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A Review of Relief Supply Chain Optimization

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ABSTRACT

With a steep increase of the global disaster relief efforts around the world, the relief supply chain and humanitarian logistics play an important role to address this issue. A broad overview of operations research ranges from a principle or conceptual framework to analytical methodology and case study applied in this field. In this paper, we provide an overview of this challenging research area with emphasis on the corresponding optimization problems. The scope of this study begins with classification by the stage of the disaster lifecycle system. The characteristics of each optimization problem for the disaster supply chain are considered in detail as well as the logistics features. We found that the papers related to disaster relief can be grouped in three aspects in terms of logistics attributes: facility location, distribution model, and inventory model. Furthermore, the literature also analyzes objectives and solution algorithms proposed in each optimization model in order to discover insights, research gaps and findings. Finally, we offer future research directions based on our findings from the investigation of literature review.

Keywords: Relief Supply Chain, Humanitarian Logistics, Disaster, Optimization, Modeling

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1. INTRODUCTION

In the early twenty-first century, the earth supports a human population that is more numerous and—in general—is healthier and wealthier than ever before. At the same time, there is an unprecedented awareness of the risks that face people and what they value (Smith, 2013). While some of this resulting in an event of the loss of life and destruction caused by natural hazards, other concerns deal with man-made (technological) disaster. This could be illustrated by the evidence of the disaster statistics shown in Figure 1.

In 2012, 357 natural triggered disasters were registered. Although this was less than the average annual disaster frequency observed from 2002 to 2011 (394), the contrary indicator, economic damages from natural disasters did show an increase to above average levels (US$143 billion), with estimates placing the figure at US$157 billion. However, natural disasters still killed a significant number from 2002 to 2011, 107,000 people were killed annually and 268 million people became victims worldwide (Guha-Sapir *et al.*, 2013). Relief supply chain management has recently gained attention due to many natural and man-made disasters and the recognition of the central role of logistics in responding to these (Kovacs and Spens, 2012). The field of humanitarian logistics and relief supply chain management is receiving increasing attention among academics, as well as practitioners. The number of related publications has been increasing steadily (Kovacs and Spens, 2008). However, the Haiyan typhoon in early November 2013, like many previous disasters all over the world, shows once again to test our responsive system, especially the major of the logistics and supply chain management system to capable providence of humanitarian relief. Unfortunately, 2013 Haiyan typhoon illustrates a significant example of this lack of a proficient system. Typhoon Haiyan devastated portions of Southeast Asia, particularly the Philippines. It is the deadliest Philippines typhoon on record (BBC News, 2013). To date, over 14 million people have been affected and at least 5,959 people have been killed by this disaster (United Nations Office for the Coordination of Humanitarian Affairs, 2013). Van Hentenryck (2013) stated that other dramatic

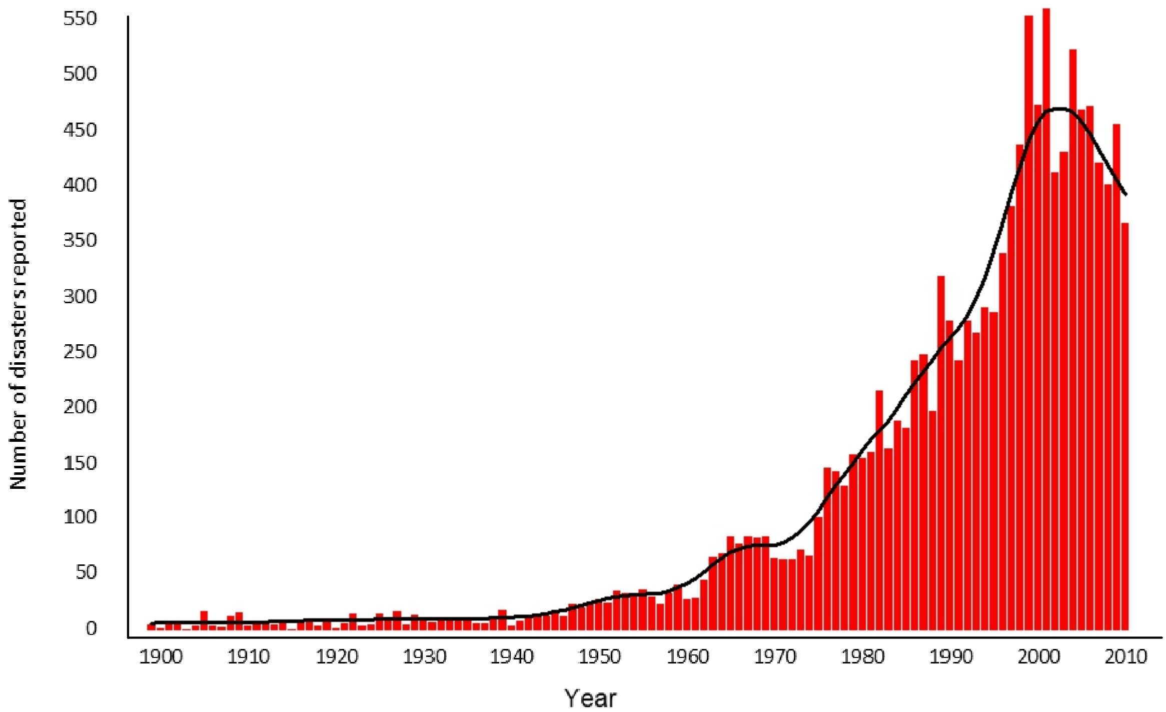

Figure 1. Natural disaster reported 1900–2011 (Source: EM-DAT The International Disaster Database, 2011).

events, such as Hurricane Katrina and Tohoku tsunami, have also highlighted the need of operations research/ management science (OR/MS) tools, in particular, in relief distribution, and evacuation planning and scheduling.

According to the steep increase in the number of articles on relief supply chain management in recent years (Altay and Green, 2006), a broad overview of the issues is addressed ranging from a principle or conceptual framework to the analytical methodology and case study applied. Among a number of distributions in this field, the operations research encompasses most objective challenges, such as decision-making, simulation, mathematical optimization, queuing theory and other stochastic process models. However, the first review paper on operations research in disaster relief was published in 2006 by Altay and Green (2006). They survey the literature on OR and MS models for disaster operations management. They offer an overview on OR/MS model following disaster life cycle in general which is now seven years old. The second was released by Wright *et al.* (2006) to examine the previous OR work in homeland security. The areas specified by the US Department of Homeland Security mainly on the four phases in the disaster life cycle: planning, prevention, response, and recovery. Natarajarathinam *et al.* (2009) provided a framework for classifying supply chain management literature in crisis management. De la Torre *et al.* (2012) expanded the analysis of the use of such models from the academics perspective to the practitioners by interviewing representatives from government organizations and commercial partners. They also include findings from the general media, trade publications and other publications in disaster relief and humanitarian logistics. Caunhye *et al.* (2012) proposed a literature review using content analysis on optimization models in emergency logistics. In the same year, Dasaklis *et al.* (2012) proposed the literature from their logistical attributes into four groups: epidemics logistics network configuration, stockpiling medical supplies, triage operations and other approaches. Finally, the latest review paper on this topic is released at the beginning of year 2013. Galindo and Batta (2013) reviewed recent OR/MS research in disaster operations management as a continuation of the previous work of Altay and Green (2006). Their analysis is performed by classifying papers based on several issues such as author's affiliation, disaster type, methodology, etc. As far as we know, such an analysis of solution algorithms for optimization models has not been performed before in this field. So, in addition to classification approach in this review, we present the analysis of solution algorithms related to the characteristics of model formulation in details as well as the study of the most common objective functions in this research area. The reason to study focusing on only optimization models among other OR techniques is because it is the most popular tools in emergency logistics and relief supply chain systems (Caunhye *et al.*, 2012). This definitely brings both major challenges and growing contribution to this field. Furthermore, each modeling has also created valuable and important insights which lead our review to address research gaps and future trends in this study.

Table 1. The different characteristics between commercial supply chain and relief supply chain

Characteristic	Commercial supply chain	Relief supply chain
Parties involved	• Well linked with each other • Long-term relationship	• Unknown and voluntary • Develop instantaneously during the relief operations
Network configuration	• Relatively stable	• Unstable and many suppliers only supply once during the relief operations
Demand	• Generally quite stable • Past data can be used to forecast the level of demand by standard technique	• Largely unpredictable • Very unstable with time • Need quick assessment and knowledge • No standard technique available
Supply	• Predetermined suppliers • The level of supply activities reflect the level of demand (demand from customer order) • Proper selection and performance monitoring	• Not possible to limit supplies from certified suppliers • Supply not reflect the demand (demand from aid agencies) • Non-essential and shortages most often seen

Adapted from Pujawan *et al.* (2009).

While there are several evidences providing the literature review focusing on operations research techniques for disaster relief, only a few specially offered a concentration for optimization models (Caunhye *et al.*, 2012; Dasaklis *et al.*, 2012; De la Torre *et al.*, 2012). Nevertheless, the thorough study and analysis of solution approaches for optimization is not discovered yet. Therefore, the advantages of this study are that it not only surveys the literature to identify findings and insights but also is capable of filling the stated gap from the previous review papers. So, the objectives of this paper are to:

1) Review recent progress and summarize the current stage of knowledge in a particular topic on the optimization models for relief supply chain system.
2) Organize and classify papers on optimization model for disaster relief supply chain management by an appropriate approach.
3) Create an understanding of this topic for audience by discussing the findings presented in recent research.
4) Synthesize the results of future trend on optimization model for disaster relief supply chain management from several primary literature papers by producing a coherent argument about the focused description of this field.

2. DISASTER MANAGEMENT SYSTEM AND RELIEF SUPPLY CHAIN MANAGEMENT

2.1 Relief Supply Chain Management

The formation or reformation of supply chains following large-scale and catastrophic disasters is a complex undertaking. Established and impromptu organizations and government agencies, attempting to work together, in some cases for the first time, quickly must provide goods and services that help save lives, provide comfort, and even restore entire communities (Day *et al.*, 2009). The disaster relief supply chain operates under conditions that would frustrate most commercial supply chain managers. Different objectives and mechanisms drive disaster relief supply chains; their operating environment is extremely uncertain and dynamic, and unique management principles are often employed. Nevertheless, there are lessons to be learned that could apply to the most publicized commercial sector supply chains, such as those found at Wal-Mart, Toyota, Apple, and MacDonald's, and vice versa (Whybark *et al.*, 2010).

Recent studies have demonstrated the increasing contribution of relief supply chain management due to a number of natural and man-made disasters and the recognition of the central role of logistics in responding to these (Kovacs and Spens, 2012). A disaster relief supply chain starts from suppliers of federal and local government or private donors to regional distribution warehouses, to local warehouses, finally to the disaster recovery centers (Feng *et al.*, 2013). Sheu (2007b) defined specifically to an emergency logistics as a process of planning, managing and controlling the efficient flows of relief, information, and services from the point of origin to the points of destination to meet the urgent needs of the affected people under the emergency conditions. Oloruntoba and Gray (2006) argued that relief supply chains are clearly unpredictable turbulent and requiring flexibility. In principle, locations are frequently unknown until the demand occurs. Short lead times dramatically affect inventory availability, procurement, and distribution. Transportation and supply information is unreliable, incomplete, or non-existent (Russell, 2005). However, relief supply chain framework have been developed by numerous agencies and governments around the world, many of them seem to be purely theoretical and relatively ineffective in their initial response or subject to unforeseen constraints (Banomyong and Sodapang, 2012). While commercial and relief supply chains are sharing a number of commonly ways of principle and operation, the different characteristics are able to summarize as shown in Table 1 which is adapted from

Table 2. Major activities of disaster management system

Phase activity	
Mitigation	**Response**
• Establishing land-use planning and control to prevent occupation of high hazard areas • Using technological advancement to mitigate disasters effects • Establish preventive measures to control developing situations • Ensuring application of proper methods in rebuilding buildings and infrastructures after disasters • Measuring potential for extreme hazards using risk-analysis techniques • Enforcing the use of insurance plans to reduce disasters' financial impacts	• Activating emergency operations plan • Activating emergency operations centers • Evacuating disaster areas • Opening shelters and providing mass care • Providing emergency rescue and medical care • Firefighting • Performing search and rescue • Providing emergency infrastructure protection and recovering lifeline services • Establishing fatality management • Ensuring the security of affected areas by deploying police or military forces
Preparedness	**Recovery**
• Recruiting personnel for emergency services • Establishing community volunteer groups • Emergency planning and logistical planning • Acquiring and stockpiling necessary items • Budgeting • Acquiring necessary vehicles and equipment • Acquiring, stockpiling, and maintaining emergency supplies • Constructing central and regional emergency operations centers	• Providing disaster debris cleanup • Providing financial assistance to individuals and governments • Rebuilding roads, bridges, and key facilities • Providing sustained mass care for displaced people and animals • Reburying displaced human remains • Fully restoring lifeline services • Providing mental health and pastoral care

Adapted from Altay and Green (2006).

Pujawan *et al.* (2009).

2.2 Disaster Management System

Disaster management is a set of processes designed to be implemented before, during, and after disasters to prevent or mitigate their effects (Nikbakhsh and Farahani, 2011). In general, it is carried in a cycle system consisting of several main stages. In the United States comprehensive emergency management is commonly described in terms of four programmatic phases: mitigation, preparedness, response, and recovery (Altay and Green, 2006). This discipline involves preparing for disasters, responding to them, and finally supporting and rebuilding the society after initial disaster relief operations have ended. Many representatives and organizations involved in disaster management. These vary from small to large NGOs, local, state and federal governmental relief organizations and commercial partners of relief organizations. Also, the success of these systems relies heavily on effective and efficient cooperation and coordination of organizations participating in relief operations. The main activities during each phase are shown in Table 2 (Altay and Green, 2006).

3. SCOPE OF STUDY

In order to review the literature in this study, sources and searching approach are firstly necessary to identify. This paper concentrate upon academic publications and journals related to relief supply chain management for disaster operations. The review focuses on only papers presenting optimization models on which are the most popular among other OR techniques. Those publications are selected in the year published from 2004 to present shown in Figure 2 in order to study the update trend and findings. We use journal search engines, such as Science Direct, ISI Web of Science, the INFORMS Journal Database, Emerald Group Publishing, Springer Journal Database and various individual journal's search engines. The query refers to the keywords "logistics", "supply chain", "disaster", "emergency", "humanitarian", "resilient", "large-scale" and other forms of the words such as "disastrous", "hazard", "resilience" and "catastrophe." Moreover, the literature of relief supply chain management is followed with the concept of disaster operations management. According to Section 2.2, many of disaster

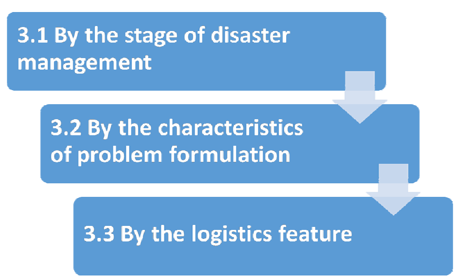

Figure 2. The classification approach for the literature on relief supply chain management.

operations management have been presented in a different number of stages. However, those are basically carried as a cycle with both short-term and long-term systems. In order to react with crucial time, literatures with long-term planning are excluding our interest. The review study focuses on only short-term operations which will be discussed in the following section.

4. CLASSIFICATION APPROACH

This section aims to classify those related papers on relief supply chain operations based on an appropriate procedure. After collecting those articles by searching approach from the earlier section, we eliminate some which are not in our interest. The consideration resulted in 50 articles related with optimization models for disaster operations management. The review study indicates that it is able to group those articles based on Figure 2.

4.1 The Stage of Disaster Management

The initial step of grouping could be identified following concept of disaster management. Basically, disaster operations management comprises of several stages following the timeframe, for example, mitigation, preparedness, response and recovery. The study found that there are a number of articles develop their models response to different stages of disaster management concept. Many of them formulate their problem for planning and preparing the community system before the occurrence of disaster while a variety of models aware of the emergency response and recovery operations during or after disaster strike. Therefore, the category as beginning could be three clusters of articles with pre-disaster, post-disaster and integrated following the period of disaster management system.

4.2 The Characteristics of Problem Formulation

After identification by the stage of disaster management, all of those optimization models interest us to study the characteristics of problem formulation. We found that some of them are problems with single period level while others deal with two or multi period level. Moreover, deterministic and stochastic problem are the criteria for the characteristics consideration to classify those optimization model as well.

4.3 The Logistics Feature

According that the literature focuses on relief supply chain models, the feature of logistics optimization model is the important criteria to classify those articles at the last approach in this study. They are able to be grouped into three different models following the logistics characteristics: facility location model, distribution model, and inventory model.

5. FINDINGS FROM REVIEW PROCEDURE

The objective of this section is to breakdown the literature following the stated methodology in order to discover the findings and other relevance from the study.

5.1 The Grouping by Disaster Lifecycle Stage

Figure 3 displays the portion of three clusters of articles due to the time frame of disaster from Section 4.1. The review found that the majority of optimization models focus on post-disaster operations mainly on the emergency response requirements, such as

- Activating emergency operations planning;
- Identification of sources for the procurement of medical supplies and relevant commodities;
- Transportation management for relief items.

Barbarosoglu and Arda (2004) offered a multi-modal network flow to plan the transportation of vital first-aid commodities to disaster affected areas during emergency response. Similarly, Yi and Kumar (2007) presented the transport of wounded people from affected areas to emergency medical centers besides the commodities transportation from major supply centers to distribution centers in the affected areas. Gkonis *et al.* (2007) proposed the actions required to respond to a specific oil spill. The approach model is to respond optimally on cost basis in term of facilities dispatch to the spill site.

On the other hand, about a quarter of total number of review articles construct the optimization models for planning and preparing the community system in pre-disaster stage. For example, Jia *et al.* (2007) proposed models and solution approaches for determining the facility locations of medical supplies in response to large-scale emergency. The study is to investigate which facilities should be opened and the order in which facilities are opened can have a significant effect on the quality of coverage. Balcik and Beamon (2008) and Rawls and Turnquist (2010) created an optimization model whose solution provides a prepositioning strategy for facility locations and inventory decision under uncertainty. The mathematical models determine the number

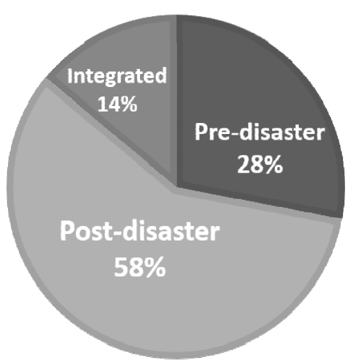

Figure 3. The portion of three clusters of articles due to the time frame of disaster.

and locations of the distribution center in relief network and the amount of relief supplies to be stocked at each distribution center.

However, the number of articles which consider models for both pre-disaster and post-disaster is quite small. Most of them address their models as multi period problem for each requirement of pre- and post-disaster. Irohara *et al.* (2013) proposed a tri-level programming model for this integrated category. The top level addressed facility location and inventory decisions; the second level represents damage caused by the disaster, while the third level determines response and recovery decisions.

5.2 The Characteristics of Problem Formulation

Another important issue of this study approach is to investigate the problem formulation characteristics of each related article model. The research concentrates on the comparison of the problem stage between single-period and multi-period and the problem process characteristics between deterministic and stochastic. The study is shown in Figure 4.

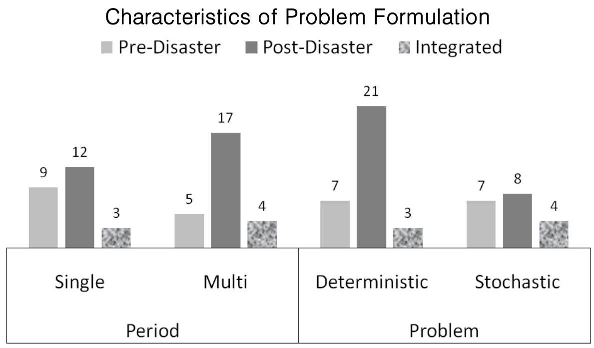

Figure 4. The study of problem formulation characteristics.

Post-disaster problems resulted in multi-period models rather than single-period while pre-disaster models bring their results much more in single-period. Ukkusuri and Yushimito (2008) presented a single stage model incorporate the idea of the most reliable path in a facility location problem in which used in solving the inventory prepositioning problem for humanitarian supply chains. Another single stage model proposed by Jia *et al.* (2005) showed how the general large-scale emergency facility location problem leads to covering, *P*-median, and *P*-center problems. On the other hand, other researchers such as Ozdamar and Demir (2012), Ben-Tal *et al.* (2011) and Wohlgemuth *et al.* (2012), are concerned with multi-period management problems with inherent time dependent information uncertainly for post-disaster phase.

Moreover, the study found that overall deterministic problem is more popular than stochastic ones. To determine the characteristic between deterministic or stochastic is affected by the disaster scenarios considered. We found that many optimization models deals with stochastic model but solves flexibly as deterministic instead. This is because a deterministic problem is possible to result similar performance with less computational by additional constraints (Wohlgemuth *et al.*, 2012). Many deterministic problems are modeled in various aspects for relief supply chain and humanitarian logistics. For example, Sheu *et al.* (2005) utilized fuzzy clustering and linear programming to solve the disaster relief resource allocation problem. Abounacer *et al.* (2014) consider the multi-objective emergency location-transportation problem in a static and deterministic environment since the decisions to be made are taken immediately after the disaster. Aksu and Ozdamar (2014) proposed a dynamic path based mathematical model focus on the planning of road restoration efforts during the first three days of response. They addressed the issue of restoring blocked links in a road network with the goal of opening access paths for all locations as early as possible. Similarly to Rekik *et al.* (2013), Sebbah *et al.* (2013), and Taniguchi and Thompson (2013) whose models are deterministic problem for post-disaster response phase.

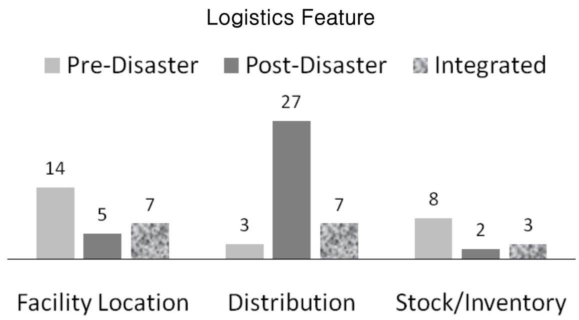

Figure 5. The study of logistics feature.

While the number of deterministic model is greater released, stochastic model articles are also increasing gradually recently. Song *et al.* (2009) applied stochastic simulation with a hybrid intelligent algorithm to optimize bus routing and passenger pick up points during the hurricane evacuation. Salmeron and Apte (2010) developed a two-stage stochastic optimization model to guide the allocation of budget to acquire and position relief assets, decisions that typically need to be made well in advance before a disaster strikes. Najafi *et al.* (2013) proposed a robust approach for stochastic models to incorporate humanitarian and cost issues in managing both disaster relief commodities and injured people during the initial phase of earthquake response. The use of radio frequency identification (RFID) technology for emergency stochastic inventory model was proposed by Ozguven and Ozbay (2013). They developed the humanitarian emergency management framework based on the real-time tracking of emergency supplies and demands through the use of RFID technology integrated with a multi-commodity stochastic humanitarian inventory management model. Then, the model proposed to determine the optimal emergency inventory levels to prevent possible disruptions at the minimal cost. Recently, an integrated inventory allocation and transportation planning was represented by Kristianto *et al.* (2014) as a two stage stochastic programming where the inventory allocation acts as the first stage decision and transportation planning as the two-stage decision at different sets of future stochastic scenarios. However, there is an article by Falasca *et al.* (2009) proposed deterministic and stochastic model as a multi-modal in the same humanitarian logistics problem. They constructed a deterministic model to develop a multi-criteria optimization model to assist in the assignment of volunteer management and stochastic model for the procurement of goods in the humanitarian efforts.

5.3 The Logistics Feature

In terms of the logistics viewpoint, the study indicates that literature can be classified as three different models comprising of facility location, distribution model and inventory decision. Figure 5 illustrates that facility location and inventory model are popular for the problem focusing on pre-disaster stage while the distribution model is mainly applied with problems on post-disaster phase. This is affected by the characteristics of each disaster period. Firstly, the research assists that the most important aspect of preparedness stage before the occurrence of disaster is to determine the location of various facilities and infrastructures. This is including but not limited to central warehouses of relief items, local warehouses, permanent relief facilities such as major hospitals and positioned relief equipment and vehicles, and temporary relief facilities such as mobile hospitals. Also, humanitarian logistics systems are usually forced to keep some of their required relief items and equipment in stock, in order to increase their levels of preparedness against sudden disasters. However, similar to commercial supply chains, high levels of inventory holding costs could be a burden on humanitarian organizations because of their limited funds and operating resources. Therefore, designing effective inventory systems for humanitarian organization can be of great importance (Nikbakhsh and Farahani, 2011). Kongsomsaksakul *et al.* (2005) studied the optimal shelter locations for the flood evacuation planning. McCall (2006) developed and suggested prepositions for humanitarian assistance pack-up kits that contain emergency relief material commonly used in these missions in order to expedite delivery to those impacted by a disaster. Gunnec and Salman (2007) presented a two-stage multi-criteria stochastic programming model for a multi-facility location problem in pre-disaster planning for effective post-disaster emergency logistics. Ukkusuri and Yushimito (2008) presented a model incorporate the idea of the most reliable path in a facility location problem in which used in solving the inventory prepositioning problem for humanitarian supply chains. Opit *et al.* (2013) developed the previous model (Lee *et al.*, 2011) focusing on stock prepositioning model to support an emergency disaster relief response in the event of earthquake.

Secondly, the distribution of relief commodities is another important aspect in disaster supply chain system especially for post-disaster stage. When the disaster strikes, a large-scale demand is forced to release immediately. It is undeniable that the community needs a good and reliable system which is able to dispatch relief items from suppliers and distribution centers to affected areas with the right quantity, the right place and the right time. The optimization models are developed as distribution models mainly applied with post-disaster level. For example, Sheu (2007a) presented a hybrid fuzzy clustering-optimization approach to the operations of emergency logistics co-distribution responding to the urgent relief demands in the crucial rescue period. Tzeng *et al.* (2007) constructed a relief-distribution model using the multi-objective programming method for designing relief delivery systems in a real case. Yi and Ozdamar (2007) proposed a mixed integer multi-commodity network flow model that treats vehicles flows for coordinating logistics support in disaster response activities. Likewise Ji and Zhu (2012) and Afshar and Haghani (2012) that developed optimization model describing the integrated logistics operations in response to disasters.

5.4 The Review of Objective Function

Besides of the problem characteristics of optimization models as the earlier sections, we study objective functions and algorithms to discover some findings and relationships. The literature found that those optimization models formulate their objective functions in many different aspects. However, according to the feature of logistics model, in terms of facility location, inventory model and distribution model, cost and time effectiveness seem to be most important aspects for this field. Figure 6 depicts that the most popular greatest objective function is to minimize cost. These resulted in various perspectives, such as transportation cost (Horner and Downs, 2010), inventory cost (Ozguven and Ozbay, 2013), shortage cost (Lin *et al.*, 2009; Falasca, 2009), facility opening cost (Mete and Zabinsky, 2010) or a combination (Sheu, 2007a; Klibi *et al.*, 2013).

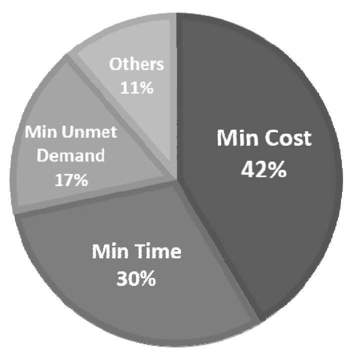

Figure 6. The review of objective function.

The second greatest general objective function is time aspect only to minimize response travel time (Duran *et al.*, 2011; Yan and Shih, 2009; Rachaniotis *et al.*, 2013) and evacuation time (Kongsomsaksakul *et al.*, 2005; Song *et al.*, 2009) for relief supply chain and humanitarian logistics system. However, while cost and time familiarize the objective function for mathematical models in this interest field, Yi and Kumar (2007), Yi and Ozdamar (2007), Dessouky *et al.* (2006) and Ozdamar *et al*. (2004) minimized sum of unsatisfied demand of effected people. Similarly, Balcik and Beamon (2008) and Kusumastuti *et al.* (2013) maximized the total expected demand covered by the established facilities during the considered periods of response time. Travel time was considered instead of distance with reason that in the post-disaster period, distance can be short but traveling time can take longer due to damages in transportation infrastructure (Kusumastuti *et al.*, 2013). Moreover, there are some optimization models which objective functions are considered out of those aspects. A mathematical model for post-disaster road restoration of Aksu and Ozdamar (2014) maximized the total weighted earliness of all paths restored while Sebbah *et al.* (2013) maximized the utility function of the relief plans for military logistics planning. Yoshimito *et al.* (2012) considered a disaster relief incorporating social costs within the modeling framework as to minimize the urgency social function.

5.5 The Review of Solution Algorithm

Our study concern the detailed breakdown on optimization techniques for the field of relief supply chain management as listed in the Appendix. Mathematical programming is entirely applied for problem formulation, such as mixed or pure integer programming, linear or non-linear programming, stochastic programming, etc. Among those literatures, a variety of solution approaches, either exact or heuristic method, have been proposed to solve optimization problems in this emergency logistics field. Exact methods guarantee that the optimal solution is found if the method is given sufficiently time and space whereas heuristics are solution methods that typically relatively quickly can find a feasible solution with reasonable quality (Ropke, 2005). The review found that those papers with stochastic model mainly used heuristic methods rather than the exact ones while deterministic models commonly solved by both of them. Several details are discussed below.

Firstly, stochastic programming models, in general, are difficult to solve by the classical algorithm methods compared with deterministic problems. Thus, a variety of heuristic approach is mainly found to solve them, such as shortest-path algorithm (Song *et al*., 2009), Lagrangian L-shaped method (Rawls and Turnquist, 2010), sample average approximation method (Klibi *et al.*, 2013; Chang *et al.,* 2007) fuzzy logic and spreadsheet modeling (Falasca, 2009). Song *et al.* (2009) formulated the transit evacuation operations as a location-routing problem with uncertain demands based on shortest path algorithm. The hybrid genetic algorithms, artificial neural network, and hill climbing heuristic algorithms have been proposed for solving problems. Kristianto *et al.* (2014) used the fuzzy shortest path algorithm to convert the shortest path problem with time windows and capacity constraint to the original shortest path problem, and thus the problem is easier to solve. Not so many stochastic problems found to use the exact method such as branch and bound algorithm (Salmeron and Apte, 2010). Bozorgi-Amiri *et al.* (2013) gave recommendations to apply meta-heuristics for stochastic optimization programming in their future research work.

Secondly, both exact method and heuristic are commonly solved for deterministic problems. The branch and bound algorithm was used by Gkonis *et al.* (2007) to solve linear mixed integer programming with oil spill response problem. Similarly, Sebbah *et al.* (2013) presented this exact method to maximize the utility function of the relief plans of military logistics planning in humanitarian relief operations. Jia *et al.* (2007) applied and evaluated three heuristic algorithms to solve maximal covering problem which are genetic algorithm, locate-allocate and Lagrangian relaxation. Lagrangian relaxation was also found in Ozdamar *et al*. (2004) to compute linear and integer multi-period multi-commodity network flow problem. Moreover, they gave suggestions on how to select the most appropriate heuristic to solve different location problem instances. Meta-heuristic of ant colony optimization was applied to solve the relief distribution problem (Yi and Kumar, 2007) and the path selection model (Yuan and Wang, 2009). The fuzzy clustering method was proposed by Sheu *et al.* (2005) formulated to group affected areas and to associate the respective distribution priority with them. The computational procedures embed the fundamentals of the fuzzy clustering and multi-objective optimization models are needed to search for the optimal solutions. Hamedi *et al.* (2012) addressed the genetic algorithm based heuristic to solve a problem of the humanitarian response planning for a fleet of vehicles with reliability considerations. Branch-and-cut is also found to solve pickup and delivery problems by Wohlgemuth *et al.* (2012) and Irohara *et al.* (2013).

Moreover, other efficient solution algorithms and heuristics have also been offered in this research investigation to solve NP-hard problems. Ben-Tal *et al.* (2011), proposed affinely adjustable robust counterpart as a robust optimization associated to linear programming with uncertain parameters in humanitarian relief supply chains. Ozdamar and Demir (2012) presented hierarchical cluster and route procedure to deal with large scale relief networks by using the k-means partitioning heuristic. Abounacer *et al.* (2014) and Rath and Gutjahr (2014) proposed both exact solution method and heuristic as an approximation method. These two papers applied an epsilon-constraint method and prove that it generates the exact Pareto front of a complex multi-objective location–transportation problem.

6. CONCLUSION AND FUTURE RESEARCH

This paper proposed a literature review of relief supply chain and humanitarian logistics focusing on optimization models. We found that the number of articles in this field is quite limited because the awareness of disasters has just increased recently. However, they have provided a variety of contributions in this field, it is still not enough. The rapidly changing world and global problems lead to the increasing number of both natural and man-made disasters. It is both vital and necessary to continue to strengthen and expand this challenging area. From the survey, a broad overview of the issues is addressed from a principle conceptual framework to the analytical methodology and case study applied in recent literatures. However, we focused only on papers presenting optimization models which are the most popular among other OR techniques. Researchers and practitioners propose their models in different stages of disaster concept system.

Problem formulation varies from mixed or pure integer programming to stochastic programming while both exact and heuristic method play an important role in solution approach. The existing review papers in this field lack in study and analysis of the solution algorithms related to each problem formulation. This could be an original for our study. Many problems according to the logistics attributes like vehicle routing problem and warehouse location routing problem considered in those disaster relief articles are usually known to be NP-hard. A variety of heuristic methods, are found to be developed and applied to solve such problems. Heuristic is a technique designed for solving a problem more quickly when classic methods are too slow, or for finding an approximate solution when classic methods fail to find any exact solution (Ropke, 2005). Our study discovered that those papers with stochastic programming models mostly solved by many heuristics rather than the exact method while deterministic problems are commonly found with both of them. This is because stochastic problems are difficult to solve by the classical algorithm methods compared with deterministic problems. However, some papers proposed their heuristic algorithms as an approximation method to optimize their problems.

Our literature survey found that most researchers from during 2004 to present published their works on post-disaster stage while Wright *et al.* (2006) discovered very few papers in this category. This implies that many critical issues in the stage of post-disaster gain significantly more attention than the past. Figure 7 depicts the positioning of research interests in this emergency logistics field. Each number refers to the amount of models

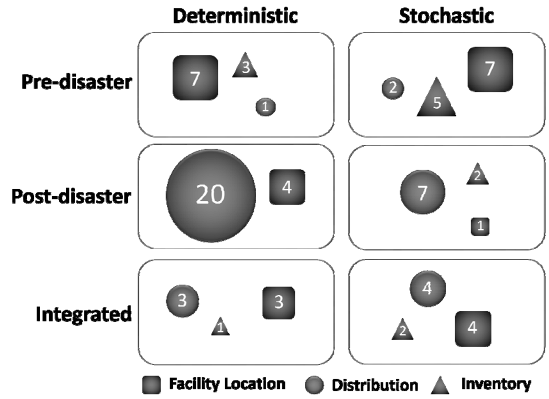

Figure 7. Positioning of research interest on optimization model for relief supply chain system.

on current research according to the time frame of disaster stages, problem formulation with stochastic or deterministic and the logistics characteristic. At first glance, we can see that there is a lack of distribution model in the stage of pre-disaster. Most research is mainly considering the facility location and inventory model for pre-disaster stage. Planning of both aspects seems to be critical issues to be addressed before the disaster strikes. In contrast, the number of facility location and inventory models are limited in the post-disaster phase level. More attention has been paid to the distribution model. Only a few papers are found to be concerned with stochastic problems with facility location and inventory models. Moreover, there is no model considering the inventory decision as a deterministic problem at this stage. However, the system of relief supply chain during the response phase of disaster lifecycle also needs to consider facility location and inventory problems. This is because there is still risk and uncertainty after the disaster occurs. The situation may probably change anytime. There is no guarantee that disaster will not happen again within a short period of time. Many facilities such as shelter, warehouse and DC may need to move or relocate because they face a dynamic problem according to the new scenario of catastrophe. Relief supply chain and humanitarian logistics have many new opportunities to contribute to the advancement of knowledge in this area. With more thorough preparations, therefore, our future work will consider the situations as a problem which integrates both pre- and post-disasters. Also, our consideration will include those three aspects of logistics in the post-disaster stage in order to narrow the gap in this research area.

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Appendix. The review study of optimization model on relief supply chain

No	Author	Year	Logistics feature	Period		Problem		Mathematical model	Solution algorithm
				Single	Multi	Deter-ministic	Stochastic		
1	Barbarosoglu and Arda	2004	Distribution		✓		✓	linear programming	exact method
2	Ozdamar *et al*.	2004	Distribution		✓	✓		linear integer programming	heuristic algorithm (Lagrangean relaxation)
3	Sheu *et al.*	2005	Distribution	✓		✓		fuzzy linear programming	heuristic algorithm (fuzzy clustering method)
4	Jia *et al.*	2005	Facility location	✓		✓		linear integer programming	exact method
5	Kongsomsa-ksakul *et al.*	2005	Facility location Distribution		✓	✓		non-linear mixed integer programming	exact method
6	McCall	2006	Facility location Inventory	✓		✓		integer linear programming	exact method
7	Dessouky *et al.*	2006	Facility location Distribution	✓			✓	integer programming	heuristic algorithm
8	Chang *et al.*	2007	Facility location Distribution	✓			✓	stochastic programming	heuristic algorithm (sample average approximation method)
9	Gunnec and Salman	2007	Facility location		✓		✓	goal programming	exact method
10	Jia *et al.*	2007	Facility location	✓		✓		integer programming	heuristic algorithm (genetic algorithm, locate-allocate, Lagrangean relaxation)
11	Yi and Kumar	2007	Distribution		✓	✓		mixed integer programming	heuristic algorithm (ant colony optimization)
12	Gkonis *et al.*	2007	Distribution	✓		✓		linear mixed integer programming	exact method (branch and bound)
13	Sheu	2007a	Distribution		✓	✓		dynamic linear programming	heuristic algorithm (fuzzy clustering method)
14	Tzeng *et al.*	2007	Distribution		✓	✓		fuzzy multi-objective linear programming	heuristic algorithm
15	Yi and Ozdamar	2007	Facility location Distribution		✓	✓		mixed integer programming	heuristic algorithm (pseudo-polynomial algorithm)
16	Balcik and Beamon	2008	Facility location Inventory	✓			✓	mixed integer programming	exact method
17	Ukkusuri and Yushimito	2008	Facility location Inventory	✓		✓		integer programming	heuristic algorithm (shortest-path algorithm)
18	Song *et al.*	2009	Facility location Distribution	✓			✓	stochastic programming	heuristic algorithm (hybrid genetic algorithm, artificial neural network, hill climbing algorithm)
19	Yan and Shih	2009	Distribution	✓		✓		mixed integer programming	heuristic algorithm
20	Yuan and Wang	2009	Distribution		✓	✓		integer programming	heuristic algorithm (Dijkstra's algorithm, ant colony optimization)
21	Lin *et al.*	2009	Facility location Distribution	✓		✓		integer programming	heuristic algorithm (vehicle assignment heuristics)
22	Falasca	2009	Distribution		✓		✓	stochastic programming	heuristic algorithm (fuzzy logic, spreadsheet modeling)
23	Falasca *et al.*	2009	Facility location	✓		✓		integer programming	exact method
24	Horner and Downs	2010	Facility location Distribution	✓		✓		linear programming	exact method
25	Mete and Zabinsky	2010	Facility location Distribution Inventory		✓		✓	stochastic programming	heuristic algorithm
26	Rawls and Turnquist	2010	Facility location Inventory		✓		✓	stochastic mixed integer programming	heuristic algorithm (Lagrangian L-shaped method)

No	Author	Year	Logistics feature	Period		Problem		Mathematical model	Solution algorithm
				Single	Multi	Deter-ministic	Stochastic		
27	Salmeron and Apte	2010	Facility location Distribution Inventory		✓		✓	stochastic mixed integer programming	exact method (branch and bound)
28	Duran *et al.*	2011	Facility location Inventory	✓			✓	mixed-integer programming	exact method
29	Ben-Tal *et al.*	2011	Distribution		✓		✓	linear programming	heuristic algorithm (affinely adjustable robust counterpart)
30	Ozdamar and Demir	2012	Distribution		✓	✓		integer programming	heuristic algorithm (multi-level clustering algorithm)
31	Yoshimito *et al.*	2012	Facility location	✓		✓		non-linear mixed integer programming	heuristic algorithm (Voronoi diagrams)
32	Ji and Zhu	2012	Distribution	✓		✓		integer programming	heuristic algorithm
33	Wohlgemuth *et al.*	2012	Distribution		✓	✓		mixed integer programming	heuristic algorithm (branch and cut)
34	Afshar and Haghani	2012	Distribution	✓		✓		mixed integer programming	exact method
35	Hamedi *et al.*	2012	Distribution	✓		✓		linear integer programming	heuristic algorithm (genetic algorithm)
36	Opit *et al.*	2013	Facility location Inventory	✓		✓		linear programming	exact method
37	Klibi *et al.*	2013	Facility location Inventory		✓		✓	stochastic programming	heuristic algorithm (sample average approximation method)
38	Najafi *et al.*	2013	Distribution		✓		✓	linear programming	exact method
39	Rekik *et al.*	2013	Facility location Distribution		✓	✓		linear programming	heuristic algorithm (genetic algorithm)
40	Rachaniotis *et al.*	2013	Facility location Distribution		✓		✓	stochastic programming	not applied
41	Sebbah *et al.*	2013	Distribution		✓	✓		linear integer programming	exact method (branch and bound: column generation)
42	Taniguchi and Thompson	2013	Distribution	✓		✓		linear programming	heuristic algorithm (NSGA-II)
43	Ozguven and Ozbay	2013	Inventory	✓			✓	stochastic programming	approximation method (p-level efficient points)
44	Kusumastuti *et al.*	2013	Facility location Distribution		✓	✓		mixed integer programming	exact method
45	Irohara *et al.*	2013	Facility location Inventory		✓	✓		mixed integer programming	heuristic algorithm (branch and cut)
46	Bozorgi-Amiri *et al.*	2013	Facility location Inventory		✓		✓	mixed integer programming	exact method
47	Rath and Gutjahr	2014	Distribution	✓			✓	mixed integer programming	heuristic algorithm, approximation method (adaptive epsilon-constraint method)
48	Kristianto *et al.*	2014	Distribution Inventory		✓		✓	non-linear programming	heuristic algorithm (fuzzy shortest path)
49	Abounacer *et al.*	2014	Distribution	✓		✓		mixed integer programming	approximation method (adaptive epsilon-constraint method)
50	Aksu and Ozdamar	2014	Distribution		✓	✓		integer programming	heuristic algorithm