciseness of the information during planning horizons are important to establish TLHs quickly to save more lives. During response period, the operations revolve around uncertainty due to randomness. Uncertainty can be modeled in facility location problem by using stochastic or probabilistic models that the probability distributions of the random variables or future scenarios for the uncertain parameters are considered. On contrary, the deterministic models are used to simplify the problems by forecasting with specific values. (Jia, Ordóñez, & Dessouky, 2007) proposed general medical supply facility location model that can be cast as covering model, P-median model and P-center model. Coverage problems aimed to provide coverage to PODs by a facility that should be located within defined area or distance limit. The objective function of P-median (minsum) models is minimization of the average or sum distances between PODs and the nearest

facilities, while P-center models (minmax) aim to minimize the travel time or the maximum distance between the facilities and the PODs, therefore, all demand points are served using the same number of the available facilities (P). The model relies on scenarios with occurrence probabilities to consider the uncertainty nature of the parameters. Finally, proper comparison between the proposed models and the traditional models were conducted for Los Angeles area. Integer programming was used to solve the mathematical models.

(Maharjan & Hanaoka, 2020) proposed probabilistic multi-objective model for relief supply and distribution under uncertainty in response stage. This model considered time varying coverage due to impreciseness and time varying parameters such as demand, costs and available relief items. Fuzzy chance-constraint programming was used to solve the problem. The objective function is maximization total demand coverage and minimization total cost. Figure 3 illustrated the concept of time-varying coverage. The service made within time $s(t)$.

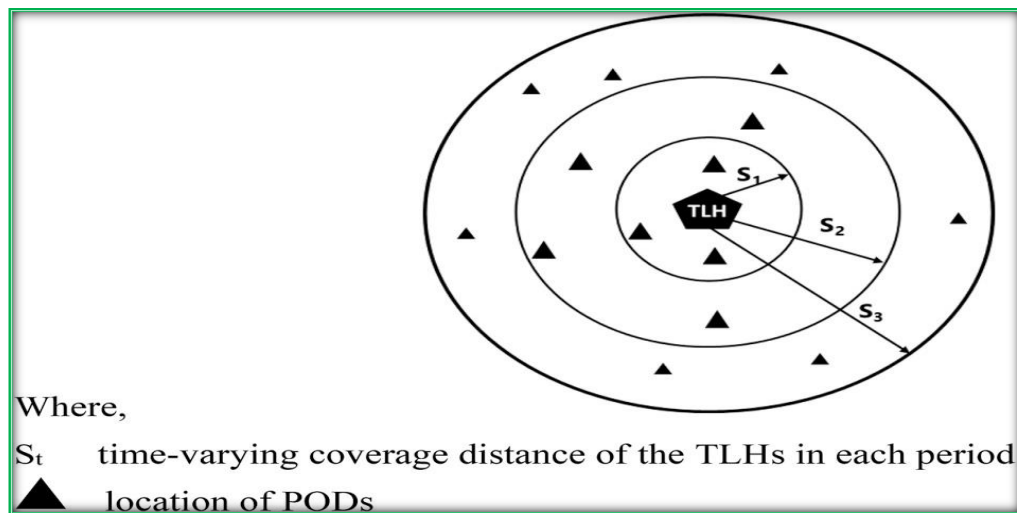


Figure 3: Time-varying coverage concept (Maharjan & Hanaoka, 2020)

(Hashim, Shariff, & Deni, 2021) proposed capacitated LSCP and it was solved using excel solver to locate and allocate the victims of flood disaster. The aim of this model is minimization the number facilities (evacuation hubs or relief centers) to cover all the evacuees within travelled distance which are 3 km, 5 km and 10 km. Three new constraints were added: rainfall amount, elevation from sea level and distance from river. For allocation process, split and non-split scenarios were tested for allocation process utilizing case study of river flood. The proposed model can be considered for better evacuation plan.

Heuristic algorithms are used to solve the set covering problems. (Hashemi et al., 2022) proposed a new solution for the set covering problem based on coefficient and fitness values. The proposed algorithm improves the solution of the set covering problem. The qualification of the subsets is evaluated in which that the subset of the selected set has the lowest probability to be selected in the following iteration. The proposed method compared with simulated annealing algorithm (SA). The new methods are better than SA algorithm in terms of quality and time, and it can be used to solve complex problems without conventional restrictions.

Hybrid coverage location problems can be used in one model to take the advantages of both SCLP and MCLP. (Alizadeh & Nishi, 2019) proposed hybrid mathematical model of coverage location problem. The primary facilities are gradually located during the planning phases, ensuring full coverage for PODs. Furthermore, after being assured that all demand points are under full coverage of the facilities, a specific number of resources such as staff, equipment, food, truck and ambulances are assigned to the located facilities in order to optimize the PODs in operational periods.

(Blanquero, Carrizosa, & Gazdag-Toth, 2016) proposed a more realistic location problems with network of high density-areas such as cities. In this model, it is assumed that the demand distributed along the network edges. Therefore, the expected demand covered is maximized. Mixed integer non-linear program (MINLP) with branch and bound algorithm was utilized to solve the location problem for small values of the facilities. This problem has two parts: the first one is choosing the suitable edge to locate the facility and this is called combinatorial part, the other part is defining the optimal locations of the facilities in the chosen edges and this is called continuous global optimization part.

Set covering problem with side constraints can be used to model the problem of providing UAVs based wireless network in disaster response stage considering the operational constraint. Exact branch and price algorithm and two approximation models of the quadratic coverage radius constraints and linear-pairwise conflict constraint based on Jung's problem were proposed. The results found that they are suitable to solve real life problems and serve up to 100 demand points and 2000 m of coverage radius (Park et al., 2020).

In this literature review, we can observe that many papers used multi-objective complex models to solve facility location problem with different parameters. To the best of our knowledge, no paper proposed simple mathematical model with reasonable parameters that can be obtained easily in real life. Some parameters are difficult to obtain or they are not accurate. In order to construct reasonable model that take little time to solve and this is crucial in disaster operations, we propose two simple mathematical models to find the optimal location of two types of temporary hubs: production hubs in case of pandemic disease that presented in chapter 4 and

this is the first model that investigate the production hubs in case of serious pandemics such as COVID 19, and temporary warehouses hubs in case of river using logical constraints in chapter 5.

Chapter 3

LITERATURE SURVEY ON OPTIMIZATION MODELS OF HUBS IN NATURAL DISASTERS-EMERGENCY LOGISTICS

3.1 Introduction

Disaster research is difficult due to several reasons, the most important problem is data collection and the methodology used for analysis, so disaster statistics have problems and even the term “disaster” has no unified definition. The difficulty of disaster measuring cannot support disaster management. The disaster definition is clarified terminologically into 3 categories: subjective, objective, and numerical approach. The analysis of disasters gives relevant information to political decisions and policies development, empirical studies of disasters, determining disaster costs and impacts. Data collection is important to regional and global disaster risk identification, also it helps to develop short-term and long-term goals to face effectively with emergencies, (Papp, 2019).

Emergency logistic planning is an important discipline to save lives and help the affected people to rapidly recover to normal life. It is an important tool to deliver emergency resources in the suitable time to affected areas and also for rescue activities and achieve effective and efficient corporation between several actors such as government, special humanitarian agencies, international support teams,

volunteers and rescue teams. Optimization models are good tools to tackle the problems of emergency logistics. They are more popular than decision theory, stochastic models, probabilistic models and fuzzy methods.

In this chapter we present a literature survey for emergency logistics which introduced optimization modeling of operation research in solving the hub problems related to humanitarian logistics in case of natural disasters. Then we identify the gaps of research and suggested future directions.

We prepared this survey using 58 papers from the literature that were published between 2010 and 2021 as shown in (Appendix B). Content analysis was used to break down the main structure of optimization models into several parts such as type of disaster, hub problem, model stage, transportation, data, program method, period of decision making, triage system, decision making period that involves pre-disaster operations and post-disaster operations, risk of facilities and other parts. Furthermore, we prepared source classification to define all papers that discussed each key characteristic.

The primary contribution of this chapter is preparing the essential key characteristics and proper classifications for optimization modeling connected to hubs in emergency logistics. Some new classifications and characteristics are not explicitly discussed in previous survey works. Furthermore, new and creative figures are prepared to describe the relationship between papers. Then we prepared a description and simple statistics for the key characteristics related to emergency logistics and optimization models.

The question to be answered after finalizing this research is:

Does the optimization modeling is useful to tackle the problems of the emergency logistics such as: location of hubs, distribution of the relief items to the affected people?

3.2 The Methodology and Scope of the Analysis

The main methodological tool is content analysis (Caunhye, et al., 2012). This tool was implemented on a group of research articles that are focus on hubs problems related to emergency logistics. During content analysis the literature has broken down into small parts according to the objective of the research, scope, tools and methods, source of research, decision variables, parameters, optimization model, data and context of research.

In order to simplify content analysis, symbolic and key words are identified. This method saves time and effort to find the individual contents which followed by a discussion and description of gaps and define future directions.

Several tables were prepared with a specific content that extracted from the literature, such as disaster type, mathematical model, transportation modes, risk of facilities, triage system, hub problem, hub types, model stage, method, etc.

Two types of classifications used in content of analysis approach: classification of research and classification of sources. These classifications are crucial to find gaps easily and to identify future directions based on missing operations, activities combinations, suggest new activities. Furthermore, new technological and science inventions specially in transportation vehicles, data and information devices and technical-prepared temporary hubs.

For the research classification type, this survey considered published literature including journal papers which focus on emergency logistic planning during all disaster operations which conclude essentially two disaster operations: 1) pre-disaster operations that represent an important role in strategic planning. They consist mitigation operations that include evacuation of people and utilizing disaster-resistance building. Preparedness operations like facility location-allocation and pre-positioning (stock level). 2) post-disaster operations that consist short-term post disaster planning like evacuation of affected people to temporary hubs, transportation of casualties to hospitals, relief items distributions and recovery operations.

Research papers that were analyzed are those which are used optimization models to solve complete problems related to hub problems. Furthermore, this survey focuses on the references of each paper.

In the first stage of searching, 120 research papers, abstracts and book chapters are collected by using general pre-defined key words related to emergency logistic planning such as disaster, humanitarian logistics, hub problem. We extracted all the key words that are located in each paper. The set of the keywords was reduced to ones which are related to hub problems from the first list such as temporary logistic hub, potential demand points, facility location-allocation problem, emergency logistics, humanitarian supply chain, humanitarian logistics, disaster relief, warehouse location-routing problem, centralized emergency supply network, preparedness stage, response stage, disaster relief, inventory pre-positioning, mobile clinics, OR in disaster relief, post disaster response, relief supply distribution, humanitarian assistance, helicopters, rapid response, humanitarian air transport, emergency response planning, temporary facility location, facility location,

emergency planning, location-transportation problem, mitigation, inventory management, emergency medical services.

Other research articles were collected related to second group of key words which will be analyzed. We collected 58 research articles related to hub problem in emergency humanitarian logistics. The papers that were used in the literature survey are the following (See Appendix B):

(Abo-Elnaga, El-Sobky, & Al-Naser, 2017; Berkoune, Renaud, Rekik, & Ruiz, 2012; Camacho-Vallejo, González-Rodríguez, Almaguer, & González-Ramírez, 2015b; Cao, Li, Yang, Liu, & Qu, 2018; Caunhye et al., 2012; Fatih Cavdur, Merve Kose-Kucuk, & Asli Sebatli, 2016; A. Y. Chen & Yu, 2016; A. Y. Chen et al., 2015; J. Chen et al., 2016; Y. Chen, Zhao, Wang, & Dessouky, 2016; Cotes & Cantillo, 2019; Das, 2018; Garrido, Lamas, & Pino, 2015; Ghasemi, Khalili-Damghani, Hafezalkotob, & Raissi, 2019; Ghasemi, Khalili-Damghani, Hafezalkotob, & Raissi, 2020; Golabian, Arkat, Tavakkoli-Moghaddam, & Faroughi, 2021; S.-L. Hu, Han, & Meng, 2017; Z.-H. Hu, Sheu, & Xiao, 2014; Huang & Rafiei, 2019; Ji & Zhu, 2012; Jiang & Yuan, 2019; Kelle, Schneider, & Yi, 2014; A. C. Li, Nozick, Xu, & Davidson, 2012; L. Li, Jin, & Zhang, 2011; Liberatore, Ortuño, Tirado, Vitoriano, & Scaparra, 2014; Lin et al., 2011, 2012; Yang Liu, Cui, & Zhang, 2019; Yajie Liu et al., 2019; Lu & Sheu, 2013; Y. Ma, Xu, Qin, Zhao, & Du, 2019; Maharjan et al., 2020a; Mahootchi & Golmohammadi, 2018; Mete & Zabinsky, 2010; Mohamadi & Yaghoubi, 2017; M. Mohammadi, Jula, & Tavakkoli-Moghaddam, 2019; R. Mohammadi, Ghomi, & Jolai, 2016; Mollah, Sadhukhan, Das, & Anis, 2018; Momayezi, Chaharsooghi, Sepehri, & Kashan, 2021; Moreno, Alem, & Ferreira, 2016; Moreno et al., 2018; Najafi et al., 2013; Nadjati, Vizvari, & Izbirak, 2016;

Papp, 2019; Jomon Aliyas Paul & MacDonald, 2016; Jomon A Paul & Wang, 2019; Pradhananga, Mutlu, Pokharel, Holguín-Veras, & Seth, 2016; Rawls & Turnquist (2010) & Turnquist, 2010; Rezaei-Malek, Tavakkoli-Moghaddam, Zahiri, & Bozorgi-Amiri, 2016; Rivera-Royero et al., 2016; Rodríguez-Espíndola, Albores, & Brewster, 2018; Roh, Shin, Seo, & Logistics, 2018; B. Rottkemper, Fischer, & Blecken, 2012; Safaei, Farsad, & Paydar, 2018; Schempp, Zhang, Schmidt, Hong, & Akerkar, 2019; Sebatli, Cavdur, & Kose-Kucuk, 2017; Vahdani, Veysmoradi, Noori, & Mansour, 2018; Verma & Gaukler, 2015; Wang, Du, & Ma, 2014; Widener & Horner, 2011; Wisetjindawat, Ito, Fujita, & Eizo, 2014; Xavier, de Mello Bandeira, de Oliveira Silva, Bandeira, & Campos, 2019; J.-H. Zhang, Li, & Liu, 2012).

A data base was created such that all characteristic data and information of the papers as follows. temporary and permanent hubs, hub problem-decision type, transportation (mode, type and vehicles), model programing type, method, model stage, data (provided or existed), triage system, risk of facilities, historical data, using social media and authoritative data, data type (temporal and static) multi-objective function approach, number of indices and the authors.

The collected papers were published in several journals such as: European Journal of Operation Research, Disaster Risk Reduction, Transport Geography, Cleaner Production, Computers and Industrial Engineering, Socio-Economic Planning Sciences, Transportation Research, International Journal of Disaster Risk Reduction, Journal of Humanitarian Logistics and Supply Chain Management.

After collecting the information from intended articles, content analysis is applied followed by discussion and define the gaps and future directions.

3.3 Analysis of Content and Classification

Literature content were categorized into sub-classifications according to emergency logistic operations and planning. Each classification contains operations that are discussed and analyzed as follows.

3.3.1 Type of Disaster

Table 1-C (see appendix C) shows the papers that discussed different types of disasters. Most of the papers focused on earthquake. Some papers discuss more than one disaster or multiple disasters to reflect the uncertainty of multi-disaster occurrence. For example, flooding disaster can cause landslide disaster in some coastal countries. Some countries are not prepared to face the consequences of the disasters due to lack of support and money and they are severely considered unprepared for future disasters like Nepal that face the risk of 3 disasters: earthquake, flood and landslide (Mahrajan, et al., 2020).

Each type of disaster has special consequences and conditions. They are different in time and place of happening, disaster types that were investigated in the literature survey are: earthquake, flood, hurricane or typhoon, snowstorm, landslide, pandemic diseases like malaria. Most of the optimization models in emergency logistic planning focus on earthquake. Earthquake, flooding, snowstorm and landslide are happening suddenly, the time is not known in case of earthquake, but in case of typhoon, the time and place are known, pandemic diseases outbreak like Malaria, Sars, Cholera and Corona virus are happened suddenly and spread widely. Each type of disaster needs special logistic planning to face the consequences and save more lives. The need for emergency logistic planning is crucial to prepare the countries and communities to deal with these crises. The case studies that are used in the

papers actually are employed to test the mathematical models, and it is worth noting that, in order to leverage the accuracy of the mathematical models, we can utilize multiple disasters case studies. disasters.

3.3.2 The Period of Decision Making

Pre-disaster operations may include: evacuation, stock pre-positioning and facility location. Post-disaster operations include relief distribution, casualty transportation to mobile clinics or hospitals and evacuation of victims from disaster areas to shelters. (Liberatore et al., 2014) presented a mathematical model of planning the recovery of damaged parts of the distribution network like bridges and roads which make it possible or unsafe for the vehicles to reach demand centers (towns and villages) since the distribution of relief items to the affected areas is the most fundamental operation in humanitarian emergency logistics. Table 2-C shows that the most research articles focused on pre-disaster period and post- disaster period and few of them focused on reconstruction.

3.3.3 Hub Type

Hubs of emergency logistics are stock stores, evacuation shelters and hospitals. They could be both temporary and permanent hubs. Permanent hubs are strategical big buildings and they are considered as global warehouses that used to store food, water, blankets and other relief items. Temporary hubs are shelters for evacuation of affected people, and they could be wide areas in some places like schools, activity centers, universities, etc. The function of temporary hubs can be evacuation tent, mobile clinics or small hospitals.

There are technical solutions for these functions. As we see in table 3-C, most papers discussed the two types of hubs.

3.3.4 The Types of Problems Related to Hubs

The location of the hubs and stock level are the main problems that are focused by most researches. Hub location problem in emergency logistics aims to determine the geographical location of warehouses to meet all of victims demands (Elnaga, et al., 2017). In order to save lives aftermath of the large-scale disasters, emergency supplies such as food, water, blankets and tents should be provided immediately to the affected people. The vital supplies should be propositioned and provided to warehouses in preparedness stage of decision making and in response stage, the supplies should be distributed to demand points and purchase new and extra items in case of deficits (Pradhanang, et al., 2015). Table 4-C shows that most papers focused on the two types of hub problem.

3.3.5 Transportation Mode

Most papers discussed the problem of transportation as a strategic decision in emergency logistics which is used to provide the relief items for affected people and transfer injured victims to hospitals and displaced people to shelters, according to table 5-C, most papers used road transportation mode in distribution relief items. A few papers used aerial mode, and just 3 papers discussed water transportation mode and one paper used combined transportation mode.

3.3.6 Transportation Type

Two types of transportation are discussed in most papers: emergency type and normal type. Table 6-C shows the types and the number of the papers.

3.3.7 Transportation Vehicles Types

Table 7-C shows that truck or van was the most popular transportation vehicle then helicopters and equipped vehicle ambulances. No paper discussed about unmanned autonomous vehicles (UAV) for several reasons: (a) concentrating on hubs and road

transportation, (b) transportation of large amount of relief items since UAV can hold small number of items and medicine, (c) partially because of the fact that the UAVs became more famous after 2010.

3.3.8 Model Program Type

Several classical optimization techniques are used to solve the optimization problems and generated exact solutions such as linear programming (LP), linear mixed integer programming (LMIP), pure integer programming (IP), mixed nonlinear programming (MNIP), etc. (Mollah, et al.2018) explained that mixed integer programming as a classical optimization approach is used when some variables in the model are real-valued variables and the other variables are integer-valued, also the constraints should be in linear form. MIP problem is solved in most of the cases by branch and bound method.

Table 8-C shows that most papers focused on linear mixed integer programming. Stochastic programming models occur also in large number because of uncertainty in all conditions of disaster like demand including number of victims and displaced people, communication channels, the status of roads and buildings. Deterministic programming used in several papers; these models can use certain data. Few papers discuss scenario-based modeling of disaster management process. Scenario modeling is used when the data are not certain and the problem has randomness in some parameters like the location and amount of demand, transportation routes and time. Disaster scenarios can be prepared using some applications in the literature or using technical disaster experts since the identification of the scenarios and their probabilities is complex task and due to the critical importance of their parameters. Number of scenarios can be extended to distinguish working hours, rush hours and

non-working hours (Mete, et al. 2010). Stochastic programming can use scenario-based methods besides other methods.

3.3.9 Heuristic Method

Several optimization methods are used in solving optimization problems in emergency logistics such heuristic, metaheuristic, average approximation, genetic algorithm, epsilon constant, local search, k-median and k-mean clustering, modified particle swarm, global particle swarm and Multi-Layer Reception. The methods are used to obtain approximate solutions for optimization problems and it is important to use this solution firstly for emergency logistics to save lives as soon as possible and then use exact solutions. Approximate solutions may be checked and validated by conducting comparisons with exact solution. Heuristic techniques are more preferable than classic techniques to solve complex real-life optimization problems when the solution research space is large. For example, genetic algorithm (GA) is a stochastic search method, and it is better than mixed integer programming (MIP) in case of solution search space grows exponentially or polynomial. (Mollah, et al., 2018). The methods can be used with exact programming technique to compare the results of the two methods and define the proper one. (Mollah, et al. 2018) proposed two methodologies to solve the optimization problem based on mixed-integer programming and genetic algorithm and the results are compared. Genetic algorithm is an algorithm that depends on the rules of genetics and natural selection, it means that it is a population-based algorithm (Golabian, et al., 2021). Table 9-C shows all the programming methods that are used by the authors of the papers.

3.3.10 Model Stage

There are single stage and two stage models. Single stage model can create many strategic decisions in the same period of time. Two stage model create the first

strategic decision in specific period of time and create another strategic decision depending on the first decision in different period of time. The decision of the second stage concerns to different factors than the decision of the first stage. Two stage models may use two mathematical models or more which means that the second mathematical model solution depends on the first mathematical model solution and each model could be solved in different period of time. Table 10-C shows that most papers used the two types to solve the optimization problem.

3.3.11 Risk of Facility

The physical status of facilities is very important for modeling; it considers the damage in buildings and roads that happens after disaster striking the cities and communication channels and this situation affects the effectiveness and efficiency of emergency logistics.

Table 11-C shows that only 26 papers discussed risk of facilities. Some papers discussed the risk of facilities aftermath of the natural disaster, and the authors consider damage in facilities when solving the optimization problem such as the buildings, global hubs of relief items, shelters, roads and communication channels.

In case of disruptive disasters, damage for distribution infrastructure like bridges and roads can be occurred, this damage would make it unsafe or impossible for the distribution vehicles to reach centers of demand points like towns and villages, that is the case of Haiti 2010 earthquake where the airport with low capacity was destroyed so the distribution of relief items to victims was extremely constrained. This serious situation needs recovery to repairing of damage for distribution infrastructure as fast as possible to reach victims easily (Liberatore, et al., 2014).

3.3.12 Triage System

After the disaster happened, a wide range of injured people needs urgent medical treatment to survive and they should be treated immediately and continue during the first 24-48 h. The resources for treating all injured people immediately are insufficient for everyone at once. High demand for medical supplies will appear within a short time. For this reason, the priority of injured medical treatment determination based on the severity of the affected people status is essential issue on emergency medical services, all injured and wounded victims are classified into colors such as red, orange, green and blue according to the severity of their medical status. This is called triage system, also each classification or triage has its own medical commodities. It is worth to be note that injured people who belongs to the orange triage should be immediately treated, the response time here is very important to save more lives since any delay for treating the orange triage may convert them to red triage and lose more lives. The red triage color may include breathing damages or neck and head damages and the response time is about 15 minutes, also irregular pulse and the symptoms that are related to angina are assigned in orange triage and they need about 25 minutes to response. Triage system is useful for defining transportation routes between facility locations such as transfer points for providing the high speed of transferring injured victims to the closest hospitals or directly to the hospital according to the shortest travel time. Furthermore, these transportation routes should be safer and better than the other routes for transferring casualties (Mohammadi and Yaghoobi, 2017). (Najafi, et al., 2013) defined the external criteria such as magnitude of earthquake and population affected that are used to define types of injuries, types of commodities and their priorities. As we observe in table 12-C,

triage system that means categorization of casualties according to the severity of injuries in order to treat the most urgently cases firstly.

3.3.13 Multi-Objective Function Approach

Multi objective function approach uses two or more objective functions to solve using the mathematical model. The most frequent objective functions are minimization of total travel time, minimize total network costs consisting of locating facilities and costs of transportation (Mohamadi and Yaghoubi, 2017).

(Najafi, et al., 2013) proposed multi objective model which minimizes the total unserved injuries, total unsatisfied demands and total vehicles utilized and they are minimized hierarchically. (Maharjan and Hanaoka, 2019) proposed multi-objective model using 4 objective functions, minimization of amount of relief items that transported from supply points to temporary hubs, amount of relief items shipped from temporary hubs to demand points and operational costs of opening the temporary hub, and maximization of covered demand by the temporary hub at each demand point. In order to solve multi-objective optimization models, several methods can be used such as: epsilon constraint method, goal programming and hierarchical optimization technique (Moreno, et al. 2018). Table 13-C shows that only 38 papers discussed more than one objective.

3.3.14 Data

Real data received at disaster management center such as the amount of demand, hospital capacities, available commodities, number of injured people and network situation is uncertain and imprecise (Najafi, et al., 2013). Disaster-related data is important in emergency logistics to save more lives and for rapid distribution of relief items and transfer injured victims to hospitals. Because of uncertainty, these

data may not be accurate, to solve this problem, stochastic models are used in case of uncertain data, also deterministic models are used in case of certain data or in case of ignoring the uncertainty situation.

Real data is necessary for testing the mathematical model that is used to solve the emergency logistic problem, data should be existed and easily obtained. It is also important that data should be provided, that is the authors should define the resources of data such as authorities, historical data, government and non-government agencies such as red cross agency, police offices or traffic analysis zones, and emergency logistics centers. Table 14-C shows that only 11 papers used easy-obtained data and the consists data that may difficult to obtain in real life such as deprivation costs that represent social concern according to (Moreno, 2018). Also 23 papers consist data which is provided. Most papers do not deal with data (Lin, et al. 2011, Najafi, et al. 2013, Cao et al. 2018, Liu, et al. 2019).

3.3.15 Discussing the Existence of the Data

Obtaining real data to estimate the parameters to be used in testing the mathematical model is a key challenge. This step is critical as these the values of parameters effect significantly on the validity of the optimal solution and the decision making (Paul and MacDonald, 2016). The accuracy of all data and information related to humanitarian operation logistics are crucial for saving the victims as fast as possible, therefore, the decision makers should focus on obtaining the accurate real data from trusted resources in order to obtain the correct decisions using the proposed mathematical models. Places of demand points, the number of evacuees and casualties, number of temporary and permanent warehouses, the status of the road's routings, different transportation modes availability, types and number of relief

items, the communication channels and the travel time are some important information that can help the emergency logistic offices to reach quickly to demand points and save lives. (Maharajan et al., 2020) mentioned that less than 15% of analytical papers that are focused on humanitarian logistics used real data to test the proposed model, this fact highlights that a big imbalance between these models and the practice. In this survey we can observe that a lot of papers did not focus on the importance of using real-life data to test the mathematical model. They assumed the data to test the mathematical model and also the resource of the data is not provided. Table 15-C shows that a few papers discussed the existence of data but, some of them used simulated data using some kind of software such as HAZUS which uses geographic information system to prepare scenarios of disasters. A few other papers discussed clearly the types of used data such as the number of victims and the demand points that can be obtained them from several resources such as: disaster command centers, relief agencies, information board-disaster web-page, local population, police offices. (Li, et al., 2018) defined humanitarian relief chain such as: international relief organization, local and regional relief organization, private sector companies, government and military forces. (Widener and Horner, 2011) defined the spatial data which include the location of neighborhood centers and their individual populations along with the facility relief hub's locations and their maximum capacity are managed with using GIS and the spreadsheet software. Table 15-C shows the papers that discussed the existence of data.

3.3.16 Historical Data

According to table 16-C, most papers used historical data to test the mathematical model, they used several resources to obtain the historical data such as governmental and non-governmental agencies. Sufficient and accurate data is a challenge in

disaster relief operations, in order to obtain raw data from affected areas aftermath of disaster, we can use many sources such as: news media, police officers, traffic cameras, sensors and phone calls. Common data also may appear in a disaster including reports of traffic flow, structural damage, road conditions and casualties. Emergency management centers receive data and these data may be incomplete, inaccurate and duplicate due to chaotic situations, so it is very difficult to obtain useful information to facilitate disaster response. Data fusion is one of the technologies that is used to efficiently organize and interpret massive amount of data related to disaster-affected areas to emergency response centers when data is varied (Lin, et al., 2011).

3.3.17 Using Social Media and Authoritative Data

Using social media is a challenge for extracting the rescue demand requests and their location, data-driven disaster management is emerged with various authoritative data that can be obtained by cadastral surveys, censuses, and satellite imagery and road surveys. Social media data can be considered as an indicator for rescue demand and awareness of the real situation of affected people after disaster occurs, since the individuals can express their needs and demands, descriptions and opinions and urgency of their current situation (Schempp, et al., 2019). Table 17-C shows the papers that used social media and authoritative data.

3.3.18 Data Type

Two types of data are used in testing mathematical model: static data (deterministic model) and temporal data or uncertain (stochastic model). Static data is used in deterministic models that uses limited parameters like demand, delivery capacity of vehicles and limited working times, in contrary, the temporal data are uncertain data, because of disaster uncertainty the important parameters such as demand, capacity

and communication channels are difficult to obtain them precisely and these uncertain data are used in stochastic models. Usually, deterministic models use one scenario that represents the real case of data and the stochastic model uses several scenarios which represents several cases such as the worst case, best case and medium case. According to table 18-C, 33 papers used temporal data and 16 papers used static data to test the mathematical model.

3.3.19 Number of Indices

All papers used variables in mathematical model. The number of indices is the indication of complexity of mathematical model and its solution, all papers used indices from 1 to 6. Problems using 5 or 6 indices try to solve complex problems. Moreover, the higher the number of indices, the higher amount of individual data are needed to construct the model numerically. However, it is possible that this data is not available. Another difficulty caused by high number of indices, that the numerical problem becomes large and more difficult to solve. However, in emergency logistics we need simple problems to quick solving the problems and to have a reasonable solution to save lives of victims' aftermath of large-scale disasters.

3.3.20 Papers Distribution Analysis

The distribution of the papers has been investigated according to 2 factors: year of publication and the journal. Table 1 shows the number of the publications per year.

Table 1: Number of publications per year

The year of publication	Number of publications/years
2010	2
2011	3
2012	8
2013	2
2014	5

2015	3
2016	12
2017	4
2018	10
2019	15
2020	2
2021	2

Figure 4 shows the frequency distribution for the papers that were published between 2010 and 2021. We can see that 15 papers were published in the year 2019. In the year 2016, 12 papers were published and 10 papers were published in the year 2018. In the other years, little number of papers were published.

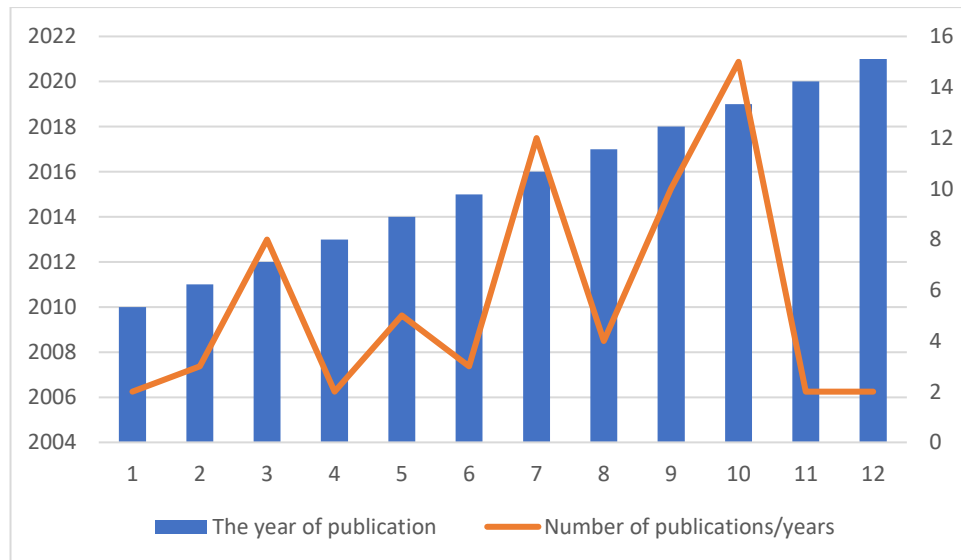


Figure 4: Frequency distribution for the papers published between 2010 and 2021

Table 2 shows the number of the papers according to the journal. The maximum number of the papers that has been published was 9 papers that were published in socio-economic planning science journal. Followed by the journal computers and industrial engineering with 8 papers, and then 6 papers that were published in 2 journals.

Table 2: Number of publications per journal

Journal	Number of publications / journals
Journal of Taibah University for Science	1
Transportation in Disaster Response Operations	1
Journal of Cleaner Production	2
Socio-Economic Planning Sciences	9
International Journal of Environmental Research and Public Health	2
Transportation Research Part B: Methodological	4
Journal of Testing Evaluation	1
International Journal of Aerospace Engineering	1
Computers and Industrial Engineering	8
Expert Systems with Applications	1
Transportation Research Part E: Logistics Transportation Review	6
Applied Mathematics Computation	1
Journal of Ambient Intelligence Humanized Computing	1
Systems Engineering Procedia	1
International Journal of Production Economics	5
Computers Operations Research	4
Natural Hazards Risk	1
Annals of Operations Research,	1
Applied Mathematical Modelling	2
Operation Research	1
European Journal of Operational Research	2
Natural Hazards	1
Egy Statisztikai Vizsgálat	1
The Asian Journal of Shipping	1
Transportation Research Procedia	3
Journal of Transport Geography	1
Procedia-Social Behavioral Sciences	1
International Journal of Disaster Risk Reduction	6

Figure 5 shows the number of the publications per journal. Socio-economic planning sciences journal published 9 papers and computers and industrial engineering journal published 8 papers. Transportation research part E and International journal of disaster risk reduction published 6 papers. International journal of production economics published 5 papers. The rest of journal published few papers.

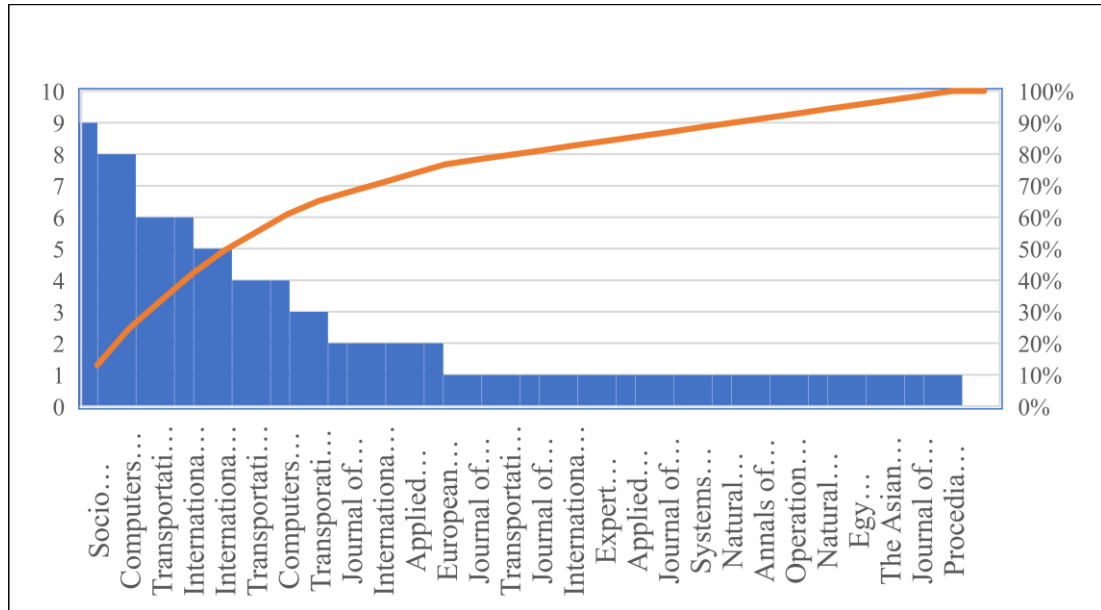


Figure 5: Journal-wise publication distribution for the papers published between 2010 and 2021

3.4 The Relationships Between the Papers

The relationship between papers is important in order to find the most important common properties of the papers, and to find easily the gap and future recommendations. Two methods were used to investigate the relationships: 1) the relationship according to the topic that they discussed, 2) the relationship according to citation between the papers.

Firstly, a set of attributes or properties were collected from each paper as follows. disaster type, hub type, hub problem type, method type, model program, transportation type, mode and vehicles, model stage, data type, data existence and providence, risk of facilities, no. of indices, historical data usage, triage system, social media and authoritative data usage, multi objective function approach. Each attribute or property has many categories or factors. The nature of the collected factors is mostly 0/1 variable. Zero value means that this factor is not discussed in the paper. On the contrary, value 1 means that the factor is discussed in the paper.

The method of this work is used to calculate the correlation between the papers. The correlation is very important to measure how strong the relationship between the papers. Correlation is a very numerical factor. That is why we stored the numbers on the papers.

We selected the correlations of at least 0.9 and at least 0.88 between the papers and then prepare the sparse matrices for each correlation as shown in tables 3, 4 and 5. From the sparse matrices we can find the papers that have relationships. Then specific figures were prepared using MATLAB software as shown in figure 6 and figure 8. Appendix D shows the coding for the figure of correlation 0.9. The figures have a lot of superfluous edge crosses between papers and in order to reduce the crosses we prepared them manually to be more obvious as shown in figure 7 and figure 9. Figure 7 does not contain any extra crossing points. However, the graph of figure 9 contains a $K_{3,3}$ at the nodes $\{\{19, 47, 25\}, \{44, 26, 52\}\}$, thus according to the Kuratowski theorem, it is not planar graph. It means that it is not possible to draw without extra crossing points.

Then specific tables were prepared which contain the common topics between papers followed by suitable interpretation and find easily the similarities and differences between the papers. This work can help in drawing the gap and future recommendations.

For the citation relationship, we prepared specific tables to show the nature relations between papers by finding the cited papers and the citing papers and then we prepared figures to show the citation relations between papers followed by suitable discussion.

Table 3: Sparse matrix for the correlation of at least 0.9

Index	2	1	47	35	19	18	36	44	53	17	26	49
2	1	1	1	0	0	0	0	0	0	0	0	0
1	1	1	0	0	0	0	0	0	0	0	0	0
47	1	0	1	1	0	0	0	0	0	0	0	0
35	0	0	1	1	1	1	1	0	0	0	0	0
19	0	0	0	1	1	1	1	1	1	1	0	0
18	0	0	0	1	1	1	1	1	1	0	1	0
36	0	0	0	1	1	1	1	0	0	0	0	1
44	0	0	0	0	1	1	0	1	0	1	0	0
53	0	0	0	0	1	1	0	0	1	0	0	0
17	0	0	0	0	1	0	0	1	0	1	0	0
26	0	0	0	0	0	1	0	0	0	0	1	0
49	0	0	0	0	0	0	1	0	0	0	0	1

Table 4: Sparse matrix for the correlation of at least 0.88-part 1

Index	1	2	19	35	47	36	18	44	53	17	48	24	34	38	37	49	26	55	51	4	41	58
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
35	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
47	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0
18	0	0	1	1	0	1	1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
44	0	0	1	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0
53	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
17	0	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
48	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
24	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
34	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
38	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
37	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
49	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
26	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
55	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
51	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1

Table 5: Sparse matrix for the correlation of least 0.88-part 2

Index	5	15
5	1	1
15	1	1

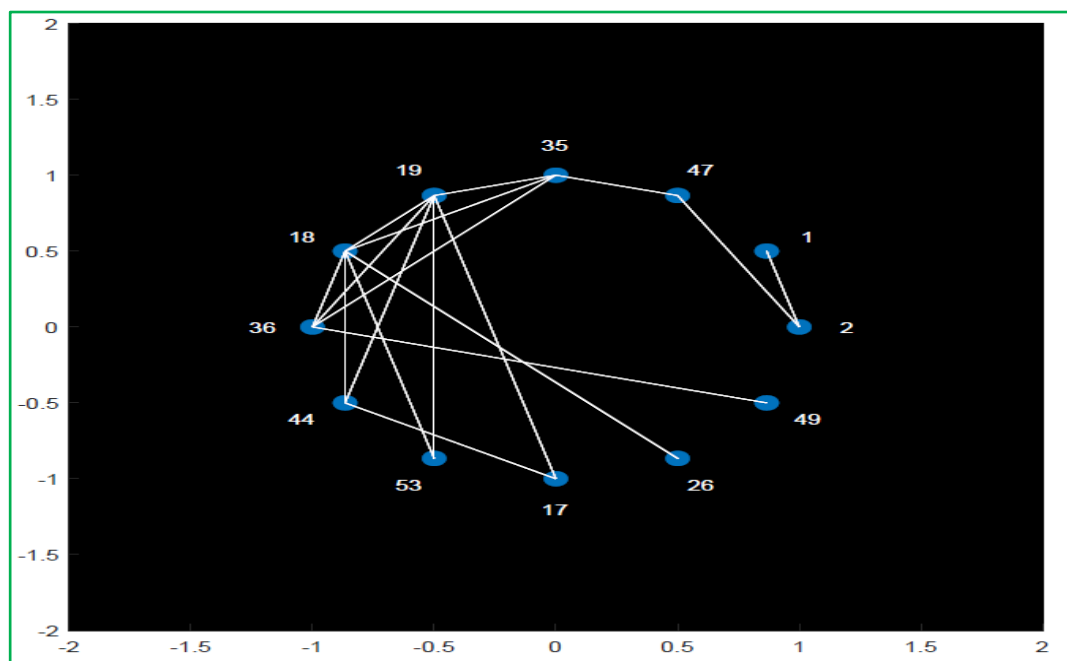


Figure 6: Original figure of regression at least 0.9

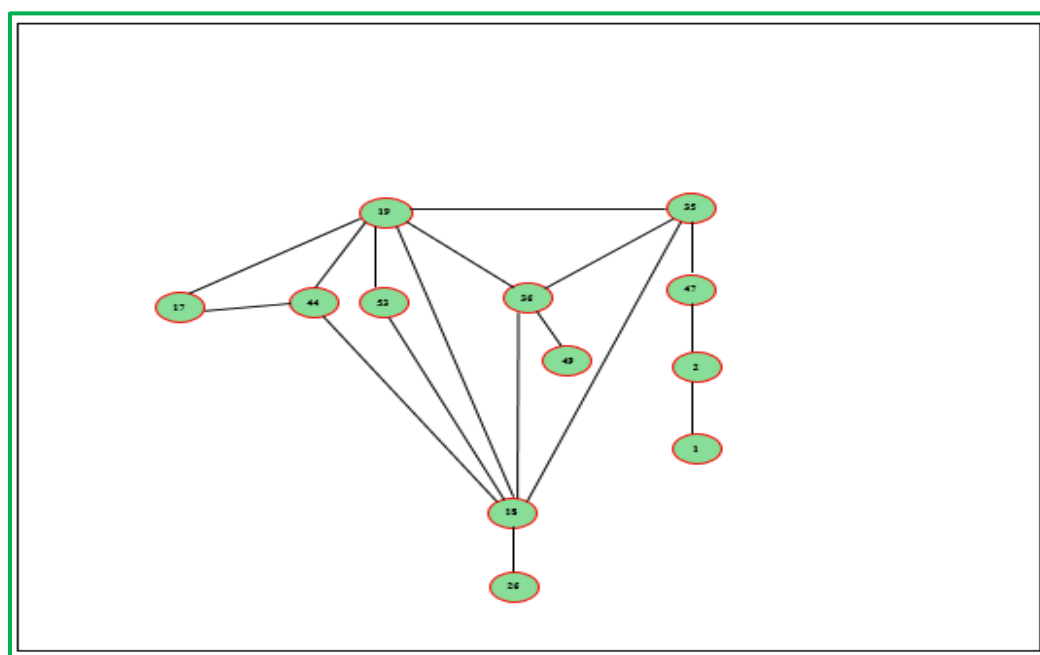


Figure 7: Manual figure of regression at least 0.9

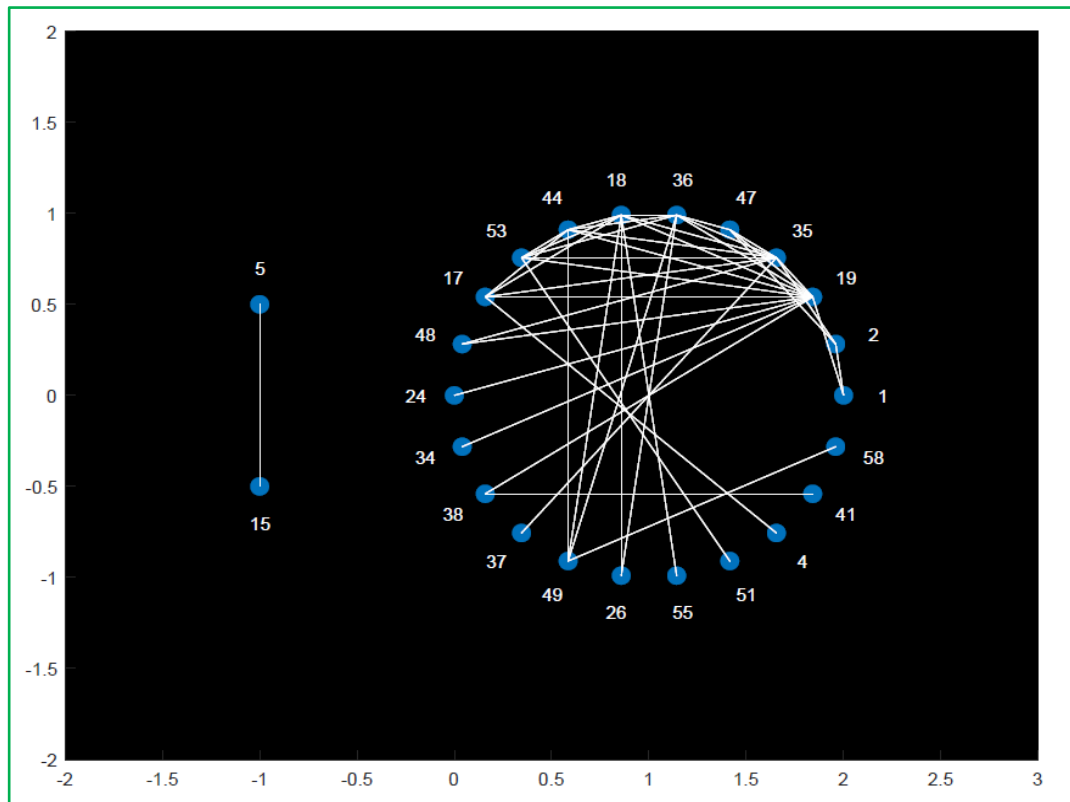


Figure 8: Original figure of regression at least 0.88

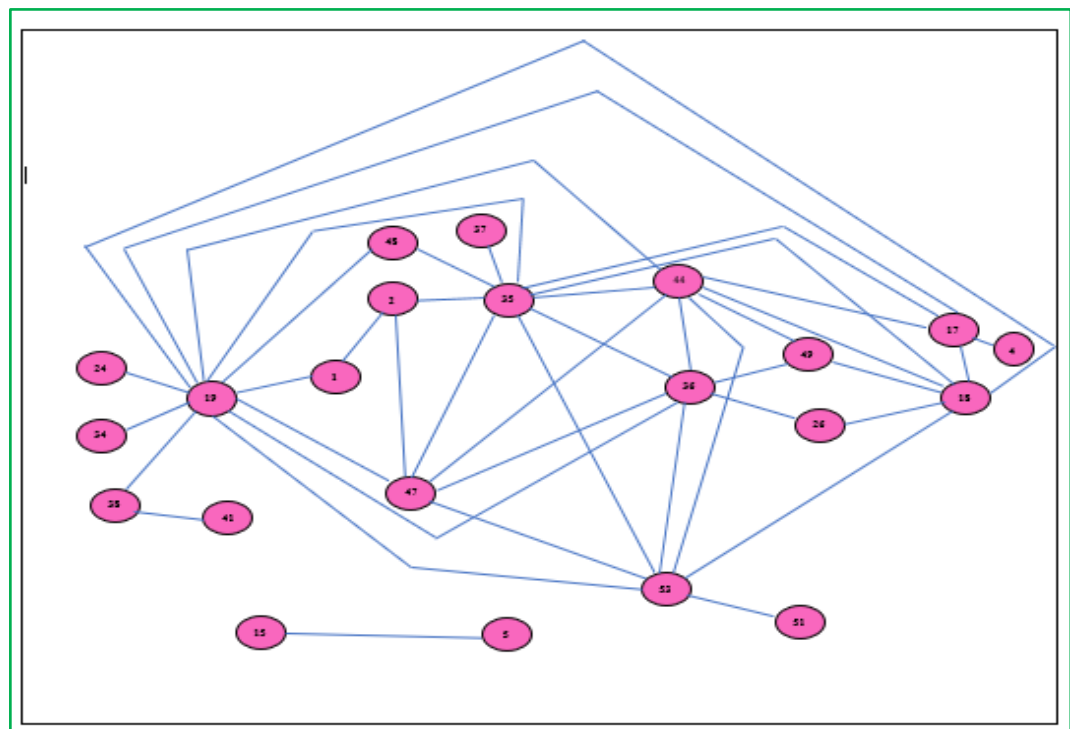


Figure 9: Manual figure of regression at least 0.88

3.4.1 The Relationships Between the Papers According to the Topics

For correlation 0.9 or more, the papers {1, 2, 47, 35, 19, 18, 36, 44, 53, 17, 26, 49} have different relationships in the context of the topics that they discussed (12 papers out of 58).

Table 6 shows the common properties of the 12 papers with correlation 0.9 or more.

Table 6: Common properties of the papers with correlation at least 0.9

Pape No.	Authors	Topic								
		Disaster type	Pre	Post	Hub type - Permanent	Stock level problem	Location problem	Transportation mode	Transportation type	Model program
1	Mete, et al. (2010)	Earthquake	√	√	√	√	√	Truck	Emergency	Mixed Linear, Integer
2	Mohammadi, et al. (2017)	Earthquake	√	√	√	√	√	Truck	Emergency	Mixed Linear, Integer
47	Mohammadi, et al. (2019)		√	√	√		√	Truck+Boat	Emergency+Normal	Mixed NL Integer
35	Vahdani, et al. (2018)	Earthquake	√	√	+Temporary	√	√	Truck	Normal	Mixed Linear, Integer
19	Malek, et al. (2016)	Earthquake	√	√	√+Temporary	√	√	Truck	Normal	Mixed Linear, Integer
18	Pradhananga, et al. (2016)	hurricane	√	√	√	√	√	Truck	Normal	Mixed Linear, Integer
36	Ghasemi, et al. (2019)	Earthquake		√	√+Temporary	√	√	Truck	Emergency+Normal	Mixed Linear, Integer
44	Wang, et al. (2014)	Earthquake	√	√	√+Temporary	√	√	Truck	Normal	Mixed NL Integer
53	Lu, et al. (2013)	Earthquake	√				√	Truck	Normal	Integer
17	Moreno, et al. (2018)	Flood+landslide	√	√	√+Temporary	√	√	Truck+Boat+Helicopter	Normal	Mixed Linear, Integer
26	Momayezil, et al. (2021)		√	√	Temp.		√	Truck	Normal	Mixed Linear, Integer
49	Ma, et al. (2018)		√	√+Reconstruction	√		√	Truck	Normal	Mixed Linear, Integer

Paper No.	Topic										
	Type of model	Method	One stage model	Two stage model	Data provided	Historical data	Triage system	Risk of facilities	Data type	Multi objective approach	Using social media and authoritative data
1	Stochastic		√		√						
2	Stochastic		√		√	√	√				
47	Stochastic	Meta-heuristic, genetic		√		√		√	Temporary/uncertain	√	
35	Robust	Meta-heuristic		√		√		√	Temporary/uncertain	√	
19	Stochastic			√		√		√	Temporary/uncertain	√	
18	Stochastic			√		√		√	Temporary/uncertain	√	
36	Scenario base	Heuristic, genetic, epsilon constant, global particle swarm	√			√	√	√	Temporary/uncertain	√	
44	Scenario base	Heuristic, genetic		√	√	√		√	Temporary/uncertain	√	√
53	Robust	heuristic	√			√			Temporary/uncertain		
17	Stochastic			√		√		√	Temporary/uncertain	√	
26	Stochastic	Meta-heuristic		√		√		√	Temporary/uncertain	√	
49		Modified particle swarm		√		√			Deterministic/Static	√	

As shown in table 6, the papers {1, 2, 35, 19, 36, 44, 53} discussed Earthquake disaster (7 out of 12). Earthquake as a large-scale disaster has a catastrophic consequence and cause a lot of death to human and the research focused on this kind of the disasters to save more lives and to protect the properties and maintain the economic situation. Hurricane, flood and landslide are also considered as large-scale disasters and have catastrophic consequences. However, only 2 papers {17, 18} discussed these disasters. The researchers should focus on these disasters also to save more lives and maintain the economic situation. Also, we have drought, pandemic

diseases like Covid 19, Sars and Cholera and other disasters that need more attention to save the lives and we can use optimization modeling to solve the problems.

Most papers focused on the post and pre-disaster periods as period-decision making phases. Only one paper {49} discussed the reconstruction. Pre-disaster and post-disaster operations are essential to prepare the community to face the disaster. In pre-disaster operations, relief items supply, hubs and warehouse's locations and transportation plan are the most important operations which are needed. In the post-disaster period, distribution of relief items, transportation the casualties to medical centers and shelters are the most important operations. There are more operations that are important after disaster strike, recovery of the community, rebuilding the damaged building and debris removing. These operations were discussed rarely. The research of humanitarian logistics should be considering the operations of recovery stage and reconstruction.

Due to complexity of the real-life problem, all papers discussed both temporary hub and permanent hub problems. The stock level is essential in disaster operations, the stock of relief items is stored in permanent hubs partially before disaster happening. The coordination and corporation between several actors such as donators and government are very important to provide all types of relief items that are sufficient to all victims.

For the hub problem-decision type, most papers combine between location and stock level. These decisions are essential for disaster operations management. Location decision is important to choose the optimal locations of different hubs such as

evacuation hubs, warehouses hubs. Stock level decision is important to manage the amounts of relief items to be stored before and after disaster happening.

The transportation type generally was normal type, a few used emergency types, in cases of natural disaster. The transportation mode should be prepared as emergency type to save more lives and to give first aid easily and professionally. Most of transportation vehicles are normal and some of them used emergency equipped vehicles, it is important to focus on the emergency vehicles for transportation the casualties.

Real life data give accurate information about the victim's number, locations of demand points, the type and number of relief items. Only 3 papers provided the source of the information. In order to provide real life results or at least reasonable solution, the research should define the source of information that can be used to solve the problem.

For the transportation, it seems that all papers used road transportation to transfer the relief items and the casualties except papers {17, 47} they used water and air transportation besides ground transportations. The ground transportation and even the airport may expose to damage. It is important to study another type of transportation such as unmanned autonomous vehicles (UAV), railway, and water transportation. The new types of transportation should be compared with ground transportation in order to obtain the most economic and safe solution.

Most papers discussed the mathematical models using multi-objective approach. The most common objective functions are minimization of transportation costs in terms

of distance and time, minimization of number of facilities for full coverage, minimization of unmet demand and maximization of covered demand points with limited number of facilities. We can see most papers used 6 or 5 indices. These models are too difficult to solve. The mathematical models are complex and need a lot of real-life data. The collection of information takes a lot of time to solve. In cases of natural disasters, we need to solve the mathematical models in easy way to help the decision makers to decide the strategic decision as fast as possible to save more lives.

Most papers used mixed linear integer program for solving the problem as exact model program (9 papers out of 12), two papers discussed mixed nonlinear integer and one paper discussed integer programming. Some of papers (7 papers out of 12) used heuristic and meta heuristic approximate methods such as genetic-the most used and effective, epsilon constant, global particle and modified swarm. Heuristic methods used to solve complex problems to find approximate solution for decision makers.

Most papers treated the uncertainty aspect of the disaster. Stochastic programming is the most approach that was used to deal with uncertainty aspect (7 papers out of 12). Furthermore, robust (2 papers out of 12) and scenario-based (2 papers out of 12) approaches are also used. Uncertainty of disaster is common due to the sudden situation of the disaster and the different consequences aftermath of the disaster. Some factors that may cause the uncertain situations of the disaster such as: the place and the time of disaster happening, the intensity of the earthquake that causes building and communication channels damage, etc. As a result, demand quantity and the number of victims is dynamic and changing over time.

For model stage, most papers used two stages to solve the problem (8 papers out of 12), and 4 papers used one stage model. Two stage model or sometimes called it bi-level modeling, uses the leader and the follower decisions, it means that in the first model, the first decision is obtained (the leader decision), and according to the first decision, the second decision is solved (follower decision). The first decision or the leader becomes a constraint for the second mathematical model.

Most papers (8 out of 12) considered risk of facilities in the models, it means that the facilities such as warehouses or other hubs can expose to damage. Furthermore, communication channels and roads expose to damage. This aspect is very important for rescue operations, casualties' transportation and distribution of relief items.

Triage system, that means classify the injuries according to the severity of the victim status, was discussed only by two papers. It needs more investigation to treat this important aspect.

Only 3 papers provided the sources of the data used in the model. Most papers used temporary or uncertain data type (11 papers) and only one paper used deterministic (static) data. Most of papers (11) used historical data to solve the model. It is worth to be noted that one paper discussed the usage of social media and authoritative data. Social media occupies a very important place in communication. Artificial intelligent and internet of things also are added value in collecting real information of number of victims, the place of victims, the quantities of relief items needed in each area and other important information. It is worth to recommend to focus on social media and connect it with emergency command system of the country.

For correlation at least 0.88 we have the following relationships as shown in table 25, the common properties and the descriptions are as correlation 0.9 or more. The first 12 papers are the same papers in correlation 0.9 or more, another 8 papers were added to the list which are: (4, 24, 34, 37, 38, 41, 38, 51). One paper (41) discussed dynamic approach to treat the uncertainty aspect of the problem. The papers (4, 83, 51) discussed flood disasters and the rest focused on earthquake. The paper used indices from 2 to 6 in the mathematical model, most of the problems are complex and used 5 or 6 indices and this is one of the important problems that we found in this study.

Table 7: Common properties of the papers with correlation at least 0.88

Paper No.	Topic											
	Type of model	Method	One stage model	Two stage model	Data provided	Historical data	Triage system	Risk of facilities	Data type	Multi objective approach	Using social media and authoritative data	No. of indices
1	Stochastic		√		√							5
2	Stochastic		√		√	√	√					5
47	Stochastic	Meta-heuristic, genetic		√		√		√	Temporary/uncertain	√		6
35	Robust	Meta-heuristic		√		√		√	Temporary/uncertain	√		5
19	Stochastic			√		√		√	Temporary/uncertain	√		6
18	Stochastic			√		√		√	Temporary/uncertain	√		4
36	Scenario base	Heuristic, genetic, epsilon constant, global particle swarm	√			√	√	√	Temporary/uncertain	√		5
44	Scenario base	Heuristic, genetic		√	√	√		√	Temporary/uncertain	√	√	3
53	Robust	heuristic	√			√			Temporary/uncertain			2
17	Stochastic			√		√		√	Temporary/uncertain	√		6
26	Stochastic	Meta-heuristic		√		√		√	Temporary/uncertain	√		3
49		Modified particle swarm		√		√			Deterministic/static	√		3
4			√			√		√				5
24	Robust		√			√	√		Temporary/uncertain	√		4
34	stochastic	genetic		√		√	√	√	Temporary/uncertain	√		6

37	deterministic	heuristic		✓		✓			Deterministic /static	✓		6
38	Stochastic , Lagrange multiplier	heuristic		✓		✓			Temporary/ uncertain	✓		2
41	dynamic			✓		✓			Deterministic /Static	✓		3
48	Robust			✓		✓			Temporary/ uncertain	✓		4
51	Deterministic		✓			✓			Deterministic /Static	✓		4

3.4.2 The Relationship Between the Papers According to the Citation

In order to investigate the relationship between the papers according to the citation, we studied the citation of papers by checking the list of references of each paper for the regression 0.9 or more, at least 0.88. Tables and figures were prepared properly to describe the relationship according to the citation that can be illustrated by further discussion in the following sub-sections.

3.4.2.1 The Relationship Between Papers of Regression 0.9 or More

We checked 12 papers {36, 53, 49, 1, 2, 47, 26, 17, 18, 19, 35, 44}, as a result, according to the table 26, papers {37, 1, 2, 18, 4, 44} were cited from 7 papers {36, 53, 49, 17, 18, 19, 35}

Table 8: The relationship between papers of regression at least 0.9 according to citation

The cited paper	The title of the cited paper	The authors	The citing paper	Times of citation
37	Location of temporary depots to facilitate relief operations after an earthquake	Lin, et al. (2012)	17	1
1	Stochastic Optimization of Medical Supply Location and Distribution in Disaster Management	Mete, et al. (2010)	53, 49, 17, 18, 19	5
2	A bi-objective stochastic model for emergency medical services network design with backup services for disasters under disruptions: An earthquake case study	Mohamadi, et al. (2017)	15	1
18	An integrated resource allocation and distribution model for pre-disaster planning	Pradhananga, et al. (2016)	17	1

4	A dynamic model for disaster response considering prioritized demand points	Royero, et al. (2016)	17	1
44	Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake	Wang, et al. (2014)	35	1

The most cited paper is paper 1 with the title of “Stochastic Optimization of Medical Supply Location and Distribution in Disaster Management”, it is cited 5 times. On contrary, paper 17 with title “An effective two stage stochastic multi-trip location-transportation model with social concerns in relief supply chains” cites the most papers among the 12 papers in question which are {37, 1, 18, 4}. It was written later and it must get to further than the previous papers. It is the reason why it cites several times. The papers {37, 2, 18, 4, 44} were cited only one time. The papers {36, 53, 49, 18, 19} cites one paper. The paper 18 has relationship with two papers, it cites one paper {1} and it is cited from one paper {17}.

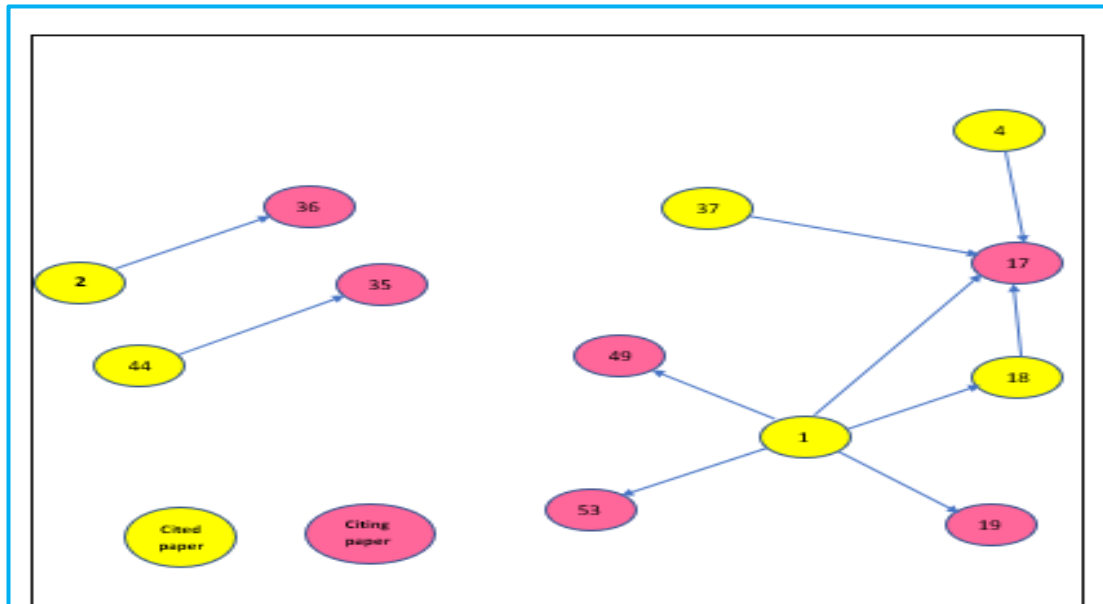


Figure 10: Figure of the papers with regression at least 0.9 according to the citation relationship

Figure 10 shows clearly the relationships between the papers, we can see that paper 1 is the most frequent paper, it has 5 relationships, however, paper 17 also has clear relationship with 4 papers, and paper 18 has relationship with 2 papers and the rest of papers has only one relationship.

3.4.2.2 The Relationship Between Papers of Regression at Least 0.88

We checked 24 papers {51, 24, 36, 34, 41, 38, 55, 37, 53, 49, 1, 2, 47, 5, 26, 17, 18, 19, 4, 48, 35, 44, 15, 58}. The table 27 shows that those 11 papers {24, 36, 47, 53, 1, 2, 5, 18, 4, 35, 44} were cited from 13 papers {51, 24, 36, 34, 38, 55, 53, 49, 17, 18, 19, 48, 35}.

Table 9: The relationship between papers of regression at least 0.88 according to citation

The cited paper number	The title of the cited papers	The authors	The citing paper number	Times of citation
24	A stochastic programming approach for flood emergency logistics	Garrido, et al. (2015)	48	1
36	Uncertain multi-objective multi-commodity multi-period multi-vehicle location-allocation model for earthquake evacuation planning	Ghasemi, et al. (2019)	34	1
37	Location of temporary depots to facilitate relief operations after an earthquake	Lin, et al. (2012)	17	1
53	Robust vertex p-center model for locating urgent relief distribution centers	Chung-Cheng Lu and Jiuh-Biing Sheu b,al.(2013)	24	1
1	Stochastic Optimization of Medical Supply Location and Distribution in Disaster Management	Mete, et al. (2010)	51, 55, 53, 49, 17, 18, 19	7
2	A bi-objective stochastic model for emergency medical services network design with backup services for disasters under disruptions: An earthquake case study	Mohamadi, et al. (2017)	36	1
5	A cost optimization model and solutions for shelter allocation and relief distribution in flood scenario	Mollah, et al. (2018)	38	1
18	An integrated resource allocation and distribution model for pre-disaster planning	Pradhananga, et al. (2016)	17	1
4	A dynamic model for disaster response considering prioritized demand points	Royero, et al. (2016)	17, 51	2
35	Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty	Vahdani, et al. (2018)	34	1
44	Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake	Wang, et al. (2014)	35	1

Table 9 illustrates the relationship among the papers having regression at least 0.88 and figure 11 visualizes these relationships. As we observe, paper 1 is the most important paper, 7 papers {51, 55, 53, 49, 17, 18, 19} cites the paper 1. The paper 17 cites 4 papers {37, 1, 18, 4}. Paper 4 has relationship with 2 citing papers: 17 and 51. The papers 35 and 36 cited by the 34. Also papers 4, 18, 1, 37 cited by the paper 17.

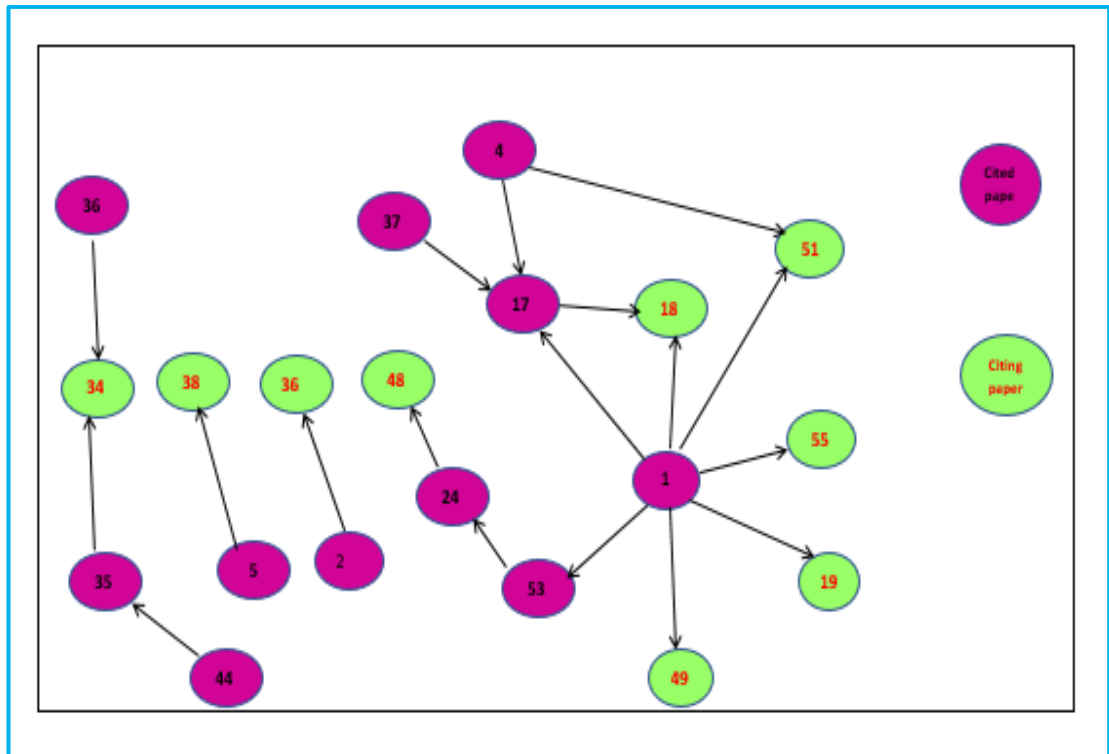


Figure 11: Figure of the papers with regression at least 0.88 according to the citation relationship

The papers {51, 18, 4, 24, 34, 53, 35} have relationships with two papers and the rest of papers have one relationship with others. It means that there are some differences, common properties and interactions between the papers.

We can find the relationship between the papers by comparing the key characteristics of each paper. Table 28 illustrates the differences between paper 31 and paper 35.

The correlation coefficient between paper 35 and paper 31 is 0.75. Paper 35 is a typical for applying stochastic model and scenario-based approach to disaster relief but it is a general paper and some specific information are missing. Paper 31 covered some improvements in the solution as mentioned in the table.

Table 10: The differences between paper 31 and paper 35

Key Characteristic	Paper No. 31	Paper No. 35
Title of the paper	A multi-verse optimizer algorithm for ambulance repositioning in emergency medical service systems	Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty
Year of publication	2021	2018
Disaster type	Not defined-general	Concerns to earthquake
Type of equipment	Equipped emergency vehicle (more restricted, however deeper results can be obtained)	No specific vehicle
Type of vehicle	Ambulance vehicles (same remark)	Truck vehicle
Model program-exact method	Integer programming model (pure integer)	MILP (as a matter of fact not necessarily big difference)
Uncertainty aspect	Robust vertex p-center model	Stochastic model and scenario-based model
Heuristic algorithm	Genetic algorithm	No specific algorithm
Another heuristic algorithm	Metaheuristics and relaxation-multiverse optimizer algorithm	Metaheuristic – not specific
Model stage	one stage	Stage is not defined-two stage
No. of indices	2 indices, less complex solution	5 indices, more complex solution
Data Type	Static data type/deterministic	Data type is temporal/uncertain
Usage of social media	Used social media, more reliable information	No usage of social media

3.5 Results and Discussions

This chapter reviews 58 optimization models related to emergency logistics in case of large-scale natural disasters such as earthquake, flooding, hurricane. Content analysis technique used to break down the structure into several parts and the key

characteristics of optimization models are extracted such as type of disaster, hub problem, programming method, transportation, data, triage system, risk of facility and other parts. Tables and simple statistics are prepared and followed with discussions and analysis.

The most of the analyzed papers focused on earthquake then flooding and typhoon, just one paper discussed about pandemic disease (malaria). It is necessary to focus on pandemic diseases, we need more strict and logical procedures to face the quick spread of these diseases and protect the humans. In this context, we can use temporary tents and prepare them technically, and we can produce also enough quantities of protective masks and other personnel protective materials.

The vast majority of research focuses on the mathematical models and on their solutions. The models are complex. Furthermore, some papers include parameters such that it is not possible to obtain in real life accurately like deprivation costs. Moreover, the authors suggest the solution of complex mathematical model several times in cases of multi objective functions and bi-level optimization. These methods take more time. On the other hand, decision makers should decide as fast as possible the location of hubs and transportation of relief items and injured people for saving more life. Another problem that we found in this study is data existence and providence is not discussed. Most of the authors did not define the resources of data needed to construct the mathematical model. It can be difficult to obtain the data in real life. It is noticeable that more than 50% of research papers in emergency logistics used multi-objective models, although according to (Caunhye, et al.,2012), the emergency logistics research seems reluctant to apply multi-objective models because they are difficult to solve and need a lot of time. In this survey, most of

authors focused on pre-disaster operations and post-disaster operations, but very few papers discussed the reconstruction and recovery to restore the normal life such as: psychological situations for the victims, repairing the cracked roads and buildings, amending the electric and water lines, communication channels. Most papers discussed pre-disaster and post-disaster operations and just 5 papers discussed the reconstruction and recovery after disaster happening. Distributing emergency goods to demand points, emergency personnel and equipment moving to affected areas, repairing damaged road and bridges and other communication channels and removing debris are vital operations in emergency logistics to save more lives, so the authors should focus on reconstruction and recovery to solve different problems. It is noticed also from the survey that most papers focused on road transportation and no paper discussed other new and technological ways of transportation like unmanned autonomous helicopters (drones) which can be used to help in transferring the medicines and food to victims in isolated areas. (Nedjati, et al., 2016) proposed to introduce small unmanned aerial vehicles (UAV) as a new relief distribution system after earthquake strikes specially for highly populated cities, since the road transportation faces difficulties in distributing the relief items due to road blockage and time limits. Also, we can use UAV for collecting real time data and send them directly to emergency command centers. (Chen, et al., 2016) mentioned that UAV system and its aerial image analysis are used to evaluate the damage degree of earthquake area, and a new index of damage degree evaluation was proposed in this paper to assess the damage intensity that produced from earthquake disasters.

It is noticed in this survey that only 11 papers discussed using social media and authoritative sources to obtain the important information aftermath of disaster such

as rescue demand, casualties' number and the degree of damage that happened to buildings and infrastructure routing lines. Nowadays, social media data set and technological applications on the mobile phones and the inventions in the field of information system, artificial intelligent and internet of things are improved dramatically, it is necessary to focus on information technology and how to use social media and mobile phones and other inventions to obtain real life disaster information to save more lives.

The following directions are recommended for future work:

- The current survey was prepared depending on the research papers that are published between 2010 and 2021, new survey can be prepared to cover the publications that are published before 2010 and after 2021 and conduct comparisons between different surveys.
- We studied 58 papers related to hub problem in emergency logistics, we can increase the number of surveyed papers to obtain more realistic study.
- We can add more key characteristics in the following survey paper such as: pre-disaster operations and post-disaster operations and categorization for each kind of operation, like: stock-propositioning, short-notice evacuation, casualty transportation, relief items transportation, evacuation of displaced persons to shelters, relief distributions...etc. The literature can be analyzed based on other parameters in order to prepare holistic study such as: objective functions, decision variables, constraints, type of facilities such as shelters and medical centers.

Chapter 4

DESIGN and PREPARATION of MASS PRODUCTION SYSTEM for PROTECTIVE ITEMS in the EUROPEAN UNION (EU) for the CASE of SERIOUS PANDEMICS

4.1 Introduction

Pandemic diseases like, Malaria, Sars, Ebola virus and recently Covid 19 are disasters and cause death that may exceed millions of people. Pandemics are happened suddenly in any time and place. Therefore, the governments of the world should prepare a new strategic plan to face these emergency situations in both pre-disaster and post-disaster periods.

In this chapter we will focus on the situation of COVID 19 pandemic that happened in the year 2020. The study is carried out to evaluate the defense procedures that had taken place in European Union (EU) and propose a robust and new plan to face the sudden pandemics in the future in order to protect the population from the infection and death. The defense against COVID 19 consists of two main parts. The infected people must be treated and cured, and the spread of the infection must be hindered. The first needs medical processes which may require special equipment and materials. The second needs vaccination if any vaccine exists, protective tools, personal protective equipment such as face masks, clothes like gowns and disinfectants in great amounts, as even healthy persons must use them. Branches of

science which deals with logistics and production can help in the preparation and organization of the production and distribution of the finished products. They are mainly protective items which were needed in the case of the pandemics. There is one exception: the medical ventilator. The production technology of the protective items is simple. It was a surprise that Europe in general and particularly the European Union (EU) were not prepared for the production of these items. It shows a certain kind of vulnerability of the area. The production was considered as a market economy issue and not as a security issue. The reason is that it was the first time that the EU had needed a huge quantity of these items. The market reacted slowly to the suddenly appearing new demand and to the equally suddenly disappearing previous demand. Companies showed limited and late flexibility. The EU was in need of Asian, mainly Chinese's imports. Italy was able to get very little help from other parts of the EU. There was no action which showed the EU functioning as a single system.

This chapter considers the production of protective items and disinfectants to be a "National security issue" on the level of the EU. It suggests principles for how to organize such a system and provides calculations about the way in which the system works. The case of production face masks elaborated in this chapter. It also considers the production of gowns. The reason for this choice is that both items need the technology of the fashion industry. Optimization modeling of operation research is utilized to solve the problem of facility location problem in order to define the optimal location of the production hubs that produce face mask to cover the whole population of the EU.

4.2 Types of Protective Items and Their Production

The simplest protective item is the mask, which can be used by anybody. Several types of masks can be produced in factories. The common raw material of surgical masks as seen in figure 12 and N95 masks in figure 13 is polypropylene, also masks can be produced by using nanofibers as in figure 14 and textiles as figure 15.

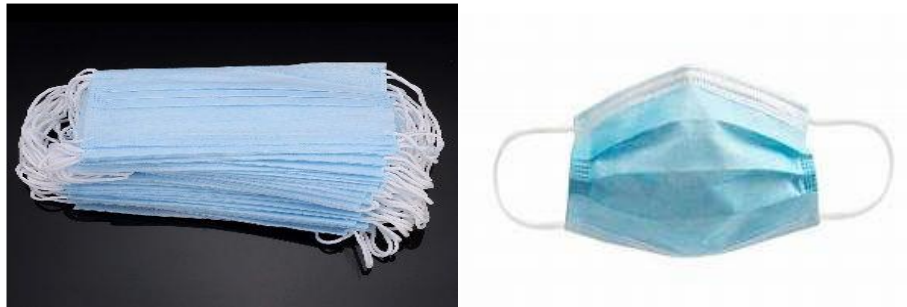


Figure 12: Surgical face mask



Figure 13: N95 masks



Figure 14: Non-fiber mask



Figure 15: Textile face masks

3D printer production can help to produce personal protective items in case of polypropylene (PP) shortage during the pandemic. Presents the detailed procedure for printing 3D face shields and ventilator promptly and effectively as shown in figure 16. Bio-cellular face shield with relative comfortability made of bio-macromolecules polymerized polyvinyl chloride (BPVC) and other biomaterials are produced with 3D printers. Furthermore, 3D printing used to produce bio-macromolecules antiviral respiratory assistance and other medical devices to help patients in hospitals (Oladapo, Ismail, Afolalu, Olawade, & Zahedi, 2021). (For more information see Appendix D).



Figure 16: 3D printing face shields and ventilator

Textiles can also be used as raw material. The use of textile is typical for the smaller factories. The raw material is folded and the shape is fixed by sewing or welding and the fixture is added. The fixture is an ear loop or band from the same material as the mask. General Motors (General Motors, 2020) and several Chinese companies (BYD, 2020; China 1, 2020; and China 2, 2020) show a highly automated technology for production.

In general, the operations are as follows. 1. folding of the raw material, 2. cutting of the folded raw material to proper size, 3. fixing of the shape, 4. the addition of ear loops or other fixtures, 5. sterilization, and 6. packing. Depending on the particular technology, some operations can be done in a single step. Different operations are automated on different production lines and thus, different operations are executed by workers. The operation times are also very different. For example, the fixing of the ear loop takes 23 seconds at General Motors (General Motors, 2020) and four seconds at (China 3, 2020), although in both cases it is done by workers. If the operation is automated, then it takes 1 second (BYD, 2020).

The capacity of the factory depends on the number of production lines and workers. The raw material is polypropylene in most cases. However, textiles can be used as well. It is clear that mask is a very simple product. Any company in the fashion industry can produce them. Many companies lost their orders in this sector as the suppliers had to close their factories. Interestingly, not all companies in the fashion industry reacted in a flexible way by starting to satisfy the new demand. However, this was a way to survive the crisis; see for example the reaction of a small Hungarian company (Szombathely, 2020). On the other hand, a large quantity of

masks needed by Italy arrived from China, although Italy has a large fashion industry.

The advantage of a factory operating in the fashion industry switching to the production of masks and gowns is that it can be done in one day and does not need any investment. The production of gowns cannot be automated because of the complex shape of the product. Small factories and workshops in the fashion industry can play a crucial role in satisfying local demand.

There are factories in China which specialize in the production of protective items. They started production several years prior to the pandemic (China1, 2020).

4.3 Estimation of Demand and Capacity

The estimation of the demand is difficult. The questions to be answered are: who needs the masks? How many pieces are needed by a person? Masks are not recommended for children under the age of six years. Thus, the theoretical answer is that every person above the age of six years needs one mask per day. However, persons who work in some sectors, like health care, public transport, and shops, may need more than one per day. A surgical mask can be used once in principle. Thus, every person who must wear one needs a new mask every day. However, the demand determined in this way is a rough overestimation of the real demand. Surgical masks can be sterilized in an autoclave or using other options for sterilization (Autoclave, 2020). This phenomenon decreases the demand of medical and veterinary practices. Another reason is that many people keep to the curfews and do not need masks. Similarly, other people do not change their masks, unfortunately.

The production capacity increased greatly in 2020 in China, which has a complete technology for the automated production of masks. China even has a producer of this automated technology (China 3, 2020). (Parker, 2020) stated that the production capacity of China is 200 million masks per day. Starting in May 10, the company BYD alone had a capacity of 50 million masks per day (BYD, 2020). Consumption in the country was 8 million masks per day (China 4, 2020). Thus, most of the production is exported. The increase in capacity is a serious investment. The payback period of the capital should be very short as it is not known when the next pandemic will occur. This makes the prices high. The high cost of air transportation from China to Europe contributes to the high prices as well (China 4, 2020).

Thus, the demand rises in different areas at different times. This is good from the point of view of supply, because a lower total capacity is sufficient. The population of China was estimated to be 1,400 million in 2019 (China 5, 2020). The 8 million masks consumed daily accounts for less than 0.6% of the population. The gap between the theoretical demand and the real-life demand is too large to draw exact conclusions. Wearing of masks is very likely concentrated in cities, with people tending not to use them in large rural areas due to lack of supply and disobeying the rules.

It can be supposed that relative demand in the EU is proportionally higher. The population is 440 million people (Wikipedia, 2020). Table 11 lists the daily demand of masks that are provided to different percentages of the population.

Table 11: Potential daily demand for masks in the EU

Percentage of the population requiring masks		Demand in millions of pieces
1		4.4
5		22
10		44
15		66
20		88

It is clear that the demand in the EU is less than the production in China. Thus, it is possible to have the needed capacity even in Europe. The production quantity depends on the available quantity of the raw material as well.

4.4 The Structure of the Suggested System

There are three main sources of masks in the suggested system. The most important sector consists of the production units in the EU which are not under the juridical supervision of the member states during the pandemic. The distribution of their production is planned and supervised by the Committee of the EU in accordance with the temporary situation. The production and distribution must be financed from a special fund by the Committee. This arrangement also means that the governments of the member states may not prohibit the export of the items produced by these factories from their own countries. Air and road transportation are used for distribution. Local governments are responsible for the distribution of the quantities allocated to the country by the Committee.

The selection of the production companies on EU level must be made according to principles of supplier selection in supply chain management (Alkahtani & Kaid, 2018). First, an invitation to tender must be announced to companies. The applicant

companies must estimate the future capacity, the set-up time for starting production, the price, technological level of the production lines, service quality and safety, time of delivery, responsiveness, affordability, capability, flexibility and reliability. The applications must be accepted or rejected. The selected companies must be located far from each other. The next section shows a simple mathematical model like the capacitated plant location model (Sridharan, 1995) for selecting companies from the accepted applications such that the total transportation cost is minimized.

The member states obtain the delivered products at a priori selected centers. A member state may have several centers, because some states have large areas. Each state is responsible for the distribution within the state.

The establishment of the factories needs investment on the level of the EU. It is more economic to create supplementary capacity in existing factories. Production lines must be purchased and maintained from time to time. Some raw materials must be stored to allow a rapid start of production if necessary. These raw materials must be replaced by new ones from time to time. The factory must have a plan for how to make space for labor-intensive operations.

Small local factories in the fashion industry are the second main source. There are many such companies which can react in a flexible way. The necessary measures taken by governments may claim to stop the production in these factories. The production of protective items can help avoid the financial collapse of these factories. Even when there is a lack of polypropylene raw material, they can produce masks from the available textiles, although these masks are less effective. The total capacity in this sector is considerable. It can produce masks without investment but in a more

labor-intensive way. This sector can contribute in another way to the production of protective items. Companies in the fashion industry have complete technology even for gown production. Gown production can be supported technically even on the level of EU by providing cutting patterns for the raw material and patterns for gowns.

This sector can satisfy local demand for masks or the demand for gowns in a larger area. The cost and required transportation capacity for distribution of the items obtained from the first and second sources can be decreased in this way. It is difficult to estimate the capacity of the sector as the structure of the fashion industry is variable in EU countries. Based on the example given by (Szombathely, 2020), it is supposed that there is one facility for every million people and that it is able to produce 30,000 masks per day. Thus, the capacity of the sector can be huge. However, only a part of this capacity can be converted to production of masks, gowns, or both.

Import is the third main source. Obviously, China and even India will be able to satisfy a large demand (India, 2020). Imports can be a great help at the beginning of a pandemic when the factories in the EU are still switching production to protective items. Imports can help to solve critical situations when a factory has a breakdown.

Another important sector in the system is the chemical industry, which produces polypropylene, the most important raw material for the textiles used for protective items, and the textile itself, which is the direct raw material for the safety items. Thus, the system goes at least two technological steps back. There is the supplier of the textile-type raw material and the supplier's supplier, who provides the necessary chemicals.

An important principle of the system is that no single capacity satisfies the demand. If a production facility is located in an infected area, it can easily happen that its products cannot be used. Each facility must have a higher capacity than would suffice if all facilities can work.

Companies join the system of emergency production on both the level of the union and on the national level by bidding contracts. They must have the necessary technology and a certain amount of raw material. They must obtain financial support if investment is necessary to purchase the technology. The source of the financial support depends on the level at which the company joins the system. However, each member state of the EU must have a certain amount of emergency capacity depending on its size and population. Obviously, the member states must agree on the principles and parameters of the system. Let us assume that the potential pandemic is detected outside the EU. Then the system works as follows.

STEP 1. The world health organization (WHO) detects an epidemic which could develop into a worldwide pandemic. The WHO issues an alarm to the rest of the world.

STEP 2. The commissioner for the EU responsible for health care alerts the companies belonging to the system that they need to prepare for emergency production. This preparation includes the production of a relatively small initial stock. The alert concerns the chemical industry as well, that is, the suppliers and their suppliers.

STEP 3. When the pandemic is detected within the EU, then the commissioner orders the start of the emergency production. The states where the pandemic appeared start their own production as well. The commissioner has the right to ask states where the pandemic is not yet occurring to start production and distribute items to other member states.

STEP 4. Distribution starts from the EU level production. The reports of the member states form the basis for determining the daily quantities. These quantities are transported from the EU level companies to the a priori determined centers of the member states. The member states must pay for the items obtained.

If the pandemic is detected in the EU, then the health authorities of the member state, the commissioner of EU, and the WHO must cooperate directly.

4.5 The Methodology of Selection of Facility Location (Production Hub) and Capacity

The aim of the model is to provide a calculation tool for the decision maker to select the facilities. An economic production network can be created in this way. The network can serve the whole EU by the proper cooperation of the member states. The objective that must be achieved is as follows.

- What is the optimal number of the production hubs from a set of pre-defined accepted applicants that can produce the face masks which are covered all the demand points at minimum transportation distance?

4.5.1 Assumptions Before Problem Formulation

Assume that the first round of the evaluation is over and that there is a known set of companies which have acceptable application. However, the final selection is still to

be made. The locations and potential capacities of the companies are known. In the second round, the selection of the EU level companies is carried out based on careful calculations. The demands are based on the population of the regions represented by centers in the model. Each center is assigned to a production facility such that its total demand can be obtained from that facility. The capacity of each production facility is at least as great as the total demand assigned to that facility. All demand points (centers) have road access to and from the candidate production hub. In this way the population demands are distributed among production facilities according to population distributions and all demands are produced and provided to all population. As a result, all population are covered using pre-determined number of production facilities.

4.5.2 Formulation of Production Hubs Model

A mathematical model is discussed here which minimizes the total transportation distance in order to define the optimal location of the production facilities that have acceptable application from the first trial and cover all demand. The model has been formulated as a single-stage deterministic problem with coverage constraint. This model categorized as a new version of maximal coverage facility location problem in which we have limited number of facilities that can serve the maximum population within a stated service time or total transportation distance. The original maximal covering location problem (MCLP) is mentioned in (Maharjan, 2020) where the objective function is maximization of total demand points that are covered within a specified maximal service distance, which is subjected to a limited number of facilities. All demand must be covered in the model below. It is why its objective function is a kind of cost minimization.

4.5.3 The Data that are used in the Model

- The demand of the centers
- The potential capacities of the accepted applicants
- The distances between the production facilities and the centers.

The model uses two types of variables:

- A 0–1 decision variable for each applicant representing its acceptance or non-acceptance
- The quantities transported from facilities to centers.

These parameters and variables are summarized in Table 12 as follows.

Table 12: Parameters and decision variables for face mask model

Parameters	
I	The set of accepted applicants
J	The set of centers
p	The number of applicants to be accepted
d_j	The demand of center j
K_i	The capacity of applicant/facility i
c_{ij}	The distance between applicant/facility i and center j
Decision Variables	
x_{ij}	Percentage of the demand of center j that is delivered from applicant/facility i
y_i	The decision variable for the acceptance of applicant/facility i

The assumptions and the objective function of the model are as follows. It is assumed that the system is feasible, that is, that the total capacity exceeds the total demand which is defined according to the population distribution and this fact guarantees the coverage of all demand points, that is,

$$\sum_{i \in I} K_i \geq \sum_{j \in J} d_j.$$

In the case of the equation, the only feasible solution is to establish all facilities. This constraint is called coverage constraint which is a kind of logic constraint (Maharjan, 2020).

The objective function is to minimize the total transportation performance:

$$\min \sum_{i \in I} \sum_{j \in J} c_{ij} d_j x_{ij}$$

The total demand of each center is assigned to facilities:

$$\forall j \in J: \sum_{i \in I} x_{ij} = 1.$$

A facility cannot deliver more than its capacity:

$$\forall i \in I: \sum_{j \in J} d_j x_{ij} \leq K_i y_i.$$

The number of accepted facilities is p :

$$\sum_{i \in I} y_i = p.$$

The quantities transported are non-negative:

$$\forall i \in I: \forall j \in J: x_{ij} \geq 0.$$

The decision variable is either 0 or 1:

$$\forall i \in I: y_i = 0 \text{ or } 1.$$

The problem is an integer programming problem and exact optimization solution is obtained. Instead of the non-negativity requirement of the x variables, it is also possible to claim that they must be 0 or 1 as well. This means that a facility is

completely responsible for centers assigned to it. There is no significant difference from a computational point of view, as discussed in the next section.

4.6 Example and Numerical Results

An example is elaborated for the continental countries of the EU, i.e., Cyprus and Malta are not included with the exception of Luxembourg. In most cases, the country is represented by its capital. Italy and Spain are each represented by two cities: Rome and Milan in Italy and Madrid and Barcelona in Spain. Germany is represented by Hamburg, Berlin, and Munich in the example. In these cases, the demand is distributed equally among the representative cities. Thus, the number of cities is 28. The basic data are listed in Table 13.

Table 13: The countries and their cities (the estimated demand of face mask in the EU countries)

Country	Cities	Population	Estimated demand
Germany	Berlin, Hamburg, Munich	83900000	469700000
France	Paris	67100000	375600000
Italy	Milan, Rome	60400000	338100000
Spain	Madrid, Barcelona	46700000	261400000
Poland	Warsaw	38400000	215000000
Romania	Bucharest	19500000	109200000
Netherlands	Amsterdam	17400000	97400000
Belgium	Brussels	11500000	64400000
Greece	Athens	10800000	60500000
Czech Rep.	Prague	10700000	59900000
Sweden	Stockholm	10300000	57700000
Portugal	Lisbon	10300000	57700000
Hungary	Budapest	9800000	54900000
Austria	Vienna	9000000	50400000
Bulgaria	Sofia	7000000	39200000

Denmark		Copenhagen		5800000		32500000
Finland		Helsinki		5500000		30800000
Slovakia		Bratislava		5400000		30200000
Iceland		Dublin		4900000		27400000
Croatia		Zagreb		4100000		23000000
Lithuania		Vilnius		2800000		15700000
Slovenia		Ljubljana		2100000		11800000
Latvia		Riga		1900000		10600000
Estonia		Tallinn		1300000		7300000

The demand is determined in a simple way. It is assumed that 2.5 billion masks must be produced and distributed in a time period of 20 days. This represents more than five masks per person. Hence, the daily production is 125 million pieces which quantity is a lower bound for the necessary total capacity. This assumption takes into account that the distribution takes time. We assume road distributions. The route of the distribution is:

$$\begin{aligned}
 & facility \rightarrow center \rightarrow other\ cities\ in\ the\ country \\
 & \rightarrow \{pharmacies, hospitals, etc.\}
 \end{aligned}$$

The distances used in the calculation are surface distances from facilities to centers. The cost of this type of calculation is which appears on the level of the EU. Thus, the objective function contains these transportations. The costs of further transportation, i.e., the transportation from the centers to the final customers are covered by the member states. The unit of the transportation cost is 100,000 pieces of mask $\times$ km. It is supposed that the real transportation cost is proportional to this quantity.

Two different capacities of facilities have been investigated. The smaller one is a capacity of 25 million pieces per day and the larger is 50 million pieces per day. In the case of the larger capacity, there must be at least three facilities. In the case of the smaller one, five facilities are sufficient. However, for safety reasons, it is better to use more. Figure 17 shows that the total transportation cost of the EU level distribution decreases exponentially with the number of facilities.

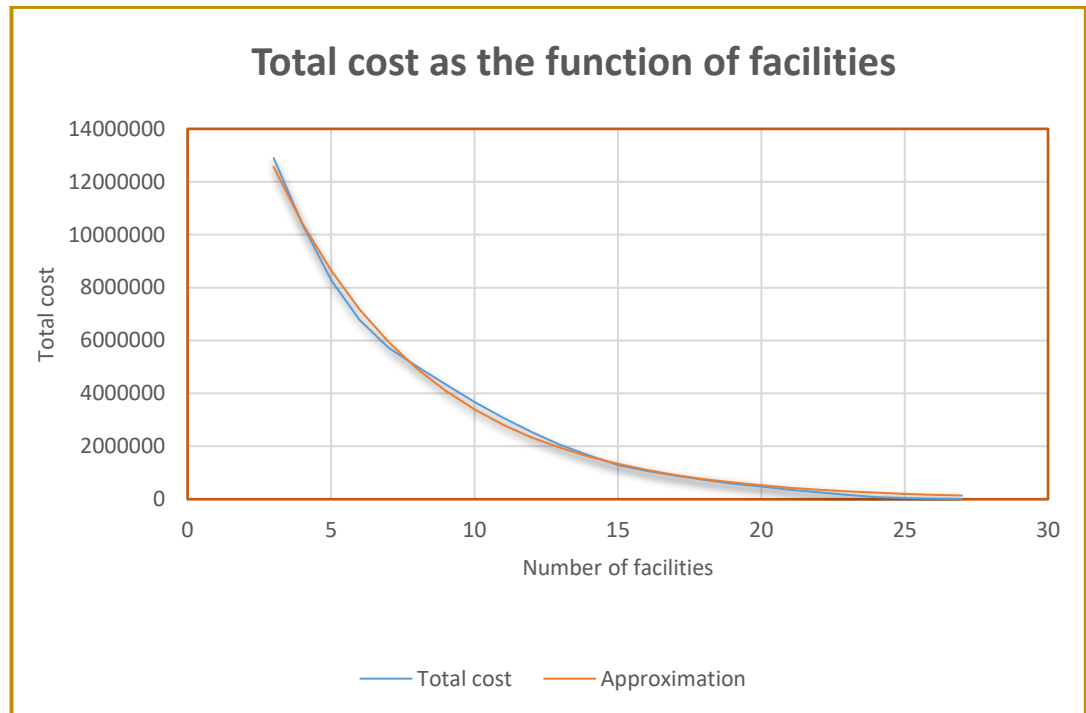


Figure 17: The total cost versus the number of facilities. The capacity of each facility is 50 million mask per day (Total cost = $220142189e^{-0,18689p}$, p: the number of facilities).

Figure 17 contains the results of sensitivity analysis; the formula can be used to find the total cost if number of facilities is changed.

The structure of the system is given in Table 14. It depends on the number of facilities. There is one structure if the number of facilities is not greater than six.

Another structure exists if it is between seven and ten. It is not realistic to establish even more facilities on EU level.

Table 14: The locations of the facilities with different numbers of facilities

Number of facilities	Cities in which the facilities are located
3	Munich, Paris, Warsaw.
4	Berlin, Madrid, Paris, Sofia.
5	Berlin, Madrid, Milan, Paris, Sofia.
6	Berlin, Madrid, Milan, Paris, Sofia, Warsaw.
7	Hamburg, Madrid, Munich, Paris, Rome, Sofia, Warsaw.
8	Hamburg, Madrid, Munich, Paris, Rome, Sofia, Stockholm, Warsaw.
9	Athens, Bucharest, Hamburg, Madrid, Munich, Paris, Rome, Stockholm, Warsaw.
10	Athens, Barcelona, Bucharest, Hamburg, Madrid, Munich, Paris, Rome, Stockholm, Warsaw.

If the capacity of each facility is 25 million masks per day, then there must be at least five facilities. The results are identical with the exception of five facilities. Furthermore, there is no significant difference between the results obtained when the x variables are allowed to be continuous or have to be binary. The obtained optimal solutions are exactly the same if the number of facilities is at least four in the case of a capacity of 50 million pieces and if the number of facilities is at least six in the case of a capacity of 25 million pieces. The optimal solution of the locations of the production hubs is clarified in the map of EU as we see in figure 18



Figure 18: The optimal solution of the 3 cities, Munich, Paris, Warsaw

The optimization problems were solved by Xpress solver on a laptop with 64 bits, 4G of memory, and an Intel Core I3-2310 M processor operating at 2×2.10 GHz. If the x variables were claimed to be integer, then integer programming iterations were performed in the case of the larger capacity when the number of facilities was three or four and in the case of the smaller capacity when the number of facilities was five. In any other case, the optimal solution was obtained immediately, that is, within one second.

4.7 Discussion and Results

During the COVID-19 pandemic, the EU showed itself to be technologically inferior to Eastern Asia. The production of protective items with simple technology started with a long time-lag. The EU needed huge amounts of Chinese imports. This implies that the EU is vulnerable and this fact raises security issues.

The demand for protective items is high in the case of a pandemic. Otherwise, it is low. This chapter suggests a system on the level of the EU that can produce sufficient amount of protective items in the case of a pandemic. Manufacturers selected from applicant companies can cover the demand of the whole EU. The facilities must be located far from each other as the pandemic does not occur in the whole of the EU at the same time. The fashion industry may play a great role in the system. Participation can help companies to survive the economic crisis caused by the pandemic. The calculation to select the set of companies producing the items at the minimum cost is easy and fast. New version of simple mathematical model with coverage constraint was used to find the optimal locations of the companies to cover all demand points.

A similar study can be carried out for the chemical industry in the future. The chemical industry produces the raw material for important protective items and disinfectants which are important to overcome the pandemic. Also, we can use unmanned autonomous vehicles (drones) to transport the relief items like the face masks and distribute the demand to the centers. Using drones is a faster way than the road transportation using vehicles and railway. The industry of the drones is developed quickly with remote communication channels and multi-rotors. The endurance of the drones will be considered as the coverage distance of the demand. Some of the drones called multi-copters (CAVs) can hold up to 150 kg (Saastamoinen & Taipale, 2020). It can be seen on figure 18. Using aerial distribution system besides ground transportation vehicles together (tandems) in both reachable and isolated areas (split transportation) can serve more demand points.



Figure 19: Multi-copters drones

Chapter 5

ON LOCATION OF TEMPORARY HUBS FOR POST- DISASTER SUPPLY ALONG A RIVER

5.1 Introduction

Flood is a disaster that accounts for about one-third of all natural geophysical disasters in all the world. Affecting a huge number of victims compared to other natural misfortunes. According to the natural international flood network, about 471000 fatalities and approximately \$49 billion USD were owed by natural disasters between 1995 and 2004, and about 20 percent of the fatalities and 33 percent of the economic damage was caused by floods alone. India is mostly exposed by flooding due to the presence of large number of the rivers. About 83 percent of the total floods happens in Asia. According to international disaster database, a total of 143 floods have occurred in India since the year 1900, affected more than 300 million people. The 2013 North India flood, leading in death of more than 5700 people and more than 500 people were killed and 1.8 million were displaced in the 2015 Chinni flood. (Mollah et al., 2018).

Most of the floods occur along rivers. The place of these floods is known. There are periods of the year when the probability of flood is higher. Assume for example that the river gets its water partially from high mountains. When snow is melting, the river gets much water and the occurrence of flood is more likely. If there was large amount of snow, then the flood can be expected. Notice that there is still time to the

outbreak of the flood. In that case, the place and time of the flood are known. It makes possible to do preparations in the pre-disaster period. Not all floods have this structure. A single rain which is exceptionally heavy can cause flood in an area of a plain.

To protect the people in the areas of the world that exposed to flooding, pre-disaster operations can contribute in saving more lives. The displaced victims need shelters to be evacuated. The distribution of humanitarian relief items among the affected people is essential as fast as possible. The relief items are pre-positioning in permanent hubs in preparedness stage. Temporary hubs such as tents or wide areas such as schools, stadium, churches, mosques and sport lands are used as an evacuation hub. Furthermore, temporary hubs are using as warehouses to store the relief items close to the affected people but they should be located in safe place and not damaged by the flood. These temporary hubs or warehouses called relief centers and they can be wide areas or temporary tents. Perishable items should be store in places that are temperature-controlled. The aim of this chapter is to provide a tool for pre-disaster decision making and preparedness for the flood.

5.2 The Methodology

To find the optimal location of the temporary hubs along the river, optimization modeling with simple mathematical model was used. The concept of location coverage problem was introduced in the model using the coverage distance.

There are two cases: the river with dam and the river without dam. In the two cases, we used the concept of maximal coverage in which the maximum number of demand points are covered using minimum number of temporary hubs within specified distance along the river. All demand points will be covered with the service, i.e.,

evacuation and/or relief items distributions. In the two cases, we use the distance constraint in different ways in order to help in choosing the optimal locations of temporary hubs. In the case of the river with dam, we used logical constraints. The idea of the algorithm k out of n is used that proposed by (Habib and Szantai, 2000). A possible constraint is that a certain number of consecutive locations has at least one intact hub. The potential locations of the temporary hubs are in equidistant places along the river. In the case of the river without dam, the potential locations of temporary hubs are safe if their places are higher than the flood. Therefore, we should find the optimal locations of the temporary hubs as high as possible and they are the right-hand neighborhood of the starting point of a segment along the river. The closest hub to any place of the river may not be longer distance from the place than the safety distance. This guarantees a maximal coverage of demand points within this distance which starts from an initial point along the river. The maximum level of the river should be observed to find the probability distribution of extreme values. The safe places to locate the temporary hubs are those above the highest level of the flooding. The objective that must be achieved is as follows.

What are the optimal locations of the temporary hubs in case of flood from a set of the neighborhood places that can serve all demand points within a specified safe distance along the river?

5.3 On the Modeling the Height of the Flood

The maximal value of the flood is observed every year. The weather has a lot of random factors. Thus, the numerical values of factors depending on the weather are random as well. If the factors can be measured rarely, for example only once in each year, then the values measured in different years are considered independent in the

sense of probability theory. The maximal value of a factor should be understood as follows. A time series collects the values of the factor. The time series are divided into disjoint blocks of equal length. The blocks cover the whole time series. The maximal value in a block is a random variable. Its distribution is important in case of statistical methods. It can be modeled by so-called extreme value distributions. The three most important ones are Fréchet, Weibull, and Gumbel distributions. Each of them is the member of the Generalized Extreme Value Distribution family. Gumbel distribution has been successfully applied in (Bozso, et al., 2005). This paper also discusses Fréchet, and Weibull distributions. Gumbel distribution is used in the numerical example discussed below.

If a location is covered by water, then it cannot be used as a hub. In case of random events, it is not possible to select locations such that the whole area will be served from hubs on them for sure. However, it is possible to increase the probability of this positive outcome.

Two cases must be distinguished. The first one is if no dam protects the area along the river. The maximal height of the flood is determining that hubs can work on which locations. It worth to take into account that the distribution of relief items should be finished even before the flood reaching its maximal height. Thus, the existence of hubs may make sense even if they cannot work in the whole-time frame of the flood. If dam exists, then the probability that a location is covered by water is less, but it is not impossible. Sometimes, water is moving under the dam and forms an abundant source on the protected side of the dam. Dams can even collapse causing a catastrophic event. One or more location can be covered as the consequence of such events. Thus, it is necessary to estimate the probability that neighboring

location are covered by water. In what follows, different mathematical models are suggested to the without and with dam cases.

5.4 Mathematical Model for the Case of No Dam

In this and the next section, two different cases of the selection of the temporary hubs are discussed. The factor which makes the cases different is the existence versus non-existence of dam along the river. The selection takes place still in the pre-disaster period. It is part of preparedness. It also means that the necessary technical preparations can be done on the selected locations.

Dams along the river are saving the area behind the riverside. In the case of no dam, a place is safe from a flood only if it is higher than the flood. Therefore, the main criterion of the selection is to find potential locations of temporary hubs as high as possible. This principle still does not determine a unique criterion as it is discussed below. The selection also must fulfill another technical requirement. It is that every place which may need help from hubs during the flood is close to a hub. Figure 20 shows that the flood covers most of the homes, we can select safe places that are higher than the flood to locate the temporary hubs to serve the victims along the river.



Figure 20: Flood Covers the Houses

The general assumptions on the problem which are valid in this section and even in the next one discussing the case of the existence of dam, are as follows.

1. In the case of flood, the passing the river by large amount of relief items can be dangerous. Therefore, the methods and models discussed below concern for the defense of one side of the river. However, if aerial transportation is possible with drone having large transportation capacity, then the hubs can be on both sides of the river. A single system can serve both sides in that case.
2. The part of the river where the defense take place, can be considered as a linear segment. It is $[0, L]$ where the length of the segment is L .
3. Positions of the potential locations are determined by two data. The first one is that how far it is from the starting point 0 of the segment. The second one is the height.
4. All places within the segment must have a hub within an a priori defined distance d .

5. A preliminary investigation selects finite many potential locations. Each one is a possible place of a temporary hub.

6. The number of the selected potential locations is fixed.

The necessary notations to the assumption are described in table 15:

Table 15: The notations of the assumption-Group 1

Notation	Description
L	The length of the segment $[0, L]$ to be defended.
n	The number of potential locations selected preliminary.
p	The number of hubs to be selected in the final solution.
d	The safety coverage distance, i.e., the closest hub to any place of the river may not be to a longer distance from the place than d .
(l_i, h_i)	The position of a potential location where l_i is the distance from the initial point of the segment, and h_i is the height of the location.

Before continuing the listing of the notations, some remarks must be done. It is assumed that:

$$0 \leq l_1 < l_2 < \dots < l_n \leq L. \quad (1)$$

The restriction of the index order in this way does not affect the generality of the discussion. Let i and j be two indices such that $i < j$. Assume that both locations are selected as location of temporary hub; however, no location between them is selected. Locations i and j cover all the places along the river in the intervals $[l_i - d, l_i + d]$ and $[l_j - d, l_j + d]$, respectively. Thus, if there is no uncovered place between the two intervals, the inequality

$$l_i + d \geq l_j - d \quad (2)$$

must hold as it follows from (1). The inequality

$$0 \leq l_j - l_i \leq 2d \quad (3)$$

is a consequence of (1) and (2). Moreover, if (1) holds, it is equivalent to (2). Thus, if a potential location is selected, then within distance $2d$ on its right another one must be selected unless its distance from the right end of the segment, i.e., from L , is less than d . Figure 21 shows the river side segment and two locations, each location can serve the demand points within $2d$ and form the two directions: left and right-hand sides to guarantee that all demand points are covered. The yellow triangular represents the optimal location of the hub.

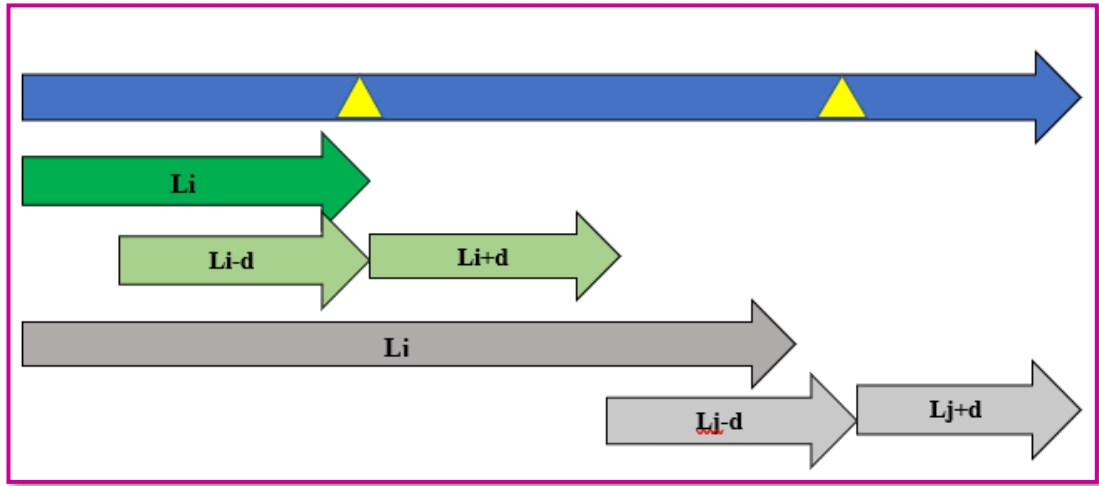


Figure 21: River Side Segment and the Optimal Locations

Formalizing the constraints, two more notations are needed as described by table 16.

Table 16: The notations of the assumption-Group 2

Notation	Description
I	The set of potential locations such that $i \in I$ implies that $L - l_i > d$.
$J(i)$	The set of potential locations such that they are right from i and their distance from i is not greater than $2d$.
M	A big positive number, see below how to choose it.

The set $J(i)$ is in a more formal way as follows.

$$J(i) = \{j | j > i, l_j - l_i \leq 2d\} \quad (4)$$

The starting point of the segment, i.e., 0 is introduced as a potential location, if it is not a potential location on its own right. It is an element of the set I by definition.

Before discussing the constraints of the optimization problem, the variables are shortly described as mentioned in table 17.

Table 17: Decision variables of no dam case

Notation	Description
x_i	The decision variable on the selection of potential location i .
h	The objective function variable.

The variables of the optimization problem of the selection $x_i (i = 1, \dots, n)$ are 0-1 variables such that

$$x_i = \begin{cases} 1 & \text{if potential location } i \text{ is selected} \\ 0 & \text{if potential location } i \text{ is not selected.} \end{cases} \quad (5)$$

The constraints which claim that along the $[0, L]$ segment all places have a selected location within distance d are as follows.

$$\text{For all } i \in I \quad \sum_{j \in J(i)} x_j \geq 1 \quad (6)$$

The restriction of selecting only a limited number of locations is expressed by the equation:

$$\sum_{i \in I} x_i = p \quad (7)$$

To make the set of constraints complete, (5) is stated in a more formal way as

$$x_i = 0 \text{ or } 1, i = 1, \dots, n \quad (8)$$

There are at least two suitable criteria for an objective function. The first one is that every location has as much safety as possible. The safety of location i depends on the height. This fact implies that the height of the lowest selected position must be maximized. Let M be a large number. For example:

$$M = \max \{h_i | i = 1, 2, \dots, n\} - \min \{h_i | i = 1, 2, \dots, n\} + 1$$

is a proper choice. The minimal height of the selected locations is denoted by h . If a location is selected, then its height is at least as much as the minimal height, if a location is not selected, then the location does not affect the objective function. Thus, the selection is formalized by the inequalities:

$$M(1 - x_i) + h_i \geq h, i = 1, \dots, n \quad (9)$$

Notice that if location i is not selected, then the value of left-hand side is:

$$\begin{aligned} M + h_i &= \max \{h_i | i = 1, \dots, n\} - \min \{h_i | i = 1, \dots, n\} + h_i + 1 > \\ &\max \{h_i | i = 1, \dots, n\} + 1, \end{aligned}$$

i.e., the constraint is automatically satisfied if $p \geq 1$. If the location is selected, then the left-hand side is h_i which is a constant value. It restricts the value of h . Thus, the objective function of the problem is:

$$\max h \quad (10)$$

The summary of the problem is that the objective function (10) is to be optimized under the conditions (6) - (9).

Another objective is to maximize the total height of the selected location, it is:

$$\max \sum_{i \in 1}^n h_i x_i \quad (11)$$

The summary of that problem is that the objective function (11) is to be optimized under the conditions (6) – (8).

The disadvantage of the first objective function is that it may have many optimal solutions. Some hubs might be moved to higher position without violating the constraints. The disadvantage of the second objective function is that it is possible that some locations are selected on low position. It is also possible that the problem (6) – (10) is solved first. Let h^* be the optimal value. A second optimization is also possible. Besides the condition (6) - (9) a new constraint is introduced which is:

$$h \geq h^* \tag{12}$$

The objective function (11) is optimized under the conditions (6) - (9) and (12). This model is the lexicographic solution of the bi-objective problem (6) - (9) and objective functions (10) and (11). The lexicographic order concerns to the objective functions.

The numerical solution of the problem is shown by an example. The data of the example can be found in the Appendix E. There are 50 potential locations which must provide relief items along a 190+ kilometer long segment of the river. It is supposed that it is possible to transport relief items for a distance not longer than 20 kilometers to both direction along the river from every location. The model (6)-(10) of this numerical problem has 50 binary variables and one continuous variable. The number of constraints is 95. In principle, the model is NP-complete. However, its structure is simple. Thus, the CPU time used by Lingo 12 software for optimization is negligible, i.e., less than 1 second. The computer had Intel (R) Pentium (R) D 3.00 GHz processor and 2.00 G RAM.

Example: If $M=12$ hubs available to locate, then the optimal solution is shown in table 18.

Table 18.: The optimal solution of the mathematical model without dam

The available hubs to locate	Distance (KM)	Objective Function value	The selected locations to locate the hubs (optimal solution)
12	20	13.69	X3, X9, X12, X17, X18, X19, X20, X21, X23, X28, X33, X34, X37, X38, X47

Figure 22 shows the locations of the candidate hubs and the optimal solution that are presented in red color, we can observe that the optimal solutions are the highest locations. This solution guarantees that these locations of hubs are safe and far from any future flooding.

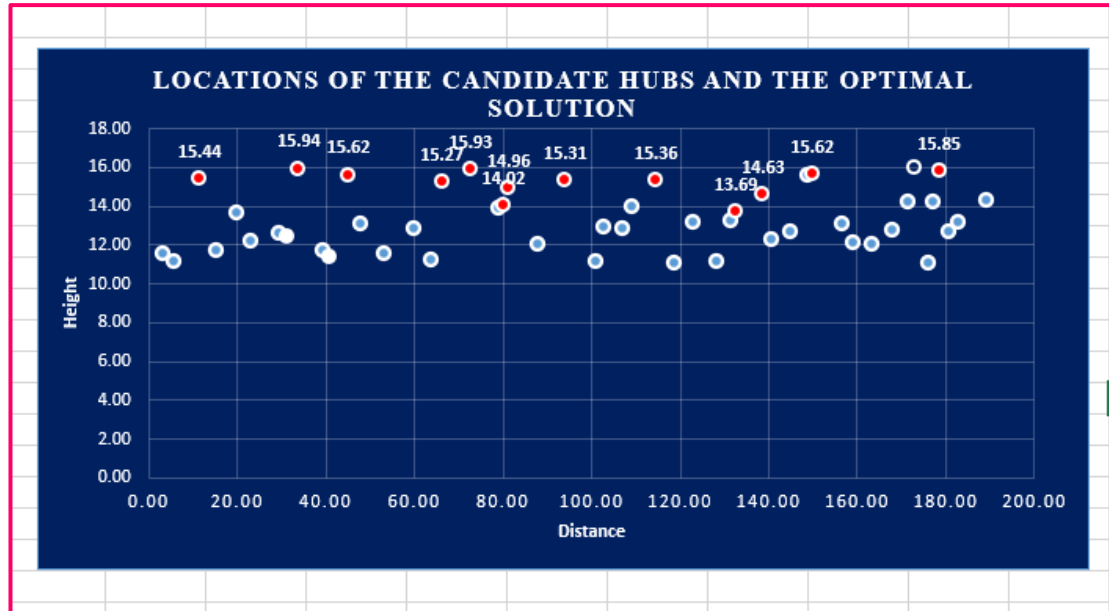


Figure 22: The Candidate Locations and The Optimal Solution

For sensitivity analysis purpose, we tested the mathematical model using different values of parameters as shown in table19.

Table 19.: The sensitivity analysis of the mathematical model without dam

The available hubs to locate	Distance (KM)	Objective function value
12	20	13.69
15	20	13.69
25	20	13.14
12	19	13.96
12	25	14.63
15	25	14.25
20	25	13.69
25	25	13.14

According to table, with 12 and 15 hubs available to locate, the objective function=13.69, and with 25 hubs the objective function = 13.14. It means the minimal height decreased when increasing the number of the available hubs to be located. For the safety distance to locate the hub, with 20 km and 19 km, the objective function value = 13.69, and with 25 km, the objective function =14.63. It means that the minimal height increased if we increase the safety distance.

5.5 Mathematical Model for the Case of Existing Dam

The task of dams is to keep the water on the inundation area and keep the populated area water free. The populated area is covered by water in two cases only. Either the flood is higher than the dam or there is bursting of a dam as shown in figure 22. The water can cover the whole populated area behind the dam in the first case. If bursting occurs, the water runs to the populated area at one point and it takes time to cover the whole populated area. Thus, the flood control has time to build a second line of the defense and repair the collapsed part of the dam. Some hubs temporary or permanent cannot work as they are covered by water. However, the larger part of the populated area remains safe.



Figure 23: Flooding in Case of Dam Existence

This section is devoted to the second case. The option that the flood is higher than the dam is disregarded as a rare event.

A hub can be covered by water not only in the case that the dam collapses in front of the hub. If the dam collapses at one of its neighboring hubs, then the water can still flow to the hub and cover it, i.e., the hub becomes out of order for a while. A location is called intact, if it is not covered by water. Similarly, a hub is intact if it exists and is not covered by water. The intact hubs can give support for areas such that the hub responsible to that area is not intact. It is not possible to claim that the whole area is supplied by relief items for sure as future events cannot be forecasted for sure. What can be claimed is that the probability of the continuous supply is high. Suppose that the potential locations of the temporary hubs are in equidistant places along the river. A possible constraint is that every 3 or 4 etc. consecutive location have at least one intact hub. A hub on a location is intact if the location is selected for a temporary

hub, the hub is settled there and the location is not covered by water. The selection depends on the decision maker. Being intact location depends on the nature. Figure 23 shows the river side with candidate locations to locate the temporary hubs and the consecutive locations here are 3. At least one intact location should be selected from the 3 consecutive locations. The model gives important tool for selection the intact locations form a list of candidate locations.

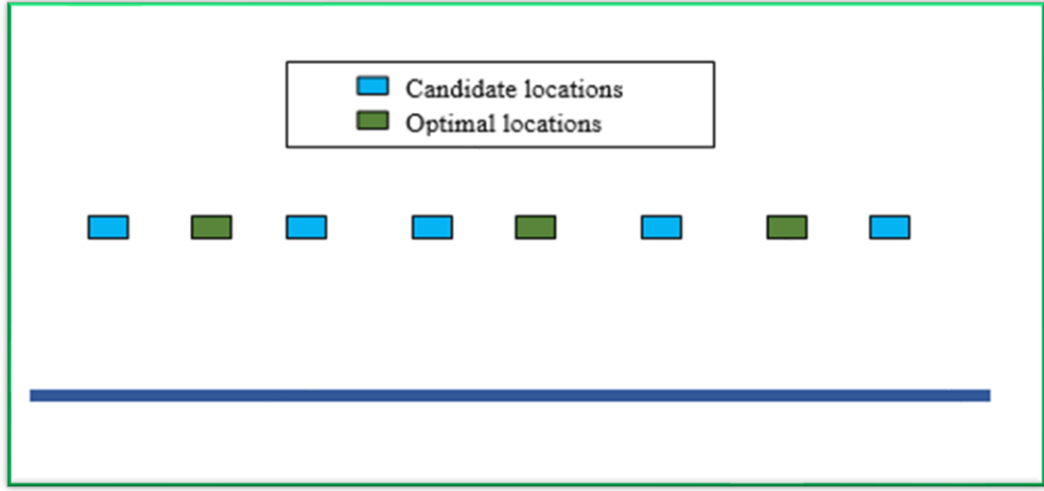


Figure 24: The River Side as A Segment with Candidate and Optimal Locations

The variables x_i 's of the previous section is used here as well for the description of the selection. Let A_i be the event that location i remains intact. The probability of the event is denoted by $P(A_i)$. Hence,

$$P(A_i)x_i = \begin{cases} 0 & \text{if } x_i = 0, i.e. \text{location } i \text{ is not selected} \\ P(A_i) & \text{if } x_i = 1, i.e. \text{location } i \text{ is selected} \end{cases} \quad (13)$$

The upper row of this equation says that if a location is not selected, then there is no intact hub on that location for sure. Formula (13) can be generalized. For example, if $i \neq j$ then the event that at least one of the two locations is intact is denoted by $A_i + A_j$ and the event that both locations are intact is $A_i A_j$. The probability of the event

$A_i + A_j$ is the well-known formula $P(A_i) + P(A_j) - P(A_i A_j)$. Taking into account the decisions on the selections of the two locations, the probability that there is at least one intact hub on the two locations is

$$P(A_i)x_i + P(A_j)x_j - P(A_i A_j)x_i x_j = \begin{cases} 0 & \text{if } x_i = 0 \text{ and } x_j = 0 \\ P(A_i) & \text{if } x_i = 1 \text{ and } x_j = 0 \\ P(A_j) & \text{if } x_i = 0 \text{ and } x_j = 1 \\ P(A_i) + P(A_j) - P(A_i A_j) & \text{if } x_i = 1 \text{ and } x_j = 1 \end{cases} \quad (14)$$

Further generalizations exist. Let S be a set of locations. Assume that S has m elements. Then the probability that there is at least one intact hub on the locations of S is

$$\begin{aligned} & \sum_{i \in S} P(A_i) x_i - \sum_{\substack{i, j \in S \\ i < j}} P(A_i A_j) x_i x_j + \sum_{\substack{i, j, k \in S \\ i < j < k}} P(A_i A_j) x_i x_j x_k \\ & - \dots (-1)^{m+1} P\left(\prod_{i \in S} A_i\right) \prod_{i \in S} x_i \end{aligned} \quad (15)$$

One possible mathematical model is that the value of (15) is at least a priori given threshold $\bar{p}$ probability for all consecutive m locations and the number of hubs is minimized. Let $S_l = \{l, l + 1, \dots, l + m - 1\}$. Then the model is more formally

$$\min \sum_{i=1}^n x_i \quad (16)$$

$$\begin{aligned} & \sum_{i \in S_l} P(A_i) x_i - \sum_{\substack{i, j \in S_l \\ i < j}} P(A_i A_j) x_i x_j + \sum_{\substack{i, j, k \in S_l \\ i < j < k}} P(A_i A_j) x_i x_j x_k \\ & - \dots (-1)^{m+1} P\left(\prod_{i \in S_l} A_i\right) \prod_{i \in S_l} x_i \geq \bar{p} \quad l = 1, 2, \dots, n - m + 1 \end{aligned} \quad (17)$$

$$x_i = 0 \text{ or } 1 \quad i = 1, \dots, n \quad (18)$$

The problem (16)-(18) is nonlinear as there are the products of the binary variables in (17). However, there is a linearization technique obtained in integer programming. It introduces new variables and constraints. The new problem which has an increases size becomes linear. Let again S be a set of locations and assume that S has m elements. Let

$$y_S^m = \prod_{i \in S} x_i.$$

Notice that the value of y_S^m is either 1 if for all $i \in S$ the equation $x_i = 1$ and it is 0 in any other case. Suppose that y_S^m is introduced as a new 0-1 variable which must satisfy the constraints as follows.

$$\sum_{i \in S} x_i - y_S^m \leq m - 1 \quad (19)$$

$$\sum_{i \in S} x_i \geq m y_S^m \quad (20)$$

Notice that (19) claims if all variables $x_i (i \in S)$ equal 1, then y_S^m must be 1. On the other hand, if any of the variables $x_i (i \in S)$ equal 0, then y_S^m must be 0 according to (20). Thus, adding the proper variables and constraints the problem (16)-(18) a linear integer programming problem is obtained.

Example 1: Assume that $n = 4$, and $m = 3$. The target probability to be achieved at every consecutive three locations is 0.91 or more. The probabilities are as follows.

$$\begin{aligned} P(A1) &= P(A2) = P(A3) = P(A4) = 0.9, P(A1A2) = 0.8901, P(A1A3) \\ &= 0.8891, P(A2A3) = 0.8891, P(A2A4) = 0.886, P(A3A4) \\ &= 0.887, P(A1A2A3) = 0.8801, P(A2A3A4) = 0.885. \end{aligned}$$

The optimization problem (16)-(20) has the form

$$\min x_1 + x_2 + x_3 + x_4$$

$$0.9x_1 + 0.9x_2 + 0.9x_3 - 0.8901y_{12}^2 - 0.8891y_{23}^2 - 0.8891y_{13}^2 + 0.8801y_{123}^3 \geq 0.91$$

$$0.9x_2 + 0.9x_3 + 0.9x_4 - 0.8891y_{23}^2 - 0.886y_{24}^2 - 0.887y_{34}^2 + 0.885y_{234}^3 \geq 0.91$$

$$x_1 + x_2 - y_{12}^2 \leq 1, x_1 + x_3 - y_{13}^2 \leq 1, x_2 + x_3 - y_{23}^2 \leq 1, x_2 + x_4 - y_{24}^2 \leq 1,$$

$$x_3 + x_4 - y_{34}^2 \leq 1$$

$$x_1 + x_2 - 2y_{12}^2 \geq 0, x_1 + x_3 - 2y_{13}^2 \geq 0, x_2 + x_3 - 2y_{23}^2 \geq 0, x_2 + x_4 - 2y_{24}^2 \geq 0,$$

$$x_3 + x_4 - 2y_{34}^2 \geq 0$$

$$x_1 + x_2 + x_3 - y_{123}^3 \leq 2, \quad x_1 + x_2 + x_3 - 3y_{123}^3 \geq 0$$

$$x_2 + x_3 + x_4 - y_{234}^3 \leq 2, \quad x_2 + x_3 + x_4 - 3y_{234}^3 \geq 0$$

$$x_1, x_2, x_3, x_4, y_{12}^2, y_{13}^2, y_{23}^2, y_{24}^2, y_{34}^2, y_{123}^3, y_{234}^3 = 0 \text{ or } 1$$

The optimal solution of the problem is $x_2 = x_3 = y_{23}^2 = 1$, all other variables are equal to 0.

Example 2: If we have number of candidate locations to locate the temporary hubs, let say 7 locations, for every 3 consecutive locations (every 3 long interval), the probability of having an intact box ≥ 0.95 . Figure 24 shows the probabilities of the 3 locations. We can calculate the other probabilities using this figure according to the mathematical model.

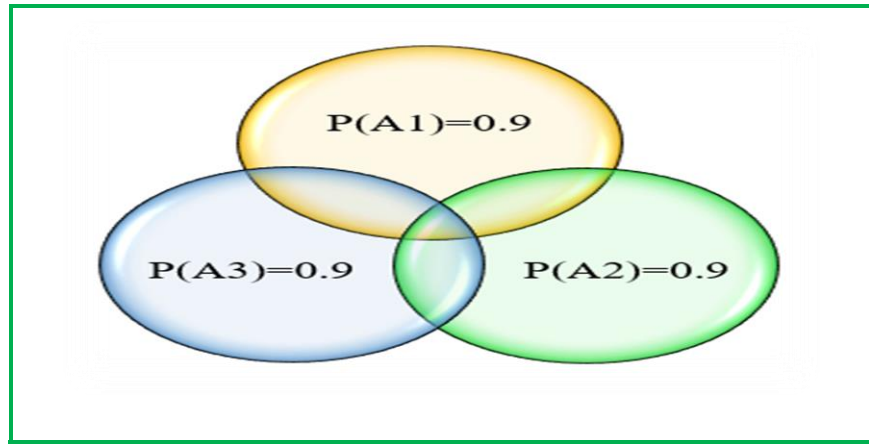


Figure 25: Probabilities Calculations of 3 Consecutive Locations

For sensitivity analysis and in case of dynamic data, we can test the optimal solution considering 3 consecutive locations as shown in table 20, with probabilities equal to 0.9 for each event and $M \geq 0.95$, no feasible solution for choosing from the candidate locations, but for probabilities equal to 0.95, the optimal solution = X1, if the probabilities are 0.88, the objective function = 2, and the optimal solution = X2, X3 and Y23. If we decreased M to be less than 0.95, the objective function decreases to be equals to 1.

Table 20: Sensitivity Analysis of the Model with Dam

Events	A1	A2	A3	A1A2	A1A3	A2A3	A1A2A3	M	Obj.F. value	Optimal Solution
Probabilities	0.90	0.90	0.90	0.89	0.8711	0.89	0.8701	0.95	-	No feasible solution
	0.90	0.90	0.90	0.89	0.8711	0.89	0.8701	0.98	-	No feasible solution
	0.95	0.90	0.90	0.89	0.8711	0.89	0.8701	0.95	1	X1
	0.95	0.90	0.90	0.89	0.8711	0.89	0.8701	0.80	1	X1
	0.88	0.88	0.88	0.70	0.70	0.70	0.90	0.95	2	X2, X3, Y23
	0.88	0.88	0.88	0.70	0.70	0.70	0.90	0.9	2	X2, X3
	0.88	0.88	0.88	0.70	0.70	0.70	0.90	0.8	1	X3
	0.88	0.88	0.88	0.70	0.70	0.70	0.90	0.7	1	X3

5.6 Results and Discussions

Flood is a natural disaster that happened periodically in specific areas of the world. The governments of the countries should prepare carefully before happening the flood to avoid the extreme consequences that may happen to the population and to the economy. Humanitarian logistics are essential to save lives. The relief items should store in safe places. Evacuation operations for the affected people should be happen in the suitable time and place. Temporary hubs can be used for the purpose of storing the relief items and for evacuation of the evacuees. The optimal number and the location of the temporary hubs can be found using mathematical models of operation research. We implemented the method developed in two cases: with dam and without dam. In case of dam existence, the locations of the hubs should be safe, in order to achieve this, logical constraints were used. The potential locations of the temporary hubs are assumed to be in equidistant along the river and at least one location will be intact to serve the demand points in that area. Simple mathematical model used to solve the problem and it is coded using lingo 12 optimization modeling software. The results of the example produced in just few seconds. The case of no dam existence, the candidate locations for the temporary hubs should be far from flooding. In this case, the maximal height of the flood is important to define the safe locations for hubs. Each location has two parameters: how far from the starting point of the segment and the height. In this case, the number of the temporary hubs are fixed and the optimal locations will cover all demand point. Simple mathematical model used to solve the problem and it is coded using lingo 12 optimization modeling software and the optimal solution is obtained in just few seconds. The methods that are used to solve the problem in the two cases are feasible

and simple. The decision maker can easily utilize it. All parameters and variables are easy to obtain in real life.

Chapter 6

CONCLUSION

Humanitarian logistics and disaster operations are very important to save lives in case of natural disasters such as earthquake, flooding, landslide, typhon and pandemic diseases. Temporary logistic hubs play an important role. They can be used as warehouses of relief items and as shelters to evacuate the affected people. The optimal locations of temporary hubs can be found easily using simple mathematical models.

The topic of this methodology represents a strategic plan for the decision makers in both preparedness stage and response stage of disaster happening.

The optimization models for humanitarian logistic planning in context of temporary hubs were studied carefully. Survey study has prepared firstly. Most mathematical models in this study were sophisticated and complex. Even some of the parameters and variables were difficult to obtain in real life and the solving of such models takes time and efforts. In order to prepare for the disaster in pre-disaster planning horizon, we suggested simple mathematical models to be solved using simple optimization modeling software like lingo.

Three mathematical models were proposed. The first one solved the problem of production hubs in case of pandemic disease to produce face masks to cover all the

places of European Union as example. The second practical problem is of temporary hubs in two cases: with dam and without dam. The effectiveness of the proposed mathematical models evaluated using numerical examples. The results show that the models are feasible and took a few second to solve them.

For future directions, stochastic optimization modeling can be used to solve uncertainty parameters such as demand quantities that can be dynamic over time. On the other hand, transportation problem can be solved by using bi-level optimization modeling using road vehicles and aerial vehicles such as unmanned autonomous vehicles (drones) to cover isolated areas besides reachable areas. It is very important to obtain real life data and accurate information, in this case, we can introduce two factors: crime rate and damage degree for the mathematical model. Furthermore, the fourth stage operations of disaster life cycle should be investigated more. The most important contribution is saving the lives under debris, this needs technical tools to define exactly the locations of the victims. Some kinds of biological sensors can measure the biological features of the victims such as body temperature, breathing degree and heart pulse and connected with mobile phones or computers using some technological methods like internet of things and artificial intelligent. Other operations are important such as: reconstruction, rebuilding, debris removal, psychological treatment of the victims and other operations.

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APPENDICES

Appendix A: Temporary Hub Types



Temporary hospital



Hospital surge intensive care



Hospital tents



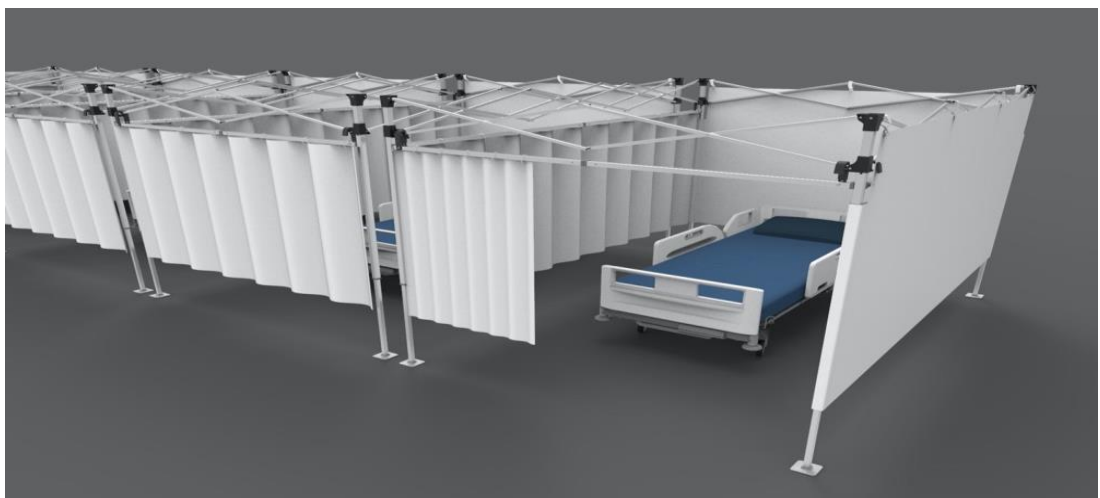
Stadium area as temporary hospital-case of China



Stadium area as temporary hospital-infrastructure-case of China



Temporary hospital tent/intensive care unit



Pop-up-medical-partition-system-for-field-hospitals



Patient Screening Facility



Shower trailer



Dry storage



Evacuation tents



Emergency disaster service bus



Mobile medical hub

Appendix B: List of Survey Papers

No.	Authors	Year of publication	Paper Title
1	Huseyin Onur Mete and Zelda Zabinsky	2010	Stochastic optimization of medical supply location and distribution in disaster management
2	Ahmad Mohamadi and Saeed Yaghoubi	2017	A bi-objective stochastic model for emergency medical services network design with backup services for disasters under disruptions: An earthquake case study
3	Fatih Cavdur, Merve Kose Kucuk and Asli Sebatli	2016	Allocation of temporary disaster response facilities under demand uncertainty: An earthquake case study
4	Daniel Rivera Royero, Gina Galindo and Ruben Yie Pinedo	2016	A dynamic model for disaster response considering prioritized demand points
5	Amlan K. Mollah, Sounak Sadhukhan, Prasun Das And Md.Zafar Anis	2018	A cost optimization model and solutions for shelter allocation and relief distribution in flood scenario
6	Beate B. Rottkemper A,Kathrin Fischer, Alexander Blecken	2012	A transshipment problem for distribution and inventory relocation under uncertainty in humanitarian operations
7	Jiang-Hua Zhang, Jin Li, Zhi-Ping Liu	2012	Multiple-resource and multiple-depot emergency response problem considering secondary disasters
8	Albert Y. Chen, Jihn-Sung Lai, Wen-Ling Chuang, Wei-Zen Sun	2015	Ambulance Service Area Considering Disaster-Induced Disturbance on the Transportation Infrastructure
9	Albert Y. Chen and Ting-Yi Yu	2016	Network based temporary facility location for Emergency Medical Services considering the disaster induced demand and the transportation infrastructure
10	José-Fernando Camacho-Vallejo, Edna González-Rodríguez, F.-Javier Almaguer, Rosa G. González-Ramírez	2015	A bi-level optimization model for aid distribution after occurrence a disaster
11	Masoud Mahootchi, Sajjad Golmohammadi	2018	Developing a new stochastic model considering bi-directional relations in a natural disaster: a possible earthquake in Tehran (the Capital of Islamic Republic of Iran)
12	Timothy Schemppa, Haoran Zhangb, Alexander Schmidtc, Minsung Hongd, Rajendra Akerkard	2019	A framework to integrate social media and authoritative data for disaster relief detection and distribution optimization

13	Huseyin Onur Mete, Zelda Zabinsky	2010	Stochastic optimization of medical supply location and distribution in disaster management
14	Rajali Maharjan, Yashaswi Shrestha, Biplob Rakhal, Saurav Suman And Jurgen Hulst	2020	mobile logistics hubs prepositioning for emergency preparedness and response in Nepal
15	Michael J. Widener, Mark W. Hrner	2011	A hierarchical approach to modeling hurricane disaster relief goods distribution
16	F. Liberatore, M. T. Ortuo, G. Tirado, B. Vitoriano, M. P. Scaparra	2014	A hierarchical compromise model for the joint optimization of recovery operations and distribution of emergency goods in humanitarian logistics
17	Alfredo Moreno, Douglas Alem, Deisemara Ferreira, Alistair Clark	2018	An effective two stage stochastic multi-trip location-transportation model with social concerns in relief supply chains
18	Rojee Pradhananga, Fatih Mutlu, Shaligram Pokharel, Jose Holguin-Veras, Dinesh Seth	2016	An integrated resource allocation and distribution model for pre-disaster planning
19	Mohammad Rezaei-Malek, Reza Tavakkoli-Moghaddan, Behzad Zahiri, Ali Bozorgi-Amiri	2016	An interactive approach for designing a robust disaster relief logistics network with perishable commodities
20	Yen-Hung Lin, Rajan Batta, Peter A. Rogerson, Alan Blatt, Marie Flanagan	2011	A logistics model for emergency supply of critical items in the aftermath of a disaster
21	Mehdi Najafi, Kourosh Eshghi, Wout Dullaret	2013	A multi-objective robust optimization model for logistics planning in the earthquake response plan
22	Cejun Cao, Congdong Li, Quin Yang, Yang Liu, Ting Qu	2018	A novel multi-objective programming model of relief distribution for sustainable disaster supply chain in large-scale natural disasters
23	Yajie Liu, Hongtao Lei, Zhiyong Wu, Dezhi Zhang	2019	A robust model predictive control approach for post-disaster relief distribution
24	Rodrigo A. Garrido, Patricio Lamas, Francisco J. Pino	2015	A stochastic programming approach for flood emergency logistics
25	Guojun Ji, Caihong Zhu	2012	A study on emergency supply chain and risk based on urgent relief service in disasters
26	Farid Momayezi S. Kamal Chaharsooghi Mohammad Mehdi Sepehri ¹ Ali Husseinzadeh Kashan ¹	2021	The capacitated modular single-allocation hub location problem with possibilities of hubs disruptions: modeling and a solution algorithm
27	Peter Kelle, Helmut Schneider, Huizhi Yi	2014	Decision alternatives between expected cost minimization and worst-case scenario in emergency supply – Second revision
28	Asli Sebatli, Fatih Cavdur Merve Kose-Kucuk	2017	Determination of relief supplies demands and allocation of temporary disaster response facilities
29	Rubel Das	2018	Disaster preparedness for better response: Logistics perspectives

30	Oscar Rodríguez-Espíndola, Pavel Albores, Christopher Brewster	2018	Dynamic formulation for humanitarian response operations incorporating multiple organizations
31	Hamed Golabian, Jamal Arkat, Reza Tavakkoli-Moghaddam, Hiwa Faroughi	2021	A multi-verse optimizer algorithm for ambulance repositioning in emergency medical service systems
32	Zhi-Hua Hu, Jiuh-Biing Sheu, Ling Xiao	2021	Post-disaster evacuation and temporary resettlement considering panic and panic spread
33	Shao-Long Hu, Chuan-Feng Han, Ling-Peng Meng	2017	Stochastic optimization for joint decision making of inventory and procurement in humanitarian relief
34	Peiman Ghasemi, Kaveh Khalili-Damghani, Ashkan Hafezalkotob, Sadigh Raissi	2019	Stochastic Optimization Model for Distribution and Evacuation Planning (A Case Study of Tehran Earthquake)
35	Behnam Vahdani, D. Veysmoradi, F. Noori, F. Mansour	2018	Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty
36	Peiman Ghasemi, Kaveh Khalili-Damghani, Ashkan Hafezalkotob, Sadigh Raissi	2019	Uncertain multi-objective multi-commodity multi-period multi-vehicle location-allocation model for earthquake evacuation planning
37	Yen-Hung Lin, Rajan Batta, Peter A. Rogerson, Alan Blatt, Marie Flanigan	2012	Location of temporary depots to facilitate relief operations after an earthquake
38	Anna C.Y. Li, Linda Nozick Ningxiong Xu, Rachel Davidson	2012	Shelter location and transportation planning under hurricane conditions
39	Sae Yeon Roh, Young Ran Shin, Young Joon Seo	2018	The Pre-positioned Warehouse Location Selection for International Humanitarian Relief Logistics
40	Iran Rosa Xaviera, Renata Albergaria De Mello Bandeira, Leandro De Oliveira Silva, Adriano De Paula Fontainhas Bandeira, Vânia Barcellos Gouvêa Campos	2019	Employing helicopters in the modelling of last mile distribution system in large-scale disasters
41	Kai Huang, Rezvan Rafiei	2019	Equitable last mile distribution in emergency response
42	Yang Liu, Na Cuib, Jianghu Zhang,	2019	Integrated temporary facility location and casualty allocation planning for post-disaster humanitarian medical service
43	Alfredo Moreno, Douglas Alem, Deisemar Ferreir	2016	Heuristic approaches for the multi period location-transportation problem with reuse of vehicles in emergency logistics

44	Haijun Wang, Lijing Du, Shihu Ma	2014	Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake
45	Jomon Aliyas Paul and Leo Macdonald	2016	Location and capacity allocations decisions to mitigate the impacts of unexpected disasters
46	Jomon A. Paul and Xinfang Jocelyn Wang	2019	Robust location-allocation network design for earthquake preparedness
47	Mehrdad Mohammadi, Payman Julab, Reza Tavakkoli-Moghaddamc,	2019	Reliable single-allocation hub location problem with disruptions
48	Abdul Sattar Safaei, Saba Farsad, Mohammad Mahdi Paydar	2018	Robust bi-level optimization of relief logistics operations
49	Yunjia Ma, Wei Xu, Lianjie Qin, Xiujuan Zhao & Juan Du	2018	Hierarchical supplement location-allocation optimization for disaster supply warehouses in the Beijing–Tianjin–Hebei region of China
50	Anurag Verma, Gary M. Gaukler	2015	Pre-positioning disaster response facilities at safe locations: An evaluation of deterministic and stochastic modeling approaches
51	Nathalie Cotes, Victor Cantillo	2019	Including deprivation costs in facility location models for humanitarian relief logistics
52	R. Mohammadi, S.M.T. Fatemi Ghomi, F. Jolai	2016	Prepositioning emergency earthquake response supplies: A new multi-objective particle swarm optimization algorithm
53	Chung-Cheng Lu, Jiuh-Biing Sheu	2013	Robust vertex p-center model for locating urgent relief distribution centers
54	Carmen G. Rawls & Turnquist (2010), Mark A. Turnquist	2010	Pre-positioning of emergency supplies for disaster response
55	Lingfeng Li, Mingzhoujin, Lizhang	2011	Sheltering network planning and management with a case in the Gulf Coast region
56	Djamel Berkoune, Jacques Renaud, Monia Rekik, Angel Ruiz	2012	Transportation in disaster response operations
57	Yingzhen Chen, QiuHong Zhao, Lei Wang, Maged Dessouky	2016	The regional cooperation-based warehouse location problem for relief supplies
58	Wisinee Wisetjindawat, Hideyuki Itob, Motohiro Fujita, Hideshima Eizoa	2014	Planning Disaster Relief Operations

Appendix C: List of Survey Tables

Table1-C: Type of disaster papers

Disaster type	Number	Research Papers
Earthquake	13	Mete & Zabinsky (2010), Mohamadi & Yaghoubi, (2017), F. Cavdur, et al. (2016), A. Chen, et al. (2015), Chen & Yu (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), R. Mahrajan, et al. (2020), F. Liberatore, et al. (2014), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), J. Ji, et al. (2012), A. Sebatli, et al. (2017), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), Y. Lin , et al. (2012), I. Xaviera , et al. (2019), K. Huang , et al. (2019), Y. Liu , et al. (2019), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), Verma & Gankler, (2015), R. Mohammadi, et al. (2016), Lu & Sheu (2013), W. Wisetjindawat , et al. (2014)
Flooding	12	D. Royero, et al. (2016), A. Mollah, et al. (2018), H. Mete, et al. (2010), Y. Shrestha, et al. (2020), A. Moreno, et al. (2018), R. Garrido, et al. (2015), O. Espindola, et al. (2018), S. Hu, et al. (2017), A. Moreno, et al. (2016), A. Safaei, et al. (2018), A. Cotes, et al. (2019), Y. Chen, et al. (2016)
Hurricane	11	A. Chen, et al. (2015), Chen & Yu (2016), T. Schemppa, et al. (2019), Widener & Hrner (2011), R. Pradhananga, et al. (2016), P. Kelle et al. (2014), O. Espindola, et al. (2018), S. Hu, et al. (2017), A. Li, et al. (2012), Rawls & Turnquist (2010), L. Li, et al. (2011)
Snowstorm	1	S. Hu, et al. (2017)
Landslide	4	Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), A. Moreno, et al. (2018), A. Moreno, et al. (2016)
Multiple	4	B. Rottkemper, et al. (2012), J. Zhang, et al. (2012), S. Hu, et al. (2017), R. Mahrajan, et al. (2020)
Malaria	1	B. Rottkemper, et al. (2012)

Table 2-C: Period of decision-making papers

Period phase	Number	Research Papers
Pre-disaster	43	J. Zhang, et al. (2012), Mahootchi & Golmohammadi (2018), R. Pradhananga, et al. (2016), Kelle, et al. (2014), A. Sebatli, et al. (2017), R. Das, (2018), H. Golabian, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), Mete & Zabinsky (2010), F. Cavdur, et al. (2016), D. Royero, et al. (2016), Y. Lin , et al. (2012), A. Li , et al. (2012), S. Roh, et al. (2018), I. Xaviera , et al. (2019), Huang & Rafiei, (2019), Y. Liu , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadi, et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), Verma & Gaukler (2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), C. Lu , et al. (2013), Rawls & Turnquist (2010), L. Li , et al. (2011), Y. Chen , et al. (2016), W. Wisetjindawat , et al. (2014).
Post-disaster	52	F. Cavdur, et al. (2016), D. Royero, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012), A. Chen, et al. (2015), Chen & Yu (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), Mete & Zabinsky (2010), Widener & Hrner. (2011), F. Liberatore, et al. (2014), R. Pradhananga, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), Ji & Zhu (2012), P. Kelle, et al.

		(2014), A. Sebatli, et al. (2017), R. Das (2018), O. Espindola, et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), S. Hu, et al. (2017) P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi, et al. (2019), Y. Lin , et al. (2012), A. Li , et al. (2012), I. Xavieria, et al. (2019), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Y. Chen , et al. (2016), W. Wisetjindawat , et al. (2014)
Pre and Post	6	Mete & Zabinsky (2010), Mohamadi & Yaghoubi, (2017), T. Schempp, et al. (2019), R. Mahrajan, et al. (2020), Moreno, et al. (2018), M. Malek, et al. (2016), R. Garrido, et al. (2015), F. Momayezi, et al. (2021)
Reconstruction	5	F. Cavdur, et al. (2016), R. Mahrajan, et al. (2020), F. Liberatore, et al. (2014), H. Hu, et al. (2021), Y. Ma, et al. (2018)

Table 3-C: Hub type papers

Hub Type	Number	Research Papers
Permanent hub	35	Mete & Zabinsky (2010), Mohamadi & Yaghoubi, (2017), D. Royero, et al. (2016), B. Rottkemper et al. (2012), J. Zhang, et al. (2012), J. Vallejo, et al. (2015), Mahootchi & Golohammadi (2018), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), S. Hu, et al. (2017), P. Ghasemi , et al. (2019) B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012), S. Roh , et al. (2018) I. Xavieria , et al. (2019) K. Huang , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014) J. Paul , et al. (2016) J. Paul , et al. (2019), M. Mohammadi. , et al. (2019), Y. Ma , et al. (2018), A. Verma , et al. (2015) N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Y. Chen , et al. (2016)
Temporary hub	39	F. Cavdur, et al. (2016), D. Royero, et al. (2016), A. Mollah, et al. (2018), A. Chen, et al. (2015), Chen & Yu (2016), Mahootchi & Golmohannadi (2018), T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Widener & Hrner. (2011), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), C. Cao, et al. (2018) Y. Liu, et al. (2019), R. Garrido, et al. (2015), Ji & Zhu (2012), F. Momayezil, et al. (2021) P. Kelle, et al. (2014), A. Sebatli, et al. (2017) R. Das (2018), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012), A. Li , et al. (2012), I. Xavieria , et al. (2019), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), A. Safaei , et al. (2018), C. Lu , et al. (2013), L. Li , et al. (2011), D. Berkoune , et al. (2012), W. Wisetjindawata , et al. (2014)

Table 4-C: hub problem type papers

Hub problem	Number	Research Papers
Stock level	39	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), F. cavdur, et al. (2016), D. Royero, et al. (2016), B. Rottkemper et al. (2012), Mahootchi & Golmohammadi (2018), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), R. Garrido, et al. (2015), Ji & Zhu (2012), P. Kelle, et al. (2014), A. Sebatli, et al. (2017), O. Espindolaa , et al. (2018), S. Hu, et al. (2017), P. Ghasemi, et al. (2019), B. Vahdani , et al. (2018), Y. Lin , et al. (2012), I. Xavieria , et al. (2019), K. Huang , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), A.

Safaei , et al. (2018), Verma & Gaukler (2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Chen & Yu (2016), W. Wisetjindawata , et al. (2014)

Location	45	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), F. cavdur, et al. (2016), A. Mollah, et al. (2018), A. Chen, et al. (2015), A. Chen, et al. (2016), Mahootchi & Golmohammadi (2018), T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Widener & Hrner. (2011), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), F. Momayezil, et al. (2021), A. Sebatli, et al. (2017), R. Das (2018), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019) Y. Lin , et al. (2012) A. Li , et al. (2012), S. Roh , et al. (2018), I. Xaviera , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), Chen & Yu (2016), M. Mohammadi , et al. (2019), A. Safaei , et al. (2018), D. Berkoune , et al. (2012), Y. Ma , et al. (2018), Rawls & Turnquist (2010) , C. Lu , et al. (2013), L. Li , et al. (2011), R. Mohammadi , et al. (2016), N. Cotes , et al. (2019), Verma & Gaukler (2015), W. Wisetjindawata , et al. (2014)
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Table 5-C: Transportation mode papers

Transportation mode	Number	Research Papers
Road	53	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), F. cavdur, et al. (2016), D. Royero, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012) J. Zhang, et al. (2012), A. Chen, et al. (2015), A. Chen, et al. (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), R. Mahrajan, et al. (2020), Widener & Hrner (2011), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), R. Garrido, et al. (2015), Ji & Zhu (2012), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), R. Das (2018), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012, A. Li , et al. (2012), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadia. , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), Verma & Gaukler ((2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), C. Lu , et al. (2013), Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Chen & Yu (2016), W. Wisetjindawata , et al. (2014)
Aerial	12	D. Royero, et al. (2016), B. Rottkemper et al., (2012), J. Vallejo, et al. (2015), A. Moreno, et al. (2018), M. Najafi, et al. (2013), Y. Liu, et al. (2019), Y. Lin, et al. (2012), Y. Liua, et al. (2019), I. Xaviera, et al. (2019), N. Cotes, et al. (2019), Rawls & Turnquist (2010)
Water	3	J. Vallejo, et al. (2015), A. Moreno, et al. (2018), Cotes, et al. (2019)
Combined	1	M. Najafi, et al. (2013)

Table 6-C: Transportation type papers

Transportation Type	Number	Research Papers
Emergency	15	Mete & Zabinisky (2010), Mohamadi & Yaghoubi, (2017), F. Cavdur, et al. (2016), A. Chen, et al. (2015), A. Chen, et al. (2016), R. Mahrajan, et al. (2020) H. Golabian, et al. (2021), P. Ghasemi, et al. (2019), I. Xaviera, et al. (2019), Y. Liua, et al. (2019) J. Paul, et al. (2019), M. Mohammadi, et al. (2019), W. Wisetjindawata, et al. (2014).
Normal	49	D. Royero, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012), J. Zhang, et al. (2012), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), R. Mahrajan, et al. (2020), Widener & Hrner (2011), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), R. Garrido, et al. (2015), Ji & Zhu(2012), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), A. Sebatli, et al. (2017), R. Das (2018), O. Espindola, et al. (2018), H.Hu, et al. (2021), S. Hu, et al. (2017), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012), A. Li , et al. (2012), I. Xaviera , et al. (2019), K. Huang , et al. (2019), A. Moreno , et al. (2016), H. Wang, et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018) ,Verma & Gaukler (2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), C. Lu , et al. (2013), Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Chen & Yu (2016),W. Wisetjindawata , et al. (2014).

Table 7-C: Transportation vehicles types papers

Transportation vehicles	Number	Research Papers
Helicopter	9	D. Royero, et al. (2016) A. Moreno, et al. (2018) M. Najafi, et al. (2013) Y. Liu, et al. (2019) Y. Lin, et al. (2012), I. Xaviera, et al. (2019) Y. Liua, et al. (2019) N. Cotes, et al. (2019), Rawls & Turnquist (2010), et al. (2010)
Boat / ship	3	D. Royero, et al. (2016) A. Moreno, et al. (2018), N. Cotes, et al. (2019).
Truck/Van	52	Mete & Zabinisky (2010), Mohamadi & Yaghoubi, (2017), F. cavdur, et al. (2016), D. Royero, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012), J. Zhang, et al. (2012), A. Chen, et al. (2015) A. Chen, et al. (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), R. Mahrajan, et al. (2020), Widener & Hrner (2011), F. Liberatore, et al. (2014) A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), R. Garrido, et al. (2015), Ji & Zhu (2012), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), A. Sebatli, et al. (2017) R. Das (2018), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019) B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012) A. Li , et al. (2012), K. Huang , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019) A. Safaei , et al. (2018) Y. Ma , et al. (2018), Verma & Gaukler (2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016) C. Lu , et al. (2013) Rawls & Turnquist (2010), L. Li , et al. (2011), D. Berkoune , et al. (2012), Y. Chen , et al. (2016), W. Wisetjindawata , et al. (2014)

Equipped ambulance	12	Mohamadi & Yaghoubi, (2017), A. Chen, et al. (2015), Chen & Yu (2016), R. Garrido, et al. (2015), H. Golabian, et al. (2021), P. Ghasemi, et al. (2019), I. Xavier, et al. (2019), Y. Liua, et al. (2019), J. Paul, et al. (2019), W. Wisetjindawata, et al. (2014)
Rail way/train	1	M. Mohammadi,et al. (2019)

Table 8-C: Model program type papers

Model program	Number	Research Papers
LP	6	D. Royero, et al. (2016), J. Zhang, et al. (2012), M. Najafi, et al. (2013), G. Ji, et al. (2012), P. Kelle, et al. (2014), L. Li, et al. (2011)
LMIP	35	H. Mete, et al. (2010), Mohamadi & Yaghoubi, (2017), A. Mollah, et al. (2018), B. Rottkemper et al. (2012) J. Zhang, et al. (2012), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), T. Schempp, et al. (2019), Widener & Hrner.(2011), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Liu, et al. (2019), R. Garrido, et al. (2015), F. Momayezil, et al. (2021), R. Das (2018), O. Espindolaa , et al. (2018), H. Hu, et al. (2021), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), A. Li , et al. (2012), I. Xavier , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), J. Paul , et al. (2016), J. Paul , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), Verma & Gaukler ((2015), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010) , D. Berkoune , et al. (2012)
IP	13	F. Cavdur, et al. (2016), J. Zhang, et al. (2012), Chen & Yu (2016), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Y. Lin, et al. (2011), A. Sebatli, et al. (2017), H. Golabian, et al. (2021), S. Hu, et al. (2017), Y. Lin, et al. (2012), C. Lu, et al. (2013), L. Li, et al. (2011), W. Wisetjindawata et al. (2014).
MINLP	6	J. Vallejo, et al. (2015), C. Cao, et al. (2018), K. Huang, et al. (2019), H. Wang, et al. (2014), M. Mohammadi, et al. (2019), N. Cotes, et al. (2019)
Stochastic	23	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), F. cavdur, et al. (2016), B. Rottkemper et al. (2012) J. Zhang, et al. (2012), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), M. Najafi, et al. (2013), R. Garrido, et al. (2015), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), H. Golabian, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), A. Li , et al. (2012), A. Moreno , et al. (2016), J. Paul , et al. (2016), M. Mohammadi. , et al. (2019), Verma & Gaukler (2015), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010) , L. Li , et al. (2011).
Scenario-base problems	4	P. Ghasemi, et al. (2019), Y. Liua, et al. (2019), H. Wang, et al. (2014), Y.Chen , et al. (2016)
Robust	6	Y. Liu, et al. (2019), B. Vahdani, et al. (2018), J. Paul, et al. (2019), A. Safaei, et al. (2018), C. Lu, et al. (2013), D. Berkoune, et al. (2012)
Dynamic	4	C. Cao, et al. (2018), O. Espindola, et al. (2018), H. Hu, et al. (2021), K. Huang, et al. (2019).
Deterministic	20	F. Cavdur, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012) J. Zhang, et al. (2012,) A. Chen, et al. (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Widener & Hrner (2011), F. Liberatore, et al. (2014), Y. Lin, et al. (2011), A. Sebatli, et al. (2017), R. Das (2018), Y. Lin , et al. (2012), I. Xavier , et al. (2019),

		Verma & Gaukler (2015), N. Cotes , et al. (2019), W. Wisetjindawata , et al. (2014)
Lagrange multiplier	3	A. Chen, et al. (2016), A. Li, et al. (2012), Rawls & Turnquist (2010)
Greedy	5	A. Chen, et al. (2016), A. Chen, et al. (2016), Verma & Gaukler (2015), Rawls & Turnquist (2010), D. Berkoune, et al. (2012)
Special problems	1	A. Chen, et al. (2016)
Professional Solver	2	J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018)
Branch and Bound	2	J. Vallejo, et al. (2015), D. Berkoune, et al. (2012)
Scenario based	4	P. Gasemi, et al. (2019), Y. Liu, et al. (2019), H. Wang, et al. (2014), Y. Chen, et al. (2016)

Table 9-C: Optimization methods papers

Method	Number	Research Papers
Genetic	10	Y. Lin, et al. (2011), C. Cao, et al. (2018), H. Golabian, et al. (2021), P. Ghasemi, et al. (2019), H. Wang, et al. (2014), J. Paul, et al. (2016), M. Mohammadi, et al. (2019), D. Berkoune, et al. (2012), W. Wisetjindawat, et al. (2014)
Multiverse Optimizer algorithm	1	H. Golabian, et al. (2021)
Relax and fix heuristic-fix and optimize heuristic	1	A. Moreno, et al. (2016)
Heuristic	11	P. Ghasemi, et al. (2019), Y. Lin, et al. (2012), A. Li, et al. (2012), A. Moreno, et al. (2016), H. Wang, et al. (2014), J. Paul, et al. (2016), Verma & Gaukler ((2015), R. Mohammadi, et al. (2016), C. Lu, et al. (2013), Rawls & Turnquist (2010), et al. (2010)
Metaheuristic	4	F. Momayezil, et al. (2021), H. Golabian, et al. (2021), B. Vahdani, et al. (2018), M. Mohammadi, et al. (2019)
Decomposing	1	Y. Lin, et al. (2011)
Sample Average Approximation	1	R. Garrido, et al, (2015)
Epsilon Constant	2	P. Ghasemi, et al. (2019), Y. Liua, et al. (2019)
Local Search and priority	1	J. Zhang, et al. (2012)
K-Median	1	Verma & Gankler, et al. (2015)
K-mean clustering	1	A. Chen, et al. (2015)
Modified Particle Swarm	1	Y. Ma, et al. (2018)
Global Particle Swarm	3	T. Schemppa, et al. (2019), P. Ghasemi, et al. (2019) R. Mohammadi, et al. (2016).
Multi-Layer Reception	1	A. Chen, et al. (2015)

Table 10-C: Model stage papers

Model stage	Number	Research Papers
One stage	31	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), D. Royero, et al. (2016), A. Mollah, et al. (2018), B. Rottkemper et al. (2012), J. Zhang, et al. (2012), A. Chen, et al. (2015), A. Chen, et al. (2016), T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Widener & Hrner.(2011), F. Liberatore, et al. (2014), Y. Lin, et al. (2011,) M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019) R. Garrido, et al. (2015), Ji & Zhu (2012), R. Das (2018), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), P. Ghasemi , et al. (2019), S. Roh , et al. (2018), J. Paul , et al. (2016), J. Paul , et al. (2019) N. Cotes , et al. (2019), C. Lu , et al. (2013), D. Berkoune , et al. (2012), W. Wisetjindawata , et al. (2014)
Two stage	28	F. Cavdur, et al. (2016) J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), A. Sebatli, et al. (2017), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), Y. Lin , et al. (2012), A. Li , et al. (2012), I. Xaviera , et al. (2019), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016) H. Wang , et al. (2014), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018) Y. Ma , et al. (2018), Verma & Gaukler (2015), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010), L. Li , et al. (2011), Y. Chen , et al. (2016)

Table 11-C: Risk of facility papers

Risk of facility, (24 papers)

F. Cavdur, et al. (2016) D. Royero, et al. (2016), Mahrajan, et al. (2020), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016) M. Malek, et al. (2016) M. Najafi, et al. (2013) R. Garrido, et al. (2015) Ji & Zhu(2012) F. Momayezil, et al. (2021) A. Sebatli, et al. (2017) H. Hu, et al. (2021) P. Ghasemi , et al. (2019) I. Xaviera , et al. (2019) Y. Liua , et al. (2019) A. Moreno , et al. (2016) H. Wang , et al. (2014) J. Paul , et al. (2016) J. Paul , et al. (2019) M. Mohammadi. , et al. (2019) Verma & Gaukler ((2015) R. Mohammadi , et al. (2016) Rawls & Turnquist (2010) .

Table 12-C: Triage system papers

Triage system, (8 papers)

A. Mohammadi, et al. (2017), M. Najafi, et al. (2013), C. Cao, et al. (2018) Y. Liu, et al. (2019), P. Ghasemi, et al. (2019), Y. Liua, et al. (2019), J. Paul, et al. (2016), J. Paul, et al. (2019)

Table 13-C: Multi objective approach papers

Multi objective, (38 papers)

F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), R. Garrido, et al. (2015), Ji & Zhu(2012), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), A. Sebatli, et al. (2017), R. Das (2018), O. Espindolaa , et al. (2018), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012), A. Li , et al. (2012), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), Verma & Gaukler ((2015), N. Cotes , et al. (2019), R. Mohammadi , et al. (2016), Rawls & Turnquist (2010) , L. Li , et al. (2011), D. Berkoune , et al. (2012), Y.Chen , et al. (2016).

Table 14-C: Data usage papers

Data used	Number	Research Papers
Real	11	A. Mollah, et al. (2018), B. Rottkemper et al. (2012), A. Chen, et al. (2015), A. Chen, et al. (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi(2018) T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), Widener & Hrner.(2011), W. Wisetjindawata , et al. (2014).
Provided	23	Mete & Zabinsky (2010), Mohamadi & Yaghoubi (2017), F. cavdur, et al. (2016), D. Royero, et al. (2016) A. Mollah, et al. (2018), B. Rottkemper et al. (2012) J. Zhang, et al. (2012), A. Chen, et al. (2015), A. Chen, et al. (2016), Mahootchi & Golmohammadi(2018) T. Schempp, et al. (2019), Mahrajan, et al. (2020,) Widener & Hrner.(2011), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), R. Garrido, et al. (2015), Ji & Zhu(2012) P. Kelle, et al. (2014), A. Sebatli, et al. (2017), O. Espindolaa , et al. (2018,) H. Wang , et al. (2014), L. Li , et al. (2011).

Table 15-C: Existence of data discussion papers

Existence of data discussion, (46 papers)

Widener & Horner (2011), Y. Lin, et al. (2011), R. Pradhananga, et al. (2016), F. Liberatore, et al. (2014), C. Cao, et al. (2018), Y. Lio, et al. (2019), Y. Ma , et al. (2018) A. Safaei , et al. (2018) Verma & Gaukler (2015), Cotesand & Cantillo (2019), M. Mohammadi , et al. (2016), Y. Liu , et al. (2013), A. Li , et al. (2011), Chen & Yu (2016), A. Moreno , et al. (2016), Paul & MacDonald (2016), Paul & Wang (2019), Y. Lin , et al. (2012), P. Ghasemi , et al. (2019), J.Vallejo, et al. (2015), T. Schempp, et al. (2019), Mete & Zabinsky (2010), A. Mollah, et al. (2018), R. Garrido, et al. (2015), Y. liu, et al. (2019) M. Malik, et al. (2016), F. Cavdur, et al. (2016), Bakioglu & Karaman (2018), D. Royero, et al. (2016), A. Moreno, et al. (2018), Mohamadi & Yhghoubi (2017), Ji & Zhu, (2012), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), M. Najafi, et al. (2013), F. Momayezi, et al. (2021), P. Kelle, et al. (2014), O. Espindola, et al. (2018), R. Mahrajan, et al. (2020), H. Golabian, et al. (2021), Z. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), A. Li , et al. (2012), I. Xaviera , et al. (2019)

Table 16-C: Historical data usage papers

Historical data usage, (55 papers)

A. Mohamadi, et al. (2017), A. Mollah, et al. (2018), B. Rottkemper et al. (2012) A. Chen, et al. (2015), A. Chen, et al. (2016), J. Vallejo, et al. (2015), Mahootchi & Golmohammadi (2018), T. Schempp, et al. (2019), Mete & Zabinsky (2010), Mahrajan, et al. (2020), Widener & Hrner.(2011), F. Liberatore, et al. (2014), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), Y. Lin, et al. (2011), M. Najafi, et al. (2013), C. Cao, et al. (2018), Y. Liu, et al. (2019), R. Garrido, et al. (2015), Ji & Zhu (2012), F. Momayezil, et al. (2021), P. Kelle, et al. (2014), L. Li , et al. (2011), D. Berkoune , et al. (2012), A. Sebatli, et al. (2017), O. Espindolaa , et al. (2018), H. Golabian, et al. (2021), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), P. Ghasemi , et al. (2019), Y. Lin , et al. (2012), A. Li , et al. (2012), S.Roh , et al. (2018), R. Mohammadi , et al. (2016), C. Lu , et al. (2013), Rawls & Turnquist (2010) , I. Xaviera , et al. (2019), K. Huang , et al. (2019), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018), Y. Ma , et al. (2018), Verma & Gaukler ((2015), N. Cotes , et al. (2019), Chen & Yu (2016), W. Wisetjindawata , et al. (2014)

Table 17-C: Social media and authoritative data usage papers

Social media and authoritative data usage, (10 papers)

Schempp, et al. (2019), Mete & Zabinsky (2010), Y. Lin, et al. (2011), R. Garrido, et al. (2015), Ji & Zhu (2012), P. Kelle, et al. (2014,) A. Sebatli, et al. (2017), O. Espindola, et al. (2018), H. Golabian, et al. (2021), H. Wang, et al. (2014)
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Table 18-C: Data type papers

Data type	Number	Research Papers
Temporal	33	T. Schempp, et al. (2019), Widener & Hrner.(2011), A. Moreno, et al. (2018), R. Pradhananga, et al. (2016), M. Malek, et al. (2016), M. Najafi, et al. (2013) C. Cao, et al. (2018), Y. Liu, et al. (2019,) R. Garrido, et al. (2015), F. Momayezil, et al. (2021), A. Sebatli, et al. (2017), O. Espindolaa , et al. (2018), H. Hu, et al. (2021), S. Hu, et al. (2017), P. Ghasemi , et al. (2019), B. Vahdani , et al. (2018), A. Li , et al. (2012), S.Roh , et al. (2018), Y. Liua , et al. (2019), A. Moreno , et al. (2016), H. Wang , et al. (2014), J. Paul , et al. (2016), J. Paul , et al. (2019), M. Mohammadi. , et al. (2019), A. Safaei , et al. (2018), Verma & Gaukler ((2015), R. Mohammadi , et al. (2016), C. Lu , et al. (2013), Rawls & Turnquist (2010) , L. Li , et al. (2011), D. Berkoune , et al. (2012), Y.Chen , et al. (2016).
Static	16	T. Schempp, et al. (2019), Mete & Zabinsky (2010), R. Mahrajan, et al. (2020), F. Liberatore, et al. (2014), Y. Lin, et al. (2011), Ji & Zhu (2012), P. Kelle, et al. (2014), R. Das (2018), H. Golabian, et al. (2021), Y. Lin, et al. (2012), I. Xaviera , et al. (2019), K. Huang , et al. (2019), Y. Ma , et al. (2018), N. Cotes , et al. (2019), W. Wisetjindawata , et al. (2014).

Appendix D: MATLAB Coding of Figure of Regression at Least 0.9

```
% Initializing
clc; clear; cla
a=[0, 2, 1,47,35,19,18,36,44,53,17,26,49
2, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0
1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
47, 1, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0
35, 0, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0
19, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 0, 0
18, 0, 0, 0, 1, 1, 1, 1, 1, 1, 0, 1, 0
36, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1
44, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0
53, 0, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0, 0
17, 0, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0
26, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0
49, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1];

%% Assigning each City to a node around a circle
Nodes = a(2:end,1);
k=1;
for i = 0:360/(numel(Nodes)):360-360/(numel(Nodes))
Nodes(k,2:3) = [cos(deg2rad(i)), sin(deg2rad(i))];
k=k+1;
end
Lines = [];
Record = [];
k=1;
for i = 2:size(a,1)
for j = 2:size(a,2)
if a(i,j) == 1
Record(k,:) = [a(i,1),a(1,j)];
[row1, ~]=find(Nodes(:,1)==Record(k,1));
[row2, ~]=find(Nodes(:,1)==Record(k,2));
Start(k,:)=Nodes(row1,2:3);
End(k,:) = Nodes(row2,2:3);
k = k+1;
end
end
end
%% Illustration
scatter(Nodes(:,2),Nodes(:,3),100,'filled'); hold on
set(gca,'Color','k')
xlim([-2, 2])
ylim([-2, 2])
for i = 1:size(Start,1)
plot([Start(i,1),End(i,1)],[Start(i,2),End(i,2)],'white');
end
text(Nodes(:,2)+ Nodes(:,2)*0.2-0.06,Nodes(:,3)+ Nodes(:,3)*0.2,...
num2str(Nodes(:,1)),'color','white');
```

Appendix E: Face Mask Types

There are many types of face masks. Two main types of masks are available according to the nature of raw material that used in manufacturing of filter part of the mask, the first common one is Melt-blown Polypropylene (PP) non-woven fabrics with a fiber diameter of 0.5–10 μm is widely used in current masks and they are disposable masks. Their relatively large diameter is insufficient to efficiently filter 0.3 μm particles or aerosols, electrostatic treatment is needed to improve filtration efficiency, during wearing or cleaning, and static electricity is easily lost. The second new type is reusable electrospun nanofiber membranes with fiber diameter below 0.3 μm . (Zhang, Ji, He, & Ramakrishna, 2021) achieve physical barriers to particles and viruses through smaller fiber diameters and pore diameters, getting rid of the limitation of static electricity. They are able to reuse suitable disinfection method like water washing and alcohol sterilization. They also describe details about the methods for manufacturing the electrospun nanofiber and fabrication from polymer solution and melt such as synthetic polymers like Poly (vinyl alcohol) (PVA) and Poly (ethylene oxide) (PEO) and natural polymers like thermoplastic carboxymethyl cellulose (TCMC), starch and Cinnamon Oil. Furthermore, producing innovative types according to the purpose of using such as antiviral, transparent, biodegradable to maintain the environment, nostril for filtering allergic substances (Zhang et al., 2021). Face masks can be classified also according to the usage purpose into two main types, the first one is surgical mask as shown in figure 4 which prevent the exposure of nose and mouth in fluids or large droplets, this type contains at least 3 layers, the first one is cover layer which is hydrophobic to protect from water droplets and moisture, the second layer is filter-type fabric such as a non-woven

polypropylene fabric, the third layer is a shell that give comfortable to wearer. The second part of masks are respirators and they are used to protect wearers from certain levels of contaminants in the air in the form of half-face or full-face masks. The N95 mask as shown in figure 5 is one of nine anti-particulate masks certified by National Institute of Occupational Safety and Health (NIOSH). The healthcare workers must wear medical-grade masks and respirators to prevent the exposure toward a high concentration virus environment. In case of the shortage of filtering face-piece respirators, the surgical mask is recommended to protect individuals in public (Zhang et al., 2021).

N95 filtering facepiece respirators (FFR) can be decontaminated and reused to compensate the shortage in masks during sudden pandemic disease infection, and a systematic review on different disinfectants to decontaminate these filters conducted and it is found that a single cycle of vaporized H₂O₂ successfully removes infectious pathogens without affecting mask function or fit (O'Hearn et al., 2020).

Researchers have also evaluated the size and content characteristics of the SARS-CoV-2 particles. Upon analysis of negative-stained SARS-CoV-2 articles by electron Microscopy. Researchers have determined the diameter of this virus to range between 60 nanometers to a maximum diameter of 140 nanometers (Boonmee et al., 2017). (One nanometer (nm) = 0.001 micrometers (μm)). In addition to measuring the spherical size of the virus particle, it has also been confirmed that the length of the size tumors that surround the outermost surface of SARS-CoV-2 can vary in length from 9 to 12 nm respiratory droplets are typically 5-10 micrometers (μm) in length. The protective capabilities offered by N95 masks are largely attributed to the masks' removal of more than 95% of all particles with an average diameter that is

300 nm or less. In fact, it has been estimated that N95 masks can filter approximately 99.8% of particles that have an average diameter of 100 nm (News Medical Life Science, 2020)

The electrospun fibers with diameters ranging from 0.3–7 μm were prepared using polycaprolactone (PCL) and Poly-L-Lactic Acid (PLLA). PCL and PLLA were mixed in proportions of 25: 75, 50: 50 and 100: 0, and dissolved in chloroform, and added a certain amount of N, N-Dimethyl-Formamide (DMF) to obtain the spinning solution of 4 wt%, 6 wt% and 8 wt%, respectively. The abovementioned solution was stirred at about 25 °C for 4 h, as the electrospinning solution. The electrospinning parameters are as follows. the voltage, 15 kV; the receiving roller speed, 100 r/min; the injection propulsion rate, 10 mL/h; the receiving distance, 15 cm; the temperature, 15 °C; the humidity, 45 %; the spinning time, 30 min (Ma, Zou, & Huang, 2020).

Non-woven fabric forming technology is cheaper than other fabric forming technology like woven or knitted. Most of the surgical face mask manufacturers produce the surgical face mask using Spunbond Meltblown Spunbond (SMS) technology (Chellamani, Veerasubramanian, & Balaji, 2013). Surgical face masks were originally developed to contain and filter droplets containing microorganisms that are liberation from the mouth and nasopharynx of healthcare workers during surgery, thereby providing protection for the patient (Chellamani et al., 2013).

Appendix F: Data of The Example Without Dam

Location	Distance kilometer	Height meter	Location	Distance kilometer	Height meter
1	3,00	11,57	26	106,74	12,87
2	5,78	11,19	27	108,90	14,00
3	11,53	15,44	28	114,56	15,36
4	15,08	11,78	29	118,72	11,13
5	19,67	13,66	30	122,69	13,18
6	22,97	12,24	31	128,16	11,17
7	29,27	12,63	32	131,50	13,28
8	31,21	12,45	33	132,59	13,69
9	33,90	15,94	34	138,75	14,63
10	39,11	11,76	35	140,70	12,33
11	40,73	11,39	36	144,75	12,74
12	45,12	15,62	37	148,75	15,65
13	47,62	13,14	38	149,85	15,62
14	52,89	11,55	39	156,49	13,13
15	59,87	12,88	40	159,08	12,18
16	63,84	11,27	41	163,23	12,07
17	66,23	15,27	42	167,88	12,77
18	72,69	15,93	43	171,42	14,24
19	78,92	13,93	44	172,89	15,99
20	80,13	14,02	45	175,79	11,07
21	81,33	14,96	46	177,16	14,25
22	87,62	12,10	47	178,46	15,85
23	94,07	15,31	48	180,37	12,69
24	100,80	11,18	49	182,59	13,17
25	102,71	12,96	50	189,11	14,33