DYNAMICS OF DEPRIVATION COST IN LAST MILE DISTRIBUTION: THE INTEGRATED RESOURCE ALLOCATION AND VEHICLE ROUTING PROBLEM

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Maher N. Itani

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By

Maher N. Itani

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

SUPERVISORY COMMITTEE:

Dr. Rodney Traub
Chair

Dr. Denver Tolliver

Dr. Ibrahim H. Osman

Dr. Om Prakash Yadav

Approved:

July 17 2014
Date

Dr. Denver Tolliver
Department Chair

ABSTRACT

One of the most critical tasks after a natural disaster is to organize and execute humanitarian relief operations effectively and efficiently while reaching an equitable outcome. However, due to limited resources in the initial stage of response, it becomes challenging for logistics planning authorities to target needed individuals. The concerns would be with providing an unbiased platform to make decisions about equitable distribution schedules. Therefore, developing an effective and efficient disaster relief plan that tries to treat individuals as equitable as possible was the main motivation in this research.

For this purpose, this dissertation studied a novel last mile distribution plan in the initial response phase where the key focus is the preservation of lives. An integrated vehicle routing and resource allocation problem was investigated and formulated in an routing-allocation model (RAP). The theoretical foundation of RAP is formulated as an egalitarian model where resources are to be distributed so as to maximize the welfare of those in greatest need. The strategic goal is to alleviate human deprivation and suffering by minimizing the response time in regard to each beneficiary's needs fulfillment and delivery delay on the route. Equity is quantified with a *min-max* objective on a deprivation cost, which is a non-linear function of deprivation time. The objective function is set to minimize the maximum deprivation cost of the deliveries so that supplies arrive in a cyclical manner while all demand sites are treated equitably.

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In addition to dedications of this dissertation, special thanks is deserved for my wife, who continuously supported me in this research and helped me in all non-academic ways during this long process. There is no simple way to tell how much she means to me.

DEDICATION

This work is dedicated to my family: *Fatme, Ahmad, Reina and Louna*…..

TABLE OF CONTENT

ABSTRACT iii

ACKNOWLEDGEMENTS iv

DEDICATION v

LIST OF TABLES xi

LIST OF FIGURES xiii

LIST OF SYMBOLS xvii

LIST OF APPENDIX TABLES xviii

CHAPTER 1. INTRODUCTION 1

1.1. Introduction to Logistics System 1

1.2. Motivation 2

1.3. Problem Statement 4

1.4. Research Objectives 6

1.5. Expected Contributions 8

1.6. Organization of the Dissertation 10

CHAPTER 2. LITERATURE REVIEW 11

2.1. Overview 11

2.2. Disaster Relief Operations 12

2.2.1. Managing Disaster Relief Operations 12

2.2.2. Phases and Life Cycle of Disaster Management 15

2.3. Humanitarian Logistics 21

2.3.1. Importance of Humanitarian Logistics 21

2.3.2. Activities Involved in Humanitarian Logistics 23

2.3.3. Challenges Encountered in Humanitarian Logistics 26

2.4. Commercial Supply Chain Management 28

2.4.1. Commercial Aspect in Supply Chain Management 28
2.4.2. Commercial Supply Chain Structure and Fit 28
2.4.3. Actors, Activities and Flows in CSC 30
2.4.4. Measuring CSC Performance 31
2.4.5. Corporate Social Responsibility 32
2.5. Humanitarian Supply Chain Management 33
2.5.1. Humanitarian Aspect in Supply Chain Management 33
2.5.2. Actors, Activities and Flows in HSC 35
2.5.3. Supply Characteristics 38
2.5.4. Demand Structure 40
2.5.5. Humanitarian Space 41
2.5.6. SPHERE Project 43
2.5.7. Measuring HSC Performance 43
2.5.8. Humanitarian Supply Chain Structure and Fit 45
2.5.9. Structure of the Humanitarian Chain in the Last Mile Distribution 49
2.6. Humanitarian vs. Commercial Supply Chains 50
2.6.1. Previous Comparisons on CSC - HSC 50
2.6.2. A Conceptual Framework for Distinguishing CSC and HSC 51
2.6.3. Cross Learning Possibilities 78
2.7. Summary of Key Differences Between CSCM and HSCM 81
2.8. Understanding Resource Allocation in Humanitarian Supply Chain 81
2.9. A Bankruptcy-Based Framework for Resource Allocation 85
2.9.1. Bankruptcy Rules 86
2.9.2. Bankruptcy Applied to Resource Allocation Problem 91
2.9.3. Linking Bankruptcy Axiomatic Properties with Resource Allocation Principles 91

2.9.4. Applying Bankruptcy Concepts to General Resource Allocation Problem 96

2.10. Philosophical Framework for Resource Allocation 98

2.10.1. Philosophical Approaches to Equitable Allocation 98

2.10.2. Building Utilitarian and Egalitarian Resource Allocation Models 101

2.11. Utility-Based Framework for Resource Allocation 105

2.11.1. Minimizing the Range of Dissatisfaction for Equity 105

2.11.2. Minimizing the Maximum Total Expected Loss 107

2.12. Time-Space Network Framework for Resource Allocation 109

2.12.1. Single-Period Resource Allocation Model 110

2.12.2. Multiple-Period Resource Allocation Model 112

CHAPTER 3. MODEL DEVELOPMENT 117

3.1. Setting up the Network Key Features 117

3.1.1. Initial Response Phase 117

3.1.2. Depot and Demand Sites 118

3.1.3. Emergency Relief Resource 120

3.2. Model Basic Components 120

3.2.1. Vehicle Routing 120

3.2.2. Resource Allocation 122

3.2.3. Multi-Objective Decision Making 122

3.3. Pèrez’s Allocation Model Based on Deprivation Cost 124

3.3.1. Deprivation Cost at One Demand Point 126

3.3.2. Deprivation Cost at Two Demand Points 128

3.3.3. Deprivation Cost at Cluster of more than Two Demand Points 130

3.4. Model Formulation Framework 132

3.4.1. Problem Formulation 132

3.4.2. Modifications on Pèrez Model 133

3.4.3. Delivery-Allocation Joint Strategies 135

3.4.4. Allocating Resources on a Single Route Assuming Enough Supplies at Depot 145

3.5. Mathematical Model for Single Route Resource Allocation 151

3.5.1. Assumptions and Simplifications 152

3.5.2. Mathematical Notation 154

3.5.3. Mathematical Model 155

3.5.4. Illustrative Example 156

3.5.5. Implications of Idle Time on Allocation Structure 164

3.5.6. Summary 167

CHAPTER 4. MODEL FOR MULTIPLE ROUTE RESOURCE ALLOCATION 169

4.1. Mathematical Notation 169

4.1.1. Parameters 169

4.1.2. Decision Variables 170

4.2. Mathematical Model 171

4.3. Illustrative Example 173

4.4. Heuristics for RAP 175

4.4.1. Routing Problem 176

4.4.2. Allocation Problem 180

CHAPTER 5. RESULTS AND ANALYSIS 184

5.1. Implementation of Bankruptcy Rules: Allocation of NFIs for Syrian Refugees 184

5.1.1. Emergency Non-Food Item Assistance to PRS in Lebanon 186

5.1.2. Allocation Results 188

5.1.3. Comparison of Rules Results 188

5.1.4. Managerial Implications and Future Strategies 190

5.2. Implementation of RAP Model to Food Packages Distribution to PRS 192

CHAPTER 6. SUMMARY AND FUTURE RESEARCH... 201

6.1. Summary 201

6.2. Future Research 205

REFERENCES 207

APPENDIX. SUMMARY DIFFERENTIATING CSC AND HSC 217

LIST OF TABLES

Table Page

2.1. Humanitarian logistics throughout the disaster management cycle (Howden, 2009) 24

2.2. Matching supply chains with products (Fisher, 1997) 29

2.3. Comparison of responsive and efficient supply chains (Chopra, 2010) 29

2.4. Goals per flow (Tomasini & Van Wassenhove, 2009) 38

2.5. Matching supply chain structure with disaster management phases (Awan and Rahman, 2010) 47

2.6. Comparison of humanitarian supply chain structures in immediate response phase and recovery phase (Awan and Rahman, 2010) 48

2.7. Supply chain management scenarios (Samii, 2008) 59

2.8. Supply chain agility capabilities: Assessment for CSCM and HSCM (Charles 2010) 80

3.1. Variation in idle time and its impact on site deliveries and trips loads 147

3.2. Variation in idle time and its impact on number of trips 150

3.3. Effect of service level on resource allocation for a two node network 158

3.4. Effect of service level and number of trips on deprivation time and deprivation cost 163

3.5. Effect of service level and number of trips on deprivation time per person-hrs 164

3.6. Variation in idle time within same service level and its impact on network metrics 167

4.1. Time matrix for the five node network 174

4.2. Impact of service level on route direction 175

5.1. Results of allocation rules based on 4,500 NFI sets 188

5.2. Number of PRS families per area 192

5.3. Improved TSP route per clustered area 197

5.4. Results on 100% service level ... 197

5.5. Results on 70% service level ... 198

5.6. Minimize the maximum deprivation time among clusters ... 198

5.7. Final allocation of supplies per demand site ... 198

LIST OF FIGURES

Figure Page

1.1. Interdependence between resource allocation, and routing ... 6

1.2. Structure of proposed heuristics ... 8

2.1. A Venn diagram depicting relationships among SCM, Logistics, HL, and HSCM (Day et al., 2012) ... 11

2.2. Tufinkgi's three-phase model (Haddow & Bullok, 2004) ... 16

2.3. The four main phases of a disaster management system ... 16

2.4. Relief mission life cycle (Beamon, 2004) ... 18

2.5. Life cycle of response (Tomasini & Van Wassenhove, 2006) ... 19

2.6. Disaster management lifecycle with the time-spaces for the two different types of disasters (Charles et al., 2007) ... 20

2.7. Emergency response cycle of humanitarian organization (Heigh, 2006) ... 21

2.8. Main actors and flows in commercial supply chains ... 30

2.9. Main activities in commercial supply chains ... 30

2.10. Humanitarian logistics and humanitarian supply chain flows (Howden, 2009) ... 35

2.11. Main actors and flows in HSC ... 36

2.12. Main activities in HSC ... 36

2.13. Humanitarian supply chain (Van Wassenhove et al., 2006) ... 37

2.14. Relief supplies categorization and examples ... 38

2.15. Humanitarian space (Tomasini & Van Wassenhove, 2004) ... 42

2.16. Structure of the relief chain (Balcik et al., 2008) ... 49

2.17. A conceptual framework for distinguishing CSC and HSC ... 52

2.18. Buyer and user in CSC (Samii, 2006) ... 53

2.19. Buyer and user in HSC (Samii, 2006) ... 54

2.20. The vicious circle of logistics (Van Wassenhove 2006) ... 58

2.21. Distribution network design (Chopra and Meindl, 2010) ... 60

2.22. Impact of customs on HSC (UNJLC, 2008) ... 72

2.23. The hydraulic representation of CEA, CEL, and Talmud rules (Fleiner & Sziklai, 2011) ... 88

2.24. Satisfaction functions: Concave, descending exponential sigmoid, and semi Cauchy distribution quantity ... 107

3.1. Convex deprivation cost function ... 124

3.2. Impact of no deliveries on deprivation costs at one demand node (Pérez, 2011) ... 126

3.3. Impact of one delivery on deprivation costs at one demand node (Pérez, 2011) ... 127

3.4. Impact of multiple deliveries on deprivation costs at one demand node (Pérez, 2011) ... 128

3.5. Impact of a sequential delivery on deprivation costs at two demand nodes (Pérez, 2011) ... 129

3.6. Impact of sequential deliveries on deprivation costs at a 3-node cluster (Pérez, 2011) ... 131

3.7. Truck load meeting site demand between deliveries. The case of consumption interval matching the tour length ... 136

3.8. Truck load meeting site demand between deliveries. The case of consumption interval exceeding the tour length ... 136

3.9. Truck load not meeting site demand between deliveries. The case of consumption interval matching the tour length ... 137

3.10. Case of visit cycle longer than vehicle tour without idle time at depot ... 137

3.11. Case of visit cycle longer than vehicle tour with idle time at depot ... 138

3.12. Case of visit cycle shorter than vehicle tour without idle time at depot ... 138

3.13. Case of visit cycle shorter than vehicle tour with idle time at depot ... 139

3.14. Delivery schedule for site 1 located near the depot ... 140

3.15. Delivery schedule for site 2 located far from the depot ... 140

3.16. Impact of direct and tour trip on initial deprivation time 141

3.17. Impact of disregarding a site from delivery on total deprivation cost 142

3.18. Two nodes transportation network for calculating deprivation time on various $\boldsymbol{T}$ 143

3.19. Vehicle travel end time matching $\boldsymbol{T}$ 144

3.20. Vehicle travel end time less than $\boldsymbol{T}$ 144

3.21. Vehicle travel end time more than $\boldsymbol{T}$ 145

3.22. Two nodes transportation network for calculating delivery pattern of vehicle 147

3.23. Four-leaf diagram to represent vehicle trips under different idle time values 148

3.24. Duality of variation in idle time and shift in supplies from the last trip 149

3.25. Two nodes transportation network for allocating resources on various $\boldsymbol{\lambda}$ 157

3.26. Effect of service level on resource allocation and deprivation cost for a two node network 160

3.27. Two nodes transportation network for examining idle time effect on network 165

3.28. Effect of service level and idle time on truck load 166

4.1. Five node network structure 173

4.2. Structure of proposed heuristics 176

4.3. Flow chart diagram for allocation of supplies among and within clusters 183

5.1. Geographical dispersion of PRS families in Lebanon 185

5.2. Geographical dispersion of PRS families in Lebanon per area 187

5.3. NFI allocation based on ten bankruptcy rules 189

5.4. PRS winterization partnership response in March 2014 (UNRWA, 2014) 191

5.5. Geographical dispersion of PRS families in Lebanon per area 193

5.6. Big-route TSP for 20 demand sites 194

5.7. Five clusters for the 20 demand sites 195

5.8. Route improvement inside each of the five clusters 196

LIST OF SYMBOLS

Δ, δ ....Delta

Γ, γ ....Gamma

ε.................................Epsilon

σ ....Sigma

ξ.................................Xi

λ ....Lambda

τ.................................Tau

ω................................Omega

LIST OF APPENDIX TABLES

Table Page

A.1. Summary table differentiating between CSC and HSC 217

CHAPTER 1. INTRODUCTION

1.1. Introduction to Logistics System

Over the past few decades, the concept of integrated logistics system has emerged as a new management philosophy in business and which aims to increase distribution network efficiency. Such a concept recognizes the interdependent decisions among the location of facilities (strategic), the allocation of suppliers and customers to the facilities, inventory management (tactical), and the vehicle route structure around depots (operational). As such, the system coordinates a broader spectrum of location-allocation, inventory, and routing options available to management and consequently avoids the sub-optimization in distribution solutions. Reflecting the importance of integrated logistics system, an extensive body of combined location/allocation-inventory-routing literature has been developed recently (Yang, Ma, & Zhang, 2011); (Javid & Azad, 2010); (Zhang, Ma, & Jiang, 2008); (Shen & Qi, 2007); (Liu & Lee, 2003); (Min, Jayaraman, & Srivastava, 1998).

An integrated logistics system is recognized as playing a central role in managing a supply chain. The concept of supply chain management is defined as the integrated process-oriented planning and control of material, information, and financial flows along the entire value chain from the customers to the raw material producer, with certain objectives such as improvement of customer orientation, synchronization of supply and demand, flexible and demand-oriented production, and reduction of inventory along the value chain (Kuhn & Hellingrath, 2002). An integrated logistics system's role will be to determine a well-defined distribution network system in such a way that merchandise is produced and distributed at the right quantities, to the right locations, in the right quality, at the right time, and to the right customer in order to minimize system-wide costs while satisfying service level requirements.

Essential to the concept of a logistics system is the decision to adopt a particular allocation mechanism to distribute a fixed amount of supplies to a given number of competing activities or demand points in order to achieve the most effective results with a given level of logistical capabilities. In practice, organizations can make decisions on allocation of limited supply to satisfy demands in a timely and effective manner, either by applying egalitarian policies that maximize equality of a measure, such as delivery quantity or speed to individual demand (Hodgson, Laporte, & Semet, 1998); (Doerner, Focke, & Gtjahr, 2007); (Campbell, Vandenbussche, & Hermann, 2008); (Huang, Balcik, & Smilowitz, 2011); (Mete & Zabinsky, 2010), or utilitarian policies that maximize the amount of demand satisfied without requiring equality in distribution (Özdamar & Ekinci, 2004); (Doerner, Focke, & Gtjahr, 2007); (Yi & Kumar, 2007); (Yi & Özdamar, 2007); (Shen, Ordóñez, & Dessouky, 2009). Regardless of the mechanism adopted, diligence should be taken in configuring a well-defined distribution network, especially in circumstances where delivery time and amount to distribute are critical to one's survival.

1.2. Motivation

The occurrence of natural disasters (e.g., earthquakes, tsunami, hurricanes, etc.) has increased by more than four times in the last 20 years, according to a report released by the British charity, Oxfam. It found that the earth is currently experiencing approximately 500 natural disasters per year, compared with 120 per year in the early 1980s. Between 1985 and 1994, Oxfam found that 174 million people were affected by disasters each year. In the following decade, this figure increased by 70% to 254 million people per year. The number is expected to rise by year 2015 to an average of over 375 million people (Ganeshan & Diamond, 2009). The crucial question regarding these figures is how the world community must respond better to help more vulnerable people facing worsening disasters. Unfortunately, the United Nations, Non-Governmental Organizations (NGOs), and local governments do not perform disaster relief operations in an efficient and effective standard way to overcome the consequence of a disaster (Ertem, Buyurgan, & Rossetti, 2010).

In a disaster environment, vital resources (e.g., food, water, tents, clothing, medicine, etc.) are usually not readily available to the victims. There may be some resources available in other less- or non-affected locations that have easy access to the disaster location, but it is a challenge to satisfy the immediate need with these limited resources. Inefficiency in resource allocation means not being able to deliver the resources to the disaster location in the right quantity and at the right time. Acquiring the right amount of requested quantity is critical to responding properly to disasters. Timely response is necessary to decrease fatalities, to alleviate suffering, and to preserve the perishable food and medicine.

Efficient humanitarian logistics becomes important in addressing and optimizing the complex relief distribution process. Utilizing the available resources more efficiently is the principal objective of humanitarian organizations during disaster relief operations. Therefore, an integrated humanitarian logistics system is the key to efficient and effective alleviation of disaster impact in its immediate aftermath. Despite this important objective, not until recently has integrated logistics system received much attention as a specific field in humanitarian relief operations, and in general, there is a lack of attention on the development of mathematical models and solution algorithms for relief resource allocation decisions in this field. Although some studies provide insight into various efforts in the allocation of relief aid, where some specific conditions have to be taken into account, proper mathematical formulation has not been properly addressed until recently (Gu, 2011); (Kondavetti & Ganz, 2009).

Most studies on humanitarian supply chain management focus on three main areas: facility location (Yushimito & Ukkusuri, 2012); (Balcik & Beamon, 2008); (Jia, Ordonez, & Dessouky, 2007), inventory management (Beamon & Kotleba, 2007); (Duran, Ergun, Keskinocak, & Swann, 2010), and vehicle routing problems (Holguin-Veras, Perez, Jaller, Destro, & Wachtendorf, 2010); (Özdamar & Yi, 2008); (Balcik, Beamon, & Smilowitz, 2008); (Haghani & Oh, 1996); (Yi & Kumar, 2007); (Campbell, Vandenbussche, & Hermann, 2008); (Özdamar & Ekinci, 2004). Models have been formulated to locate regional warehouses and temporary facilities for storing donated supplies, to replenish inventory and schedule deliveries, and to design routes for last mile distribution However, decisions in each of these three areas are linked and affect each other. Thus, solving these problems individually will not give a holistic optimization strategy unless they are properly integrated; few papers discuss this integration (Park, 2007) (Sheu, 2006); (Fiedrich, Gehbauer, & Rickers, 2000).

This dissertation pursues the general lack of attention to the development of mathematical models that address resource allocations in humanitarian logistics. Since resource allocation and problems of facility location, inventory, and routing are inter-related, integrating them can lead to a more efficient supply chain. Therefore, to improve the operation of the supply chain process, this research presents a model that integrates resource allocation with vehicle routing problems.

1.3. Problem Statement

Relief resources play an important role in disaster management. Numerous goods (e.g., medical resources, special rescue equipment, food, and so on) are needed for those disasters to reduce the loss in affected areas. Due to scarce relief resources during an emergency, a critical and challenging component of relief distribution is the allocation of goods to beneficiaries. In most real-life situations, beneficiary needs exceed the available supply of goods (especially in the immediate response phase) and relief organizations must allocate limited goods to each demand location. This is referred to as the resource allocation problem. Obviously, when supply is large enough, the allocation problem is trivial. Published humanitarian guidelines and standards do not provide standard procedures for allocation when demand exceeds supply and makes no mention of specific procedures when sufficient calories cannot be provided to all people in need. Still, humanitarian organizations have an ethical responsibility to distribute limited relief resources in an equitable manner. A number of ethical questions arise when the basis of distribution takes the form of equality and is value-based. What do we mean by equity? What values should guide distribution choices if it will benefit some beneficiaries and not others? Is the current distribution of resources fair and equitable? How do we know if an equitable state is reached? Is the current distribution of resources an efficient and wise use of funding? How has equity been handled in similar allocation situations not related to relief operations?

Inequity or partiality may cause social unrest in emergent situations, and jeopardize the quality and effectiveness of relief services and the efficiency of the operations as a whole. For example, it was reported that in the first few days after the Haiti and Chile earthquakes in 2010, many victims had stolen relief aids from distribution centers because of an unfair allocation policy (Honglei & Nan, 2011a). Therefore, it is worth investigating how equity should be included in modeling the relief resource allocation problem.

A good logistical plan is essential in executing equitable resource allocation to beneficiaries. An allocation plan may require deliveries of a magnitude that surpasses the available number and capacities of vehicles. Therefore, it becomes a critical, but difficult, task to transport relief resources from distribution centers to targeted locations. According to Balcik et al. (2008), the task is made more difficult because of strict financial and time limitations, making cost-efficient vehicle routing decisions important.

1.4. Research Objectives

The first objective of this dissertation is to review the concepts of the humanitarian supply chain and address its distinctive properties that set it apart from the commercial supply chain. An understanding of the resource allocation is attempted during the review of humanitarian literature where an optimal resource allocation-routing model is developed that consolidates the non-integrated style of logistics functions with a minimized deprivation cost. The proposed model will have the prime goal of reducing the total number of fatalities and alleviating the suffering of survivors while minimizing the time spent distributing emergency relief to disaster areas.

The two key questions that will guide the relief distribution process are: (Figure 1.1):

1. How do we allocate relief aids?
2. How do we distribute them?

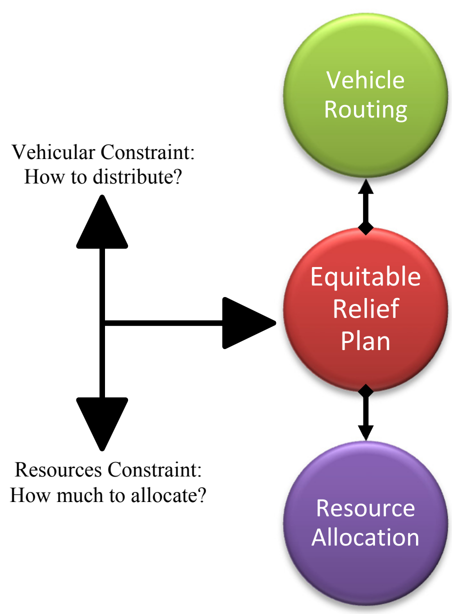


Figure 1.1. Interdependence between resource allocation, and routing

These two questions need to be addressed considering the specific challenges posed by tremendous magnitude and low frequency, large-scale emergency situations, such as:

- The supply being limited within a short time frame compared with the overwhelming demand.
- Aids needing to be delivered within a short time frame to maximize their effects.

Although operational costs are relevant in disaster response, they are of lesser importance for a humanitarian supply chain. The primary concern is with expediting the delivery of critical goods to the affected areas to minimize negative impacts on the victims. In the immediate aftermath of extreme events, disaster response organizations are usually unable to satisfy all needs and have to decide how to best use their limited resources. In doing so, they attempt to maximize the benefits from the aid delivered by minimizing the human suffering associated with the unmet demand exponential penalty cost. This is a unique characteristic of humanitarian supply chains, and the shortcomings of current models suggest the need for new paradigms for humanitarian logistics. Today, many organizations active in disaster response state the minimization of suffering as their primary goal, but none of them explicitly considers victims' well-being as part of their supply chain models.

The second objective of this study is to serve as background reading for equitable allocation discussions and policy formation in the context of humanitarian supply chain management. More generally, the study will help raise the level of awareness of equity issues among all those in the humanitarian field. It will provide practical advice on how to form policies and procedures for the establishment of allocation mechanisms for fair distribution of relief resources. It will familiarize the researcher with some specific examples of the equity issues that are outstanding in the humanitarian field.

The third objective of this study is to explore the routing allocation problem (RAP), which involves the integration and coordination of vehicle routing and resource allocation. It is concerned with providing an unbiased platform to make decisions about equitable distribution schedules to a set of beneficiaries during the immediate disaster response by a limited number of vehicles. The objective is to alleviate human suffering by minimize the response time in regard to each beneficiary's needs fulfillment and delivery delay on the route.

1.5. Expected Contributions

Although nothing can be done to stop natural disasters, the means to serve millions of people affected from natural disasters can be improved. This dissertation develops an equitable distribution model for determining optimal patterns of emergency aid deliveries to a disaster area during the immediate response phase of disaster operations management. It addresses the formulation of those complex vehicle routing problems, incorporating resource allocation and optimal distribution based on reducing the number of fatalities and alleviating the suffering of survivors instead of travel distance or cost. It focuses on an optimal vehicle routing model for a single distribution center in a two-echelon logistic system in order to deliver relief items to demand points. Two sub-models are developed: a resource allocation model and a vehicle routing scheduling model. The schematic structure of the solution for the proposed model in this study is shown in Figure 1.2.

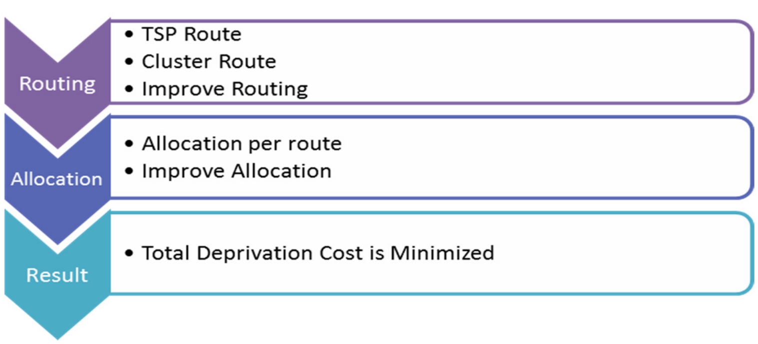


Figure 1.2. Structure of proposed heuristics

The contribution of this dissertation can be unfolded as follows:

- Identifies the key differences between commercial and humanitarian supply chains. Though seemingly similar, it will be shown that there are profound and fundamental differences between the chains.
- Develops a multi-period dynamic model for allocating relief resources and planning aid distribution routes in disaster relief operations during the initial response phase of disaster relief operations. The proposed integrated model, denoted by Routing Allocation Problem (RAP), will have the prime goal of reducing the total number of fatalities and alleviating the suffering of survivors while minimizing the response time to distribute relief items to beneficiaries.
- Incorporates an exponential humanitarian cost function into the RAP model and applies it as a decision-making tool to allocate the scarce emergency resources under the condition that relief supplied and related logistics resources are less than the demand in the beginning phase of a large-scale disaster.
- Conceptualizes the equity in resource distribution across demand points while formulating the objective function to avoid the possibility of a severely unfair relief distribution to certain affected areas in the relief distribution process.
- Decomposes the relief operations process into two closely inter-connected problems: a resource allocation problem and a routing problem, which can be solved heuristically in a coordinated manner to alleviate the suffering among affected people through minimizing the maximum deprivation cost incurred in emergency response.

- Proposes an emergency distribution scheduling model across the last mile so it can mitigate potential imbalance between supply and demand in the humanitarian supply chain and lead to effective relief operations.
- Reviews existing literature on disaster relief operations and concentrates on the intersection of three areas of interest: humanitarian logistics, supply chain management, and humanitarian supply chain management.
- Outlines the process that disaster relief management should go through to obtain equitable allocation schemes to beneficiaries.

1.6. Organization of the Dissertation

Chapter 1 introduced the problem statement and motivations of the dissertation. The research objectives are also highlighted. Chapter 2 presents the literature relevant to the topic of humanitarian supply chain in general, with emphasis on resource allocation in the second part of this chapter. Model development discussed in Chapter 3 and Chapter 4 presents the full version of the routing-allocation model followed by proposing a heuristic in an attempt to solve the model. Chapter 5 applies the model to a real case study. Summarizing what has been achieved in this dissertation and implication for future research work is given in Chapter 6.

CHAPTER 2. LITERATURE REVIEW

2.1. Overview

This chapter serves as a framework to define relevant terms and to review existing literature relevant to humanitarian supply chain management and resource allocation problems. The first part of the literature review starts with providing some general background information on disaster relief operations. Then the literature on the four-group taxonomy proposed by Day et al. (2012) is discussed while concentrating on the intersection of three areas of interest: humanitarian logistics (HL), supply chain management (SCM), and humanitarian supply chain management (HSCM) (Figure 2.1). In this way it creates the foundation for identifying the key differences between commercial and humanitarian supply chains. Though seemingly similar, it will be shown that there are profound and fundamental differences between their chains.

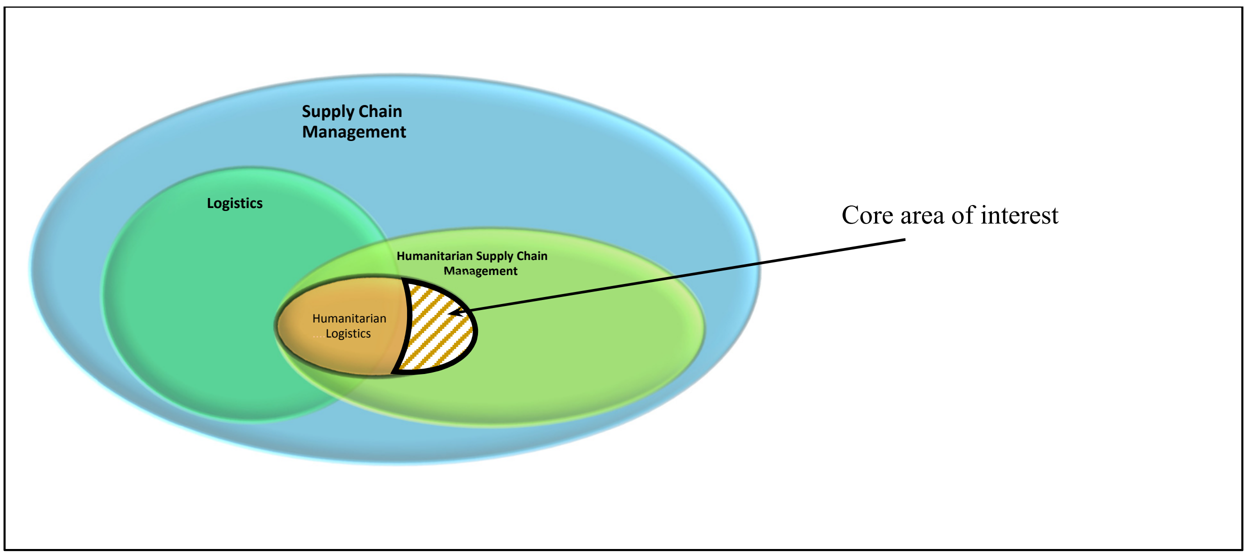


Figure 2.1. A Venn diagram depicting relationships among SCM, Logistics, HL, and HSCM (Day et al., 2012)

In the second part, the review will focus on the rationality behind the resource allocation decision and how an allocation can be reached by using standard operational procedures, ethical, philosophical, mathematical modeling, or some combination of these approaches. This review will provide the foundation while building the mathematical model in Chapter 3.

2.2. Disaster Relief Operations

This sub-chapter aims to give the reader a background for disaster relief operations. It looks at definitions, terminologies, classifications, and phases coupling this concept.

2.2.1. Managing Disaster Relief Operations

"A disaster is a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (United Nations International Strategy for Disaster Reduction Secretariat, [UNISDR], 2004). The occurrence of disasters results in different levels of mortality, injury, and damage to inhabitants and infrastructure. It has been identified with massive casualties and long-term destruction.

According to Stirn (1997) and cited in Schulz (2008), "disaster help" can be divided into two main phases: "disaster mitigation" and "disaster response." This differentiation is made with respect to time. Disaster mitigation refers to events and actions taken before a catastrophe. Disaster response means measures applied after a disaster has occurred. Relief is one part of disaster response, which means actions that are taken during or after a catastrophe in order to secure the survival of the affected persons. Relief consists of the two elements, "immediate help" and "survival help." Immediate help is given in order to rescue the population and provide emergency aid. Survival help means the supply of food, shelter, and medicine to the population living in the affected area, compensating for the destroyed facilities.

Regardless of how disaster is defined or classified, it can create extensive pain and discomfort for human beings and disrupt society's routine daily activities. Therefore, in order to cope with the massively destructive effects of a disaster, countries should prepare themselves by creating a disaster management plan in advance and enhancing necessary infrastructures.

Schulz (2008) defines disaster management as "the range of activities designed to maintain control over disaster and emergency situations and to provide a framework for helping at-risk persons to avoid or recover from the impact of the disaster. Disaster management deals with situations before, during, and after a disaster." In other words, disaster management is a set of processes designed to be implemented before, during, and after disasters to prevent or mitigate their effects. As a synonym for disaster management, the term "disaster relief" is used and defined as "foreign intervention into a society with the intention of helping local citizens" (Long & Wood, 1995).

Kovács and Spens (2007) state that the focus of disaster relief operations is to "design the transportation of first aid material, food, equipment, and rescue personnel from supply points to a large number of destination nodes geographically scattered over the disaster region and the evacuation and transfer of people affected by the disaster to the health care centers safely and very rapidly."

As shown, different researchers have defined disaster relief operations differently; however, they all share the same overall goal of disaster management, which is to provide relief to victims as soon as possible with the right supplies and services. This can be expanded with respect to three objectives:

- to reduce or avoid the human, physical, and economic losses suffered by individuals, by the society, and by the country at large
- to reduce personal suffering or deprivation
- to speed recovery

The success of meeting these three objectives is highly dependent on the characteristics of the operational and geographical environment affected by a disaster. Overstreet et al. (2011) mentioned that unlike business logisticians, humanitarians are always faced with the unknown. The greatest unknowns in humanitarian logistics are the time, place, and severity of a disaster in terms of people, property, and infrastructure. These factors will have variable influences on the efficiency and effectiveness of the logistics response. Moreover, when the impact of the crisis is so strong in its early stage, the focus will be on the most urgent issues and that everything else is disregarded. The problem is that, while ignored, the other factors become invisible, allowing them to grow and interact, leading to further consequences.

Also, the importance of a timely response is critical in the relief efforts since a delay in rescue and relief could literally mean the difference between life and death for those most severely impacted by the disaster. However, ambiguity makes it difficult to know the direction in which the crisis might escalate since the cause-effect relationships are not clear. Thus, it is hard for humanitarian organizations to forecast the implications of their decisions. Issues in a classic debate about what worsened a disaster include the lack of resources, untrained personnel, inaccurate information, or a combination of these factors.

To conclude this review on disaster relief operations management, it is important to briefly mention that disaster management systems and practices should be continually monitored and improved because disasters pose a permanent threat to any location. Also, the success of these systems relies heavily on effective and efficient cooperative efforts at the governmental, private, and community levels.

2.2.2. <u>Phases and Life Cycle of Disaster Management</u>

It is quite common in the relevant literature and in actual practice to describe relief operations as an "overlapping" sequence of different phases. The number and content of these phases differ between authors; some of them will be examined below.

Tufekci and Wallace (1998) described disaster management as a process and suggested that emergency response efforts consist of two stages: pre-event and post-event response. Pre-event tasks include predicting and analyzing potential dangers and developing necessary action plans for mitigation. Post-event response starts while the disaster is still in progress. At this stage, the challenge is locating, allocating, coordinating, and managing available resources. They also suggest that an effective emergency response plan should integrate both of these stages within its objective because separating pre- and post-loss objectives may lead to suboptimal solutions to the overall problem.

Tufinkgi (2004) discussed three phases of disaster relief operations (Figure 2.2): pre-disaster (comprising prevention, mitigation, and preparedness); response (consisting of warning, impact, and emergency response); and post-disaster recovery (involving transition/rehabilitation and reconstruction and development).

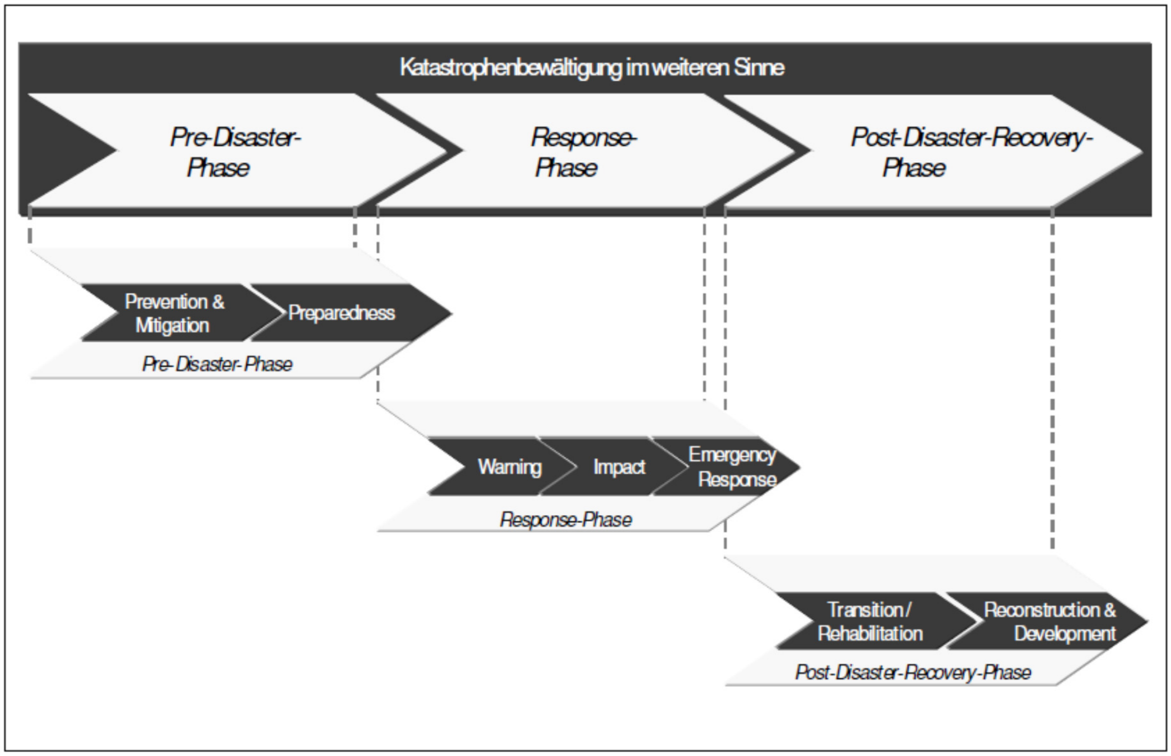


Figure 2.2. Tufinkgi's three-phase model (Haddow & Bullok, 2004)

Lee (2003) categorized disaster relief operations as a four-phase approach that covers all the actions described in Tufinkgi's classification while providing a more focused view of emergency management actions. Altay and Green (2006) list the typical activities involved in each of these four phases. The four-phase approach with some activities embraced are shown below (Figure 2.3).

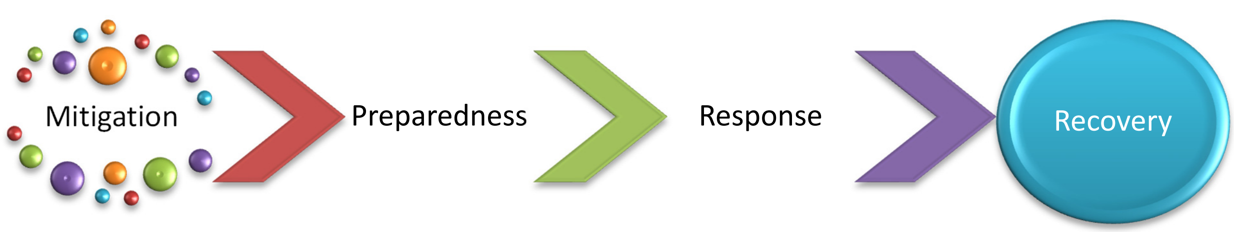


Figure 2.3. The four main phases of a disaster management system

1. **Mitigation** – application of measures through which disaster is prevented or its impacts are diminished
   - Risk analysis to measure the potential for extreme hazards
   - Building codes to improve disaster resistance of structures
   - Zoning and land use controls to prevent occupation of high hazard areas
   - Active preventive measures to control developing situations
2. **Preparedness** – activities whereby the community is sensitized to positively respond to a call for help when need arises
   - Maintaining emergency supplies
   - Conducting disaster exercises to train personnel and test capabilities
   - Budgeting for and acquiring vehicles and equipment
   - Development of mutual aid agreements and memorandums of understanding
3. **Response** – application of resources and emergency procedures to protect the environment, people's lives and properties, as well as social, economic, and political structure of the community;
   - Activating the emergency operations plan
   - Fatality management
   - Opening of shelters and provision of mass care
   - Evacuation of threatened populations
4. **Recovery** – involves the measures that are taken, in the long run, to the effect that the community stabilizes and returns to normal functioning after the immediate impacts of the disaster have passed
   - Sustained mass care for displaced human and animal populations

- Disaster debris cleanup
- Financial assistance to individuals and governments
- Rebuilding of roads and bridges and key facilities

Tufinkgi's model might be extended by an indication of the resource need within different phases. Beamon (2004), for example, developed the "life cycle" of a relief mission and distinguished the resource level that is needed during four stages (Figure 2.4):

1. **Assessment** – identify what minimum resources are needed, based on disaster characteristics
2. **Deployment** – resource requirements ramp up to meet a need
3. **Sustainment** – high resources are required for a period of time to sustain operations
4. **Reconfiguration** – operations and employed resources are reduced and finally terminated

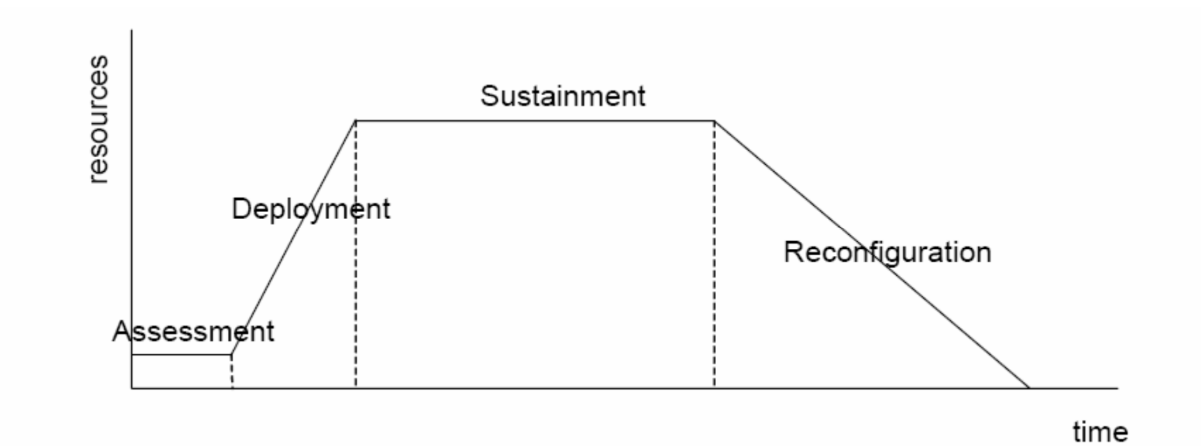


Figure 2.4. Relief mission life cycle (Beamon, 2004)

The length and importance of each phase varies depending on the characteristics of the disaster and the characteristics of the affected areas. Beamon & Balcik (2008) state that during the first days of the disaster, the speed of relief operations significantly affects the lives of many trapped victims. The ability of a relief organization to mobilize its resources during assessment and deployment phases is critical to the success of disaster response.

According to Maspero and Ittman (2008), regardless of the nature of the onset disaster, the scale of the emergency response can be divided into three distinct phases (Figure 2.5):

1. **Ramp up:** when aid and infrastructure are deployed to the area
2. **Sustainment:** when the aid and aid infrastructure are employed fully from the area for the period of responding to the crisis
3. **Ramp down:** when assets are gradually reduced and withdrawn from the area to be redeployed elsewhere

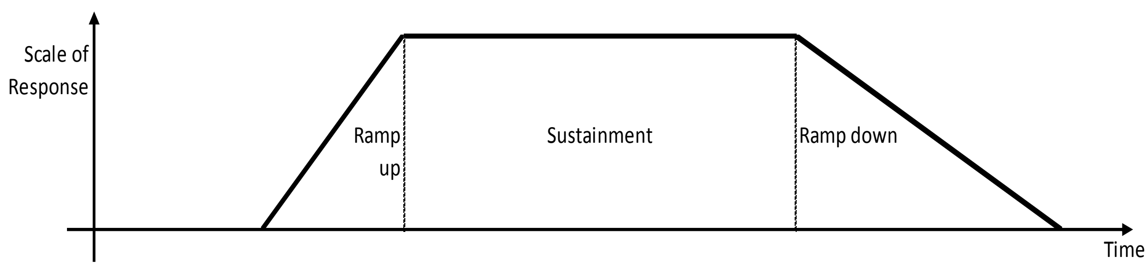


Figure 2.5. Life cycle of response (Tomasini & Van Wassenhove, 2006)

The ramp down does not signal the end of the need for aid, and it is normal for developmental or long-term aid to ramp up in the area to complement the ramping down of the emergency response.

Charles et al. (2007) combined the configurations studied by Beamon, Maspero, and Ittman, and placed a timescale next to the four phases in the sudden and slow onset disasters in order to visualize an estimated time required in each type of disaster (Figure 2.6).

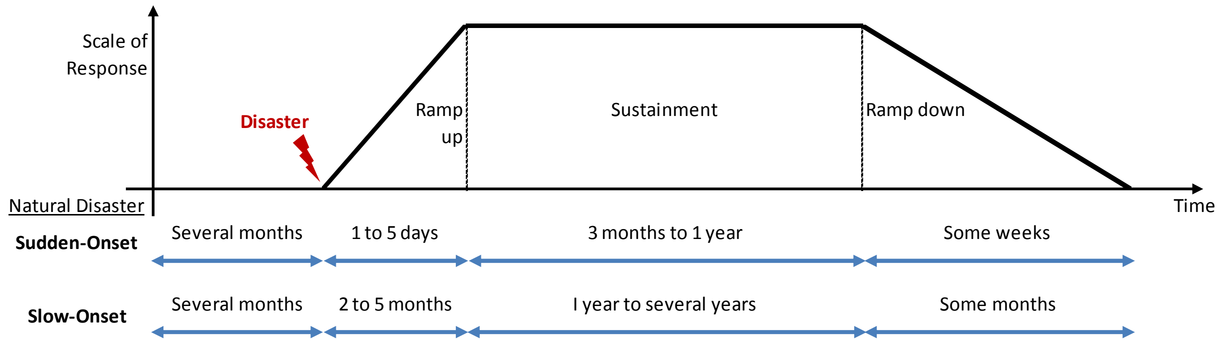


Figure 2.6. Disaster management lifecycle with the time-spaces for the two different types of disasters (Charles et al., 2007)

Sudden-onset disasters demand a different national response than do slow-onset. In the immediate response phase in a sudden onset disaster, relief is provided by local and national resources, while in the second phase, there is, generally, support from international agencies. In essence, the differentiation between the two disaster types is whether humanitarian operators have more or less than 72 hours to react and respond to a disaster. In a sudden-onset disaster, resources must be in place within 72 hours to prevent exposure, provide food and water, and ensure medical aid to deal with chronic illness, injury, and the spread of disease. Otherwise, people who could have been saved begin to suffer and die.

A final consideration about life cycle is the cyclical nature of disaster management discussed by Heigh (2006). Each of the sub-steps in Tufinkgi's three-phase model discussed above might be taken to greater depth. For example, the emergency response phase itself can be structured as a cycle, with different steps from beneficiary identification to resource distribution and evaluation of impact as shown in Figure 2.7

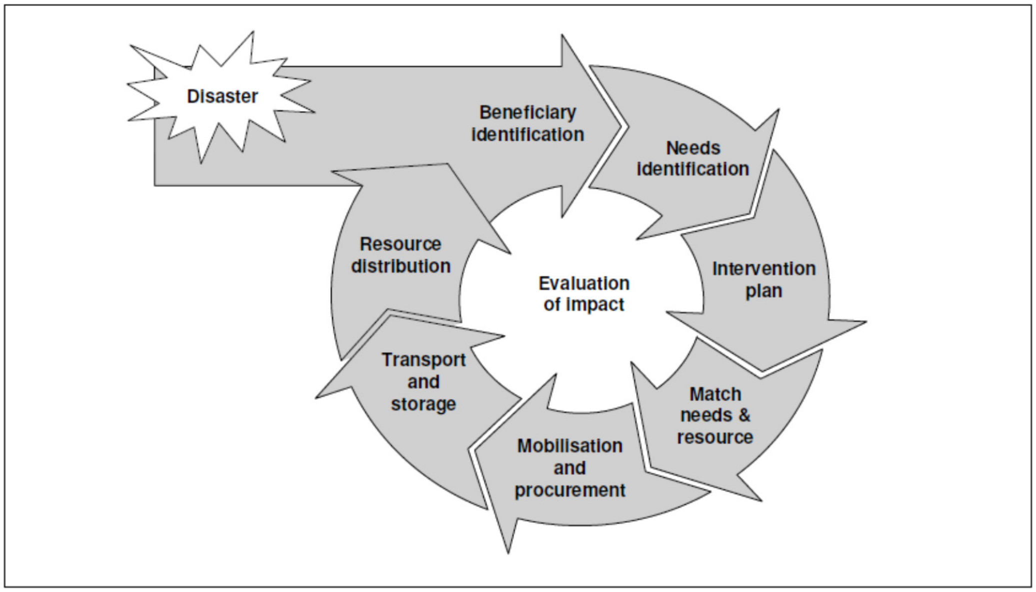


Figure 2.7. Emergency response cycle of humanitarian organization (Heigh, 2006)

2.3. Humanitarian Logistics

This sub-chapter's aim is to define and explain what humanitarian logistics is by putting it into context with disaster management. A brief description of the characteristics of commercial logistics and challenges in humanitarian logistics is given, and major similarities and differences between the two fields are pinpointed.

2.3.1. Importance of Humanitarian Logistics

Humanitarian logistics can be defined as the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods, materials, and equipment as well as related information, from point of origin to point of consumption for the purpose of alleviating the suffering of vulnerable people (Thomas & Mizushima, 2005). The process encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, and custom clearance (Thomas & Kopczak, 2005). Considering the meaning of humanitarian logistics, it focuses mainly on alleviating the affected people, while the definition of humanitarian supply chain is broader and copes with more activities to respond to the stakeholders in the supply chain. This distinction will be discussed in more detail in subsequent sections of this dissertation.

Thomas and Mizushima (2005) propose that humanitarian logistics should be regarded as tactical/operational/execution oriented. It is a system that comes into its own once the disaster has occurred. At that point, this logistics system is essential to the timely and effective mobilization of resources to aid people made vulnerable by natural disasters and crises. Furthermore, the system is primarily focused on the immediate response phase dealing with the task of matching demand with supply in a timely and cost-effective manner.

According to Van Wassenhove (2006), the field of humanitarian logistics is quite new. The humanitarian organizations are about a decade behind their business counterparts who realized the importance of logistics as a function in operations, particularly given the increasing opportunities to go global. The lack of understanding the logistical function and its importance has meant a lack of inclusion in planning and budgetary processes, resulting in logistics requirements not being met. He also explains that humanitarian logisticians have been struggling for recognition and that humanitarian organizations are just beginning to wake up to the fact that humanitarian logistics:

- is the most expensive part of any relief operation and the part that can mean the difference between a successful or failed operation
- is crucial to the performance of current and future operations and programmes
- serves as a bridge between disaster preparedness and response, between procurement and distribution, and between headquarters and the field
- provides a rich source of data, since it is this department that handles the tracking of goods, which could be used to analyze post-event effectiveness

2.3.2. Activities Involved in Humanitarian Logistics

The unpredictable nature of any disaster, in addition to the large number of casualties at stake, makes the field of humanitarian logistics a critical aspect of any disaster relief operation, to the extent that logistics efforts account for 80% of disaster relief. Thus, it represents one of the main levers to achieve improvements in terms of cost, time, and quality. Commodities such as water, food, shelter, and medicine must be sent from the relief distribution centers to the affected areas as quickly as possible to support rescue operations and help wounded individuals. The supply shortage can render emergency response ineffective and result in increased suffering. Hence, it is important to develop strategies to accelerate supply response especially when dealing with the unpredictability of demand.

As we have seen in the previous sub-chapter on disaster relief operations, the operations of humanitarian organizations in disaster management can be separated into four major phases: preparedness, response, recovery, and mitigation (Haddow & Bullock, 2004). During humanitarian operations, there will be overlap between activities from different phases, and a separate transition phase can be considered between the response and recovery phase (Howden, 2009). Humanitarian logistics must provide supplies to beneficiaries in each of these phases (Kovács & Spens, 2007) and these activities require logistic support throughout the disaster management cycle as Perry (2007) mentioned. All humanitarian logistics operations have the common aim to aid people in their survival; however, the volume, variety of supplies, and urgency of relief supplies will change according to the phase.

In the following matrix (Table 2.1) presented by Howden (2009), it is possible to understand how humanitarian logistics activities are linked to each phase (preparedness, response, transition, recovery, and mitigation). Each phase, along with its logistical activities, is explained separately below.

Table 2.1. Humanitarian logistics throughout the disaster management cycle (Howden, 2009)

Phase	**Preparedness**	**Response**	**Transition**	**Recovery**	**Mitigation**
Period	Long Term - Continuous	Days - Months		Months - Years	Long Term - Continuous
Logistics Volume	Low	High		Medium	Low
Supplies Required	Specific standard supplies prepositioned for disaster response	Specific standard supplies: Food, medical supplies, water and sanitation equipment, shelter, household kits, etc.		Varied supplies depending on the context of the disaster: reconstruction material, livelihoods equipment	Varied supplies
Urgency	Low	High: Lead times for supplies can make the difference between life and death		Medium: There may be government and donor pressure to complete recovery activities	Low
Procurement of Supplies	Local	International		Local-International	Local

Preparedness: This phase involves continuous and ongoing building of the capacity to respond to a disaster prior to its onset. Pre-positioned relief supplies tend to be standardized, as they are specific life supporting items, such as food, medical supplies, water and sanitation equipment, household kits, etc. Also, because it is not known if these supplies will be available in local markets, or if markets may be disrupted by the disasters, they might be procured internationally.

Response: Evacuation and logistics support are the two major activities in disaster response. Evacuation activities take place during the initial disaster response phase; whereas logistics support operations tend to continue for a longer time for sustaining the basic needs of survivors who remain in the affected area. One of the critical challenges is to transport sufficient critical supplies to disaster-affected areas in a timely manner in order to support basic living needs for people who are stuck in disaster-affected areas. Since demand required during and after a disaster is usually large and unexpected, and resources (e.g. supplies or transportation vehicles) are normally limited, a good logistics plan is essential in executing efficient humanitarian logistics operations and important to continue throughout the entire disaster management phase.

A large amount of literature on humanitarian logistics focuses on the response phase of a disaster (Beamon, 2004); (Beamon & Balcik, 2008); (Maspero & Ittman, 2008); (Oloruntoba R. , 2007), (Oloruntoba R. , 2005); (Rodman, 2004); (Thomas, 2003); (Thomas & Mizushima, 2005). The actual response could be influenced by a number of factors:

- This is the phase in which logistics plays the largest role in the humanitarian operation.
- The key focus of the response phase is the preservation of lives; hence, improved logistics can be directly linked to lives saved. During other phases of disaster management, the outputs become more varied, such as providing training to teachers and medical experts.
- The disaster response is the phase that creates the most media coverage, therefore, it may be the phase which experts outside of the humanitarian domain get the most exposure to and are most familiar with. Media coverage could also create a perception of more status with disaster response. For example, the sight of families with small children with no place to go convinces many of the need for an organized response.

Transition: During this phase, humanitarian organizations have information on what supplies have been distributed, and what supplies are remaining. Organizations begin to look at providing ongoing assistance, such as temporary shelter and basic social services. They will also plan strategically to transition from implementing response activities to longer-term recovery and mitigation programs. Logistics activities include identifying suppliers in either local or international markets, to provide supplies for longer-term programs, and ensure a smooth transition.

Recovery: As the emergency is brought under control, the affected people are capable of undertaking a growing number of activities aimed at restoring their lives and the infrastructure that supports them. Supplies are no longer essential for the lives of affected people and are therefore no longer required at such a high rate or with such short lead times. Recovery activities continue until all systems return to normal or better. However, these may vary hugely between different disasters. The recovery phase represents a significant proportion of the duration and funding of a humanitarian operation and may last from 5-10 years (Howden, 2009).

Mitigation: This phase involves increasing the resilience of communities to natural hazards to reduce the impact of disasters. According to the specific vulnerability of the community, these activities may include planting mangroves to protect coastlines against cyclones, constructing dams, or reinforcing buildings. Humanitarian organizations implementing these activities will require logistics support, although not typically at as large a scale as in the other phases.

2.3.3. Challenges Encountered in Humanitarian Logistics

This section explains the potential challenges for humanitarian logistics according to seven characteristics of large-scale disasters as presented by Jiang et al. (2012). These are as follows:

Problem scale and complexity: Disasters may affect large geographical areas and large populations with severe damage. Humanitarian logistics can be viewed as very complex dynamic systems since various decisions must be considered simultaneously. For example, during the launch of distribution of emergency resources to the affected areas, several interdependent tasks emerge, such as who holds the emergency resources, where one can get the resources, how much resource to deliver to the affected areas, or when to distribute the emergency resources.

Different objective and decision criteria: Disasters may cause large numbers of casualties and property damage. Thus, the objectives and decision criteria for humanitarian logistics should be linked to end results, such as life-saving and damage reduction, rather than the traditional objective of minimization of costs and maximization of profit for businesses.

Multiparty collaboration problems: Disasters require multiple agencies working together to carry out relief activities. Collaboration among different parties is required in the form of information exchange, resource sharing, and job dispatching. The lack of collaboration can lead to disaster spread and an even higher numbers of casualties.

Critical time requirement and real-time decision making: Disasters usually happen suddenly then develop rapidly. Decisions need to be made quickly since any delay in relief efforts may cause severe consequences and many failures. Sometimes a quick feasible response is better than a rather sophisticated optimization, because timeliness is a critical factor in the effectiveness and success of humanitarian logistics.

Allocation of scarce resources: Large-scale disasters are characterized by a huge demand for emergency resources, which greatly exceeds resource availability. With such imbalance, it is vital to allocate these scarce resources to those who need resources the most, and at the same time achieve a balance between priority and equality.

Stochastic and scenario-based modeling: The great uncertainty in large-scale disasters makes it difficult to exactly assess the disaster consequences, damage scenarios, and resource requirements. Hence, it is necessary to establish stochastic or scenario-based models to cope with these uncertainties. However, the challenge in modeling lies in the unavailability of suitable probability distributions for the uncertainty factors.

Logistics with damaged infrastructure: Large-scale disasters may cause severe damage to communications, power supplies, and transportation infrastructure, and make them unavailable for emergency relief operations. Humanitarian logistics needs to cope with infrastructure damage and consider the infrastructure vulnerability analysis and traffic capacity constraints during the relief operation.

2.4. Commercial Supply Chain Management

The purpose of this sub-chapter is to explore some features of commercial supply chain management that would be comparable to its humanitarian counterpart. It addresses the structure of the chain and the participants involved, methods to measure chain performance, and the ethical framework the chain operates with.

2.4.1. Commercial Aspect in Supply Chain Management

Kuhn and Hellingrath (2002) define SCM as the integrated process-oriented planning and control of material, information, and financial flows along the entire value chain from the customers to the raw material producer, with certain objectives such as improvement of customer orientation, synchronization of supply and demand, flexible and demand-oriented production, and reduction of inventory along the value chain. Hsu and Shih (2007) explain that most business activities are integrated toward the customers via a continuous, seamless flow. Moore and Taylor (2011) observed that through the application of SCM, commercial organizations have reduced their cost base and increased their profits, market share, customer satisfaction, and have been able to compete in the global marketplace.

2.4.2. Commercial Supply Chain Structure and Fit

One useful framework for understanding commercial supply chains is Fisher's (1997) seminal work on chain structure. He discussed two famous supply chain structures in the commercial sector: the “responsive chain” and the “efficient chain.” Responsive supply chains aim at being responsive and flexible to customer demands, while efficient supply chains aim at creating the highest cost efficiency. He explained that the supply chain designs depend on the business products and how those products are positioned in the market. He added that chain design for functional products needs to be cost efficient throughout the supply chain (Table 2.2).

Table 2.2. Matching supply chains with products (Fisher, 1997)

	Functional Products	Innovative Products
Efficient Supply Chain	Match	Mismatch
Responsive Supply Chain	Mismatch	Match

Fisher‘s study elaborated on how the nature of products’ demand patterns determines the type of supply chain. The efficient supply chain becomes important where products run with low-profit margins, low product variety, and a stable demand forecast. On the contrary, the responsive supply chain becomes relevant where products show high profit margins, high product variety, and volatile demand, requiring quick adaptation to constantly changing customer preferences. Chopra and Meindl (2010) also differentiated these two types of supply chains under different headings as summarized in the following table (Table 2.3).

Table 2.3. Comparison of responsive and efficient supply chains (Chopra, 2010)

	Efficient Chains	**Responsive Chains**
Strategy	Supply demand at the lowest cost	Respond quickly to demand
Product Design	Maximize performance at a minimize product cost	Create modularity to allow post-ponement of product differentiation
Pricing	Lower margins because price is a prime customer driver	Higher margins because price is not a prime customer driver
Manufacturing	Lower costs through high utilization	Maintain capacity flexibility to buffer against demand uncertainty
Inventory	Minimize inventory to lower cost	Maintain buffer inventory to deal with demand/supply uncertainty
Lead time	Reduce but not at the expense of costs	Reduce aggressively, even if the costs are significant
Supplier	Select based on cost and quality	Select based in speed flexibility, reliability and quality
Transportation	Greater reliance on low cost modes	Greater reliance on responsive modes

2.4.3. Actors, Activities and Flows in CSC

SCM in commercial activities involves a series of actors (Figure 2.8), a forward and backward flow and integration of resources – material, information, and finance flows – among supply chain members and the following processes: planning, sourcing, making, delivering (transport, storing, and distribution), and returning through reverse logistics (Figure 2.9).

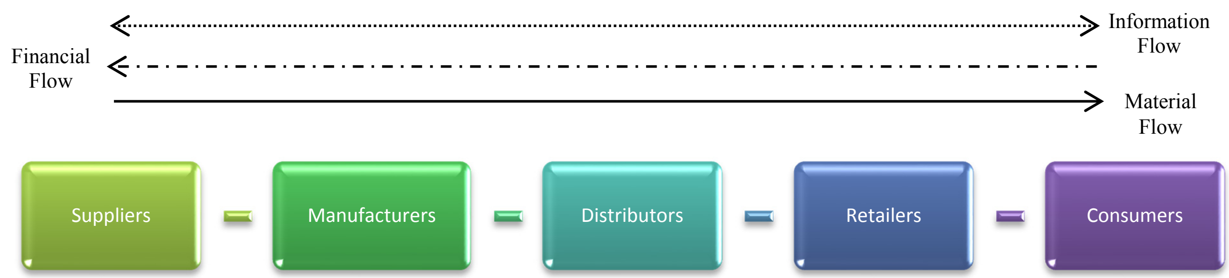


Figure 2.8. Main actors and flows in commercial supply chains

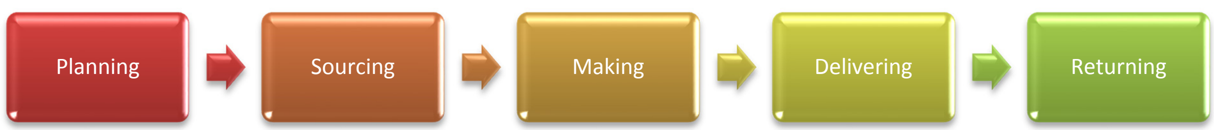


Figure 2.9. Main activities in commercial supply chains

Tomasini and Van Wassenhove (2009a) denoted the three flows as the Three Bs: Boxes, Bytes, and Bucks.

Boxes (referred to material flow): This represents the physical product flow from suppliers to customer as well as the reverse flow from product returns, servicing, and recycling.

Bytes (referred to information flow): This represents the order transmission and order tracking, which coordinates the physical flows.

Bucks (referred to financial flow): This represents the credit terms, payment schedules, and consignment arrangements.

2.4.4. <u>Measuring CSC Performance</u>

The existing literature on performance measurement in general and on commercial supply chain management in particular is extensive (Schulz & Heigh, Logistics performance management in action within a humanitarian organization, 2009). Its application continues to grow and encompass both quantitative and qualitative measurements (Hervani & Helms, 2005). The number and level of performance measures depend greatly on the goal of the organization or the individual division's characteristics. Supply chain models have mainly utilized two difference measures: cost and a combination of cost and customer responsiveness (Beamon, 1999). From these measures, the performance measurement in supply chain has been expanded into several measurements. For example, Beamon (1999) suggests that a supply chain measurement system must place emphasis on three separate types of performance measures: resource measures, output measures, and flexibility measures.

Holmberg (2000) proposes to use costs, lead time, and inventory levels as measures in supply chain collaborative activities. Keebler and Plank (2009) categorize the logistics performance measurement into effectiveness measures involving trading partners, effectiveness measures, internal focus, efficiency measures, productivity, and utilization. Thakkar et al. (2009) summarize that a number of experts and practitioners of supply chain strategy use the following metrics, which incorporate all the dimensions of supply chain performance: total supply chain cost, service level, asset management, customer accommodation, cash-to-cash cycle time, and benchmarking. Chia et al. (2009) propose to use the four perspectives of the Balanced Scorecard for supply chain entities' measurement: financial, customer, internal business processes, and the organization's learning and growth perspectives.

2.4.5. <u>Corporate Social Responsibility</u>

Corporate Social Responsibility (CSR) is about how businesses align their values and behavior with the expectations and needs of stakeholders – not just investors, but also employees, suppliers, communities, regulators, special interest groups, and society as a whole. It describes a company's commitment to be accountable to its stakeholders. CSR requires that organizations manage the economic, social, and environmental impacts of their operations to maximize the benefits and minimize the downsides. It should not be practiced as only to fulfill a duty to society; it should also bring a competitive advantage to organizations adopting it.

Valentino (2007) explains that the organization's ethics and risk management framework are incorporated in an ethical supply chain, and CSR supports and facilitates this framework by implementing actions such as:

- Helping to establish a company's value statement and employees' code of conduct.
- Developing internally an ongoing business case for judgments on social and environmental issues
- Generating measurable and verifiable indicators of performance
- Providing and communicating thought leadership
- Coordinating key functions across all of a company to support the creation and management of a comprehensive ethical supplier program

To summarize, CSR is indicated as playing a pivotal role in establishing an ethical supply chain for modern organizations. Adopting CSR will reduce risk, protect reputations, live up to stated values, enhance the productivity of suppliers, and reduce social and environmental impacts. The reality facing companies is that lasting damage to a company's reputation, brand value, and its long-term profitability are at stake, especially when a huge gap exists between the stated goals of a company and the reality that exists in their local and global supply chains.

2.5. Humanitarian Supply Chain Management

The purpose of this sub-chapter is to explore previous literature in the area of humanitarian supply chain management for forthcoming comparison purposes with its counterpart commercial supply chain. The literature review is structured into nine main sections.

2.5.1. Humanitarian Aspect in Supply Chain Management

Humanitarian logistics has moved to humanitarian supply chain management as a normal development. This imposes on humanitarian organizations to take a more strategic dimension and associated view of suppliers and customers (Kovacs, 2011). In this case, the definitions of supply chain management in the context of humanitarian relief operations encompasses the planning and management of all activities related to material, information, and financial flows in disaster relief and humanitarian assistance. Importantly, it also includes coordination and collaboration with partners in the supply chain both horizontally and vertically, third-party service providers, and across humanitarian organizations.

In line with this, Mentzer (2001) defines humanitarian supply chain as "the network created through the flow of supplies, services, finances and information between donors, beneficiaries, suppliers and different units of humanitarian organizations for the purpose of providing physical aid to beneficiaries." Simchi-Levi et al. (2004) specify that a typical SCM is a set of approaches utilized to efficiently integrate suppliers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements. If we exclude some unsuitable terms such as "user," "store," or "service level," the concept of

SCM explains what humanitarian organizations, suppliers, and donors must do to minimize the impact of a crisis; this is the humanitarian supply chain (HSC).

Another definition is stated by the Department of Supply Chain Management, University of Manitoba: “Humanitarian Supply Chain Management is the process of strategically managing flows of goods, services, people, cash and information, along with relationships within and among organizations; to save lives, ease suffering and conserve resources. It involves the interaction of various entities; including non-governmental organizations, government agencies, agencies of the United Nations, refuges and commercial suppliers of goods and services; and it focuses on satisfying relevant stakeholders, such as beneficiaries, donors, employees, communities, and policy makers” (University of Manitoba, 2011).

There is potential confusion while interchangeably using “humanitarian logistics” and “humanitarian supply chain management.” In fact, they are related but there are several traits that differentiate HSCM from its logistics component. First, the time orientation of HSCM generally spans from long-term to short-term, while humanitarian logistics tends to be more short-term. Second, humanitarian supply chains include functionalities that do not typically fall into the field of humanitarian logistics. Managing relationships with donors, performing needs assessments, planning for supplies required, and monitoring and evaluating the impact of distributed supplies are usually the responsibility of non-logistics program units. HSCM is responsible for identifying, communicating, and monitoring the supply chain outcomes as well as the transitions between the outcomes that must take place over time. Logistics is responsible for achieving these outcomes in a timely and cost-effective manner. Figure 2.10 presents a summary of the major flows within both humanitarian supply chains and humanitarian logistics (Howden, 2009).

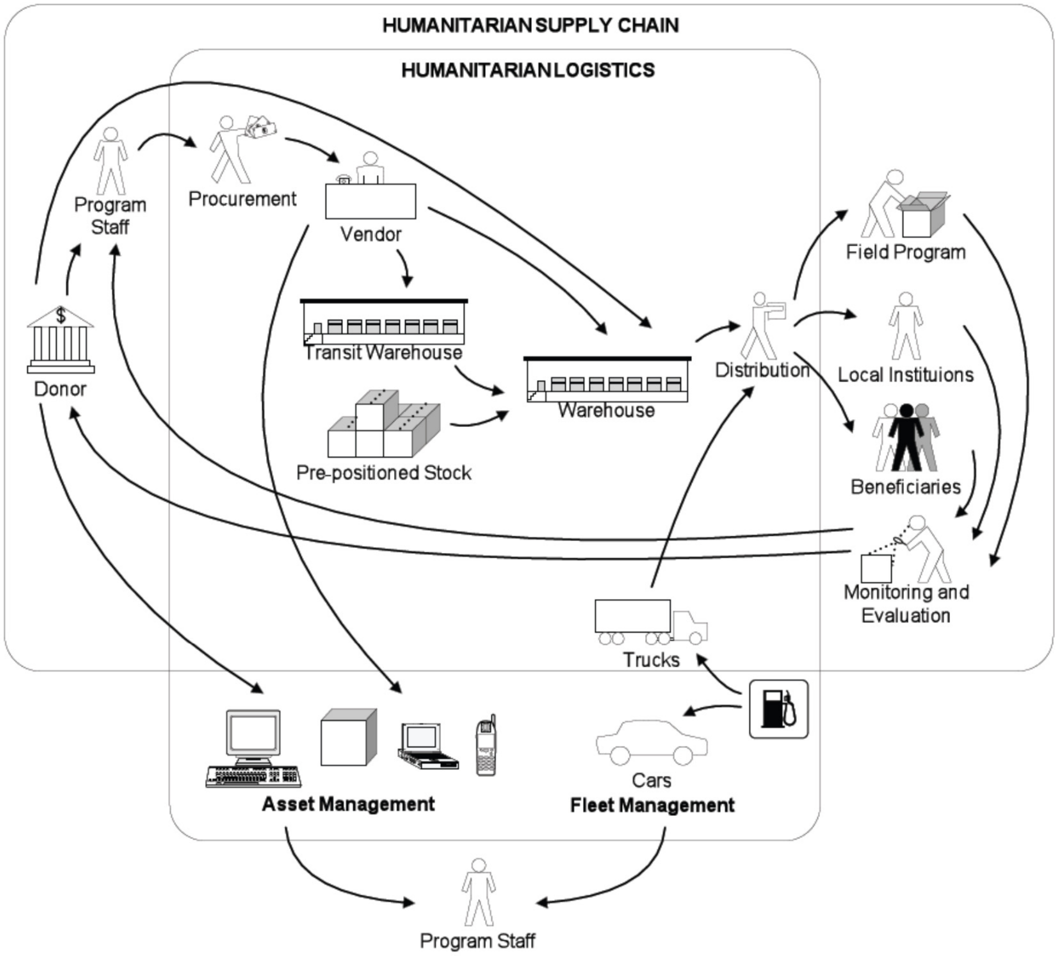


Figure 2.10. Humanitarian logistics and humanitarian supply chain flows (Howden, 2009)

2.5.2. Actors, Activities and Flows in HSC

Supply chain management in humanitarian activities involves an overlapping group of actors: beneficiaries, operational actors, donors, and media (Figure 2.11) while interacting in the following activities: planning, resource mobilization, sourcing, delivering, returning, and reporting (Figure 2.12).

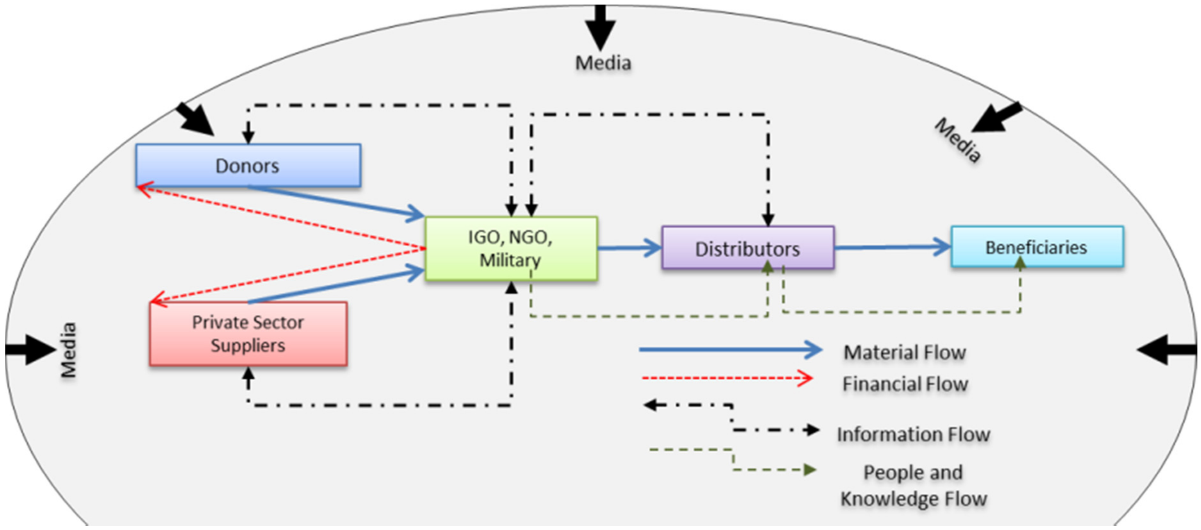


Figure 2.11. Main actors and flows in HSC

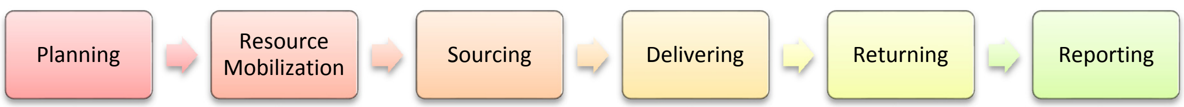


Figure 2.12. Main activities in HSC

Humanitarian operations take place in emergency environments; thus, supply chain activities are highly non-routine and carried out in extreme time pressures. When disaster strikes, to plan their activities, humanitarian organizations engage in an initial needs assessment exercise. They determine the level of destruction, number of people affected, and their initial needs. Then they assess the availability of local resources, magnitude of international assistance required, means of delivery, etc. This is with a view to prepare an initial appeal indicating how much of what type of goods and services are required, when, and where. As more information on the needs of the population becomes available, subsequent appeals are prepared.

After determining needs, humanitarian organizations mobilize cash, people, services, information, and in-kind donations. As humanitarian organizations do not have a manufacturing function, resource mobilization activities are central to their operations. The sourced relief items are then transported to the disaster area. Both procured and solicited in-kind donations are stored in warehouses before distribution to the population. Ideally, there is no need for reverse supply chain management since end-beneficiaries consume relief items, and non-consumable goods, such as vehicles, are donated to the host country. Reverse supply chain management is required only when unsolicited, contaminated, expired, or residual non-consumables and consumables are disposed of or transferred to another disaster.

Van Wassenhove et al. (2006) expanded the process and identified nine main steps to consider when responding to a major disaster. Considering the number of actors and the relief items arriving on the ground, it is vital during the disaster response operations that these nine steps are carried out under the umbrella of communication, collaboration, and coordination (Figure 2.13).

Figure 2.13. Humanitarian supply chain (Van Wassenhove et al., 2006)

As happened with the case of commercial supply chain, Tomasini and Van Wassenhove (2009a) consider that the "three Bs" can be also applied for the humanitarian sector plus a fourth and fifth B for Bodies and Brains, representing people and their knowledge and skills.

Bodies (referred to people): This represents all the manpower deployed at each intervention to implement the supply chain.

Brains (Knowledge and skills): This is particularly acute in the humanitarian sector since each time a supply chain is deployed in response to a disaster, the required skills need to be quickly reconfigured; that is, every supply chain is new and different.

Tomasini and Van Wassenhove (2009a) explain that each flow has its own goals and the key to produce an adequate response is to combine all five flows into a flawless execution plan (Table 2.4).

Table 2.4. Goals per flow (Tomasini & Van Wassenhove, 2009)

Flow	Goal
Material (Boxes)	Cost, speed and quality
Information (Bytes)	Limited access, then overflow relevance: tool for coordination
Funds (Bucks)	Liquidity: going to soft bids to cash needs-based prioritization
People (Bodies)	Getting staff to the field
Knowledge (Brains)	Making skills available to create solutions

2.5.3. Supply Characteristics

The main role of a supplier in supply chain management is to source the required items downstream in the chain. The main sources in a humanitarian supply chain management are vendors and donors. Vendors can be either local to the region where the disaster occurred or global. Donors are the sources of donations of any type (financial, products, services, etc.). Supplies consist mainly of relief items, and transportation and construction resources. Figure 2.14 shows a categorization for relief items as well as some examples.

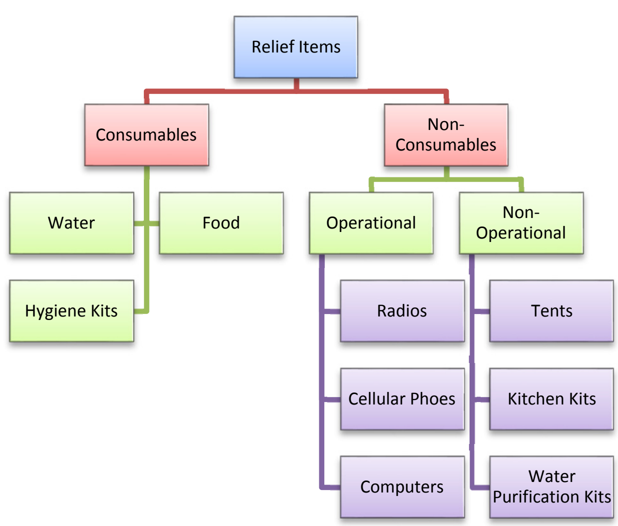


Figure 2.14. Relief supplies categorization and examples

Consumable relief items are required to meet the essential needs of the affected population and would require recurrent delivery to the affected community. Whereas, non-consumable relief items are required to set up a relief operation and would require a one-time delivery only.

There are specific challenges related to supplies that come from in-kind donations. First, there is a high uncertainty of what will be received from the donors. Moreover, the timing of these supplies might not match up with when they are needed. For example, perishable consumables that arrive too early or non-consumables that arrive after the operation was set up are wasted. Unsuitable donations cause bottlenecks in the humanitarian supply chain, and create inefficiency in the storage space or the transportation process.

Second, donations place additional difficulties on the procurement process, since it is challenging to know what will come from donors and what will have to be sourced from vendors. The procurement process is by itself a challenging task because of supply shortages or unavailability in the neighborhoods of the affected areas. Also, developing contracts with suppliers is difficult given the uncertainty of the type, quantity, and timing of items required, and the available budget. Moreover, there is competition for supply sources among local or international nongovernmental humanitarian organizations that share similar relief objectives.

Third, there are challenges of sourcing supplies which would not be available after the disaster occurs. The shortage or unavailability of supplies may cause the immediate response to be ineffective and result in increased human suffering. Hence, it is important to develop strategies to accelerate supply response or deal with unpredictability of demand. One strategic initiative recently implemented by several humanitarian organizations is the pre-positioning of inventory instead of procurement after the event. Prepositioning allows faster response, better procurement planning, and an improvement on distribution costs. However, prepositioning of supplies requires an additional investment before the event occurs, which would be very difficult to obtain.

2.5.4. Demand Structure

The demand structure of disasters is complicated and challenging because of the high unpredictability of its three main dimensions: time, location, and magnitude. Beneficiaries' needs change significantly according to the phases in the disaster timeline. The pre-disaster stage consists of planning processes that are mostly based on forecasts, so the demand is not certain. Once a disaster hits, first response relief items such as drugs, medicine, food, non-food relief items, water, and shelter are demanded in order to support basic living needs to those who are isolated in disaster-affected areas. Those demands are regarded as lumpy, i.e., they occur in irregular amounts and at irregular intervals, and occur suddenly, because disaster time, location, and intensity—and hence exact relief requirements—are not known until after a disaster occurs. There is a huge amount of uncertainty about what and how much is needed, and who needs what. Demand requirements can be estimated only on the basis of rapid damage assessments or needs analysis. There is a possibility that outcomes of these rapid assessments would give highly inflated or deflated figures or would altogether omit some important immediate demands of the affected community. As a result, misleading demand patterns could lead to inappropriate intervention and an increasing suffering level for individuals in need of relief. During the post-disaster period, demand again stabilizes and becomes more predictable based on the reported needs that are sent eventually by the assessment team in the disaster area. The lumpy demand changes to long-term recovery items such as infrastructure repair and construction equipment.

2.5.5. <u>Humanitarian Space</u>

In the mid-1990s the term “humanitarian space” was coined by Rony Brauman, former Médecins Sans Frontières (MSF) president, who defined it as “a space of freedom in which we are free to evaluate needs, free to monitor the distribution and use of relief goods, and free to have a dialogue with the people.” This topic was resumed by Tomasini and Van Wassenhove (2004). They considered the humanitarian space as an area defined by three main important humanitarian principles: humanity, neutrality and impartiality.

Humanity: brings assistance without discrimination to the wounded on the battlefield, endeavors to prevent and alleviate human suffering wherever it may be found. Its purpose is to protect life and health and to ensure human dignity is restored and suffering relieved wherever found.

Neutrality: demands for relief are provided to the needy without bias or affiliation to one party or the other. In order to continue to enjoy the confidence of all, the humanitarian organization may not take sides in hostilities or engage at any time in controversies of a political, racial, religious, or ideological nature.

Impartiality: means no discrimination as to nationality, race, religious beliefs, class, or political opinions. It endeavors to relieve the suffering of individuals, being guided solely by their needs, and to give priority to the most urgent cases of distress.

The principles of humanity, neutrality, and impartiality define the “space”, both physically and virtually, in which humanitarian organizations need to be able to operate to do their job effectively. The humanitarian space can be visualized by a triangular structure that is flexible and dynamic as in Figure 2.15.

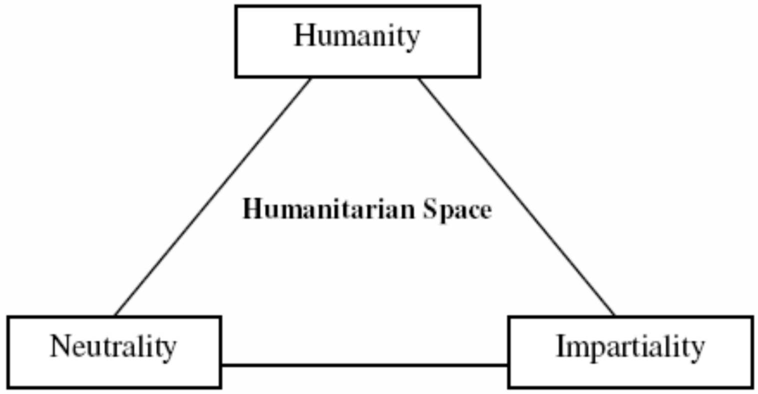


Figure 2.15. Humanitarian space (Tomasini & Van Wassenhove, 2004)

In the physical sense, humanitarian space represents a zone of tranquility where civilians, non-combatants, and aid workers are protected from gunfire so they can operate freely and deliver relief items to victims promptly and effectively. In the “virtual” sense, humanitarian space is used to guide humanitarians and help shape their decisions to ensure they remain firmly within an ethical context. This is typically achieved by providing relief repeatedly and continuously in line with humanitarian principles to those in need regardless of identity and location (Kellenberger, 2003).

These principles add many constraints to humanitarian supply chains, especially when limited relief resources are to be distributed repeatedly. Humanitarian organizations have an ethical responsibility to distribute limited relief resources in an equitable manner to affected areas. It strives for an equal outcome in which each victim’s welfare is increased to the extent possible, given limited resources, after taking proper account of disparate needs and individual circumstances. The supply chain has to be carefully designed to enable this equitable distribution to be implemented. That would be more challenging when humanitarians operate in a politically volatile climate and fear for their safety. It is quite difficult to maintain and protect the humanitarian space in which humanitarians can do their relief job independently and free from outside pressures.

2.5.6. SPHERE Project

Since donors cannot directly observe the quality of aid agencies' work, they need to rely on indicators of aid agencies' quality, but as it was shown earlier, good indicators are still largely missing. However, different guidelines exist to guarantee the level of quality by codes of conduct. One of them is the SPHERE project handbook, an initiative launched in 1997 by a group of humanitarian NGOs and the Red Cross and Red Crescent movement. It defines and upholds the standards by which the global community responds to the plight of people affected by disasters, principally through a set of guidelines set out in the Humanitarian Charter and Minimum Standards in Disaster Response (Sphere Project, 2011). It is based on two core beliefs:

- All possible steps should be taken to alleviate human suffering arising out of calamity and conflict,
- Those affected by disaster have a right to life with dignity and thus a right to assistance.

It set the minimum standards to meet the urgent survival needs of people affected by disaster in terms of water supply, sanitation and hygiene promotion, food security and nutrition, shelter, settlement and non-food items, and health services. The SPHERE project is used by humanitarian organizations to improve the quality of assistance provided to people affected by disasters, and to enhance the accountability of the humanitarian system in disaster response.

2.5.7. Measuring HSC Performance

The goal of the humanitarian supply chain is to provide humanitarian assistance in the forms of food, water, medicine, shelter, and supplies to areas affected by large-scale emergencies. As a result, an effective performance measurement system would assist humanitarian organizations in their decisions, help improve the effectiveness and efficiency of relief operations, and demonstrate the performance of the humanitarian supply chain.

Only in recent years has research on performance measurement in the context of humanitarian supply chain begun. Schulz and Heigh (2009) present and test the "Development Indicator Tool," which was developed by the International Federation of Red Cross and Red Crescent Societies (IFRC) to guide and monitor the continuous performance of their logistics units on a daily basis. The indicators are assigned to four perspectives: customer service, financial control, process adherence, and innovation and learning. They conclude that the process of designing and implementing tools for a performance measurement and management system can and should be kept simple. Important for the success of the process is the integration of key stakeholders throughout the entire process, as well as simplicity and user friendliness.

Davidson (2006) argues that disaster response involves trade-offs among speed, cost, and accuracy of an operation. This is because speed increases the cost of an operation but does not necessarily accurately meets the requirements of the beneficiaries. To make informed decisions regarding these trade-offs, four indicators are proposed: appeal coverage, donation to delivery time, financial efficiency, and assessment accuracy. The appeal coverage helps measure the extent to which an organization is meeting its appeal in terms of both finding donors and delivering items. The donation to delivery time indicator helps measure both the average and the consistency of the delivery lead times. The financial efficiency indicators compare budgeted versus actual cost of an operation. These indicators are to help logisticians make better decisions, measure actual achievements against pre-set targets, provide accountability, and develop lessons learned.

More recently, Beamon and Balcik (2008) discussed the challenges for performance measurement in the nonprofit sector given the "intangibility of the services offered, immeasurability of the missions, unknowable outcomes, and the variety, interest and standards of stakeholders." Despite these challenges, there is a need to measure the performance of non-profits in general and humanitarian organizations in particular. They have applied Beamon's (1999) performance measurement framework consisting of resource metrics, output metrics, and flexibility metrics to humanitarian supply chains. They also propose three sets of metrics to measure the performance of humanitarian organizations during disaster response, namely resource metrics, output metrics, and flexibility metrics. Different cost centers (suppliers, distribution, inventory costs) comprise the resource metric. Response time constitutes the output metric. Flexibility metrics measure the ability of a humanitarian organization to respond to different magnitudes of disaster (volume flexibility), time to respond to disasters (delivery flexibility), and ability to provide different types of items (mix flexibility).

2.5.8. Humanitarian Supply Chain Structure and Fit

Humanitarian supply chains are particularly challenging to design and manage because of the speed with which they must be built, and the uncertainty of where they will be needed. Hoffman (2005) notes that humanitarian supply chains are dynamic and volatile as information on demand and supply is not available immediately after the occurrence of a disaster. Essentially, humanitarian supply chains must be designed and built "overnight" and are also in continuous evolution from being responsive to becoming efficient during the passage of a given response effort.

In this regard, the two commercial supply chain structures, "responsive" and "efficient," discussed in section (2.4.2), will be presented in the context of HSCM. Inference will be done on some elements of a strategic fit for HSCM.

2.5.8.1. Responsiveness Structure

The number of causalities is directly proportional to the amount of time consumed to reach the affected humans for rescue and relief services. According to Perry (2007), "'In the early response stage following a natural disaster, collaboration and coordination are essential because timely response can save lives." The aim of humanitarian supply chains for the phase of disaster response is to be "responsive". To be responsive requires a proper infrastructure and fixed costs where assets and relief teams are stationed to be responsive to any emergency. Due to the unpredictability of the nature and location of sudden onset disasters, it will always be difficult to use the right response required for the situation. The starting point for needed assessment and responsive supply chain is the same. An appropriate needs assessment requires resources and a proper responsive supply chain needs information. What will be needed then is to start both simultaneously.

2.5.8.2. Efficiency Structure

In the recovery phase where relief actors have the challenge to deal with the refugees and injured, displaced, and disabled people, the supply chain should be transitioned to have a new objective of being "efficient". The recovery phase is the time that requires community support activities with a slightly longer perspective. Wassenhove (2006) says that disaster relief comprises about an 80% contribution from logistics. The only way to achieve this is through efficient and effective logistics operations and, more precisely, supply chain management. Furthermore, he narrates that setting up an efficient supply chain is always a complex operation but in the aftermath of a disaster, humanitarian organizations have to deal with multiple interventions on a global scale and often concurrently.

2.5.8.3. Matching Responsiveness and Efficiency with Disaster Management Phases

To summarize what has been covered so far, two chain structures are fitted with the two phases of responses. The supply chain design for the early days of disaster response has to be responsive and quick. The first 72 hours are crucial so that needed supplies may be flown in from abroad as quickly as possible despite being an expensive option. It is also very important for logisticians not to focus on efficiency as a key performance indicator for this phase since its primary goal is responsiveness at any cost. By the passage of time (the first 90 to 100 days), the right resources can be allocated to affected areas when clear information starts to arrive. The supply chain design becomes a mix of being effective in helping people and doing this efficiently at a reasonable cost. So humanitarians would start looking to obtain the same relief supplies locally.

Awan and Rahman (2010) stated that efficiency and responsiveness are needed in all phases of disaster management, despite that the point of difference is lower and of high importance (Table 2.5). A logical conclusion of supply chain responsiveness is that this chain must also be flexible so that it can continue to the next phase of relief. Responsiveness is key in the initial days of disasters, and efficiency is a must in the later phases of disaster relief operations.

Table 2.5. Matching supply chain structure with disaster management phases (Awan and Rahman, 2010)

	Immediate Response (Ramp Up Phase)	**Recovery (Sustainability Phase)**
Responsiveness	High Importance	Low Importance
Efficiency	Low Importance	High Importance

According to Awan and Rahman (2010), in recovery emergency situations, business processes can be used in contrast to the incident based on the initial phase of emergency response. The challenges in the recovery phase are quite different from the ones present in the immediate response phase because the supply chain is more predictable in nature. The following table (Table 2.6) summarizes the differences at the operational level to show how these two phases have different supply chain structures and are unique in humanitarian logistics.

Table 2.6. Comparison of humanitarian supply chain structures in immediate response phase and recovery phase (Awan and Rahman, 2010)

	Responsive Supply Chain (Immediate Response Phase)	**Efficient Supply Chain (Recovery Phase)**
1	Buffer Stocks are vital	Routine/ predictable stocks
2	Set Up/ Start-up of supply chain	Sustain the Supply Chain
3	Cost is not a prime driver of the chain	Cost is of significant importance
4	Forecasting is not possible	Projections of needs can be made
5	Uncertain multi modal transportation	Structured flexible transportation
6	Logistical consolidation is difficult	Consolidation & assortments is important
7	Due to the over load, excess and wrong goods sent, inventory pile up	Reverse logistics is planned to clear up unnecessary stocks
8	Procurement with lesser negotiation	Negotiation is important & time is available
9	Lead time needs to be shortest	Replenishment leads to longer lead times
10	Local sourcing is not the goal	Local sourcing is preferred
11	Finances are fetched easily (Donors are willing)	Donations are politicized
12	Distributions to Diverse location	Distribution to lesser locations
13	Large number of Volunteers available	Very few volunteers are available
14	Life-saving/ Rescue focused aid	Daily routine life aid
15	Large over lapping of organizations	Overlapping is easily identified
16	Performance is hard to be measured	Performance can be measured and defined
17	Macro Management	Micro Management
18	Availability, not specialization , is important for supplier selection	Specialization is of significant importance
19	Push based strategy	Pull based strategy
20	Cross Dock is compulsory	Pick Pack is possible
21	Less transparent sourcing & Supply chain	Transparency is must
22	Rigid supply chain (through put is less)	Supply chain may be flexible

2.5.9. <u>Structure of the Humanitarian Chain in the Last Mile Distribution</u>

Balick et al. (2008) defined last mile distribution as: "Last mile distribution is the final stage of the relief chain; it refers to delivery of relief supplies from local distribution centers to the people in the affected areas (demand locations)." The structure of the supply chain in "last mile" is very important because, knowing it, it is possible to understand how the aids move in the humanitarian operations and the locations where aids arrive, or are stored, sorted, and transferred, and which are the local distribution centers where aids are distributed to beneficiaries. The logistics situation we can typically find in a disaster relief operations is seen in Figure 2.16.

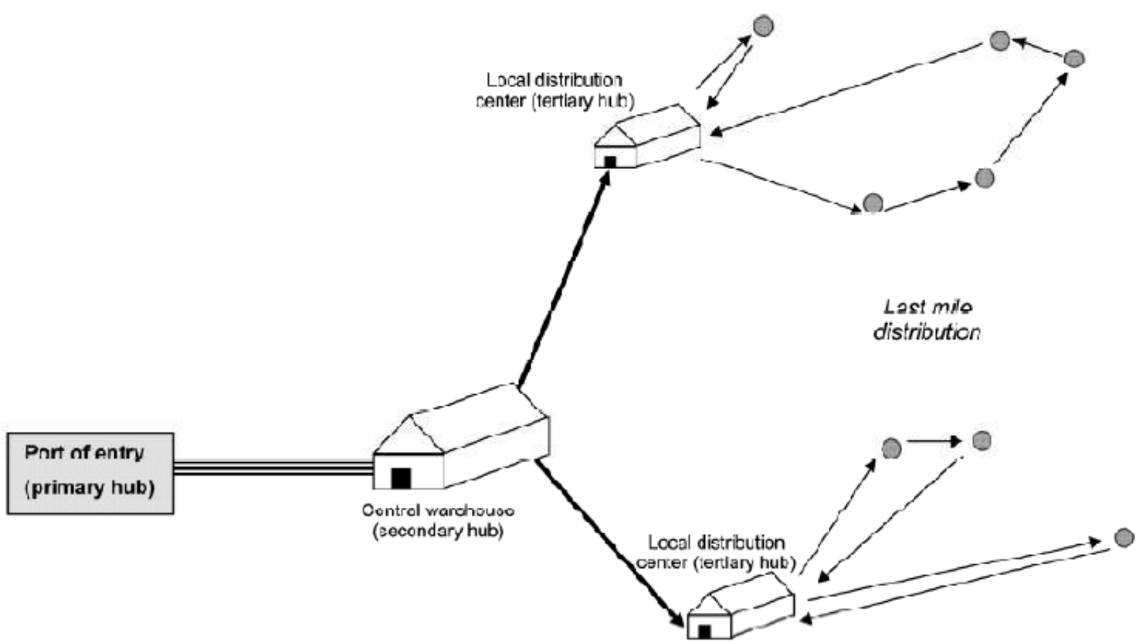


Figure 2.16. Structure of the relief chain (Balcik et al., 2008)

The primary hub is usually a seaport or airport where humanitarian aids arrive from all parts of the world. The secondary hub could be a central warehouse used to store, and transfer to tertiary hubs. The tertiary hubs usually are local and temporary distribution centers. These hubs are also called local distribution centers (LDCs), and they are used to deliver aids to beneficiaries.

The most significant logistical problems in the last mile generally stem from the limitations related to transportation resources and the sheer amount and bulk of supplies to be transported, difficulties due to damaged transportation infrastructure, and lack of coordination among relief actors. According to Balcik et al. (2008) the task is made more difficult because of strict financial and time limitations, making cost-efficient vehicle routing decisions important. It is challenging for relief agencies to develop effective and efficient distribution plans in such a complex environment while simultaneously achieving a coordinated response. (Balcik, Beamon, & Smilowitz, 2008)

2.6. Humanitarian vs. Commercial Supply Chains

In this sub-chapter, an attempt is made to review published literature on the characteristics of humanitarian supply chain that differs from commercial supply chain. A differentiation framework is suggested based on chain structure, logistical operations, and mathematical modeling. These distinctions will be explained in detail followed by presenting cross learning possibilities between the two chains. This sub-chapter is concluded by suggesting the need to formulate a mathematical model that is significantly different from the traditional formulation used in commercial problems.

2.6.1. Previous Comparisons on CSC - HSC

The management of HSC for disaster relief operations has attracted research attention in recent years. While some aspects of CSC are applicable for disaster relief operations, many are not directly transferable into a humanitarian context because of the different conditions and circumstances each chain operates in.

There is an extensive literature that highlights the key differences between HSC and traditional CSC. Beamon (2004) differentiated CSC and HSC on the basis of seven criteria, i.e., demand pattern, lead time, distribution network configuration, inventory control, information system, strategic goals, and performance measurement system. Holguin-Veras et al. (2010) built on Beamon's comparison and showed that the two chains differ in terms of: (1) objectives being pursued, (2) nature of commodity flows to be transported, (3) decision-making structure, (4) knowledge of demand, (5) state of supporting systems, and (6) periodicity and volume of activities.

Pujawan et al. (2009) present four guiding principles that permeate both types of chain management but which work in different ways in the two types of operations. These are: (1) information visibility, (2) coordination, (3) accountability, and (4) professionalism. Beamon and Balcik (2008) stated broad differences between for-profit supply chains and HSC on the basis of strategic goals, demand characteristics, and customer characteristics. Van Wassenhove (2006) stated the unique complexities in managing HSC in the context of operating conditions and physical environment. He pinpoints the cross learning potential for both the humanitarian and private sector in disaster relief operations. Ertem et al. (2010) take a different comparison perspective by reconfiguring a procurement auction-based framework of CSC in a disaster relief setting based on three phases: announcement construction, bid construction, and bid evaluation.

2.6.2. A Conceptual Framework for Distinguishing CSC and HSC

Drawing on previous literature and the unique characteristics each supply chain has, a conceptual framework is suggested to distinguish CSCs and HSCs on the basis of (1) chain structure (features, flow, coordination, ethics, professionalism, decision making, process management, lifecycle, and distribution network design), (2) logistics (uncertainties, supply and demand pattern, response time, push-pull movement, volume and periodicity, earmarking of funds, infrastructure, technology and information, and inventory management), and (3) model development (objectives, model formulation, and performance measurement) (Figure 2.17).

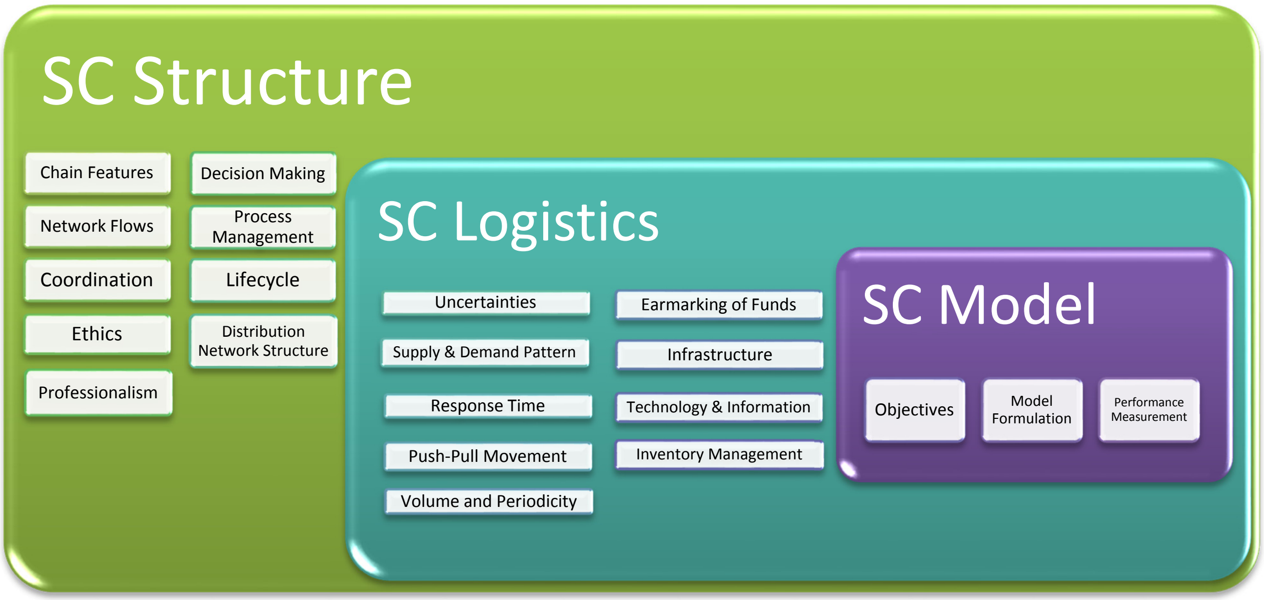


Figure 2.17. A conceptual framework for distinguishing CSC and HSC

2.6.2.1. Supply Chain Structure

The preceding review reveals that there are various definitions for CSC and HSC. One definition that highlights the chains' variance is provided by Kuhn and Hellingrath (2002) and the Department of Supply Chain Management, University of Manitoba (2011). At first glance, these two definitions reveal fundamental differences between the two chains in terms of chain structure. This section will differentiate the two chains' structures on the dimensions of functionality, flows, relationships, time, and space.

2.6.2.1.1 Core Chain Features

Commercial Supply Chain Management (CSCM) incorporates the functions of procurement, production, and distribution. The primary goal of any commercial organization is to make a profit for its shareholders by selling goods and services to consumers. It competes on the market through its products, and the transactions are regulated by the price mechanism. Its production capacity and performance are directly tied to customer satisfaction as consumers are both users and buyers of a firm's products (Figure 2.18).

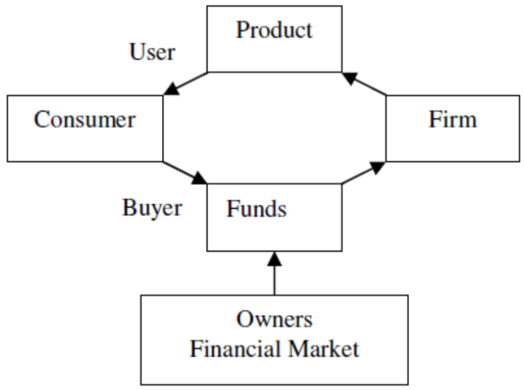


Figure 2.18. Buyer and user in CSC (Samii, 2006)

Humanitarian supply chain management (HSCM) focuses mainly on either the procurement or the distribution function. Production can be involved in humanitarian operations but is generally not a major concern. Humanitarian organizations are considered not-for-profit organizations whose activities facilitate or include the delivery of aid or assistance in order to save lives, meet basic human needs, and alleviate human suffering. Transactions are regulated by humanitarian needs and the social and moral obligation of the international community. Competition among humanitarian organizations is centered around the buyer function, i.e., the fund-raising capability and, to a lesser extent, the procurement stage. This competitive attitude makes cooperation among humanitarian organizations difficult despite it being in the best interest of the beneficiaries. Moreover, unlike commercial operations, the buyer and user of humanitarian services are two different entities. The user is the beneficiary while the buyer is the donor (Figure 2.19).

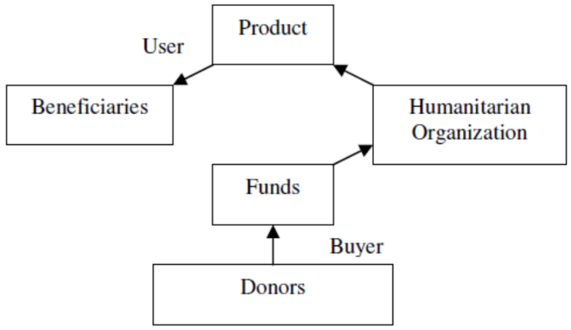


Figure 2.19. Buyer and user in HSC (Samii, 2006)

2.6.2.1.2 Supply Chain Flow

A typical CSC network consists of a network of suppliers, manufacturers, distribution centers, retailers, and consumers. The network supports three types of flow (physical, information, and financial) that require careful design and close coordination. The HSC network consists of a network of suppliers, donors and governments, distributors, and beneficiaries. It adds two additional flows: people, and knowledge and skills.

The two types of chains have differences in flows. CSC focuses on the optimization of the different flows within the network. The delivery actions of a company reflect the commodity flows from supplier to customers, and the nature of the competition among companies in that particular market. As a result, the commodity flows generated can be considered to be self-contained and within the control of the company making the deliveries. HSC focuses on establishing and maintaining a (possibly highly vulnerable) supply chain that exists only temporarily. The occurrence of an extreme event triggers a massive influx of personnel, information, and material to the impacted site. Moreover, because the media place such high pressure on agencies to compete for visibility, humanitarian organizations have to consider media flow to better control what is within their sphere of influence.

2.6.2.1.3 Ethics

Perhaps the most important concept setting apart humanitarian organizations from their business counterparts is their strict adherence to humanitarian principles (Tomasini & Van Wassenhove, 2004). In disaster relief operations, humanitarian organizations operate in accordance with the principles of humanity, neutrality, and impartiality. Humanity ensures that human dignity is restored and suffering relieved wherever found. Neutrality demands that relief be provided to the needy without bias or affiliation to one party or the other. Impartiality implies that assistance is extended without discrimination and proportionally to the most urgent needs and segments of the population.

By contrast, commercial organizations operate in accordance with Corporate Social Responsibility (CSR) to align their values and behavior with the expectations and needs of stakeholders. Each principle, humanitarian space and CSR, describes an organization's commitment to be accountable to its stakeholders. Still, there is often a politicized environment in which it is difficult to maintain a humanitarian perspective to relief operations.

2.6.2.1.4 Coordination

Reports on disaster relief operations frequently criticize aid agencies for their lack of collaboration and coordination (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010). Unlike CSCs, HSCs are in the midst of numerous requirements posted by many stakeholders, including large numbers of uncoordinated and disparate donors, the media, governments, the military, not to mention the final beneficiaries. At any one time, there can be as many as several hundred humanitarian organizations at the scene of a disaster, not always acting in a coordinated fashion. It is a highly complex task to coordinate the activities of many different aid agencies, suppliers, and local and regional actors, all with different professional backgrounds, levels of expertise, priorities, and operating under different organizational structures. These organizations typically have different mandates, political agendas, ideologies, and religious beliefs and all are fighting for media and donor attention (Blecken, 2010). This makes the application and comparability of supply chain management principles difficult. Thus, the greatest challenge lies in aligning these organizations without compromising their mandates or beliefs. In addition, a competitive environment emerges among many humanitarian organizations due to the difficulties in attaining funding; it also makes coordination, collaboration, and resource sharing among them limited or even impossible. Many Non-Governmental Organizations (NGOs) will run their disaster relief operations in parallel, leading to a duplication of the same efforts, thus wasting resources.

2.6.2.1.5 Professionalism

Humanitarian organizations often lack skilled and educated staff with career backgrounds in logistics and supply chain management. Logistics personnel are in the midst of numerous requirements imposed by local governments and officials, donors, the media, beneficiaries, and their own headquarters, potentially creating conflicts in managing logistical activities, and thus making it difficult to efficiently and effectively supervise humanitarian efforts and resources (Maspero & Ittman, 2008). While CSCM over the years has developed a set of standards and procedures, such standardized processes do not exist in HSCM, and the use of (untrained) personnel does not support the standardization of work processes. Retention of personnel is extremely difficult considering the harsh physical and psychological environment. Staff turnover rates are high and there is a heavy reliance on volunteers (Pujawan, Kurniati, & Wessiani, 2009). Disaster relief operations are mobilized and then demobilized. Since they are not an ongoing operation, it is difficult for a supply chain management professional to build a career. Thus, the high turnover rates, unprofessionalism, and volunteerism make accountability vague and expose the HSCM to ethical, reputational, and fraud risk.

2.6.2.1.6 Decision Making Structure

An important distinction between CSCs and HSCs are their vastly different decision-making structures. On one hand, decisions in HSCM are highly dynamic, complex, and often informal and/or improvised considering the stakes involved. Decisions are of heightened urgency and timeliness as they can mean the difference between life and death for disaster victims (Day, Melnyk, Larson, & Davis, 2012). Also, decisions must be robust, because data can be missing, incomplete, or even wrong and the emergency scenario may change as time passes. Humanitarian organizations are typically unable to satisfy all needs and have to decide how best to use their limited resources. On the other hand, CSCs are usually managed by formal decision-making structures, few decision makers, standard procedures, and clearly defined roles for all players. Furthermore, there is a great deal of clarity in what each chain participant is supposed to do and how they interact with others, and there are protocols to enforce compliance with rules and regulations. Also, commercial logistics do not experience the conditions of extreme scarcity found in disasters, and seldom consider the social welfare from their delivery actions as a parameter for decision making under normal business conditions (Holguin-Veras, Perez, Jaller, Destro, & Wachtendorf, 2010).

2.6.2.1.7 Process Management

Processes in a commercial setting are structured and oriented to the value chain. Processes include supplier and customer relationship management, demand management, order fulfillment, manufacturing flow management, product development, and commercialization and returns management. In contrast, processes in a humanitarian setting are required to go beyond profitability. They are structured by missions and continuous welfare programs. Product development, manufacturing, and returns management processes are not likely to be relevant to an HSC. Many actors are not linked to the benefits of satisfying demand. Suppliers (donors) have different motivations for participating, and customers (beneficiaries) are not generating a voluntary demand and will it is hoped, not create a “repeat purchase” (Kovács & Spens, 2007).

Another fundamental difference is in the motivation for improving the management of the logistics process. The business sector has for a long time realized the importance of logistics and the benefits of effective supply chains. While commercial logistics have exploited the opportunities by going global, humanitarian logistics are struggling to get recognition. Van Wassenhove (2006) states that this has been locked into a vicious circle where the humanitarian organizations lack the understanding for logistics as a core function and suffer from poor planning and budgetary skills, resulting in logistics requirements not being met. “This in turn has led to a “fire-fighting mentality.” Managers see logistics struggling and concluded that a review of logistics was not advantageous, further fuelling a lack of understanding, and so the cycle begins again” (Figure 2.20).

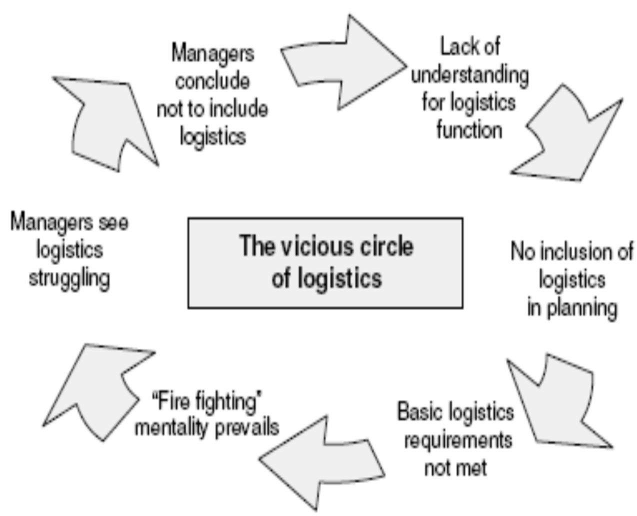


Figure 2.20. The vicious circle of logistics (Van Wassenhove 2006)

2.6.2.1.8 Supply Chain Lifecycle

To understand the context in which humanitarian organizations stage their response operations, Samii (2008) proposes a framework that differentiates between different supply chain scenarios. The framework distinguishes between routine and event-related supply chains mounted in response to predictable and unpredictable situations (Table 2.7).

Table 2.7. Supply chain management scenarios (Samii, 2008)

Event	Large Event Organization *(Olympic games, music parades, conventions, predictable disasters)*	Unpredictable Disasters *(Fire, hurricane, terrorism, flood, earthquake)*
Routine	Functional Products *(Basic apparel, food)*	Innovative Products *(Fashion, Hi-tech items)*
	Predictable	**Unpredictable**

The majority of supply chains managed by businesses are routine operations that rely on supply chain models designed for repetitious actions. On a recurrent basis, private and public entities manage a series of supply chains related to calendar- and location-fixed one-off and repeated events. Consequently, businesses have to overcome major and unpredictable failure modes only on an extraordinary basis. This can partially explain why companies have plans against recurrent, low-impact risks while few have plans that are capable of responding to high-impact, low-likelihood risks (Rice & Caniato, 2003). In contrast, humanitarian organizations are increasingly tied up in the management of large-scale, sudden, and complex disasters. Those with a global mandate operate in fast clock-speed environments and need to respond to situations in which it is not known when, where, what, how much, and how many times demand will occur. Consequently, humanitarian organizations need to repeatedly construct and manage a series of non-routine supply chains in response to predictable and unpredictable large-scale events.

2.6.2.1.9 Distribution Network Designs

Chopra and Meindl (2010) have discussed six distinct distribution network designs that can be adopted in CSCM. These six distribution network designs are:

1. Manufacturer storage with direct shipping (Figure 2.21a)
2. Manufacturer storage with direct shipping and in-transit merge (Figure 2.21b)
3. Distributor storage with package carrier delivery (Figure 2.21c)
4. Distributor storage with last mile delivery (Figure 2.21d)
5. Manufacturer/distributor storage with customer pick up (Figure 2.21e)
6. Retail storage with customer pick up (Figure 2.21f)

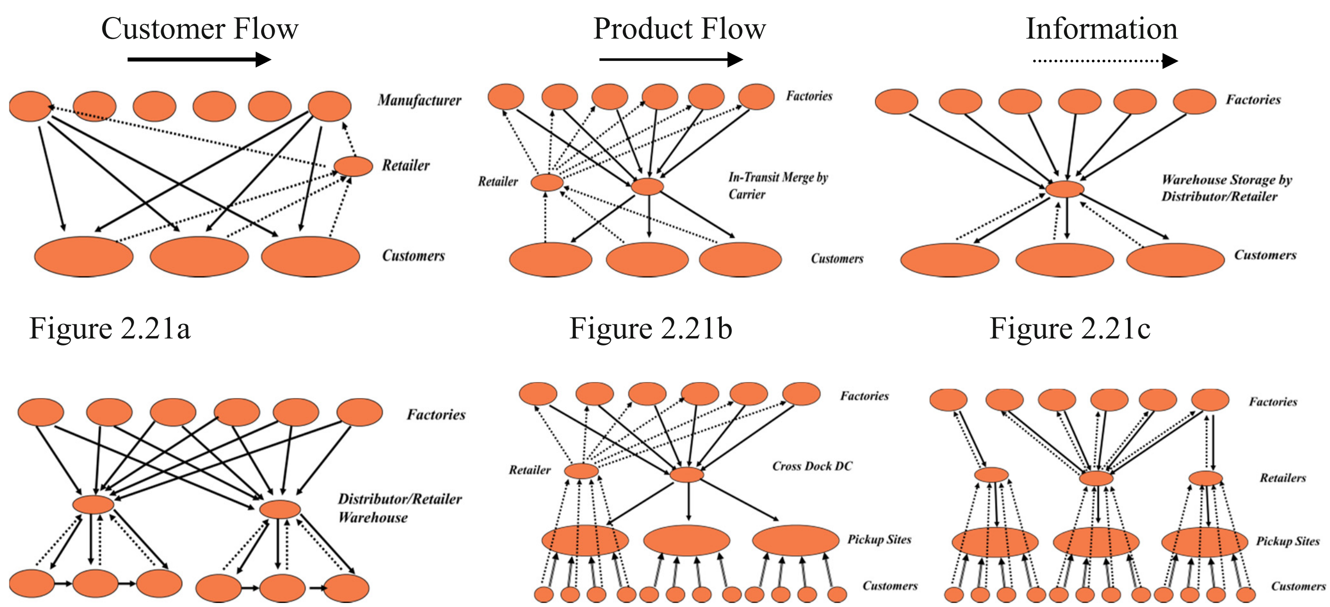


Figure 2.21a Figure 2.21b Figure 2.21c

Figure 2.21d Figure 2.21e Figure 2.21f

Figure 2.21. Distribution network design (Chopra and Meindl, 2010)

The six distribution network designs are well-defined with predetermined numbers and locations for distribution. Each is designed in such a way that it gets the right goods to the right place and distributes to the right people at the right time in order to minimize system-wide costs while satisfying service level requirements. These designs have been framed for CSC. Strict adoption of any of these designs for a humanitarian chain is neither recommended nor desired. In fact, arriving at a distribution network design for a disaster response is a complex task, as there are so many uncertainties in terms of magnitude, location, type, last mile consideration, etc. No two disasters will be the same in their characteristics; however, with enough planning in place with realistic “if-then-else” distribution network designs, implementation can be less challenging.

Each of the above distribution network designs has characteristics that can be useful in a humanitarian setting even though the overall design may not be appropriate. The outbound distance is large for manufacturer storage with direct shipping. As a result, the model performs low in response time in a disaster situation. Thus, the model initially seems to be inapplicable in a disaster situation; however, it can be applied successfully for local community donors from and around the affected area within a short period of the critical phase considering the time and distance factors. The concept of in-transit merge can be useful in an HSC. Various donors/organizations can be more efficiently managed if the relief chains of these organizations are integrated at one point. This allows appropriate packaging of relief kits, thereby ensuring greater product variety while preventing some regions from receiving duplicate aids and other regions receiving no aids at all. The intermediate warehouse setup that is created in distributor storage with package carrier delivery can help establish a better information structure among donors situated several thousand miles away. In distributor storage with last mile delivery, response time is very quick and products are delivered to customers’ homes. Thus, this design offers two of the most desirable functions in a humanitarian chain. In manufacturer or distributor storage with customer pick up, distribution centers in a disaster can be established this way to permit beneficiaries to collect their relief kits and minimize response time. Although it offers the shortest response time, retail storage with customer pick up does not have much to offer to its humanitarian chain, primarily because the retailer storage would be within the affected area, likely making the facilities dysfunctional (as it itself would be affected by the disaster) in the crucial time of need.

2.6.2.2. Supply Chain Logistics

HSC logistics is unique in four aspects that may increase the relative complexity and difficulty in solving operational problems. First, uncertainties in terms of timing, geographic location, type of commodity, and quantity of commodity; second, short lead time and suddenness of a large demand for a wide variety of products and services; third, lack of initial resources in terms of supply, human resources, technology, capacity and funding, deficient infrastructures, and security concerns; and fourth, challenging inventory management and control due to the high variations in lead times, supply, demands, and demand locations. A detailed discussion on the characteristics of HSC logistics that sets it apart from CSC logistics is presented below.

2.6.2.2.1 Uncertainties

Today, global supply chains must deal with considerable uncertainty. Prater (2005) identifies four types of uncertainty that can impact supply chains:

- **General Variation** – Cost, time, and performance levels vary randomly, but in a predictable range.
- **Foreseen Uncertainty** – A few known factors will influence the project, but in possibly unpredictable ways.
- **Unforeseen Uncertainty** – One or more major influence factors cannot be predicted.

- **Chaotic Uncertainty** – Unforeseen events completely invalidate targets, plans, and approaches.

HSCs show the extremes of a trend toward more chaotic uncertainty and risk prevalent in today's global CSCs. The HSC operates under unstable conditions that would frustrate most CSC managers. The HSC functions in the presence of high levels of uncertainty about disaster timing and location, victims' needs, donors' contributions, infrastructure, and even relief group composition. HSCs need to operate in highly volatile environments as well as provide assistance in both the short- and medium-term time horizons; i.e., in both emergency and post-emergency, or more stable contexts. Uncertainty is thus inherent to any type of relief operation whether conducted during emergency or post-emergency phases. However, the level of uncertainty declines when the relief operation evolves from the emergency to the post-emergency phase.

Uncertainty in HSCs also refers to uncertainty of demand, supply, personnel, equipment, and information as well as process instability, other actors in the supply chain, and financial resources (Blecken, 2010). Then there is the added pressure of time, which, in this context, is not just a question of money but a difference between life and death. Demand patterns are highly irregular and the environment puts unique constraints on the operations. Especially in disaster relief operations, uncertainty also includes the number of people affected, the infrastructure that is still intact, and information uncertainty. Even with accurate data, both demand and supply can vary dramatically during the length of the relief operation. In addition to the risks of a mismatch in supply and demand, disruption is an increasing risk in global supply chains even for businesses. With longer paths and shorter clock speeds, there are more opportunities for disruptions and a smaller margin for error if a disruption takes place.

2.6.2.2.2 Supply and Demand Patterns

The supply pattern in an HCS is different from a CSCs. Supply in CSCs follows a standardized order fulfillment process. There is greater certainty on the supply quantity, location and time, longer relationships with suppliers, and better information about the quantity and location of supplies available before procurement decisions are made. Also, when supply deals with routine events and not a one-time disaster event, developing a procurement strategic partner is easier. In the case of disasters, supplies come from both voluntary donations and local procurement. Local supply sources are especially variable and uncertain since the disaster has generally impacted those sources.

Demands in a commercial chain are products and services, whereas in a humanitarian chain demands are supplies (aid) and people. The inherent demand pattern and its high uncertainties are the main differences (Blecken, 2010). For many CSCs, the external demand for products is comparatively stable and predictable (Beamon, 2004). The demand for products is usually either estimated using proper forecasting techniques (i.e., push production system) or initiated by the customer (i.e., pull production system). Often, CSCs are designed to meet known or forecasted customer demands for the portfolio of goods offered by the company. The demands seen from warehouses occur from established locations at relatively regular intervals. Although there could be variations in the demand patterns, the level of randomness and uncertainty is relatively small compared with the base demand. Therefore, CSC managers try their best to eliminate the elements of uncertainty as much as possible.

The demand patterns in disasters are different from the commercial setting and are also different in each disaster phase. The pre-disaster stage consists of planning processes that are mostly based on forecasts, so the demand is not certain. Once a disaster hits, demand becomes complex: high and quickly changing, but more certain based on the reported needs that are sent by the assessment team in the disaster area. During the post-disaster period, demand again stabilizes and becomes more predictable with real data from the region. Overall, demand structure of disasters is complicated and challenging because of the high unpredictability of its three main dimensions: time, location, and magnitude. Also, disaster demand has other drivers related to those dimensions such as population characteristics, economy, and political conditions; these factors are also complex to formulate.

2.6.2.2.3 Response Time

The importance of a timely response is much different in the humanitarian sector than in the commercial sector. While a delay in the CSC is costly in terms of productivity and/or customer satisfaction, a delay in the HSC could literally mean the difference between life and death for those most severely impacted by the disaster. When a disaster strikes, humanitarian organizations work to quickly assess the relief items required to meet the relief needs of an affected population, usually within the first 24 hours of a crisis. A preliminary appeal for donation of cash and relief items is launched, often within 36 hours of the onset of the disaster. If donors do not respond and the appeal is under-funded, relief cannot proceed. This appeal is the basis for large-scale mobilization of transport capacities for the distribution of relief items to beneficiaries. The success of executing a distribution plan hinges as much on timely information as it does on mobilization of assets.

2.6.2.2.4 Push-Pull Movement

Another difference between HSC and CSC is that the former follows the shift from push to pull; a trend which is generally not common in CSC. At the ramp up phase, it is speed at any cost and the first 72 hours are crucial. At this stage, disaster relief inventories require that they be ‘‘pushed’’ out as quickly as possible and within a short time frame to their storage locations despite this approach being an expensive option. The distribution of relief items in response to a disaster may also start by pushing estimated needs into the affected areas. Later on (the first 90 to 100 days) during the sustainment phase, the actual conditions at the disaster area are determined; much better estimates of the needs can be made. This enables the managers at the site to ‘‘pull’’ the needed items to the area and also start looking to buy the same goods locally (Whybark, 2007). It becomes a mixture between being effective in helping people and doing this at a reasonable cost. This shift in technique from push to pull may also be needed in CSC, but rarely so quickly and radically as in HSC (Day, Melnyk, Larson, & Davis, 2012).

2.6.2.2.5 Volume and Periodicity of the Logistic Activities

Supply chain management is the center of any given logistical operation. A key difference is related to the amount of goods that are transported in each case of commercial and humanitarian logistics. In essence, while commercial logistics handle a large and relatively steady flow of goods, humanitarian logistics deal with a large pulse in demand in the first couple of days and then tapers down as the situation stabilizes (Holguin-Veras et al., 2010). Moreover, a disaster may require an order of magnitude increase in the amount of critical supplies to be transported. Therefore, it becomes a critical, but difficult, task to transport supplies from distribution centers to targeted locations with transportation vehicles that are frequently limited in quantity and may be limited in capacity. These increases in the amount of transportation requests, across all types of supplies, have no parallel in commercial logistics. Additionally, the challenge in humanitarian logistics is that this pulse takes place at a time when the supporting systems (e.g., transportation, communication, public order…) are at their weakest conditions.

Another distinction is related to the periodicity (frequency) of logistic activities. In the commercial sector, most of the delivery activities repeat an established pattern day after day, though there may be variations from the routine. This repetition allows companies to gradually fine tune their operations to optimize performance. In contrast, most humanitarian logistics are dealing with once in a lifetime events and, for that reason, the element of learning and improvement by repetition is difficult.

2.6.2.2.6 Earmarking of Funds on Support Activities

Logistics and other support activities, such as improvement of processes, installation of state-of-the-art information systems and communication infrastructure, operations' support with a long-term focus, and organizational learning, are important areas in CSCM. Conversely, there is consistent under-investment in these areas in HSCs even if there is potential to improve their efficiency and responsiveness. Investments in support activities are generally thought to have a lower priority function due to the nature of how HSCs are funded. As previously stated, the main stakeholder in HSCs is not the beneficiary (who should be the focus of humanitarian operations) but rather the donor. Donors frequently earmark their funds, i.e., limit flexibility in how humanitarian organizations can use these funds. They have become particularly influential in prompting humanitarian organizations to think in terms of greater donor accountability and transparency of the whole supply chain. Hence, donors have influence as to where and how relief operations take place, and the beneficiary or the affected community has little to say in this matter. This situation generally continues until a negative situation associated with this lack of funding forces adjustments to be made.

2.6.2.2.7 Infrastructure

Another main distinction between CSCs and HSCs is the destabilized infrastructures within which the humanitarian teams have to work in order to supply aid to those affected. On one hand, CSCs are fully functioning in an environment with well-defined and reliable infrastructure. Transportation network design is regarded by chain members as a strategic decision, and the choice of transportation mode creates a competitive advantage. Having an established network-based communication system will dramatically reduce the operational costs, boost productivity, and allow chain members to work closely together. On the other hand, humanitarian operations often have to be carried out in a complex environment with destabilized infrastructure ranging from a lack of electricity to limited transport and communication infrastructure. With respect to transportation and communication infrastructure, it can be observed that the impact of a disaster magnifies in areas where the local infrastructure is already in a poor state (Blecken, 2010). This situation can dramatically deteriorate during and after a disaster when the infrastructures are severely damaged and the possibly few remaining roads cannot handle the number of refugees and disaster management vehicles that pour in and out of these areas. Remaining communication posts may have been destroyed. Any pre-disaster plans on transportation network design may have become unfeasible and unreliable. The network design needs to be revised to establish reliable routes to transport large and dynamic volumes of critical supplies with time limitations to affected areas in order to support beneficiaries' basic living needs. Transportation remains vulnerable to disruptions and may require the use of multiple modes. Communication systems may have been impacted and are unable to fully function in an environment with destabilized infrastructures. Means of communication is often reduced during relief operations (no Internet access on field, etc.). Poor communication infrastructure prevents efficient information management and increases uncertainty.

2.6.2.2.8 Technology and Information System

In CSC, information is accurate and its flow is generally well structured. Well-defined, highly developed software packages are often used to integrate the supply chain stages, improve coordination, increase visibility, and maximize profitability. Obviously, visibility provided by these systems helps to improve the efficiency and service level of the supply chain simply by knowing what goods are demanded and where they are produced and sold. In a disaster relief operations, visibility becomes crucial, as shifts in demand are highly unpredictable and the key to success lies in having the right relief at the right place at the right time. Visibility also keeps track of who donated which supplies and how they were distributed.

In HSC, the availability of timely and accurate information, as in CSC, is key to any disaster response operation since it can possibly guide the respondents to identify the correct demand patterns. However, establishment of a proper information system is itself jeopardized in a post-disaster situation, due to massive destruction of the community infrastructure. Most donations are earmarked for and bound to a specific disaster response or programme, and cannot be deployed for investment purposes such as purchasing an information and communication technology system. Also, because donors tend to donate money expecting to directly help those impacted by the disaster, funding for necessary equipment and information technology has been limited – even if the investments would significantly save lives in the future. (Oloruntoba & Gray, 2006); (Thomas & Mizushima, 2005). It is not unusual for aid agencies to have multiple incompatible information systems in the field. Information typically exists in silos, preventing these agencies from collecting organization-wide metrics (e.g., resource, output, and flexibility performance measures) (Maspero & Ittman, 2008). Information is only available after assessment and often is unreliable or incomplete. Information can also flow through the media and is frequently updated, but is still generally incomplete. Logistical data are recorded and tracked manually. Data have to be written out onto multiple forms and keyed into multiple spreadsheets with no central and structured database or historical data on prices paid, transit times, or quantities received/purchased. Manual, non-standardized, error-prone processes are dominant. Data networks are non-existent or of limited visibility. This includes differing radio frequency bands and licenses, missing communication technology, outdated and unreliable IT equipment, incompatible software systems etc., (Blecken, 2010). These inefficiencies, originated from not incorporating ICT systems in their operations, make the humanitarian sector lag seriously behind its counterpart.

2.6.2.2.9 Inventory Management

Commercial inventories are used in response to economic conditions or for defense purposes, whereas relief inventories are generally of a social nature and used in the service of social goals. In spite of the vast theories available in commercial inventories, the unique characteristics of relief inventories act as inhibitors to the application of the commercial inventory theory that is so abundant.

Researchers of inventory management agree on the fact that the fundamental issues in their area of studies are (a) when to purchase, (b) how much to purchase, (c) where to store what is purchased, (d) how much to allocate, and (e) how to distribute what is allocated. Yet, the above mentioned components have different values in each of the dichotomies of relief inventories and commercial inventories. For instance, factor “c” above, i.e., where to store what is purchased, becomes significantly important in relief inventory management because of time and secure site locations.

Building on Whybark's (2007) comparison, some of the important differences from commercial inventories are in the areas of sourcing, acquisition, clearance, storage, distribution, and control.

Sourcing: All commercial inventories are obtained through cost-based sourcing. Procurement is considered a strategic decision that provides a competitive advantage. Companies usually deal with a predetermined set of suppliers (two or three on average) and build close relations with them. On the other hand, a good part of relief inventories are unsolicited in-kind donations that need sorting and special packaging. Procurement is an immediate operational decision and is generally limited to commonly needed items from suppliers who are located near potential disaster areas.

Acquisition: In a commercial setting, determining when to place an order and the amount of inventory to buy or make is based on estimations of future demand. By ordering or producing the inventory a little early there will be extra on hand to act as a buffer against higher than expected demand. Conversely, the supply chain can tolerate lead times to obtain lower prices. This logic is not very applicable to relief inventory. Relief inventories are subject to uncertain demand and timing plus the added uncertainty of location. Humanitarian supply chains cannot tolerate lead times and are ready to accept high purchase prices since it is a matter of life or death.

Clearance: It is well known that products have to go through the control procedure when being bought into a country and customs is the body performing that task of control. Unlike consignments of non-emergency supplies, clearing relief aid at a country port of entry provided by the international community needs an additional step: getting duty and tax exemptions (United Nations Joint Logistic Centre, 2008). This will involve not only the customs directorate, but, in most cases, also governmental authorities. The authorities accept the aid and normally draft ad-hoc exceptional regulations for those relief consignments being imported for the crisis without any tax payments. The supply chain would look as follows (Figure 2.22):

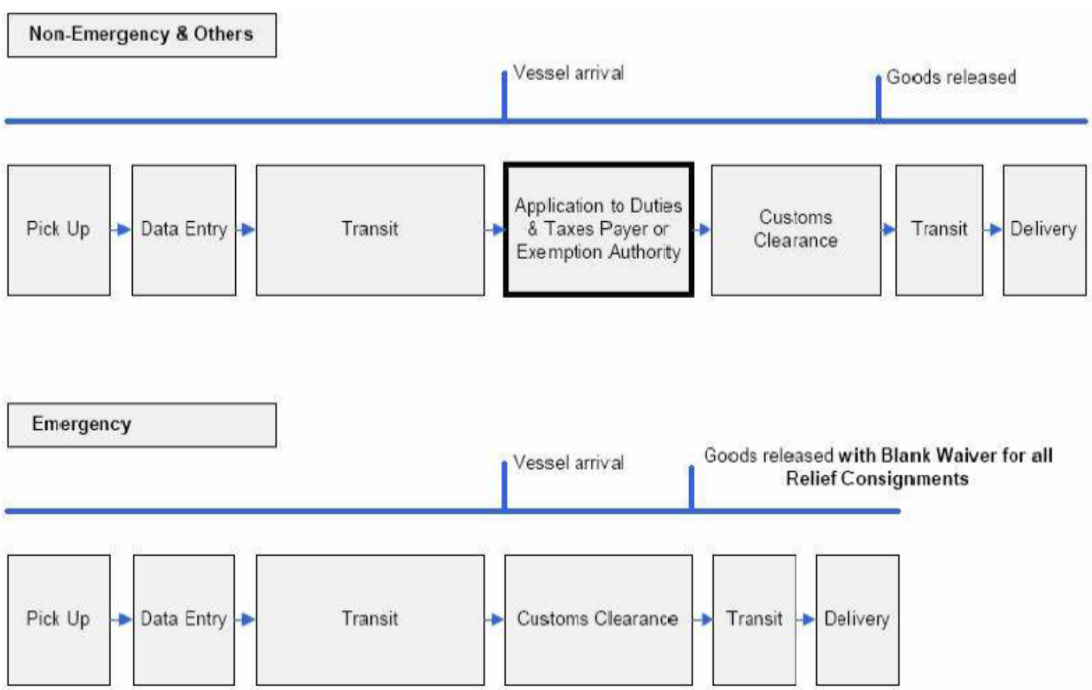


Figure 2.22. Impact of customs on HSC (UNJLC, 2008)

Storage: Commercial companies regard the location of storage mainly as a business decision and deal with asset security as an internal issue. Humanitarian organizations broaden the location search decision to consider the country's political stability and corruption level. Many time-dependent inventories, such as pre-positioned food and medicine, have expiration dates that must be monitored constantly. Items that can expire should be located in secure geographical areas. These areas would have minimum political corruptness, would prevent expired goods from entering the black market, and would assure proper disposal should it be necessary.

Distribution: Commercial companies estimate the costs and benefits of holding inventories. The theory is well developed and provides guidelines for determining the optimal inventory level or distribution schedule. Such a theory is not appropriate for disaster relief inventories for it incorporates many hard to quantify benefits such as saved lives, restored infrastructure, recovered livelihood opportunities, and other humanitarian outcomes. Furthermore, the warehouse activities of packing and preparing for shipment have different considerations in disaster relief circumstances. Packing a shipment for an aerial drop is much different than a truck delivery to another warehouse. Packaging must contemplate the final delivery means, any exposure to the elements, and the possibility of attempted theft. Shrinkage in hostile environments can also be substantially greater.

Control: Commercial companies have well-defined methods for determining inventory levels based on lead time, supply, demand, and target customer service levels. Relief inventory control is challenging for humanitarian organizations due to the high variation in lead times, supply, demands, and demand locations.

2.6.2.3. Supply Chain Model

The fundamental difference between CSC and HSC is that the former focuses on resource performance measures such as maximizing profit or minimizing costs, whereas the latter focuses on output performance measures, such as the time required to respond to a disaster or the ability to meet the needs of the affected population. In particular, when facing transportation and distribution problems in humanitarian logistics, criteria other than cost should guide the search for a solution. Because it is critical that the deliveries are fast, fair, and safe, it is not clear that the classic cost-minimizing facility, resource allocation, inventory management, or routing problems properly reflect the relevant priorities in disaster relief. A detailed discussion on how model formulation for a humanitarian chain is different than that of a commercial chain is presented below.

2.6.2.3.1 Objectives Being Pursued

The most important distinction between CSCs and HSCs is related to the different objectives that they pursue. According to Ballou (1992), the three prime objectives for a firm's logistics strategy are: (a) cost reduction, (b) capital reduction, and (c) service improvement. Based on this, the primary objective of a CSC is to provide high quality products at low cost to maximize profitability and achieve higher customer satisfaction. In contrast, HSCs are primarily concerned with minimizing loss of life and alleviating the suffering of the population impacted by an extreme event, where operational costs are typically a secondary concern (Holguin-Veras, Perez, Jaller, Destro, & Wachtendorf, 2010). In order to achieve this strategic goal, a humanitarian chain has to respond in approximately zero lead time. As lead time increases, the chance of deaths and suffering also increases. Hence, it is required to respond to the most urgent demands of the affected community within a very short period of time. Van Wassenhove (2006) points out, "the pressure of time in the relief chain is not a question of money but a difference between life and death." Establishing large inventories as preparedness toward disaster response might lead to timely and improved aid delivery. Although the strategy involves high costs, considering the stakes involved, the expenses may be considered necessary.

2.6.2.3.2 Model Formulation and Optimization

General distribution models for CSCs consider nature of supplies, cost of supplies, number of vehicles, modes of transportation, number of depots, demand for supplies, transportation networks, vehicle capacities, travel time of the route, and various operational modes. Some objectives of the distribution models are to find a combination of those variables that minimize operational costs through the use of objectives such as minimizing total travel time, minimizing the size of vehicle fleet, and maximizing service capacity. Although operational costs are also relevant in disaster response, they are of lesser importance for HSCs primarily concerned with expediting the delivery of critical supplies to the affected areas to minimize negative impacts on the victims. This is a crucial distinction, because in the aftermath of extreme events, humanitarian organizations are usually unable to satisfy all needs and have to decide how best to allocate their limited resources while pursuing efficiency and fairness as objectives. This fundamental difference between the objectives pursued by commercial and humanitarian logistics leads to significantly different mathematical formulations. HSCs cover a range of relief resource allocation models that incorporate egalitarian or utilitarian objectives such as: minimize unsatisfied demand, minimize latest arrival, minimize total response time, maximize travel reliability, minimize the loss of victims of calamity, and maximize satisfaction.

According to Holguin-Veras et al., (2010), most formulations for disaster response are still commercial and focus on minimizing operational costs only. This objective is appropriate for many commercial activities, but not for large-scale disasters where the system may be unable to meet all emerging needs, thus requiring responders to decide the optimal allocation for the limited resources available. A shortcoming of these methods aiming to minimize total unmet demands is only that they are ineffective in identifying the resource allocation providing the highest benefit to the whole system. These methods do not distinguish a particular request from another, and they are unable to account for the fact that the urgency with which supplies are needed may vary among affected areas. Although models introducing equity constraints, priority or weight factors to encourage deliveries to certain areas may provide more uniform levels of service, they require subjective consideration from the modeler regarding the definition of the equity constraints, prioritization, or weighting schemes. Therefore, the optimal distribution solutions are highly sensitive to the specific parameter values used during the optimization.

Holguin-Veras et al. (2010) added that in order for the analytical formulations of humanitarian logistics to provide a meaningful depiction of the system being modeled, they should specifically consider the costs associated with human suffering in the objective function while including important factors such as material convergence and proactive sourcing. Regrettably, many of the models in humanitarian logistics are still based on methods devised for commercial logistics with heavy focus on operational costs and little consideration of deprivation costs. There is a need to formulate a mathematical model for the design of an agile HSC that minimizes human suffering while considering material convergence, deprivation time, and the amount of unsatisfied demand.

2.6.2.3.3 Performance Measurement

Performance measurement for CSCs is based on standard supply chain metrics that focus on resource performance measures, such as reliability (fill rates, delivery performance, order fulfillment); responsiveness (lead time); flexibility (supply chain response times, production flexibility); cost (total cost, costs of goods sold, value-added productivity, warranty cost or returns processing cost); and assets (cash-to-cash cycle time, inventory turnover) (Beamon & Balcik, 2008).

Conversely, humanitarian organizations tend to measure performance in terms of financial and non-financial input metrics rather than output metrics (Kaplan, 2001); and (Henderson et al., 2002). Tomasini and Van Wassenhove (2009a) explain that humanitarian operations are not judged by their speed or costs, but rather by their impact. Identifying the proper performance measures is more difficult than when economic factors are used. Many relief operations are naturally ad-hoc and poorly structured, without effective performance measurement systems in place. Thomas & Fritz (2006) observe that the humanitarian sector measures itself in terms of how much food it has distributed or how much funding it has raised rather than how many lives it has saved or suffering it has alleviated. Since such input metrics do not necessarily imply higher levels of services or higher delivery capacity (Letts & Ryan, 1999), the sector requires a performance measurement framework that can measure how effectively and efficiently it meets its mission. The primary focus should be on output performance measures, such as the time required to respond to a disaster or percentage of demand that is met.

Unparalleled to the commercial sector, where the bottom line motivates the constant need to measure performance and invests in improving it, the humanitarian sector operates without the market forces of demand and supply regulated through price. In the commercial sector, performance is rewarded by the market (e.g., stock market, higher revenues, and profits) and internal incentive schemes such as bonuses, stock options and so on, which feeds a culture of continuous improvement. This is in direct contrast to the humanitarian sector where, until now, there has been little incentive to use the lessons learned from disasters to improve performance the next time around.

Finally, there is no way to punish ineffective organizations in an HSC because the beneficiary's voice in the performance appraisal and evaluation process is absent. Since the affected people are not directly involved in this process, their feedback in how the process could have been improved is non-existent. On the other hand, an ineffective member in a CSC will eventually be forced to pay for its behavior as its profits will suffer.

2.6.3. Cross Learning Possibilities

Despite the many fundamental differences between CSCs and HSCs highlighted previously, there is still considerable overlap. Thus, there are still many aspects that businesses can learn from studying humanitarian logistics and vice versa. Humanitarian organizations traditionally have not invested much in research on supply chain issues due to the perception of logistics as a necessary expense rather than an integrated function which necessitates high management attention. “The field of humanitarian logistics is relatively new with significant research only having begun to be undertaken within the last five years” (Maspero & Ittman, 2008). Recently, HSCM launched its own dedicated journal – the *Journal of Humanitarian Logistics and Supply Chain Management*. It can be argued that there are research growths in the field of HSCM currently, there is an increased level of awareness of the importance of HSCM, there are avenues for publishing findings, and the insights and lessons gained by studying HSCM can be applied at Walmart, Apple, Toyota, and Procter and Gamble.

2.6.3.1. Learning from Business

Disaster relief operations, with their ultimate stake of saving lives, frequently take place in highly unstable and volatile environments, under great time pressure, working in poor infrastructure, and generally exhausting working conditions. HSCs suffer from frequent breakdowns and interruptions in the material and information flow, which is in strong contrast to the extremely short lead times required. This gives rise to the possibility that HSC professionals can learn and benefit from the lessons learned from CSCM (Beamon, 2004). According to Van Wassenhove and Pedraza Martinez (2012), academics can adapt CSCM best practices to HSC in order to achieve improvements in key areas summarized as follows:

- Demand forecasting is possible from stochastic scenario analyses, but it needs to be flexible in dynamic situations and understanding of the local markets.
- Inventory prepositioning is not always possible due to budget constraints. As a substitute, vendor-managed inventory can ensure that supplies are available from suppliers.
- HSC could benefit from information integration and enable agencies to decide how to proceed depending on security, resources available, and prevailing needs . For example, the bullwhip effects for unsolicited donations can be mitigated or avoided by real-time sharing of demand and supply information.
- Unsolicited donations occupy very scarce warehouse space and create a push-based supply chain. Decentralization of the relief items into regional logistics units allows for a clear push–pull boundary from which the pre-positioned items can be pulled as needed by beneficiaries after the onset of a disaster.
- Implementing standardization and postponement would add value to the HSC. An example would be keeping standard aid kits in regional warehouses and distributing them to local hubs at the onset of a disaster with minor adjustments depending on the local needs and specific demands of the disaster.
- Logistics restructuring in HSC can help make better decisions to locate its offices and warehouses, improve supply chain efficiency, and achieve sustainability. Each office or warehouse will be closer to beneficiaries, have a different geographical scope, and designs its operations based on the specific needs of the area.
- Collaboration, resource sharing, and partnership can also be valuable to the HSC. This could be as simple as exchanging best practices, sharing training and resources, or setting a partnership structure with the private sector.

2.6.3.2. Learning from Humanitarian

Although supply chain researchers often assume that HSCs can benefit from the insights generated from research into CSCs, researchers focusing on CSCs can also benefit from research into HSCs (Christopher & Tatham, 2011). HSCs have much strength that businesses could use to improve their performance and competitive advantage. The opportunity for learning is greatest when the focus is on how supply chains are initially organized for a task, or when the goal is to understand how supply chains evolve and change over their lifespan. For example, HSCs are very agile, adaptable, and capable of setting up and changing quickly in disruptive conditions. Moreover, they are able to align the different needs and dynamic roles of many players. Businesses are notoriously poor at dealing with these types of small probability, big impact events. CSCs can learn about vulnerability assessment, emergency preparedness, and response to disasters (Van Wassenhove L. , 2006). This would enable them to deal with volatility of demand, imbalance between supply and demand, environmental uncertainties, and disruptions. This is exactly humanitarian organizations' core business and competence.

According to Charles (2010), this learning capability is becoming an order-winner for many CSCs. Furthermore, he identified in a tabular form (Table 2.8) which agility areas CSCs can benefit most from.

Table 2.8. Supply chain agility capabilities: Assessment for CSCM and HSCM (Charles 2010)

Flexibility	**Capabilities**	**Definitions**	**CSCM**	**HSCM**
Ability to change or react with little penalty in time, effort, cost or performance	Volume Flexibility	Ability to change the level of aggregated output	++	+++
	Delivery Flexibility	Ability to change planned or assumed delivery dates	+	+++
	Mix Flexibility	Ability to change the range of products made or delivered within a given time period	++	+++
	Product Flexibility	Ability to introduce novel products, or to modify existing ones	++	+
Responsiveness	Reactivity	Ability to evaluate and take needs into account quickly	+	+++
Ability to respond to change within an appropriate time frame	Velocity	Ability to cover needs quickly	+	+++
	Visibility	Ability to know the identity, location, and status of entities transiting the supply chain, captured in timely message about events, along with the planned and actual dates/times for these events	++	+
Effectiveness	Reliability (doing the right thing)	Ability to deliver the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct user	+++	++
Doing all the right things	Completeness (doing all)	Ability to realize the goals	++	++

2.7. Summary of Key Differences Between CSCM and HSCM

This comprehensive literature review has highlighted many distinctions between humanitarian and commercial supply chains. It developed a conceptual framework to help in visualizing these distinctions. These distinctions are also provided in the summary table in Appendix A-1. As researchers proceed in the humanitarian area, it is expected that this conceptual framework will be of assistance in focusing research efforts on individual areas critical to humanitarian supply chains, the interactions among these areas in a supply chain, and the potential benefits from sharing research ideas between humanitarian and commercial supply chains.

Having concluded the first part in the literature review, allocation of scarce resources will be reviewed next. It plays a central role in humanitarian supply chain management during the first few days after a disaster occurs, a time phase which is considered a critical time for the survivors.

2.8. Understanding Resource Allocation in Humanitarian Supply Chain

Relief resources play an important role in humanitarian supply chain management during the first few days after a disaster occurs, a time phase which is considered a critical time for the survivors. During this immediate response phase, numerous relief resources (e.g., medical resources, special rescue equipment, food, and so on) are needed to reduce the loss in affected areas. It is characterized by high demand of life-sustaining resources such as medicine, water, food, and shelter. The aggregated survivor or beneficiary needs generally exceed the available supply of goods. In connection, relief organizations responsible for managing such relief operations must allocate and deliver the limited lifesaving resources to several distribution locations somewhere nearby beneficiaries' gatherings to enable them to collect relief items with reduced response time, efforts, or difficulties. The shortages experienced at distribution sites have caused suffering to their designated beneficiaries because their needs are unsatisfied, partially met, or delayed to be fully met. Hence, it is essential that humanitarian organizations develop fair allocation guidelines and establish an equitable and efficacy relief resource distribution system that alleviates the suffering of beneficiaries within and among the affected areas.

A critical and challenging component of relief distribution is the rationality behind the allocation of lifesaving resources to distribution centers and, consequently, which beneficiaries to aid. This is referred to as the emergency resource allocation problem. Such allocation decisions can be reached by using standard operational procedures, ethical, philosophical, or mathematical modeling, or some combination of these methods. Obviously, when the supply is large enough, the allocation problem is trivial, whereby all beneficiaries' needs are fully met regardless of the perspective adopted. Whereas, when demand exceeds supply, the allocation problem would be complex and the solution could take a multi-faceted perspective.

The published humanitarian guidelines and standards do not provide standard procedures for allocation. For example, the emergency management plans of the Federal Emergency Management Agency (FEMA), South Carolina State (2007), and Florida State (2006) describe quantities of goods to be distributed. However, they do not address how to allocate goods when these quantities cannot be met. The Sphere Handbook (2011) provides detailed minimum humanitarian standards to be met in relief, such as ensuring each person has 2,100 daily calories of food. The Sphere Handbook also states that humanitarian agencies should provide aid impartially and according to need, but makes no mention of specific procedures when sufficient calories cannot be provided to all people in need.

Activities of all humanitarian organizations are guided by some ethical principles, namely, the four humanitarian principles: humanity, neutrality, impartiality, and independence (Sphere Project, 2011). Such principles are supposed to ensure fair procedures that generate unbiased, consistent, and reliable decisions. When these principles are applied ineffectively or not at all, confidence in humanitarian organizations may be undermined. Individuals or victims may feel alienated and withdraw their commitment to those organizations. The impartiality principle has practical operational relevance in distributing limited relief resources to beneficiaries. To ensure a fair procedure, allocation of resources must be carried out on the basis of need alone, giving priority to the most urgent cases of distress and making no distinction on the basis of nationality, race, gender, religious belief, class, or political opinions. Governed by this principle, humanitarian organizations have an ethical responsibility to distribute limited relief resources in an equitable manner. It strives for an equal outcome in which each victim's welfare is increased to the greatest extent possible, given limited resources, after taking proper account of disparate needs and individual circumstances. A number of ethical questions arise when the basis of distribution takes the form of equity and is need-based. What do we mean by equity? How is equity different from fairness? What values should guide distribution choices if it will benefit some beneficiaries and not others? Is the current distribution of resources fair and equitable? How will we know if we have reached an equitable state? Is the current distribution of resources an efficient and wise use of funding? How has equity been handled in similar allocation situations not related to relief operations?

It may seem to be a simple matter of common sense that equitable resource allocation or distribution is central to any well-functioning relief operations. However, the question of how it is achieved is a more difficult matter. Literature contains well-studied philosophies that serve as guidelines to achieve an equitable allocation. Some of the well-known philosophies are bankruptcy, utilitarian, and egalitarian theory. Bankruptcy philosophy focuses on carrying out set rules in a fair manner so that a just outcome might be reached. Choosing which rule is most appropriate is challenging as this depends on how the decision makers understand the particular circumstances of each allocation situation. Utilitarian moral philosophy holds that the proper course of action is the one that produces the greatest balance of benefits over harms for everyone affected. Researchers have challenged the utilitarian approach as it fails in certain instances to take into account considerations of justice even though it produces great welfare benefit for society. If critical supplies are provided only to people with the highest probability of surviving and denied to those with a somewhat less, but still significant chance of survival, then we may save more lives but we do so by asking some individuals to give up all chance of survival. Some argue that this approach is not fair to those who give up their chance of survival, even though more total lives are saved. Egalitarianism is a philosophical thought that emphasizes equality and equal treatment across all people. Researchers have criticized the egalitarian approach as it proposes that individuals have natural rights to be met. In such instances, a vast amount of critical supplies will be expended on many victims who will not survive. Such controversies between utilitarian and egalitarian theory on how to value a human life have led researchers to take different approaches while solving the allocation problem.

Previous research papers in humanitarian logistics cover a range of relief resource allocation models to obtain satisfactory solutions using objectives such as minimizing unsatisfied demand or minimizing the number of fatalities. Also, integrating resource allocation problems with vehicle routing problems have been extensively investigated by different researchers and practitioners. The significant shortages of many essential goods, in addition to operational limitations such as the available number of vehicles and the time window required for delivery to each affected area, makes the allocation problem more difficult to model. However, solving these two problems jointly can ensure the design of a logistics network capable of rapid distribution of relief resources in response to a large-scale emergency.

The following sub-chapters provide a detailed description of how limited emergency resources due to differing philosophies, ethical standpoints, or operational limitations are being equitably allocated. Even though equity means that each beneficiary receives a fair share of relief resources, a major inference of this study is that there can be no universal answer to equity; each resource allocation situation has its own peculiarities, which must be considered.

2.9. A Bankruptcy-Based Framework for Resource Allocation

A classical question is asked in the implementation process of many relief operations efforts: what is a fair way of dividing available supplies across distribution sites and among their beneficiaries? Answering this question is challenging, especially in the immediate response phase when the satisfaction utility function that depends on the level of resources assigned to distribution sites (and eventually to beneficiaries) is not known or readily quantifiable.

In economics, this question can be answered through a set of non-cooperative game theory solutions, namely the bankruptcy rules (Madani & Zarezadeh, 2012). These rules have been studied by O´Neill (1982), Aumann and Maschler (1985), Thomson (2003), and Moulin (2002).They are used to determine the fair shares of the creditors when the available estate is not enough to fully satisfy all creditors' claims and creditors' utilities are ignored. Similarly, we can assume that relief resource systems that cannot fully satisfy the demands of their beneficiaries are experiencing bankruptcy and thus a fair relief allocation scheme can be developed based on bankruptcy rules.

Ten classical bankruptcy rules will be reviewed to indicate their structural properties and to show different ways of applying some ethical principles in a disaster setting. These properties are intended to ensure that the solution has some desirable features or prevents some inconveniences depending on the type of situation considered. Mathematical descriptions of these rules are provided next and followed by their axiomatic properties in a disaster management situation.

2.9.1. Bankruptcy Rules

A bankruptcy situation considers a set of claimants **N** = {1, 2, . . . , n} that each have a claim on an insufficient but divisible estate **E**. Let c_i be claimant ***i***'s claim and assume that the claims are ordered so that $0 \leq c_1 \leq c_2 \leq \cdot \cdot \leq c_i \leq \cdot \cdot \leq c_n$. The total claim $c_1 + c_2 + \cdot \cdot \cdot + c_n$ is denoted by C with C > E. The bankruptcy problem then is how to divide the estate among the claimants; i.e., award x_i to claimant ***i***, taking into account their claims. Solving this problem means finding a procedure or rule that exhibits some desirable properties (or to prevent some inconveniences) and determines a well-defined allocation satisfying two basic restrictions: the exact worth of the estate is always distributed such that all claimants earn a nonnegative part of the estate and no claimant gets more than his claim. Ten known rules are briefly reviewed next along with their distinctive properties.

2.9.1.1. Proportional (P) rule

The best-known rule is the proportional rule. It is based on an ancient rule where each claimant's demand is partially met in proportion to claim size. $x_i = \frac{E}{C} . c_i \quad \forall i \in N$.

Proportionality is often taken as a definition of fairness for allocation problems. This rule distributes the estate proportionally to claims without having any background information on claimants' conditions or priority level. Hence it equalizes the ratios between needs and availability.

2.9.1.2. Adjusted Proportional (AP) rule

AP is a version of the proportional rule developed by Curiel et al. (1988). This rule first requires calculating for each claimant an amount that can be interpreted as his "minimal right" $m_i = max\{0, E - \sum_{j \neq i \in N} c_j\}$. This is the amount that remains if every other agent receives his claim or zero if the amount that remains is negative. Each claimant receives his minimal right and the remaining is divided proportionally among all of them.

2.9.1.3. Constrained Equal Awards (CEA) rule

CEA assigns equal amounts λ to all claimants subject to no one receiving more than his claim (Maimonides 12th Century, among others). Based on this rule, claimants only differ in their claims and equating awards implies ignoring these differences. Those claims that are relatively small are to be easily compensated and fully honored. As a consequence, claimants with smaller claims obtain a relatively higher satisfaction of their demands. The mathematical representation of this rule is as follows:

$$CEA_i(c_i, E):\ x_i = Min\{\lambda, c_i\} \qquad \forall i \quad if\ C > E \qquad \text{(Eq. 2.1)}$$

2.9.1.4. Constrained Equal Losses (CEL) rule

An alternative to the CEA rule is obtained by focusing on the losses claimants incur (what they do not receive), as opposed to what they receive. CEL equates the losses experienced by all claimants subject to the condition that no one ends up with a negative award (Aumann & Maschler, 1985). Hence it equalizes the rationing experienced by the claimants, as long as this is feasible. The mathematical representation of this rule is as follows:

$$CEL_i(c_i, E):\ x_i = Max\{0, c_i - \lambda\} \qquad \forall i \quad if\ C > E \qquad \text{(Eq. 2.2)}$$

2.9.1.5. Talmud (Tal) rule

The Talmud rule was proposed by Aumann and Maschler (1985) in order to rationalize examples found in the Babylonian Talmud. The rationale of the Talmud rule is based on the Talmudic principle of "more than half is like the whole, whereas less than a half is like nothing." To implement this rule, half of the sum of all claims is determined. If this half-sum is less than the estate, the CEA formula is applied; if the half-sum is more than or equal to the estate, the CEL formula is applied. In each case, the half-claims are used in the formula instead of the claims themselves. The mathematical representation of this rule is as follows:

$$Tal_i(c_i, E):\ x_i = \begin{cases} CEA\left\{\frac{1}{2}c_i\,, E\right\} & \forall i \quad if\ E \leq \frac{1}{2}C \\ \frac{1}{2}c_i + CEL\left\{\frac{1}{2}c_i\,, E - \frac{1}{2}C\right\} & \forall i \quad if\ E > \frac{1}{2}C \end{cases} \qquad \text{(Eq. 2.3)}$$

Kaminski (2000) uses a system of vessels, a water reservoir, and the principles of hydraulics to represent the CEA, CEL, and Talmud bankruptcy problem. The vessel and water correspond to the claimants and the estate, respectively (Fleiner & Sziklai, 2011). Suppose one pours a volume E of liquid, $0 < E < c_1 + c_2 + \ldots + c_n$, into this glassware. Because of the connecting tube at the bottom, the liquid will rise to the same height in all glasses. Figure 2.23 demonstrates how this system works and how much a claimant is entitled to for the CEA, CEL, and Talmud rules.

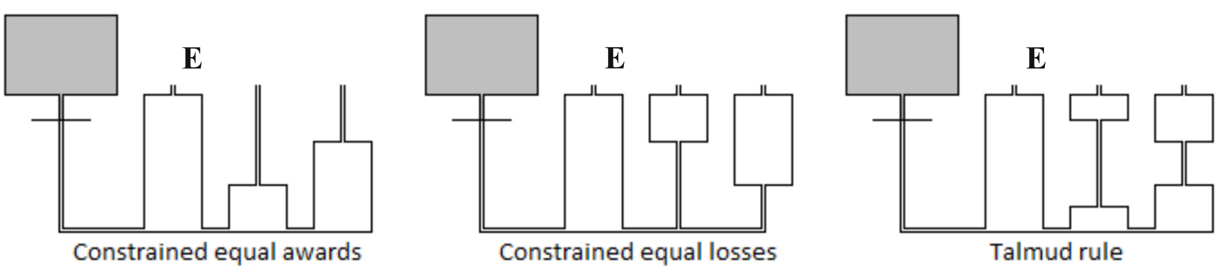


Figure 2.23. The hydraulic representation of CEA, CEL, and Talmud rules (Fleiner & Sziklai, 2011)

2.9.1.6. Reverse Talmud (RTal) rule

This rule first assigns to each claimant half of his claim and then distributes the remaining loss or surplus according to the CEL rule with half of the claims (Brink, Funaki, & Laan, 2008). It can be seen as some kind of counterpart of the Talmud rule when we distribute the remaining loss or surplus by applying the CEL rule instead of the CEA rule. The mathematical representation of this rule is as follows:

$$RTal_i(c_i, E):\ \ x_i = \begin{cases} CEL\left\{\frac{1}{2}c_i\,, E\right\} & \forall i \quad if\ E \leq \frac{1}{2}C \\ \frac{1}{2}c_i + CEL\left\{\frac{1}{2}c_i\,, E - \frac{1}{2}C\right\} & \forall i \quad if\ E > \frac{1}{2}C \end{cases} \qquad \text{(Eq. 2.4)}$$

2.9.1.7. Piniles (Pin) rule

This rule (Piniles, 1861) uses the CEA rule as the basis for allocation when the estate is more than the half of the sum of claims as opposed to the CEL rule that is used for this situation under the Talmud rule. The mathematical representation of this rule is as follows:

$$Pin_i(c_i, E):\ \ x_i = \begin{cases} CEA\left\{\frac{1}{2}c_i\,, E\right\} & \forall i \quad if\ E \leq \frac{1}{2}C \\ \frac{1}{2}c_i + CEA\left\{\frac{1}{2}c_i\,, E - \frac{1}{2}C\right\} & \forall i \quad if\ E > \frac{1}{2}C \end{cases} \qquad \text{(Eq. 2.5)}$$

2.9.1.8. Constrained Egalitarian (CE) rule

This rule is another way of implementing the idea of equality (Chun, Schummer, & Thomson, 2001). The formula is inspired by a solution to the problem of fair division when preferences are single-peaked, known as the uniform rule (Sprumont, 1991). As in Piniles, it gives the half-claims a central role, and otherwise, it makes the minimal adjustment in the formula for the uniform rule that guarantees that awards are ordered as claims are. The mathematical representation of this rule is given by:

$$CE_i(c_i, E):\ \ x_i = \begin{cases} CEA\left\{\frac{1}{2}c_i\,, E\right\} & \forall i \quad if\ E \leq \frac{1}{2}C \\ Max\left\{\frac{1}{2}c_i, CEA\{c_i\,, E\}\right\} & \forall i \quad if\ E > \frac{1}{2}C \end{cases} \qquad \text{(Eq. 2.6)}$$

2.9.1.9. *Random Arrival (RA) rule*

To define this rule, imagine claimants arriving one at a time and compensating them fully until resources run out. The resulting awards allocated depend on the order in which claimants arrive. To remove the unfairness associated with a particular order, take the arithmetic average over all orders of arrival of the award vectors calculated in this way (O'Neill, 1982). Let Ƥ collect the n! different orderings in the set N. For each ordering π in Ƥ and for each individual ***i*** in N, the set π[i] collects the predecessors of ***i*** with respect to the ordering π. The mathematical representation of this rule is as follows:

$$RA_i(c_i, E):\ \ x_i = \frac{1}{n!}\sum_{\pi\epsilon\mathcal{P}} min\{c_i, max(0,\ E - \sum_{j\epsilon\pi[\mathrm{i}]} c_j)\} \qquad \text{(Eq. 2.7)}$$

2.9.1.10. *Minimal Overlap (MO) rule*

Instead of thinking of claims abstractly, imagine that the amount to divide is composed of individual and distinct "units," and that each claim is on specific units. Then awards are chosen to minimize extent of conflict over each unit available. Chun and Thomson (2005) propose the following procedure to compute the minimal overlap value:

Add a dummy claimant, denoted by 0, to the set of claimants and let $C_0 = MO_0 = 0$ and look for the largest k^* in {0,1,2,…,n-2} for which there exists a $t \geq 0$ that satisfies:

$$c_{k^*} < t < c_{k^*+1}\ and\ (c_{k^*+1} - t) + (c_{k^*+2} - t) + \cdots + (c_n - t) = E - t.$$

$$If\ c_{k^*} < E < c_{k^*+1} \leq c_n\ with\ k^* in\ \{0,1,2, \ldots, n-1\}, then$$

$$MO_i = \frac{c_1}{n} + \frac{c_2 - c_1}{n-1} + \frac{c_3 - c_2}{n-2} + \cdots + + \frac{c_i - c_{i-1}}{n-i+1}\ for\ each\ i = 1,2, \ldots, k^* \qquad \text{(Eq. 2.8)}$$

$$MO_j = MO_{k^*} + \frac{E - c_{k^*}}{n-k^*} for\ each\ i = k^* + 1, k^* + 2, \ldots . n \qquad \text{(Eq. 2.9)}$$

$$If\ \ c_{k^*} < t < c_{k^*+1} \leq c_n < E\ with\ k^* in\ \{0,1,2, \ldots, n-2\}, then$$

$$MO_i = \frac{c_1}{n} + \frac{c_2 - c_1}{n-1} + \frac{c_3 - c_2}{n-2} + \cdots + + \frac{c_i - c_{i-1}}{n-i+1}\ \ for\ each\ i = 1,2, \ldots, k^* \qquad \text{(Eq. 2.10)}$$

$$MO_j = (c_j - t) + MO_{k^*} + \frac{t - c_{k^*}}{n - k^*} \quad for\ each\ j = k^* + 1, k^* + 2, \dots . n \qquad \text{(Eq. 2.11)}$$

2.9.2. Bankruptcy Applied to Resource Allocation Problem

The resource allocation problem is a bankruptcy problem that involves an amount of a single relief item to be allocated among distribution sites (DS) as quickly as possible to support the rescue operation and help wounded individuals. A relief item is a life supporting item that usually takes the form of a standard package or kit, such as MedKit, food package, bedding set, hygiene kit, kitchen kit, etc. The available packages at a central warehouse are insufficient to satisfy all beneficiaries' demands. This supply shortage can render emergency responses ineffective and result in increased suffering to beneficiaries. Hence, it is important to develop strategies to rationalize supply responses and apply rules that give a sensible distribution of the aid packages as a function of distribution sites' demands.

We aim at modeling the situation faced by a decision maker who has control over aid packages available at a central warehouse to be allocated among distribution sites. Each site serves a group of beneficiaries without any bargaining power when the available amount is not enough to satisfy all the admissible demands. The inputs of this allocation problem are the number of aid packages, the number of distribution sites, and their demands. Based on which bankruptcy rule is applied, the output would be the number of packages allocated to each distribution site. The decision maker has to apply some ethical and procedural criteria that may depend on the nature of the problem under consideration in order to solve the problem.

2.9.3. Linking Bankruptcy Axiomatic Properties with Resource Allocation Principles

A particular bankruptcy rule can be characterized by different sets of independent axioms. Each property provides an insight into the type of problems for which a rule is satisfactory. We will briefly introduce some of these structural properties that are further examined in a disaster context.

Consistency: A rule is consistent if applied to any of its reduced problems it gives the incumbent claimants the same amounts they obtained in the original problem. The lack of consistency implies that the resolution of the problem proposed by the rule may be altered by renegotiations within the population subgroups.

Order Preservation: Order preservation of awards says that for each problem, awards should be ordered as claims are. The larger claimant's rewards should be more than the corresponding lower claimant's rewards. Similarly, losses should be ordered as claims are in order preservation of losses (Aumann & Maschler, 1985).

Equal Treatment of Equals (Symmetry): Two claimants with the same claim have to obtain the same share of the estate (O'Neill, 1982).

Solidarity (Monotonicity): If a claimant's claim increases, ceteris paribus, he should receive at least as much as he did initially. Similarly, if there is more to be divided, ceteris paribus, nobody should lose. Neither a larger claim nor larger amount to divide should harm the claimant.

Scale Invariant (Homogeneity): Scale invariance rules out the influence of the units in which the estate and the claims are measured.

Similar to bankruptcy, resource allocation axiomatic properties can also be viewed as a checklist of potentially desirable criteria from which to choose when settling on a particular allocation mechanism. Properties that bind together philosophies of fairness and the methods that implement fairness. Honglei et al. (2011b) have reviewed those properties that are deemed most relevant to humanitarianism.

Pareto Optimality: The premier, and probably most widely accepted equity principle of allocation, is Pareto optimality, which can be linked to the consistency and order preservation properties. An allocation of resources over a set of beneficiaries is Pareto optimal if the only way to increase a beneficiary's welfare is to decrease the welfare of another beneficiary. Striving toward a Pareto optimal state is recommended on practical grounds. It seems reasonable to make one affected victim better off whenever possible, provided it is not at the expense of anyone else.

Proportionality: A more intuitive equity principle is related to the proportionality rule where (divisible) supplies should be distributed in proportion to the contribution (or demand) of each of the distribution centers. For instance, if a demanded quantity of 10,000 packages is needed in one affected area and 30,000 packages in another, but there is only 24,000 packages in the central warehouse, then the first affected area should receive ¼ of the relief supplies, or 6,000 packages, while the other relatively should receive ¾ of the relief supplies, or 18,000 packages.

Consistency: Given any subset of beneficiaries, the collective resources allocated to them are allocated as if they were the only beneficiaries and those were the only resources. A theory of equity that is not consistent would have to be enforced by humanitarian organizations that prohibit beneficiaries from collaborating on resources to improve their share.

Priority: The priority principle requires that allocations are made based on a predetermined ranking of the affected areas. Entirely destroyed areas will receive resources up to their demand amount; then the minor affected areas receive resources (if available) up to their demand amount, until all resources are exhausted.

The priority principle can be also applied to rank beneficiaries – for example, displaced beneficiaries have priority over beneficiaries who remained in their homes. This has the desirable feature that it avoids any need to assess how much more deserving one beneficiary is than another. The priority principle is especially well-suited to humanitarian-related allocations because it is quite common for the availability of resources (capacity) to be unknown or to vary over time. For instance, in a relief operation, the total number of arrival supplies available for allocation is recomputed periodically. Even though the assigned arrival relief supplies and delays of supplies may change with capacity, the ordering of the supplies remains the same. Indeed, the consistency principle and the priority principle are intimately related. When the resources are indivisible (e.g., arrival packages), every consistent allocation mechanism corresponds to a priority ranking of the beneficiary, even though it may be difficult to identify the characteristics that entitle the beneficiaries to their rankings. Moreover, every priority ranking is consistent.

Impartiality: The impartiality principle requires that allocations are made based on the availability of resources and the nature of demands, rather than the identities of the beneficiaries. Phrased another way, any two beneficiaries with identical demands to resources should be treated in an identical manner and avoid associations with characteristics that could lead to discrimination, such as nationality, race, religious beliefs, class, or political opinions; i.e., equal treatment of equals. This is a common sense notion of fairness that most would agree, whether in a bankruptcy situation or in an allocation problem, that needs to be verified. A violation of impartiality would be if arrival supplies were awarded based on distance or by the closest facility location. The closest distribution center would always receive better treatment than the farthest one.

Transparent Inequity: An allocation is transparently inequitable if one beneficiary receives more of all resources than another beneficiary with identical demands. Transparent inequity requires that the inequity be obvious to an outside observer with no knowledge of the beneficiaries' individual conditions. Suppose beneficiaries A and B have equal demands to relief resources, and that A suffers five days of supply distribution delays but no quantity reduction, while B suffers a 20% reduction in daily quantities but no distribution delays. The result may be inequitable, but it is not transparently so, because it is not obvious how the logisticians value reduced quantities distributed relative to delays. Indeed, the result may be perfectly equitable if A prefers five days of delay to a 20% quantity reduction while B's preferences are the opposite. Transparent inequity would occur if A suffered one day of delay and a 20% daily quantity reduction, while B suffered two days of delay and a 20% daily quantity reduction.

Unbiased: An allocation is unbiased if each beneficiary's average allotment would be close to its average entitlement if the allocation occurred over and over again (e.g., a similar situation on multiple days). A difficulty in dividing a finite number of indivisible resources among beneficiaries is that someone will always get a little more or a little less than they deserve due to rounding errors. This is particularly an issue if, over many resource allocations, there is some bias toward or against a particular beneficiary or, more importantly, a cluster of beneficiaries. For example, if over several allocations of arrival supplies it is observed that a particular beneficiary always receives slightly more than another beneficiary (based on some predetermined entitlement criteria), then that allocation method is biased. In order to avoid such a bias, we would have to branch on the potential nature of the resources, e.g., divisible versus indivisible goods, or multiple goods.

Monotonic: Each beneficiary's allotment becomes no worse when the amount of resources and/or his claim increases, ceteris paribus. This concept matched the solidarity property that was mentioned previously while discussing bankruptcy properties. Arrival of more relief supplies to depots will trigger additional deliveries to affected areas in order to satisfy beneficiaries' needs that weren't able to be met previously.

Scale Invariance: Scale invariance means that multiplying every beneficiary's relief resource allocation amount by a constant leaves the degree of inequity unchanged. A change of unit in which a relief resource is measured does not constitute any real change in the allocation of relief resources. For example, inequity of relief resource should not depend on whether it is measured in kilograms or tons. So, it is appropriate for resource allocation to be scale invariant.

Humanitarian operations support pursue the following equity principles: Pareto optimality, consistency, impartiality, monotonicity, scale invariance, and avoiding transparent inequity. Despite that, not all of the mentioned principles may be obtainable and might depend on the operational environment and one's value system. Still, these presented relief allocations principles provide the most flexible, efficient, and defensible solutions to equitable resource allocation. Furthermore, these schemes do not require detailed knowledge of beneficiaries' utilities for resources, which is generally not feasible to obtain during disaster circumstances.

2.9.4. Applying Bankruptcy Concepts to General Resource Allocation Problem

There is not an immense academic research work found in literature that links the bankruptcy concept to resource allocation. An exception is the proportionality rule, which is widely applied in numerous situations and disciplines. Relating this rule to a real emergency situation for example, when a commodity is available in limited quantities, the United States Department of Agriculture (USDA) will allocate the commodities provided to each state based on 60% of the number of persons in households within the state having incomes below the federal poverty level (based on the most current census data) and 40% of the number of unemployed persons within the state. This is also referred to as the 60/40 formula (California Department of Social Services, 2010).

Zarezadeh et al. (2012) show the applicability of the Adjusted Proportional (AP) rule in resolving water allocation conflict and reducing tension in eight Iranian provinces under various climate and development changes in the Qezelozan-Sefidrood watershed. Madani et al. (2012) discuss the different bankruptcy rules that minimize tensions between the beneficiaries of water resource systems. They use the plurality rule for evaluating the acceptability of different allocation schemes and determining the best option.

Kim et al. (2012) present a load-shedding scheme using the Talmud rule in islanded micro-grid operations based on a multi-agent system. Load shedding is an intentional load reduction to meet a power balance between supply and demand when supply shortages occur. A multi-agent system for islanded micro-grid operation is constructed. The proposed load-shedding scheme is tested on sample islanded micro-grids based on the multi-agent system to show feasibility, after which the test results are discussed. The proposed load-shedding scheme provides a unique solution regardless of the number of load agents because it is based on the Talmud rule.

Kim and Kinoshita (2011) compared the features of load-shedding schemes according to five bankruptcy rules from the viewpoints of the load-shedding pattern, micro-grid operation, fairness, and processing time. The proportional rule, the CEA rule, the CEL rule, and the Talmud rule can be recommended as acceptable applications, although their scores varied among operation, fairness, and processing time.. They concluded that the CEA has merit in operational convenience, the CEL and CEA have merit in fairness of load-shedding, and the RA rule is not suitable for load-scheduling application.

2.10. Philosophical Framework for Resource Allocation

As previously discussed, if faced with resource limitations, humanitarian organizations will be forced to decide how best to allocate potentially life-saving resources in order to reduce fatalities and alleviate the suffering of survivors. Among the perspectives to be adopted, the decision maker could be partially or totally guided by key philosophical principles while solving the resource allocation problem. Three main philosophies related to equitable allocation will be discussed in this sub-chapter.

2.10.1. Philosophical Approaches to Equitable Allocation

The economics and mathematics literature contains well-studied philosophies, principles, and methods for allocating goods. Some of the well-known philosophies related to distributing scarce resources are: 1) Principle of equal chances; 2) Utilitarian; 3) Egalitarian; and 4) Hybrid between utilitarian and egalitarian. These philosophies will be reviewed below while the focus would be related to the disaster context.

2.10.1.1. Principle of equal chances: First come, first served

The basic premise of the first-come, first-served approach is that all inbound beneficiaries to a distribution center deserve to be treated equally (Taurek, 1977). The easiest way to give everyone an equal chance is to use a random generating process, such as a lottery. The primary strengths of this approach are that it is easy to apply and that, at first glance, it seems fair. However, closer examination reveals several fatal weaknesses. It has been well documented that the first beneficiaries to go to distribution centers in a disaster are the healthiest and minimally injured who can extricate and transport themselves. Giving priority to this group would rapidly consume resources before the neediest beneficiaries ever arrive. Moreover, although vulnerable populations are more likely to be affected by a mass casualty incident, the people who are wealthiest are often the best able to save themselves and seek help first.

2.10.1.2. Utilitarian: The greatest good for the greatest number

Historically, allocation decisions in emergency relief operations have been driven by the utilitarian goal of maximizing net benefits. A conceptualization of maximizing net benefits is to consider maximizing the number of lives saved. The utilitarian rule of maximizing the number of lives saved is widely accepted during emergency response efforts (Childress, 2003). Some non-consequentialist views also favor maximizing the number of lives saved, not because this approach produces the most good but because each life has an equal claim on being saved (Barrett, 2009). Prioritizing individuals according to their chances for short-term survival also avoids ethically irrelevant considerations, such as race or socioeconomic status.

Some researchers have challenged the utilitarian theory and have suggested that fairness considerations be more explicitly included in policy decisions, even if doing so does not maximize the number of lives saved (Kamm, 1993). Conflict between providing fair chances and maximizing best outcomes arises when there are relatively small differences in expected benefits that may be gained by people in different prioritization groups. In the case of access to critical commodities, if critical supplies are provided only to people with the highest probability of surviving and denied to those with a somewhat less, but still significant chance of survival, then we may save more lives but we do so by asking some individuals to give up all chance of survival. Some argue that this approach is not fair to those who give up their chance of survival, even though more total lives are saved.

2.10.1.3. Egalitarian: Those most in need should receive

Under an egalitarian approach, the available critical resources would be directed to the most needy beneficiaries. This approach, which is similar to how humanitarian organizations operate daily, is morally comforting for many healthcare workers because it seems to minimize internal conflict by eliminating the need to make difficult decisions. It also fulfills the need to "do something" that many people feel when faced with someone who is suffering, especially in an emergency. However, the primary limitation of egalitarianism is that it will lead to a vast amount of resources being expended on many victims who will not survive. Also, discomfort raised with this approach includes: lack of clarity and transparency about what criteria are being used in an emergency setting (Daniels & Sabin, 1997).

2.10.1.4. Hybrid: Satisfy greatest number of people in greatest need

Instead of allocating resources where they will be the most effective in order to do the most good for the greatest number of people, or directing the resources to those in greatest need, researchers have proposed that these two principles can be combined into a composite priority score (White, Katz, Luce, & Lo, 2009). Such a hybrid allocation can be applied whereby resources will be directed to satisfy the greatest number of people in greatest need. Although such an allocation principle may be more complex to implement in a timely and practical manner than a single principle allocation system, it may better reflect the diverse moral considerations relevant to these difficult decisions. It is appealing because it balances utilitarian claims for efficiency with egalitarian claims that, because all lives have equal value, the goal should be to save the most lives. In addition, this multiple approach takes into account the degree of scarcity—victims with lower priorities can receive relief items until no more supplies remain. However, a multi-principle allocation approach that relies on a composite priority score raises difficult questions regarding what principles should be represented in the composite score and how to weight the various components that contribute to the score. People may legitimately disagree about the weights applied in an emergency setting.

2.10.2. Building Utilitarian and Egalitarian Resource Allocation Models

Previous research papers in disaster relief and humanitarian logistics cover a range of relief resource allocation models. These models incorporate utilitarian, or egalitarian components, or a combination of both.

In utilitarianism modeling, resources are distributed so as to maximize the total efficiency, independent of the welfare of individuals, and the utilitarian would award rations to those humanitarian aid distribution centers that could most improve their overall operations efficiency, even if it means imposing massive delays on general humanitarian efforts. Some widely adopted objectives are:

- **Minimize cost:** The objective minimizes total costs, which may include vehicular fixed and flow costs; pre-positioning, holding, and backlog inventory costs; establishment and operational depot costs; or combinations.
- **Minimize unsatisfied demand:** The objective minimizes the unsatisfied demand of beneficiaries. This may be minimizing the sum of unsatisfied demands over time, or minimizing the penalty from satisfying the delayed demand.
- **Minimize total response time:** The objective minimizes the total arrival time to all beneficiaries served by same vehicle.
- **Maximize travel reliability:** The objective maximizes the reliability of vehicles, such as the probability of vehicles arriving to their intended destinations.

Models that are utilitarian in delivery quantity are found in a number of papers. Ozdamar et al. (2004), Doerner et al. (2007), Yi and Kumar (2007), Yi and Ozdamar (2007), Shen et al. (2009) minimize total unsatisfied demand without considering equality of delivery. Similarly, Honglei and Nan (2011a), Clark and Culkin (2007), and De Angelis et al. (2007) minimize total unsatisfied demand but include equity constraints that all beneficiaries receive a minimum amount of goods. This may not lead to equitable solutions but can be used to enforce minimum standards such as those in the Sphere Handbook (2011). Sheu et al. (2005) try to optimize the large scale relief distribution problem with a goal of minimizing the number of fatalities. Using fuzzy-optimization techniques, their model classifies the damaged areas based on relief demand and priority and then optimizes the situation where the demand from victims is greater than the available resources.

In egalitarianism modeling, speed is the goal and resources are distributed so as to maximize the welfare of the worst-off, and the egalitarian would favor giving aids first to those beneficiaries that are the farthest behind the distribution schedule. Equality is frequently quantified with a *min-max* objective, a *min-sum* objective, or with inequality measures to be minimized.

Zhu (2012) proposed two measures of equity metrics and show how they are used while modeling resource allocation problems. They are *min-max* and sum of weighted unmet demand with equity constraint. The first model incorporates an equity measure in the objective function which aims to minimize the maximum unmet demand rate among all distribution sites in order to create fairness among all distribution sites. The model was optimally solved after being transformed to a linear programming model. An LP-rounding algorithm is proposed to find the solution in $O(n^2)$ time.

The second model modifies the objective of the first model to minimize the weighted sum of unmet demand for relief resources and imposes an upper bound on the unmet demand rate as one of the model constraints.

Honglei and Nan (2011a) identified eight inequity measures frequently incorporated in relief resource allocation models. Six of them are defined as follows:

Assume there are a total of *n* beneficiaries to be served by a humanitarian aid distribution center and the relief resource allocation to beneficiary ***i*** is X_i then $X_{max} = max_i(X_i)$, $X_{min} = min_i(X_i)$, and $\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$.

- Range R, defined as: $R = X_{max} - X_{min}$ (Eq. 2.12)

- Standard Deviation S, defined as: $S = \sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n}}$ (Eq. 2.13)

- Coefficient of Variation CV, defined as: $CV = \frac{\sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n}}}{\bar{X}}$ (Eq. 2.14)

- The Gini coefficient G, defined as: $G = \frac{1}{2n^2\bar{X}}\sum_{l=1}^{n}\sum_{i=1}^{n}|X_l - X_i|$ (Eq. 2.15)

- The Theil's entropy measure T, defined as: $T = \frac{1}{n}\sum_{i=1}^{n}\frac{X_i}{\bar{X}}log\left(\frac{X_i}{\bar{X}}\right)$ (Eq. 2.16)

- The Atkinson index A_ε, defined as: $A_\varepsilon = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{X_i}{\bar{X}}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$ (Eq. 2.17)

The first five measures are classified as statistical measures, while the last is a welfare measure derived from a social welfare function. These measures are recommended by Honglei and Nan (2011b) to be used in resource allocation problems based on nine criteria (some of them already discussed in previous section): (1) scale invariance, (2) principle of transfer, (3) decomposability, (4) impartiality, (5) principle of population, (6) normalization, (7) analytic tractability, (8) appropriateness, and (9) Pareto optimization. Among these six measures, the Gini coefficient is the most popular for it is easily solved and explained. However, the above nine criteria represent diverse disciplines, and their respective discussions often reflect a specific problem setting. Accordingly, criteria for inequity measures are important in some situations but may not be as relevant in others. There is no best inequity measure for all situations.

Models that are egalitarian in delivery quantity are found in a number of papers. Hodgson et al. (1998), Doerner et al. (2007), Campbell et al. (2008), Huang et al. (2011), and Mete and Zabinsky (2010) measure equity and efficacy of aid distribution by minimizing the time to satisfy all demands for beneficiaries. Campbell et al. (2008) study the properties of vehicle routing problems that minimize the average or, alternatively, the latest arrival time of goods to beneficiaries. The authors find that these objectives result in faster delivery at a higher total transportation cost than with traditional cost minimizing objectives. Huang et al. (2011) extend these ideas by weighting arrival times by the amount of goods delivered. Mete and Zabinsky (2010) minimize total costs of operating delivery warehouses along with minimizing total travel time of delivery. Balcik et al. (2008) minimizes the maximum unsatisfied demand over all beneficiaries.

Other research papers integrate an egalitarian measure for delivery quantity with a utilitarian measure for delivery speed. In Nolz et al. (2010), and Van Hentenryck et al. (2010), the latest arrival times are minimized along with minimizing the total amount of unsatisfied demand. Jozefowiez et al. (2007), Tzeng et al. (2007), and Lin et al. (2011) take the opposite approach to Nolz et al. and Van Hentenryck et al., minimizing the maximum unsatisfied demand over all beneficiaries while minimizing total travel time. Honglei and Nan (2011a) combine the inequity measures in a multi-objective optimization model with efficiency objectives to allow a tradeoff between efficiency and equity in relief resource allocation problems.

For each model type, whether it is utilitarian or egalitarian, there are realistic scenarios where a particular model is appropriate. Focusing on maximizing total or average speed of delivery while delivering the maximum quantity of goods possible is important in rapid and early response. With a large and urgent need, time may be better spent distributing supplies than evaluating needs. Equality in delivery is more suited to longer-term recovery and development aid where speed is less of a factor and political or social issues make equity in delivery important.

2.11. Utility-Based Framework for Resource Allocation

In this sub-chapter we assume that the utility function valued at each affected area is identified. The question is asked: what would be a fair way of dividing available supplies across distinct distribution sites and among their beneficiaries? This question is attempted to be answered mathematically by showing how a utility function influences the solution while modeling resource allocation problems. Two measures of equity metrics will be separately introduced (range and *min-max*) while building the model.

2.11.1. Minimizing the Range of Dissatisfaction for Equity

Yang el al. (2013) studied discrete resource allocation problems where the decision maker is concerned with maintaining equity between some defined subgroups of a customer population denoted by subsystems and where non-closed-form functions of equity are allowed. They assume that the utility function of each subsystem is known, and quantifiable and the waiting time distribution is based on queuing theory. They extend the *min-max* metric which considers only the maximum of the utility functions and use *range* of the service levels across all subsystems as a proxy for the inequity metric to allocate non-interacting servers.

Yang, et al. (2013) proposed the following two-phase solution. The first phase will perform min-max algorithm to obtain initial allocation and test for optimality. The second phase will perform a Local Improvement Algorithm and then evaluate whether this can be identified as a global optimum if it meets a set of conditions or only be regarded as an improved solution.

Yun-feng and Han-fen (2006) define time satisfaction utility functions as a relationship between customer's satisfaction with waiting time and the travel distance from a service facility site to the customer's demand site being served. These functions can be incorporated in the resource allocation model presented by Yang et al. (2013) earlier. A brief description on the utility functions is provided next.

Let $W(x_i)$ be the dissatisfaction level at site $\boldsymbol{i}$ given x_i resources to any of its beneficiaries. e_i is the minimum number of resources required in site $\boldsymbol{i}$. In general, the more resources allocated to a distribution site, the less its unsatisfied level. The parameter β_i $(\forall i \in D)$ is a positive sensitive coefficient and $0 \leq \beta_i \leq 1$. The bigger the parameter β_i , the more sensitive the function is to the quantity allocated. Three utility functions are considered: Concave, descending exponential sigmoid, and semi Cauchy distribution quantity satisfaction functions (Figure 2.24).

- Concave quantity satisfaction function: $W(x_i) = 1 - \left(\frac{x_i}{e_i}\right)^{\beta_i}$ (Eq. 2.18)
- Descending exponential sigmoid satisfaction functions: $W(x_i) = \frac{2e^{-\beta_i . x_i}}{1+e^{-\beta_i . x_i}}$ (Eq. 2.19)
- Semi Cauchy distribution quantity satisfaction functions: $W(x_i) = \frac{1}{1+\beta_i . x_i}$ (Eq. 2.20)

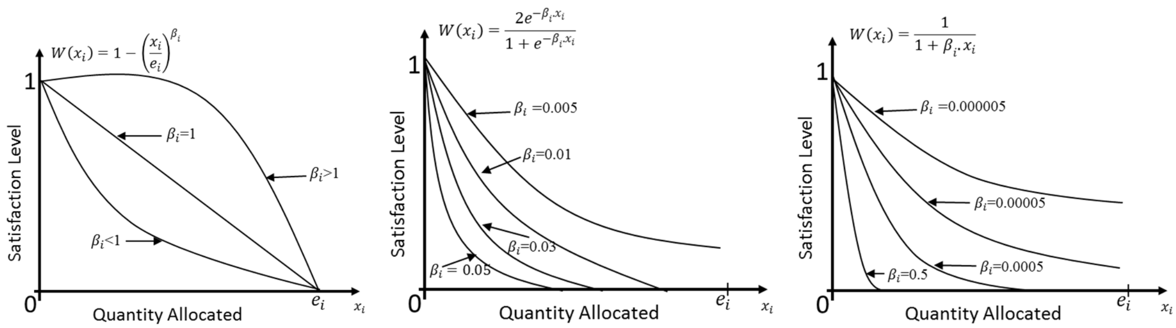


Figure 2.24. Satisfaction functions: Concave, descending exponential sigmoid, and semi Cauchy distribution quantity

The three utility functions are applicable in a situation when beneficiaries become less and less sensitive to an increase in the quantity delivered to distribution sites serving them and applying the first-come, first-served equity policy.

2.11.2. Minimizing the Maximum Total Expected Loss

Houck and Herrmann (2011) presented the MedKits model, which predicts the number of fatalities and hospitalized victims from an anthrax attack when MedKits are pre-deployed and point of distributions are opened after an attack. Additionally, Herrmann (2011) developed a model to find out the optimal allocation of MedKits to affected areas such that it equalizes the expected fatalities in the areas that receive MedKits while the expected fatalities in any areas without MedKits is even lower.

$$\text{Minimize } \max L_i(c_i) \qquad \text{(Eq. 2.21)}$$

Subject to

$$\sum_{i \in D} c_i \leq E \qquad \text{(Eq. 2.22)}$$

Where the utility function $L_i(c_i)$ is the expected fatalities in the affected area $\boldsymbol{i}$ when $\boldsymbol{c_i}$ MedKits are pre-deployed in that area. Let $\boldsymbol{P_i}$ be the population of the affected area $\boldsymbol{i}$ and $\boldsymbol{E}$ is the total MedKits available.

2.11.2.1. Solution Procedure

It is assumed that $L_i(c_i)$ is a continuous, monotonically decreasing function. Regardless of the number of MedKits distributed, some number of deaths is unavoidable. Let $\boldsymbol{P_i}$ be the upper limit on $\boldsymbol{c_i}$, then $L_i(c_i)$ reaches its minimum at this value. The range of expected fatalities can be determined as follows: $L_{max} = \max_{i=1,\dots,D} L_i(0)$ and $L_{min} = \max_{i=1,\dots,D} L_i(P_i)$

L_{min} is an upper limit on the number of MedKits that should be allocated as there is no benefit to distribute any MedKits to areas that will have a low number of expected fatalities.

For each area $\boldsymbol{i}$, if $L_i(0) \geq L_{min}$, then let c_i^{max} be the value of $\boldsymbol{c_i}$ such that $L_i(c_i^{max}) = L_{min}$; otherwise set $c_i^{max} = 0$. The upper limit on the MedKits allocation equals $E_{max} = \sum_{i=1}^{n} c_i^{max}$. If $\mathrm{E} = E_{max}$ then the optimal allocation to area $\boldsymbol{i}$ is c_i^{max}.

If $\mathrm{E} < E_{max}$ then let c_{ij}^* be the value of $\boldsymbol{c_i}$ such that $L_i(c_{ij}^*) = L_j(0) for\ i < j \leq h$. Where $\boldsymbol{h}$ be the number of areas with $c_i^{max} > 0$ and without loss of generality, renumber these areas so that $L_1(0) \geq L_2(0) \geq \cdots L_h(0)$.

Define the breakpoints $E_j = \sum_{i=1}^{j-1} \mathrm{c}_{ij}^*\ \ for\ j = 2, \dots, h\ and\ where\ E_1 = 0$. If $\mathrm{E} = E_j$, the optimal allocation is $c_i = \mathrm{c}_{ij}^*\ for\ i < j\ and\ c_i = 0\ for\ i \geq j$. The number of expected fatalities equals $L_j(0)$. If $\mathrm{E} \leq E_j$, no MedKits are allocated to cities **j** to **h**. $\mathrm{E} > E_h$ all **h** areas should receive some MedKits.

The procedure to find the optimal allocation when $\mathrm{E} < E_{max}$ is as follows:

1. Let j* be the largest value of j such that $\mathrm{E} > E_j$.
2. Find the value y such that $\sum_{i=1}^{j^*} \mathrm{L}_i^{-1}(\mathrm{y}) = E$.
3. Set $c_i = \mathrm{L}_i^{-1}(\mathrm{y})\ for\ i = 1, \dots, j^*\ and\ c_i = 0\ for\ all\ other\ areas$

Herrmann (2011) observed that the proportional allocation yields an expected number of fatalities that is greater than the MedKits model. As $\boldsymbol{E}$ approaches the total population of all affected areas, both allocations methods yield the same results. Also, the MedKits model provides a robust solution with respect to the uncertainty on the number MedKits demanded at affected areas.

2.12. Time-Space Network Framework for Resource Allocation

Unlike the previous approaches of allocation discussed so far, allocating resources based on a spatial network has been used widely in real-time disaster scenarios and extensively investigated by different researchers and specialists. This is mainly because integrating resource allocation problems with vehicle routing problems can ensure the design of a logistics network capable of rapid distribution of relief resources in response to a large-scale emergency. Furthermore, a good logistical plan is absolutely necessary in executing equitable resource allocations to beneficiaries; especially when an allocation plan requires deliveries of a magnitude that surpass the available number and capacities of vehicles. Therefore, it becomes a critical, but difficult, task to transport relief resources from depots to targeted humanitarian aid distribution locations. According to Balcik et al. (2008), the last mile distribution is made more difficult due to the strict financial and time limitations, making a cost-efficient vehicle routing decision important.

During the immediate response phase after a disaster occurs, there are likely significant shortages of many essential supplies. In addition, faced with operational limitations such as available number of vehicles and their capacities, total working time, and the time window required for delivery to each site makes the relief operations effort more difficult to run. Thus, how these limited supplies are allocated and distributed over the first few periods after a disaster is an important issue to solve. In this sub-chapter, we will review prior research related to such emergency resource distribution settings over single-period and multi-period time horizons.

2.12.1. <u>Single-Period Resource Allocation Model</u>

Planning single-period resource allocation is interrelated to the Vehicle Routing Problem (VRP). The VRP is a well-researched technique, and many heuristics, mathematical programming, and search techniques are available. Typical VRP problems have the following characteristics: a central depot location and available resources, demand point locations and quantity required, time windows for the demand points, loading and unloading times, and a set of available capacitated vehicles. The VRP details the delivery of a set of supplies to a set of demand points by a set of vehicles to satisfy all needs.

In many large-scale emergencies, it may not be possible to fully satisfy all of the demand, and priorities, or penalty functions must be employed to save as many lives as possible. With this, it is possible to formulate various objective functions to obtain an allocation solution, including minimization of transportation cost, minimization of vehicles used, balancing routes for travel times and load, and minimization of penalties from unmet demand and time delays.

In this section, an example of a single period resource allocation model will be revised. It will be formulated as the minimization of total weighted time delay to generate routes and allocate quantities to demand points while constrained with the working time deadline, the vehicle capacity, and the insufficient supply at the depot.

2.12.1.1. Deterministic-based formulation logistics models

Dessouky et al. (2006) formulate a stochastic allocation-vehicle routing model allowing split delivery to design a rapid distribution systems for medical supplies in response to an anthrax disease emergency. The objective of the model is to minimize the unmet demand over all the demand points, effectively minimizing the loss of lives. In their paper, vehicle time delay is not allowed when visiting a demand node. However, this strict limitation may be unreasonable, because in emergency situations even the urgency of need for critical supplies may not be met from a time perspective. The decision maker will still send the supply to save as many lives as possible with the least time delay.

Liu et al. (2007) rectify this and use the soft deadline window constraint while modeling. The objective of the model is to minimize both the unmet demand and time delays of the vehicles after arriving at demand points to deliver supplies. Similarly, Shen et al. (2009) kept the soft window constraint but considered instead the arrival times of the vehicles to demand points as they are directly associated with when the supplies are used.

Zhu (2012) built on the previous three works and considered instead a deterministic model minimizing the maximum unmet demand rate and the total weighted time delay. The model generates routes that are constrained with the working time deadline, the vehicle capacity, and the insufficient supply at the depot.

The above model was solved in two stages: resource allocation to determine the unmet demand in each node, and routes constructed for every vehicle. The first stage can be solved by the resource allocation model followed by the LP-rounding algorithm. The route construction phase is solved by a local search algorithm, which is a greedy algorithm Zhu (2012).

Having presented the above model as an allocation-routing problem, it remains to mention that the restrictions imposed on vehicles' availability and their operational time may lead to alteration of the initial resource allocation. Consequently, the equitability of allocation to demand points might not be ensured. This shortfall will be overcome when the multiple-period resource allocation is discussed next.

2.12.2. <u>Multiple-Period Resource Allocation Model</u>

Planning multiple-period resource allocation is interrelated to the Inventory Routing Problem (IRP). The IRP differs from the VRP because the decision maker decides when and how much to deliver to demand points. The objective is to minimize total cost over the planning horizon while ensuring that supplies are delivered to demand points in a fair manner. A single type of supply is delivered from a single depot to a set of ***n*** demand sites over a specified time period. These demand sites are served by a set of identical vehicles, each of which has a fixed capacity. A problem solution answers three questions: when to serve a demand site, how much to deliver, and which routes to follow.

Minimizing travel cost is a typical objective used in transportation-related problems, e.g., the vehicle routing problem. However, in the emergency scenario, minimizing unsatisfied demand is equally important. A conflict exists between these two objectives. For example, the best way to reduce unsatisfied demand is to send more vehicles to deliver supplies to demand locations; however, it is usually not allowed due to limitations in the number of vehicles and the budget for transportation of relief supplies. Consequently, the trade-off among different objectives becomes a critical challenge for decision makers, especially when they are making complicated decisions regarding issues such as disaster relief operations, because any decision will have an immense impact on numerous victims in a disaster.

Three valuation techniques to estimate total cost will be discussed while formulating a multiple-period equitable resource allocation model: slack, penalty, and social welfare. Each of the three techniques deals with an equitable allocation in a different perspective as we will show below.

2.12.2.1. Slack-based formulation logistics model

Hermann et al. (2009) formulate a single-product medication distribution deterministic problem to quickly and efficiently deliver resources to the demand sites from a central depot. A set of vehicles must deliver supplies over time from a depot to a set of demand sites that will dispense these supplies to beneficiaries. In general, only some of the supplies will be available at the depot at the beginning of the time horizon, and more supplies will be scheduled throughout the time horizon to be delivered to the depot in batches that we call "waves." There are ***n*** demand sites that will begin operating at a predetermined time period and continue to operate through the end of the planning horizon. Each site has a consumption rate equal to the dispensing rate, which depends upon the number of beneficiaries at the site.

The objective to minimize the cost or maximize the profit would not be adequately addressing the goal of delivering supplies in a timely manner during a short time span. Instead, the aim is to increase the earliness of deliveries prior to a site running out of supplies for each delivery made from the depot. The interval between the time of each delivery and the time at which the site would have its inventory consumed will be denoted as the slack. However, maximizing the sum of these slack values could yield an inequitable solution in which some deliveries have a large slack (overage) and other deliveries have little or negative slack (shortages).

Thus, the objective function would be to maximize the minimum slack of the deliveries so that supplies arrived in a timely manner while all demand sites are treated equitably. The key decision variables are the sequence of the sites each vehicle visits, the start time at which a vehicle departs the depot, and the quantity delivered to each site in each trip.

Instead of attempting to solve the problem as a large integer program due to its complexity, Montjoy and Herrmann (2012) adopt a three-stage solution approach that separates the problem into three sub-problems. The routing stage will assign sites to each vehicle and sequence them to create routes. The scheduling stage will determine how many trips each vehicle will make and when it will start. The allocation stage will determine the amount of supplies to deliver to each site on each trip.

2.12.2.2. Penalty-based formulation logistics model

Lin et al. (2011) proposed a tour-based multi-objective logistics model for optimized scheduling of the delivery of critical items in a disaster relief operation. The model considers multi-items, multi-vehicles, multi-periods, and a split delivery scenario in a disaster. The relief supply is limited in the depot and the demand requested from various demand points can be correctly estimated before the beginning of the planning horizon in a relief operation. It also considers the backorder scenario, and unsatisfied demand will not only accrue a penalty cost, but also be accumulated to the next period until it has been satisfied. This requires the model proposed to continuously monitor all unsatisfied demands of various items during the entire planning period.

The objective function consists of three functions. First, is a penalty function that aims to minimize unsatisfied demand. Its purpose is to account for the total accrued penalty cost from various severe delay levels during the planning periods and through the end period. Second, is an equity function that aims to minimize the difference in the satisfaction rate between clusters. Its purpose is to balance the service among clusters. Third, is a cost function that aims to minimize the total travel time for all tours and all vehicles. Its purpose is to assign as many vehicles as possible during the working hour limitation in order to deliver the largest amount of items.

A genetic algorithm is applied as the tour generator to filter out tours in order to reduce the size and difficulties of the problem. Then, the elastic constraints method (Ehrgott, 2006) is applied to optimize the result of the multi-objective integer programming model. This method tries to solve a single objective version of the problem as the weighted sum method and is also able to generate all efficient solutions as the ε–constrained method.

2.12.2.3. Social welfare-based formulation logistics model

The main focus of commercial logistics is on minimizing operational costs that include transportation and inventory costs, among others. In the case of humanitarian logistics, rather than defining performance success in terms of operational costs, the ultimate performance measure is how much human suffering is alleviated or prevented with delivered resources. If the minimization of suffering is a logical and sensible approach to humanitarian logistics, then it should be quantified. Holguin-Veras, et al. (2010) introduce the concept of deprivation costs to capture the loss in social welfare experienced by the victims of extreme events. They define deprivation cost as the economic value of the human suffering associated with not having access to resources. Those costs are not naturally internalized by the organizations delivering supplies to the population in need, as their inclination is to maximize profits.

Holguin-Veras, et al. (2010) argue that when humanitarian logistic strategies do not consider deprivation costs, human suffering is not minimized, far from it. Furthermore, traditional methods based on pre-defined levels of service in the form of equity constraints, and arbitrary penalties for unmet demands, lead to high deprivation costs and are likely to lead to either infeasible or suboptimal solutions. As a result, it is natural to think that humanitarian logistics should specifically consider the costs associated with human suffering in the objective function and focus on the minimization of social costs consisting of operational and deprivation costs. The preceding discussion suggests that it is important to reformulate humanitarian logistic modeling so that is explicitly takes into account the deprivation costs resulting from delivery actions (Holguin-Veras et al., 2010). Doing so would provide decision makers a solid foundation to design and plan an equitable, effective, and efficient use of resources. In this context, valuing and incorporating deprivation costs in the objective functions is expected to provide an unbiased and equitable platform to make decisions about delivery strategies.

The social welfare-based formulation logistical model proposed by Holguin-Veras, et al. (2010) determines the optimal quantity of supplies, and the number and timing of deliveries to each demand node that minimizes total deprivation costs over a planning horizon. Making a delivery resets the deprivation costs at the demand node, which will not start increasing again until the supplies delivered are consumed by the beneficiaries at the node. Moreover, including deprivation costs in the objective function allows for the evaluation of opportunity costs, i.e., the costs incurred by all other nodes in which no deliveries took place. The aim is to decide which node to deliver to with the highest marginal benefit to the marginal cost ratio. The marginal benefit is the reduction in the deprivation cost associated with delivering to the node; while the marginal cost is the opportunity cost, i.e., the increase in deprivation costs at all other nodes.

A heuristic was developed to solve the model in which the inventory allocation and the vehicle routing decisions are decoupled and solved in independent steps. During the first stage, a routing problem aggregates demand nodes in a set of mutually exclusive delivery clusters defining fixed vehicles routes. Vehicles make tours visiting all nodes in a cluster and return to the depot. This stage provides the routes for the second stage to find the optimal size and timing of the shipments to the disaster areas. The objective in this stage is to minimize the operational and deprivation costs of disaster response, subject to vehicle capacity and inventory constraints.

CHAPTER 3. MODEL DEVELOPMENT

This chapter starts with a description of the key features of a network in which the foundation of the mathematical model will be built. The routing and allocation component that made up the model will be explored and coupled with the framework of deprivation cost, which was mentioned in an earlier work by Pèrez (2011). Combining these three, a mathematical model for single route resource allocation is introduced with an illustrative example to explain its functionality.

3.1. Setting up the Network Key Features

The characteristics of the network setting that are interrelated in this model are: (1) an initial response phase, (2) one depot and multiple demand sites, and (3) consumable emergency relief resources. These are explained next.

3.1.1. Initial Response Phase

Consider a large-scale disaster that results in severe impacts on large geographical areas and large population groups. It causes a large number of casualties and property damage. Time is critical for life saving and there is a huge demand surge with severe resource shortages. There is time pressure for quick decision making and action since any delay in meeting basic human needs may cause severe consequences such as an increase in fatalities and aggravated sufferings of survivors.

This dissertation will study the last mile distribution plan in the initial response phase where the key focus is the preservation of lives. This phase aims to be responsive and provides improved logistical support since it is directly linked to lives saved.

Since demand required during this phase is usually large and unexpected, and resources (e.g., supplies or transportation vehicles) are normally limited, a good logistics plan is essential to allocating these limited resources to those who need resources the most, and at the same time achieve a balance between priority and equity. One critical challenge is the timely transportation of these critical supplies initially and periodically throughout the entire phase, which is assumed in this case to be the first 72 hours, in order to support basic living needs for people stuck in disaster-affected areas.

The proposed RAP model possesses the following characteristics which differentiate it from commercial models. First, it is impartial since the scheduling of deliveries is directed to the most needed demand sites. Second, it is equitable since the proportionality rule is applicable to beneficiaries within the same cluster. Third, its objective focuses on a humanitarian aspect which is to reduce suffering. Lastly, the impact of delay in response time is addressed in the model where its effect would be exponential and not linear.

3.1.2. Depot and Demand Sites

An emergency relief distribution network is often articulated around relief depots operating as distribution centers. Several depots are mobilized to receive and distribute the supplies and equipment necessary to support relief distribution operations. The depot is usually located inside the affected area as close as possible to the disaster victims in order to deliver aid in the shortest time. Government buildings or schools can be attractive locations to execute logistics distribution operations. Each depot receives, stores, and delivers relief supplies using a fleet of vehicles. In addition, it manages staff and support vehicles for delivering services. Thus, the depots' primary mission is to provide first-line relief.

Suppose in this study that one depot is established from which to run the relief operations and deliver to various demand sites (clusters) with a certain number of vehicles deployed. Its location is identified before the distribution planning process began and it possesses enough capacity to hold any shipment size. The physical distance required to reach different affected areas from the depot was used even though it does not adequately measure how easy or fast the access to a given site is, mostly because road conditions after the disaster can be affected. The depot location is translated in terms of Euclidean distance (or time) required to access the different demand sites. The operational requirements are fulfilled at the depot to enable it to provide relief service continuously to beneficiaries during the planning horizon.

In a severe disaster that affects a large area, it makes sense to think that individuals within the affected region require relief or humanitarian aid. The number of types of tangible products (e.g., food, health products, medicines, water, mattresses, etc.,) required may be very large. The amount of information to be managed is huge, and it would be impractical (if not impossible) to consider the fine details in designing emergency relief distribution networks.

To cope with these difficulties, the model approach applies the geographical aggregation, which groups the individual demands into demand sites according to certain rules. It may be aggregated into demand sites in a straightforward manner by using the census block (the smallest geographic area for which the Bureau of the Census collects and tabulates decennial census data) or the ZIP code in North America. The demand site is computed as the sum of the individual demands in a census block (or ZIP code) and a location corresponding to the centroid of the corresponding covered area. Other criteria for clustering could also be appropriate depending on the circumstances. These demand sites have attributes defined in terms of population size, number of households, number of frail population, accumulated number of fatalities, level of destruction identified by aerial satellites, or other attributes specified by the logistics managers.

In this study, it is assumed that the information about the attributes of demand sites are known and specified while developing or solving the mathematical model.

3.1.3. Emergency Relief Resource

The various life sustaining items required by beneficiaries in the affected region are grouped into one generic humanitarian package. A package fulfills the basic beneficiary's consumption for one unit time with demand for a similar package occurring for each subsequent time unit over the entire planning horizon. Time disruption in the package delivery may cause suffering to beneficiaries and which could increase in time as human body reserves are being depleted and human body functions start to slow down and ultimately shutdown. A point may be reached where physical/psychological damage is irreversible, and death could occur.

Since time is a determining factor, the quantity required by a site is expressed as a rate (packages per unit time), which in this case depends on the population at each site served. Each demand site would have a different but constant demand rate spread over the time horizon as opposed to just a total quantity demanded as is common in other models. How much and when to deliver packages to sites are decisional variables to be determined by solving the mathematical model.

3.2. Model Basic Components

The main two gears in this model are the vehicles and the emergency supplies. The trade-off between them is set in an objective function that maximizes life-saving and alleviation of suffering.

3.2.1. Vehicle Routing

Consider an environment in which the demand of each site is relatively small compared with the vehicle capacity, and the sites are located closely such that a consolidated delivery strategy is appropriate. Vehicle routing decisions are based on site locations with their respective demand rates. A vehicle routing model is proposed to determine the routing order and periodical distributed quantity associated with each site under the objective of alleviating the suffering of beneficiaries while operating a vehicle fleet with equal capacities. Delivered quantities are decided at fixed time intervals and all vehicles supply sites continuously, around the clock. When vehicles return to the depot, they immediately reload and resupply their demand sites.

A route first-cluster second method is used in this dissertation where a big tour is created first through all the sites using a travel salesman problem (TSP), and then the sites (and the route) are divided into a desired number of partitions (Bramel & Simchi-Levi, 1997).

The linear programming formulation for TSP is used as it is computationally inexpensive. TSP formulation is as follows:

Let t_0 and t_{n+1} denoted by the vehicle departure and arrival times from/to the depot. Let t_i represents the delivery time for site ***i*** and the term τ_{ij} represents the time taken to go from site ***i*** to ***j***. Let x_{ij} be a binary variable whose value is one if site ***j*** is visited immediately after ***i***, and zero otherwise. The mathematical model to minimize the tour time is:

$$\textbf{Minimize} \quad t_{n+1} - t_0 \qquad \text{(Eq. 3.1)}$$

Subject to

- Ensure that a single site is visited from depot.

$$t_j - t_0 \geq \tau_{0j} \quad \forall j \in N \qquad \text{(Eq. 3.2)}$$

- Ensure that vehicle returned back to depot.

$$t_{n+1} - t_j \geq \tau_{0j} \quad \forall j \in N \qquad \text{(Eq. 3.3)}$$

- Ensure that sites ***i*** and ***j*** are visited in any order provided that travel time τ_{ij} satisfied.

$$x_{ij} - (t_i - t_j) \leq M.\, x_{ij} \quad \forall i \in N \qquad \text{(Eq. 3.4)}$$

- Ensure that sites ***i*** and ***j*** are visited in any order provided that travel time τ_{ij} satisfied.

$$x_{ij} - (t_j - t_i) \leq M.\, (1 - x_{ij}) \ \forall i \in N \qquad \text{(Eq. 3.5)}$$

- All arrival times to sites must be non-negative.

$$t_i \geq 0 \ \ \forall i \in N \qquad \text{(Eq. 3.6)}$$

- Binary variable equal to 1 if and only if site $\boldsymbol{j}$ is visited immediately after site $\boldsymbol{i}$.

$$x_{ij} \in \{0,1\} \ \ \forall i \in N, j \in N \qquad \text{(Eq. 3.7)}$$

The mathematical model to minimize the total waiting time of all the sites before being visited would still incorporate the same constraints but the objective function would differ to become:

$$\textbf{Minimize} \quad t_1 + t_2 + \cdots + t_\text{n} \qquad \text{(Eq. 3.8)}$$

3.2.2. <u>Resource Allocation</u>

Resource allocation was reviewed earlier in Chapter Two. Many of the concepts reviewed will be used while building the model.

3.2.3. <u>Multi-Objective Decision Making</u>

In a humanitarian context, objective functions need to be analytically formulated to minimize loss of life and alleviate the suffering of the population impacted by an extreme event, while operational costs are typically considered a secondary objective (Holguin-Veras, Perez, Jaller, Destro, & Wachtendorf, 2010). On one hand, it is inevitable to incur additional costs in expediting the delivery of critical supplies to the affected areas to minimize negative impacts on the victims. As response delay decreases, the chance of deaths and suffering also decreases. Hence, it is required to respond to the most urgent demands of the affected community within a very short period of time.

On the other hand, humanitarian organizations are usually unable to satisfy all needs, thus requiring responders to decide the optimal allocation for the limited resources available while minimizing penalties from unsatisfied demand. A shortcoming of such decisions is that they are ineffective in identifying the resource allocation providing the highest benefit to the whole system. And even if that is fulfilled, the allocation wouldn't necessary hold an equitable nature. Responders do not distinguish a particular request from another, and are unable to account for the fact that the urgency with which supplies are needed may vary among affected areas. Although responders introducing equity constraints, priority, or weight factors to encourage deliveries to certain areas may provide more uniform levels of service, they require subjective consideration from the decision makers regarding the definition of the equity constraints, prioritization, or weighting schemes. Therefore, the optimal distribution solutions are highly sensitive to the specific parameter values used during the optimization of humanitarian models.

The formulating of the objective and decision criteria in this study are associated to end results such as life-saving and alleviation of suffering rather than the traditional objective of minimization of costs or maximization of profits. It will be based on a model introduced by Holguin-Veras et al., (2010) where a specific deprivation cost associated with human suffering is considered in the objective function based on deprivation time. The concept of deprivation cost will be discussed in the next section.

Since allocation needs to regard equity among sites, the *min-max* equity function is used instead. An operational cost term is still needed to be incorporated in the objective function for tradeoff with the deprivation cost. It will be a decisional factor in determining the level of logistical support in terms of number of vehicles required for such relief efforts.

This multi-objective problem will be solved with two different approaches. In the first approach, the two costs can be weighted and combined to a single sum. Therefore, preference information of the decision makers for the conflicting objectives is needed beforehand, rendering the decision-making process more difficult. In the second approach, a Pareto set approximation can be generated, enabling the decision makers to choose from a set of diverse solutions according to their preferences. In either approach, heuristics are designed to solve this model as it is regarded as an NP problem.

3.3. Pèrez's Allocation Model Based on Deprivation Cost

It is undoubtable that post-disaster delivery decisions have a significant impact on the welfare of the affected population when the delivery strategy does not provide uniform levels of service to all nodes. Affected individuals experience a deprivation period as long as they do not have access to the required supplies. Making a delivery resets the deprivation experienced at the demand node. The cost associated with this lack of access to supplies is defined as deprivation costs by Holguìn-Versa, et al. (2010). The adverse impact on welfare is caused by the variability in deprivation periods among affected individuals and by the high (and unaccounted) deprivation costs. In such cases, and apart from operational cost, human suffering is not minimized.

The deprivation cost is expected to have some rather unique characteristics, as it is likely to be monotonic, non-linear, and convex with respect to deprivation time. Deprivation costs are expected to grow non-linearly faster as the deprivation time increases (Figure 3.1).

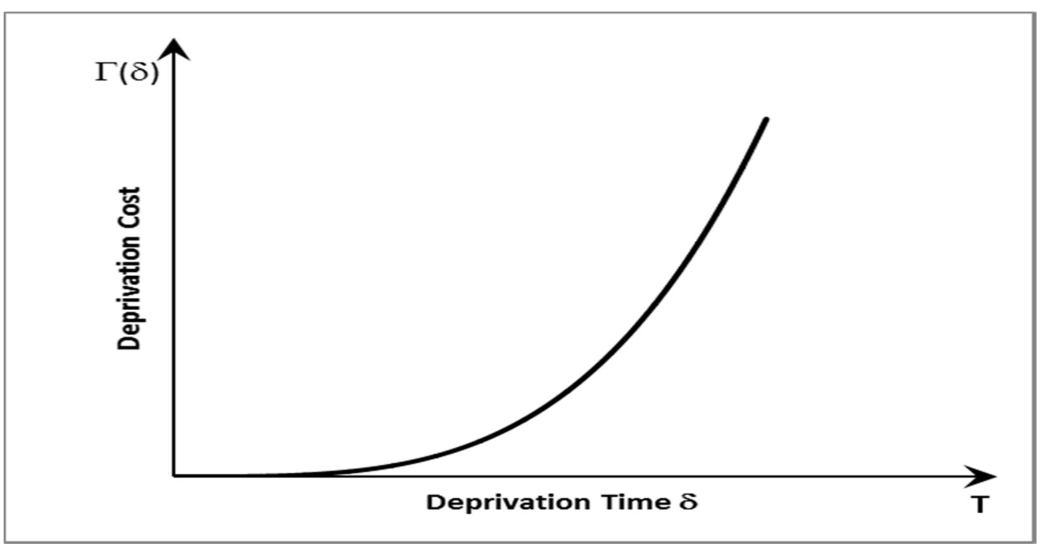


Figure 3.1. Convex deprivation cost function

It is well known that, at first, most healthy individuals are able to deal with short-term shortages in life sustaining items without much problem as they may use their human body reserves to operate in a normal fashion. As human body reserves are being depleted, their functions start to slow down and ultimately shut down. A point may be reached where physical/psychological damage is irreversible, and death could occur.

Holguin-Veras et al. (2010) considered a deprivation cost function in which the deprivation time $\boldsymbol{\delta}$ produced by the lack of water since the prior water consumption could be represented by the time function $\Gamma(\delta) = e^{1.5031+0.1172*\delta} - e^{1.5031}$. Then, they explicitly incorporated deprivation costs in humanitarian models and approached the resource allocation problem by assuming that individual welfare could be aggregated, and that it is appropriate for response agencies to allocate resources in the way they consider would lead to the greatest good, for the largest number of people (utilitarian). They investigated the important role that deprivation time plays in humanitarian logistics when linked to satisfy the physiological needs of individuals. In general, the total deprivation costs were minimized by preventing deprivation costs from reaching the steeper sections of the cost function as deprivation costs are, by definition, a non-linear function of deprivation time. This in turn requires relatively low variability in the duration of the deprivation periods among all individuals, but the frequencies of visits to each affected area and volumes delivered there could vary significantly among individuals due to the impact of travel time between the depot and the affected areas.

The following review about the impact of deprivation cost on resource allocation problems is cited from research work originated by Pèrze (2011). These concepts will be subject to further development in subsequent sections with the goal of formulating an equitable allocation routing model.

3.3.1. Deprivation Cost at One Demand Point

Consider a network consisting of a depot with known initial inventory and a single demand point $\boldsymbol{i}$=1 with no initial inventory. It will provide aids to $\boldsymbol{P_i}$ beneficiaries with consumption rate $\boldsymbol{u}$ per beneficiary per unit time. If no deliveries are made to the demand node, the deprivation cost γ is equal to $\Gamma(T)$. (Figure 3.2)

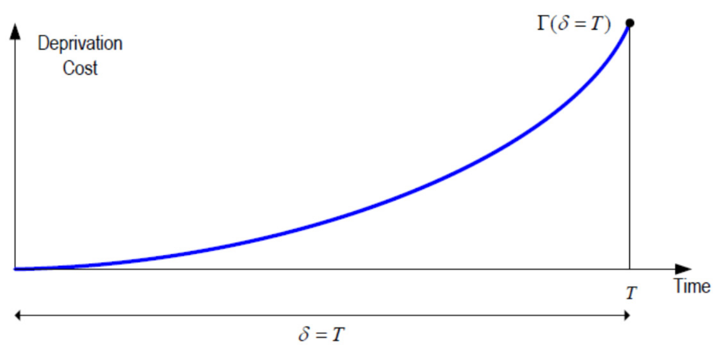


Figure 3.2. Impact of no deliveries on deprivation costs at one demand node (Pérez, 2011)

Making one delivery of size $\boldsymbol{q}$ units would satisfy the needs of the beneficiaries at the demand node for a period of $\boldsymbol{q/u.P_i}$ units of time and the total deprivation time experienced at this node would be $(\boldsymbol{T}- \boldsymbol{q/u.P_i})$. The timing of this delivery would determine its impact on deprivation cost. If supplies arrive early in the planning horizon, deprivation time δ_1 would be small but δ_2 would be large. Conversely, a delivery close to the end of the planning period would lead to a small δ_2 and a large δ_1. Since it is assumed that the deprivation cost function is convex and non-linear, deprivation costs are minimized when supplies of $\boldsymbol{q}$ units arrive at a time that deprivation periods are exactly equal to each other (Figure 3.3). Deprivation costs are thus minimized when this time is distributed evenly between δ_1 and δ_2 , that is, $\delta^* =½.(\boldsymbol{T}- \boldsymbol{q/u.P_i})$.

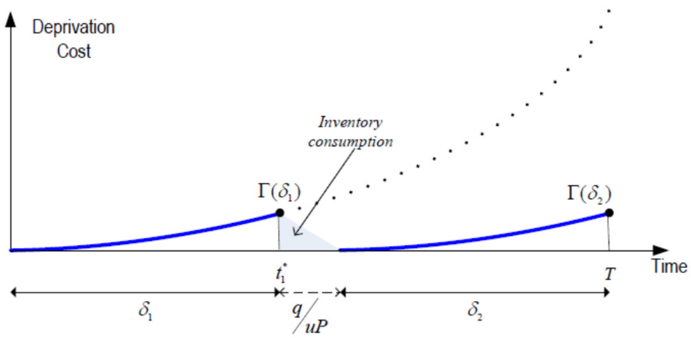


Figure 3.3. Impact of one delivery on deprivation costs at one demand node (Pérez, 2011)

This relationship can be extended to two, three and in general to h_i deliveries of size q each. Allocating h_i deliveries to a demand point would create h_i+1 deprivation periods. Then, the optimal allocation strategy would be to set the delivery of each q in such a way that all intra-nodal deprivation times are equal; that is, $\delta_i^* = \frac{1}{h_i+1}\left(T - \frac{h_i.q}{u.P_i}\right)$.

Define τ_i as the travel time between demand point i and the distribution center. Holding no initial inventory, beneficiaries at demand node i will always experience unavoidable suffering accounted by a deprivation time δ_i^1 of at least τ_i units of time prior to the first delivery, that is, $\delta_i^1 \geq \tau_i$. In such a case, a solution with no deprivation cost will not be fully implementable even under the assumption of unlimited transport capacity or with enough resources to meet all demands. However, by defining δ_i^1 as a variable that could be higher than the optimal δ_i^* at subsequent deliveries, the cumulative deprivation cost would decrease. This requires δ_i^1 to be at least equal to δ_i^* ; that is, $\delta_i^1 \geq \frac{1}{h_i+1}\left(T - \frac{h_i.q}{u.P_i}\right)$. The system would realize a cost at least equal to $\Gamma(\tau_i)$, the minimum deprivation cost possible given the starting conditions at i. The deprivation costs for the subsequent deliveries would be minimized by splitting any remaining deprivation time in h_i equal deprivation periods; that is, $\delta_i^* = \frac{1}{h_i}\left(T - \delta_i^1 - \frac{h_i.q}{u.P_i}\right)$. (Figure 3.4)

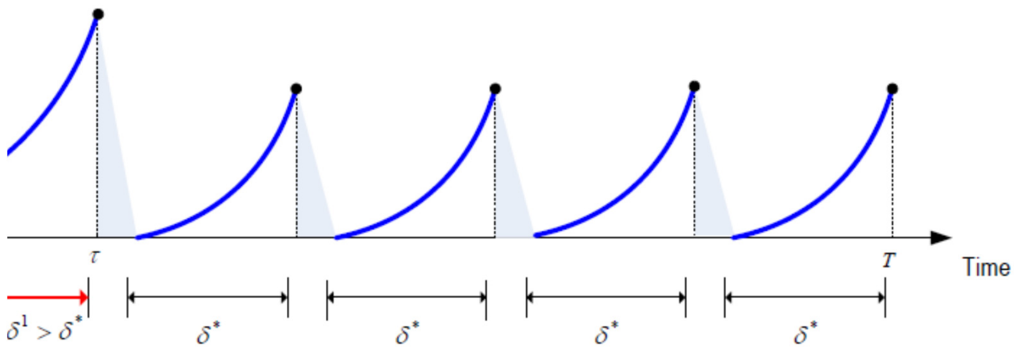


Figure 3.4. Impact of multiple deliveries on deprivation costs at one demand node (Pérez, 2011)

3.3.2. Deprivation Cost at Two Demand Points

Consider a cluster consists of two nodes 1 and 2 with same number of beneficiaries $\boldsymbol{P}$ for simplicity and located at a travel time τ_{12} from each other. If each of these nodes were to receive a single delivery of equal size $\boldsymbol{q}$ directly from the depot, then this requires optimal arrival times $t_1^* = \delta_1^* \; and \; t_2^* = \delta_2^*$ to be equal. Furthermore, if the two nodes were aggregated in a "super node" with population $\boldsymbol{P_c}$ =2.$\boldsymbol{P}$ and their deliveries consolidated in a single shipment of size $\boldsymbol{q_c}$=2.$\boldsymbol{q}$, the optimal arrival time δ_c^* would be: $\delta_c^* = \frac{1}{2}\left(T - \frac{q_c}{u.p_c}\right) = \frac{1}{2}\left(T - \frac{2.q}{u.2.p}\right) = \delta_1^* = \delta_2^*$.

Thus, spatially separated demand nodes do not change the optimal deprivation time and have no impact on the optimal allocation strategies; that is, the size and timing of any deliveries is unchanged, once the number of trips to each demand node is fixed. This result can be generalized to clusters containing nodes with different populations by assuming that any shipment to the cluster is distributed proportionally among its constituent nodes according to the number of beneficiaries at each of them $q_i = \frac{p_i}{p_c}.q_c \,, \quad \forall i \in C_c$.

However, spatial characteristics introduce some distortion in the feasibility of the optimal solution since a vehicle cannot deliver simultaneously to all nodes in the cluster at exactly the same time δ_c^*. For instance, beneficiaries at node 2 (assuming it is visited after node 1) will always receive supplies τ_{12} units of time later than the receipt at node 1. This would increase deprivation time at node 2 during the first deprivation period by δ_{21}, although it would also reduce deprivation time by the same amount during the second period δ_{22} prior to the end of the planning horizon. The net effect is an increase in the total deprivation costs for the cluster since the deprivation cost function is nonlinear. (Figure 3.5)

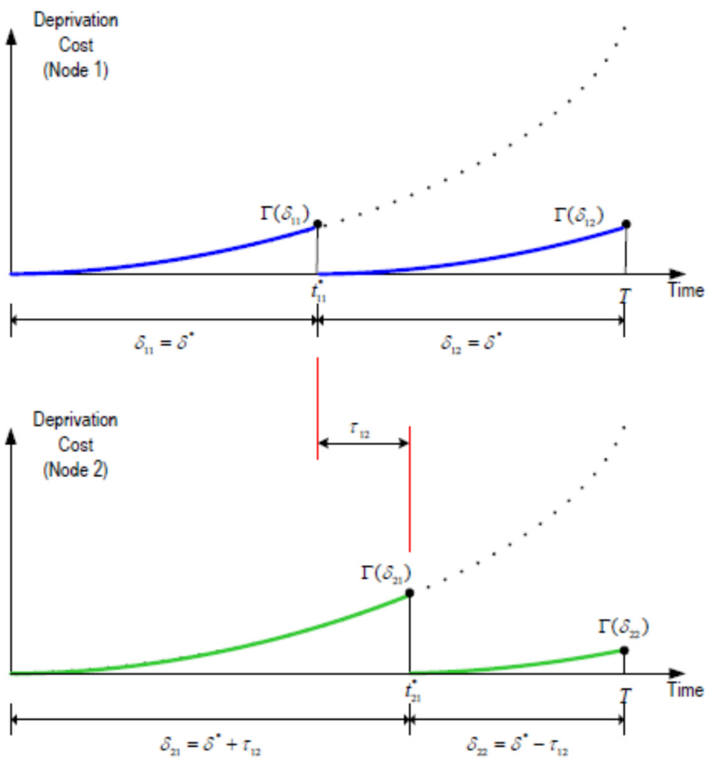


Figure 3.5. Impact of a sequential delivery on deprivation costs at two demand nodes (Pérez, 2011)

To reach an optimal solution, it is required to split equally between the two nodes the loss in efficiency introduced by the travel times; that is, rearranging shipments in such a way that the actual arrival times deviate from the optimal δ_c^* by the same factor $\frac{\tau_{12}}{2}$ from both nodes. It follows that:

$$\begin{cases} \delta_{11} = \delta_c^* - \frac{\tau_{12}}{2} \; ; \; \delta_{21} = \delta_c^* + \frac{\tau_{12}}{2} \\ \delta_{12} = \delta_c^* + \frac{\tau_{12}}{2} ; \; \delta_{22} = \delta_c^* - \frac{\tau_{12}}{2} \end{cases} \qquad \text{(Eq. 3.9)}$$

This strategy minimizes total deprivation costs for the cluster by equating deprivation costs at the demand nodes. Beneficiaries at node 1 would experience a relatively short deprivation period prior to the arrival of supplies and experience a longer deprivation period at the end of the planning horizon. The reverse is true for node 2.

If nodes 1 and 2 had different populations, the optimal deprivation time for the cluster would be the average deprivation time experienced by all beneficiaries in the cluster before the arrival of the first delivery; that is,

$$\delta_c^* = \frac{P_1.\delta_{11} + P_1.(\delta_{11} + \tau_{12})}{P_c}. \qquad \text{(Eq. 3.10)}$$

The optimal arrival time to node 1 could be found by solving for δ_{11}in the above equation:

$$\delta_{11} = \frac{P_c.\delta_c^* + P_2.\tau_{12}}{P_c}. \qquad \text{(Eq. 3.11)}$$

3.3.3. Deprivation Cost at Cluster of more than Two Demand Points

The above discussion can be extended to two, three and in general to $\boldsymbol{h_c}$ deliveries of size $\boldsymbol{q_c}$ each where the total supplies available to the cluster are distributed in proportion to the number of beneficiaries in each node. Allocating $\boldsymbol{h_c}$ deliveries to a cluster would create $\boldsymbol{h_c}$+1 deprivation periods of equal duration δ_c^*. Consequently, once the timing of the first delivery is set, any additional deliveries to the cluster should be scheduled to arrive at the first node in that tour every $\frac{q_c}{u.P_c} + \delta_c^*$ units of time, which would guarantee that all beneficiaries in the cluster experience the same deprivation period δ_c^* between consecutive deliveries. It follows that for each node the duration of all intermediate deprivation periods 2… $\boldsymbol{h_c}$ is δ_c^*, and with deviations from this optimal timing occuring only during the first and last deprivation periods. Nevertheless, the average deprivation time between the first and last deliveries to each node must still be equal to δ_c^* (Figure 3.6). As a reasonable approximation, the total deprivation cost experienced by beneficiaries during these periods can be assumed to be double the deprivation cost for the optimal δ_c^*; that is, $\Gamma(\delta_1) + \Gamma(\delta_{h+1}) = 2.\Gamma(\delta_c^*)$.

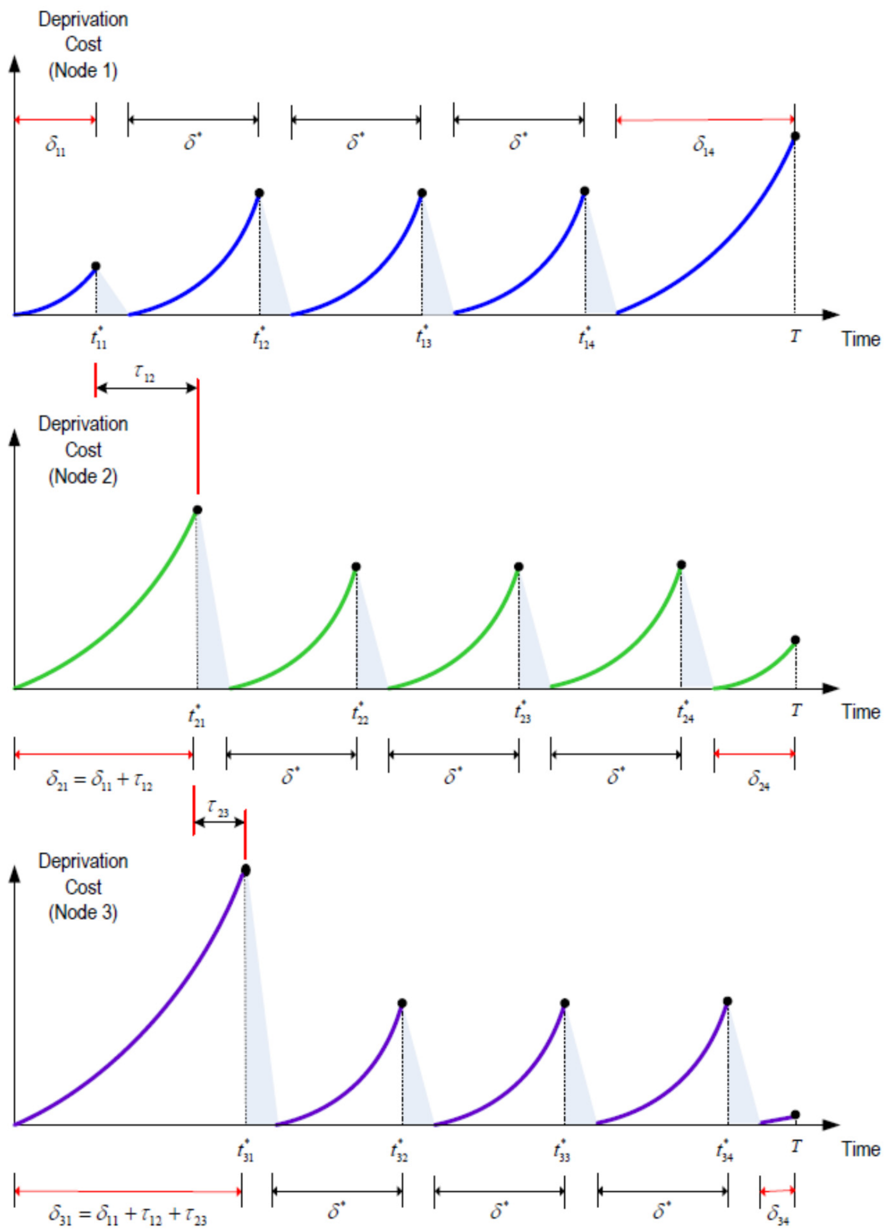


Figure 3.6. Impact of sequential deliveries on deprivation costs at a 3-node cluster (Pérez, 2011)

The deprivation costs are minimized by arranging deliveries in such a way that the average deprivation time experienced by all beneficiaries in the cluster before the arrival of the first delivery is equal to the optimal deprivation time for the cluster. Consequently, once the timing for the first delivery is set, certainly larger than the weighted travel time in the cluster, any additional deliveries to the cluster should be scheduled uniformly to arrive at the first node in that tour. All beneficiaries in the cluster would then experience the same optimal deprivation period between consecutive deliveries. Moreover, the optimal deprivation time is fairly stable for all demand nodes in a cluster when supplies are distributed in proportion to the number of beneficiaries in each node, with deviations from the optimal deprivation time occurring only during the first and last deprivation periods.

3.4. Model Formulation Framework

This sub-chapter will discuss the model mathematical framework. It starts with describing the problem and asking three main questions: 1) how frequent and when to serve a demand site, 2) how much to deliver, and 3) which routes to follow. A partial answer is given in this chapter, whereby three delivery-allocation joint strategies are discussed while assuming enough resources are available. The concept and behavior of truck idle time will be introduced for used in subsequent sections.

3.4.1. Problem Formulation

In this dissertation, we will consider allocating limited supplies (***E***) among various demand sites (***i***) based upon the travel time the truck (***v***) with capacity (***C***) requires to reach the sites from the depot via assigned route (***h***). Each site serves a number of beneficiaries ($\boldsymbol{P_i}$) by distributing lifesaving resources that require recurrent delivery to the beneficiaries. This resource is assumed to be a consumable product (food package). The theoretical total packages required by a site can be calculated based on the time horizon of the relief operations (***T***), and on the number of beneficiaries ($\boldsymbol{P_i}$) by using their unit time consumption rate (***u***) (equivalently equal to the service capacity per unit time). The truck will depart the depot and deliver on its trip an allocated quantity (***q_i***) to site ***i***, which enables the site to start distributing supplies to beneficiaries at a constant rate as long as supplies are available. It is assumed that each site will obtain quantities equal to at least one time period consumption by its beneficiaries. At the instance the site runs out of supplies, the unsatisfied demand is "*lost*" and the site's beneficiaries will experience a deprivation time (**δ**) stretched until the truck revisits the site in its subsequent trip. Such deprivation time will yield a deprivation cost $\Gamma(\delta)$ accumulated at every site throughout the relief operation. The main goal is to keep total deprivation cost to a minimum across all sites simulatanously over the time horizon. A secondary goal is to lower transportation costs by reducing the number of trucks used. A problem solution answers three questions: how frequent and when to serve a demand site, how much to deliver, and which routes to follow.

3.4.2. <u>Modifications on Pèrez Model</u>

To facilitate model formulation in the following sections, two modifications are postulated on the allocation model proposed by Pèrez (2011), which had been discussed in section 3.3.

First, the beneficiaries at demand node ***i*** will always experience unavoidable suffering accounted by a deprivation time δ_i^1 equals to τ_i units of time prior to the first delivery. Pèrze (2011) defines δ_i^1 as a variable ($\delta_i^1 \geq \tau_i$) that could be equal to the optimal δ_i^* at subsequent deliveries in order to decrease the cumulative deprivation cost. This proposed set-up in giving δ_i^1 the variability nature is not advocated in this dissertation as the first delivery is the most critical shipment that would reaches beneficiaries after the disaster occurred. It is irrational to delay sending a loaded vehicle and not sending it right away to sites, especially when beneficiaries' physiological condition would be regarded at its worst state. Moreover, initially getting at least a minimal amount of supplies to beneficiaries, would release their concerns about being forgotten in subsequent deliveries.

This requires δ_i^1 to be equal to τ_i in all cases and the system would realize a cost equal to $\Gamma(\tau_i)$, the initial deprivation cost possible given the starting conditions at ***i***. The deprivation costs for the subsequent deliveries would be minimized by splitting any remaining deprivation time in $\boldsymbol{h_i}$ equal deprivation periods, that is; $\delta_i^* = \frac{1}{h_i}\left(T - \tau_i - \frac{h_i.q}{u.P_i}\right)$.

Secondly, Pèrze (2011) assumed that after the site consumed its last delivery, the deprivation cost will continue to rise at each node until the vehicle reached the depot at time period ***T***. The planning horizon ***T*** would be a multiple of the number of trips performed by a vehicle. Furthermore, the average deprivation time between the first and last deliveries to each node must still be equal to δ_c^*. As a reasonable approximation, the total deprivation cost experienced by beneficiaries during these periods can be assumed to be double the deprivation cost for the optimal δ_c^*; that is, $\Gamma(\delta_1) + \Gamma(\delta_{h+1}) = 2.\Gamma(\delta_c^*)$.

Again, the proposed delivery set up is not promoted in this dissertation as deprivation time needs to be spread out equally among sites that belong to the same cluster. This would be possible mathematically if the unavoidable initial deprivation times prior to the first delivery are excluded from satisfying this equality and considered separately. Hence, the optimal δ_c^* is required to be fixed and constant to all nodes after each delivery including the last one. The advantage from taking this approach is that no approximation would be needed while calculating the deprivation cost in a tour allocation problem. In addition, this will create a delivery schedule with a steady state deprivation time. That is what is strived to be achieved in this dissertation: treating beneficiaries equitably when alleviating suffering is involved.

However, these two advantages come at the expense of some distortion while distributing supplies to sites. In particular, the supplies allocated in the last delivery trip to each node is neither identical to the allocation it received in earlier trips, nor is the amount proportional to other nodes. The first underperformance will be rectified when the concept of idle time is introduced in subsequent sections and after discussing the effect of deprivation cost on deliveries schedule. However, the second issue won't be resolved unless additional resources are received during the relief efforts; that is something expected to happen in any relief operations.

3.4.3. Delivery-Allocation Joint Strategies

Three delivery-allocation joint strategies discussed here will assist in answering some of the questions raised so far and in building the allocation-routing model in the sequence of this chapter. The key objective in these strategies would be to reduce the deprivation cost for any site whether visited directly or along a route.

3.4.3.1. Direct trips with fixed delivery quantities strategy:

In a situation where sites require rapid large deliveries when there is a periodic influx of supplies at a depot, then direct trips from the depot would be most appropriate. Consider the standard delivery quantities to be as large as possible; that is, shipment sizes equal to full truckload deliveries for all demand sites. This strategy will allocate supplies uniformly among all beneficiaries and simplify logistical operations by fixing one of the key decision variables in the planning process. Moreover, using standard cargo loads may also increase operational efficiency by allowing operators to move faster down the learning curve due to repetition or by reducing the number of shipments with errors in shipping quantities.

By developing this cube maximization strategy, the truckload might either meet the consumption requirement of a site between consecutive deliveries, or it won't be sufficient to meet beneficiaries' needs, and deprivation time incurs on a recurrent basis. In the first case, the truck can be in continuous motion, as shown in Figure 3.7, or can remain for some time at the depot before performing the next trip, as shown in Figure 3.8. The latter situation is feasible without experiencing deprivation time because the consumption interval for the delivered load to the site would be greater than the length of a vehicle tour.

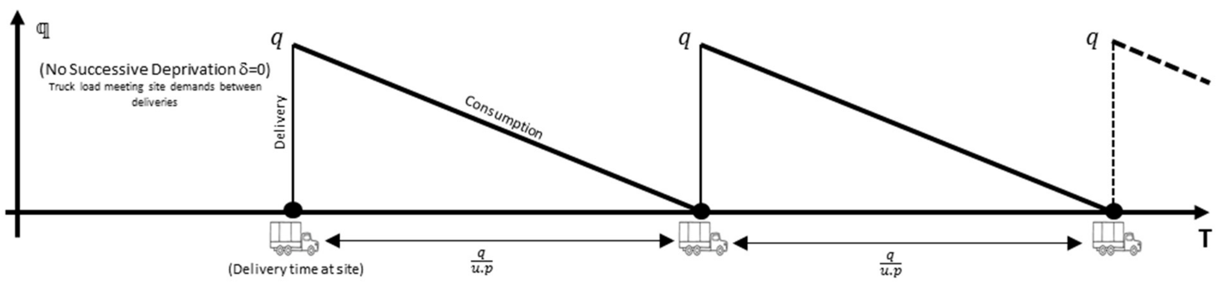


Figure 3.7. Truck load meeting site demand between deliveries. The case of consumption interval matching the tour length

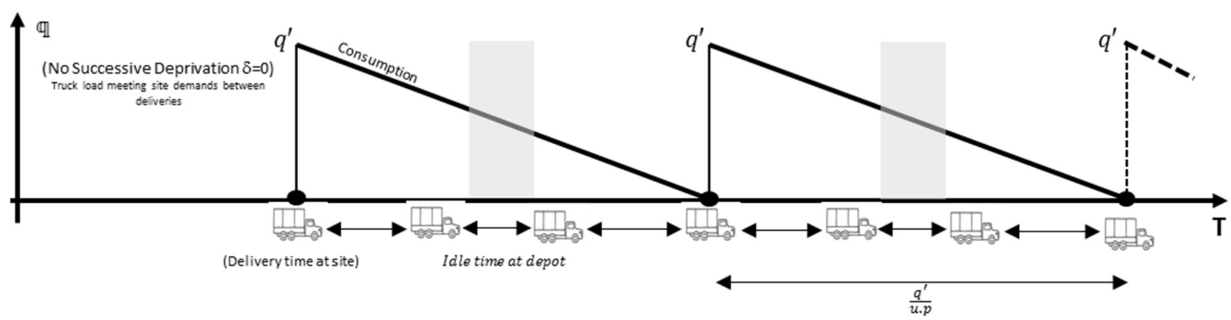


Figure 3.8. Truck load meeting site demand between deliveries. The case of consumption interval exceeding the tour length

In the second case, the shortage of supplies is translated to deprivation time experienced by the site and has a total value equal to the difference between the time horizon ***T*** and the total consumption period $\frac{h.q'}{u.p}$. The shortage of supplies situation suggests that deprivation costs would be minimized by making the times between successive deliveries to a particular demand site equal (Figure 3.9).

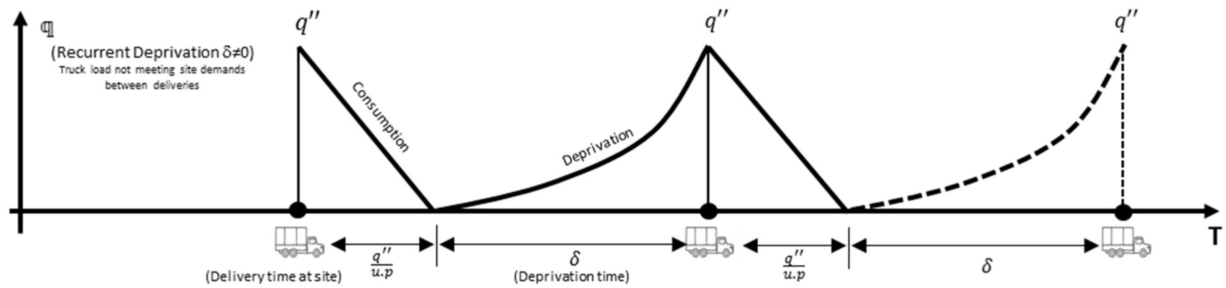


Figure 3.9. Truck load not meeting site demand between deliveries. The case of consumption interval matching the tour length

Define the visit cycle as the sum of a single consumption and deprivation period. Then one of three possible scenarios will be encountered when a site experiences deprivation time:

In the first scenario, the visit cycle coincided with the complete vehicle tour. In this scenario, the vehicle is being operated continuously and there is no idle time imposed at the depot. All depravation periods after the first one are equal in length. This situation is similar to what has been shown previously in Figure 3.9.

In the second scenario, the visit cycle is longer than the complete vehicle tour. In this scenario, the truck would reach the site while still having some supplies, as shown in Figure 3.10. Such overage in supplies is undesirable as it creates congestion or lack of storage capacity at a site. Moreover, an unreasonably high deprivation period will be recognized after the last delivery.

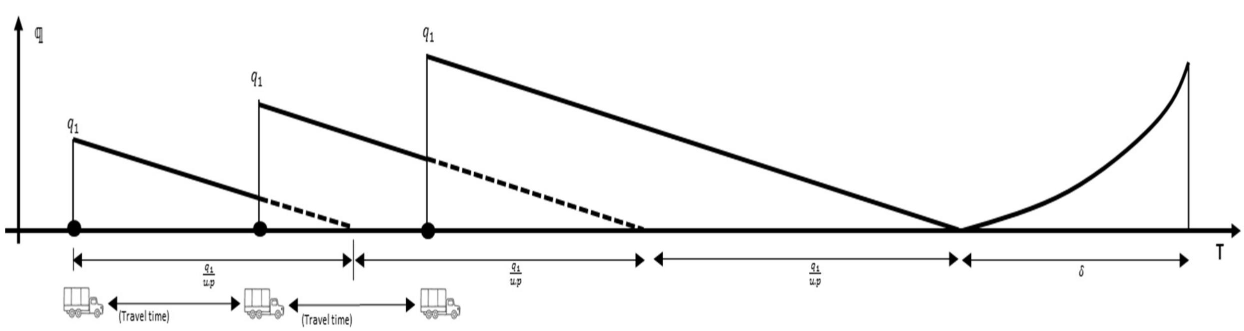


Figure 3.10. Case of visit cycle longer than vehicle tour without idle time at depot

One solution would be to make an additional trip while reducing the delivery quantities; this proposal is not applicable in this case since we are considering full truckloads. Hence, the only option is to impose some idle time at the depot before each trip to distribute the deprivation time evenly across the time horizon as was done in the previous case (Figure 3.11).

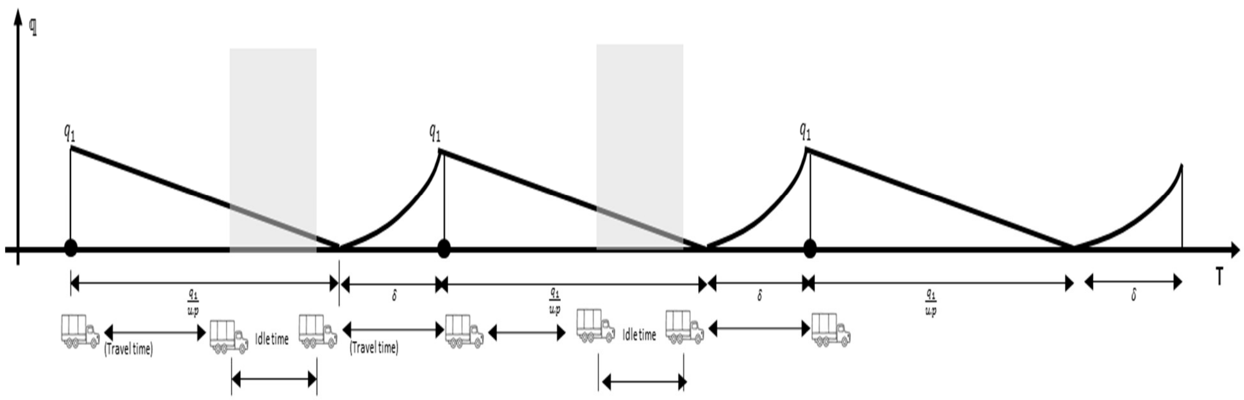


Figure 3.11. Case of visit cycle longer than vehicle tour with idle time at depot

In the third scenario, the visit cycle is shorter than the complete vehicle tour. In this scenario, deprivation time would be extended involuntarily in each visit cycle as each site is waiting for the vehicle to reach the site in its next visit, as shown in Figure 3.12. Some idle time might be imposed at the depot similar to what was done in scenario two so that deprivation time is balanced over all visit cycles Figure 3.13.

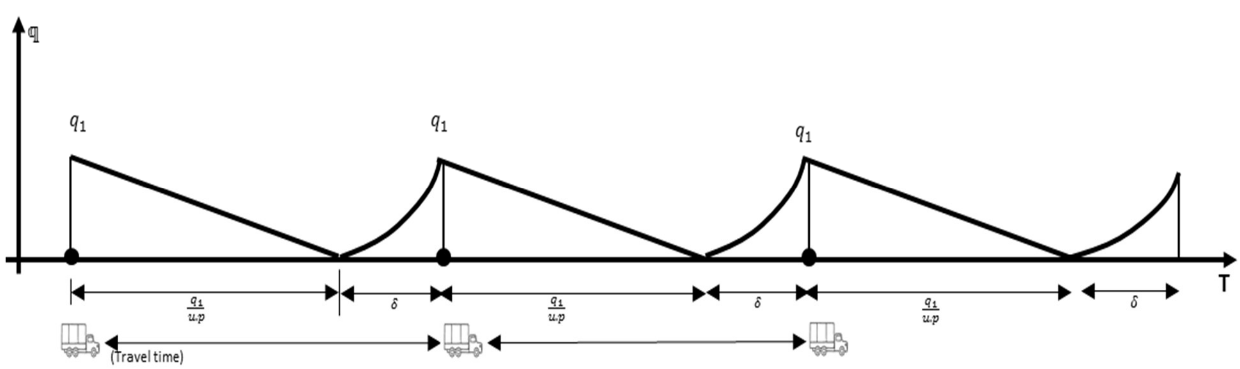


Figure 3.12. Case of visit cycle shorter than vehicle tour without idle time at depot

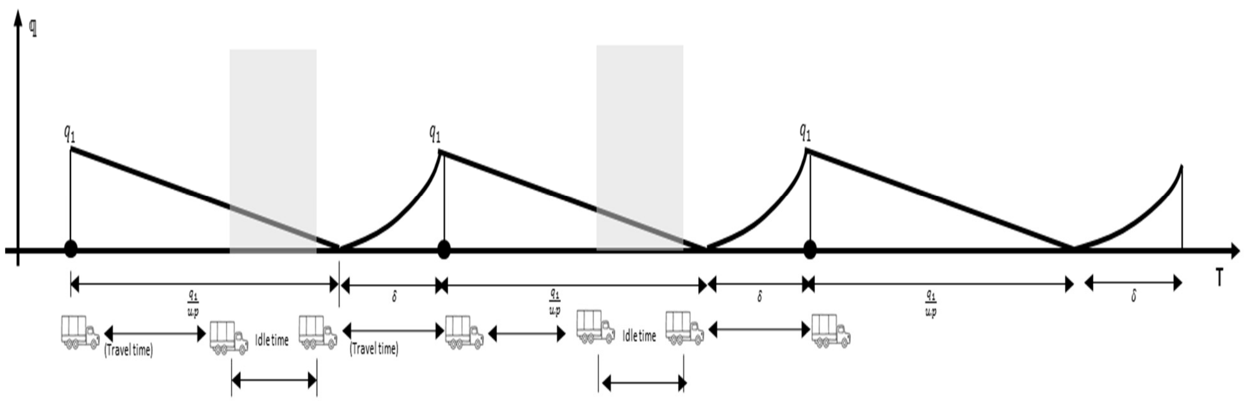


Figure 3.13. Case of visit cycle shorter than vehicle tour with idle time at depot

To conclude, incorporating idle time in this delivery strategy will prevent beneficiaries from experiencing longer deprivations periods toward the end of the planning period. In fact, the total deprivation cost would be reduced. Moreover, the same allocated quantity would be scheduled for delivery to the site, but the timing would differ taking into consideration the match between visit time and tour length. This strategy possesses operational benefits without having any negative social impact on beneficiaries.

3.4.3.2. Direct trips with adjustable delivery quantities strategy

Under high variability in sites' densities or in high levels of supply scarcity, this strategy could allow the decision maker to adjust shipment sizes of demand sites according to their particular characteristics (such as population or location), which could lower total deprivation costs. This strategy would still recommend using vehicle's exclusivity to sites; however, cube maximization won't be a condition to be satisfied while scheduling deliveries to sites. Because of the identical vehicle capacity, some sites will be served with less than a truckload. The deprivation costs are minimized by making frequent, small deliveries to sites closer to the depot (delivering less than a truckload), and fewer but larger deliveries to remote sites (full truck deliveries). Figures 3.14 and 3.15 illustrate the impact travel distance would have on two sites with an identical number of beneficiaries but where the second site is double the travel distance from the depot compared to the first site.

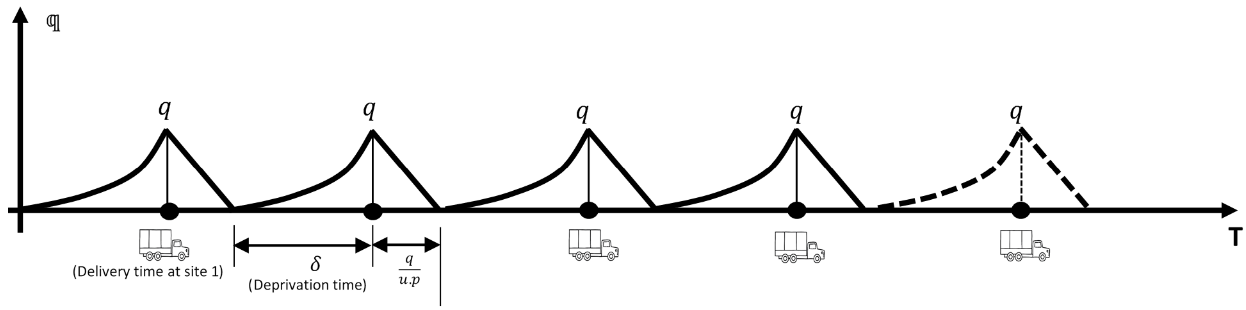


Figure 3.14. Delivery schedule for site 1 located near the depot

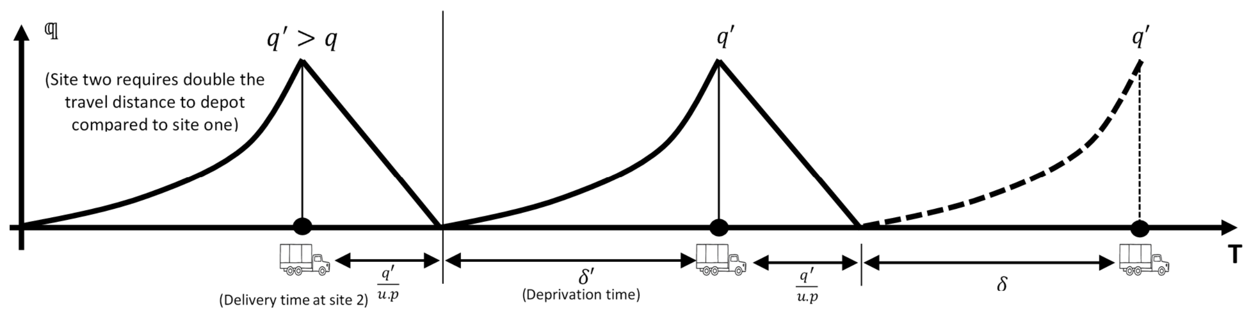


Figure 3.15. Delivery schedule for site 2 located far from the depot

The first site would be visited four times by the same partially filled truck; whereas, the second site would be visited twice with a fully loaded truck in the same time frame. This strategy aims at reducing the variability in deprivation times among sites, although it allocates a disproportionally large share of available supplies to remote nodes.

In case of abundance, the decision maker should allocate supplies uniformly among all beneficiaries and dispatch them to the demand sites in shipments as large as possible, and in such a way that any resulting deprivation periods have the same duration per site.

In either supply scenario, whether there is a scarcity or abundance of supplies, deprivation cost formulation leads to stationary solutions in which the sites are visited in a sequence that repeats time after time. This is the best way to ensure that the deprivation costs do not reach large numbers, and provides a fairer distribution of the resources.

3.4.3.3. Tour trips with variable delivery quantities strategy

So far, the discussed allocation strategies regarded sites as isolated, dense demand points where direct deliveries are initiated by exclusive trucks. Such a set-up scenario might not be apparent in last mile distribution since each site's demand is taking just a portion of a truck's capacity. Meeting their total demands would be faster if the truck were to visit nearby sites without the requisite to return to the depot immediately after each visit.

Example: Consider two demand sites A and B with 10 and 5 units, respectively, and a truck capacity of 15 units. Instead of two disjointed direct deliveries, introducing a tour trip is more appropriate in this case with one truck and a 2.65 hour delivery cycle instead of one truck that makes both deliveries in 4.5 hours, thereby increasing the initial deprivation time at B or A even more. This scenario is shown in Figure 3.16.

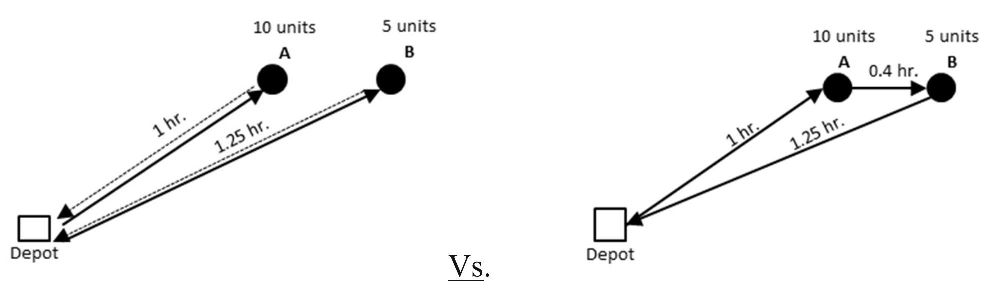


Figure 3.16. Impact of direct and tour trip on initial deprivation time

Allocating supplies along the truck route has proliferated considerations that emerged in the vehicle routing problem. One might argue that if a truck visited a site, then it should meet the site's full requirement for the whole ***T***, provided that the truck's capacity allowed it. Then the recurrent deprivation time for these fully met demand sites is low or nil; whereas, sites that are partially met or excluded from the visit will incur a relatively high deprivation cost depending on the number of beneficiaries present. Hence, taking this view might be operationally sound as it will reduce the transportation cost; however, it causes the deprivation time to stretch out and has negative implications on an equitable allocation strategy. Accordingly, this stipulates that all sites are to be visited in a sequence and supplies allocated such that the total deprivation cost of the route is kept to a minimum. That means sites are to be visited in a cyclical pattern as we will demonstrate later.

<u>*Example*</u>: Consider four demand sites A, B, C, and D, each with four units of demand per unit time and a truck with a capacity of 12 units. Instead of designing a route (0-A-B-C-0) which delivers four units to the first three nodes while node D receives nothing, aggregate deprivation cost would be reduced if all sites are visited (0-A-B-C-D-0) and each receives three units instead in each trip. This will increase the deprivation cost at A, B, and C but reduce the deprivation cost impact at site D. Due to the exponential nature of the deprivation costs, aggregate deprivation costs would decline. This scenario is shown in Figure 3.17.

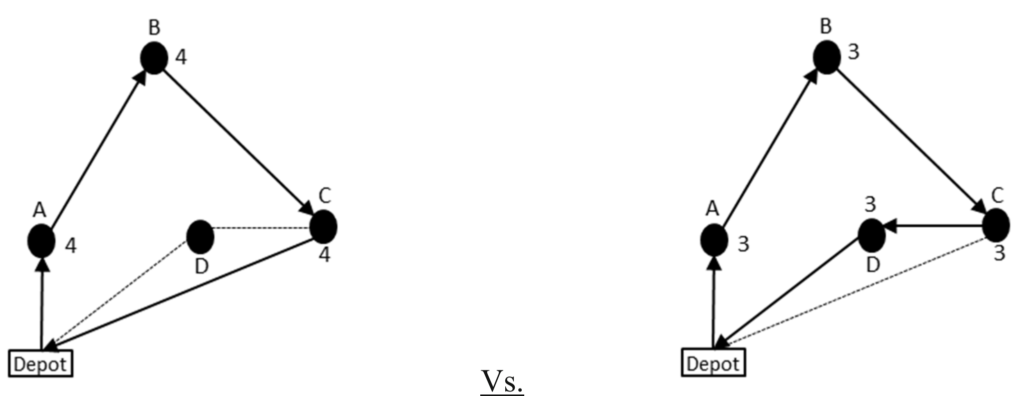


Figure 3.17. Impact of disregarding a site from delivery on total deprivation cost

Another question raised is about the arrival time of the vehicle at the depot in its last trip. Will it be identical, earlier, or later than the consumption planning horizon $\boldsymbol{T}$? Being identical necessitates that $\boldsymbol{T}$ be a multiple of complete tours. If the last trip is to be completed before $\boldsymbol{T}$, then the situation would also be favorable as a vehicle would have met the sites' demand without stretching out the deprivation time. Lastly, if a truck arrived after ***T***, any sites positioned in this additional time frame would be visited but receive no quantity as they already received their allotment in the previous trip. It is generally expected that if a truck visited a site, then some supplies are to be off-loaded and this does not occur in this case. Hence, this option is to be avoided in the problem formulation. That leaves us with the first two situations and balancing the total loads per trip by synchronizing the departure of the truck and allowing idle time between consecutive departures if needed.

Example: Consider a simplified network that consists of two demand sites A and B, both one-hour travel distance from the depot and with a tour length τ of 2.5 hours as shown in Figure 3.18.

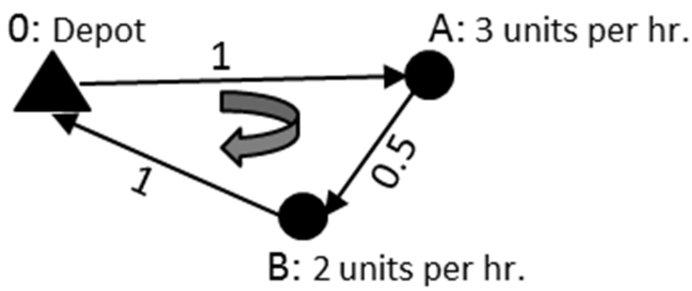


Figure 3.18. Two nodes transportation network for calculating deprivation time on various ***T***

Define ***q*** and ***q'*** as the identical delivered quantities that sites A and B will receive, respectively, in each trip except for the last trip, where they will get ***q**** and ***q*****. Let t_{0A}, t_{AB}, and t_{BO} represent the travel times of a vehicle between the depot and site A, site A and site B, and site B and the depot respectively. Thus the tour length is 2.5 hours.

Three scenarios using consumption planning horizons, ***T***= 10 hours, ***T*** =11.5 hours and ***T*** = 8.75 hours are illustrated below.

Figure 3.19 illustrates that four trips would be possible given such tour length, which added up to match ***T***=10 hours. No idle time is feasible unless the number of trips is reduced by one.

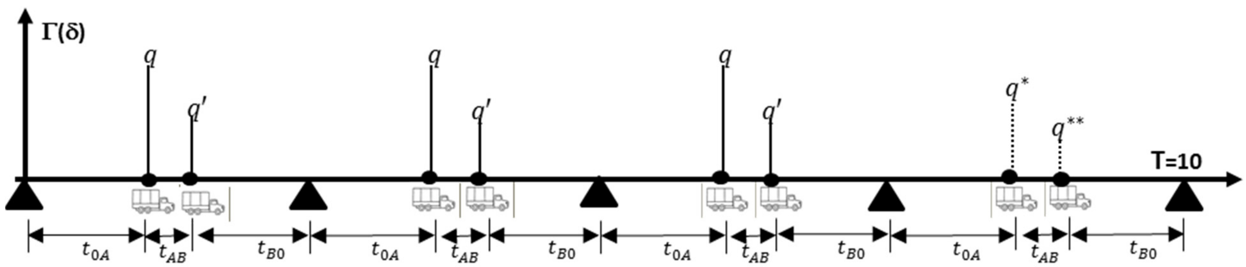


Figure 3.19. Vehicle travel end time matching ***T***

Figure 3.20 illustrates that four trips would be also possible given such tour length, which added up to 10 hours and is less than ***T***=11.5 hours. A total idle time of 1.5 is to be divided among four intervals (shaded areas) so that the tour length is 2.875 instead of 2.5 hours. This balances the total loads per trip.

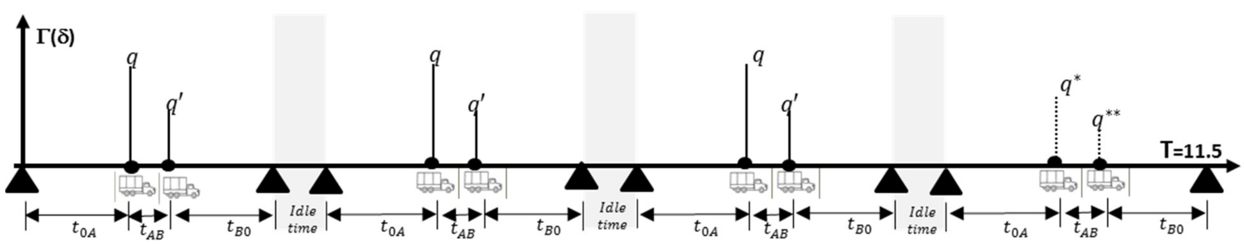


Figure 3.20. Vehicle travel end time less than ***T***

Figure 3.21 illustrates that four trips would be also possible given such tour length, which added up to 10 hours and is more than ***T***=8.75 hours. The vehicle will be scheduled to visit site "B" in its last trip without delivering any supplies. Hence, this situation will be omitted from any future allocation discussion. It will be revised by allowing the vehicle to perform three trips instead of four, and including idle time as needed.

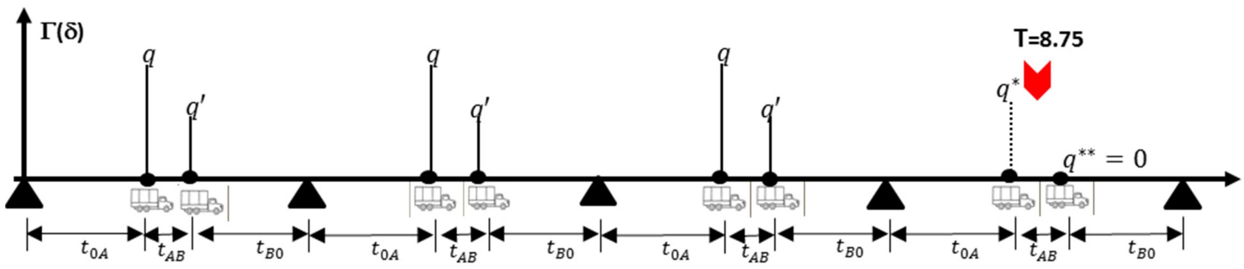


Figure 3.21. Vehicle travel end time more than ***T***

3.4.4. <u>Allocating Resources on a Single Route Assuming Enough Supplies at Depot</u>

At first, if there are enough resources at the depot to satisfy all demand sites, then dispatching the supplies will be prompt without any delay and with quantities compatible with vehicle capacity. The number of trips performed by a vehicle will depend solely on the capacity of the vehicle. The deprivation cost incurred will be associated with the initial deprivation time only.

Assume that the capacity of a vehicle is limited, and that requires scheduling multiple deliveries to each demand site. Start with the structure where a truck continuously travels without stopping. The truck will finish its last trip earlier than ***T*** as long as no additional trip is possible. The allocated quantities in this last trip are regarded as upper bounds to sites when no idle time is applied at the depot and trucks are making continuous trips. When idle time is imposed at the depot, supplies are shifted from the last trip and equally distributed among previous trips. Regardless of the magnitude of the idle time, the proportional allocation to sites is intact for all trips except the last one. For the last trip, extending the idle time will increase the disproportionality of quantities delivered to sites on that trip. Moreover, the total deprivation cost is unaffected by the size of the idle time imposed on the network.

The idle time **Δ** will range between zero and a positive number to be determined. There are certain values used for idle time that will provide some distinct configuration while setting an allocating strategy. Idle time will be identified for each of the following cases: 1) truck delivering equal load in each trip; 2) truck delivering constant quantity to site ***i*** in each trip; 3) truck reaching the depot at ***T***; and 4) latest time permitted for a truck to reach the depot.

Define ***T*** as the consumption planning horizon, ***h*** as the number of deliveries, **τ** as the tour length, and $\hat{\tau}_{0i}$ as the travel time from the depot to site ***i*** visited in the trip sequence. Four cases of idle time are considered.

- Case I - Truck delivering equal load in each trip:

$$Idle\ time\ \Delta = \frac{1}{h}\left\{T - h.\tau - \tau + \frac{p_1(\tau-\hat{\tau}_{01})+p_2(\tau-\hat{\tau}_{02})+\cdots p_n(\tau-\hat{\tau}_{0n})}{(p_1+p_2+\cdots p_n)}\right\} \quad \text{(Eq. 3.12)}$$

- Case II – Truck delivering constant quantity to site i:

$$Idle\ time\ \Delta = \frac{1}{h}(T - h.\tau - \hat{\tau}_{0i}) \quad \text{(Eq. 3.13)}$$

- Case III - Truck reaching the depot at T:

$$Idle\ time\ \Delta = \frac{1}{h-1}(T - h.\tau) \quad \text{(Eq. 3.14)}$$

- Case IV – Latest time permitted for a truck to reach depot:

$$Idle\ time\ \Delta = \frac{1}{h-1}(T - h.\tau + \tau - \hat{\tau}_{0i}) \quad \text{(Eq. 3.15)}$$

where site ***i*** is the last site visited in the trip sequence.

In case of enough resources at depot, equal size quantities are delivered to each site ***i*** except in the last trip. Let these respective quantities denoted by:

$$\begin{cases} q_i^* = (\tau + \Delta).u.p_i \\ q_i^f = (T - \hat{\tau}_{0i}).u.p_i - (h-1).q_i^* \end{cases} \quad \text{(Eq. 3.16)}$$

<u>*Example*</u>: Consider the same network structure as in previous examples (Figure 3.22). Sites A and B need 3 and 2 units per hour, respectively. Assume that the consumption period is ***T***=12 and initially there are abundant supplies at the depot.

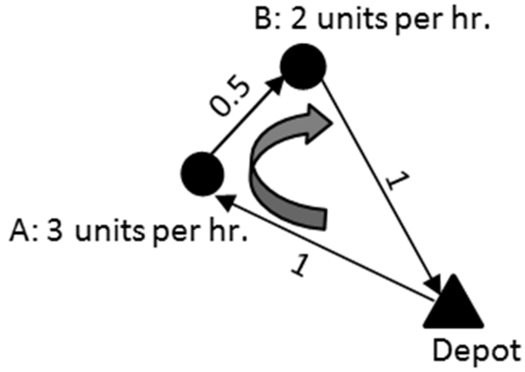


Figure 3.22. Two nodes transportation network for calculating delivery pattern of vehicle

Since we assume that there is enough supply to distribute, site A is expected to receive 36 units reduced by 3 units lost in the first hour. Similarly, site B is expected to receive 24 units reduced by 3 units lost in the first 1.5 hours. Table 3.1 presents a summary for the calculations.

Table 3.1. Variation in idle time and its impact on site deliveries and trips loads

Delivery Pattern of Truck	Idle time (hrs.)	Trip 1 load (units)			Trip 2 load (units)			Trip 3 load (units)			Trip 4 load (units)			Total Qty. (units)	Truck End Time (hrs.)
		A	B	Subtotal	A	B	Subtotal	A	B	Subtotal	A	B	Subtotal		
Continuous operation	0	7.5	5	12.50	7.5	5	12.50	7.5	5	12.50	10.5	6	16.50	54	10
Same quantity to site B	0.125	7.88	5.25	13.13	7.88	5.25	13.13	7.88	5.25	13.13	9.38	5.25	14.63	54	10.38
Equal load in each trip	0.2	8.1	5.4	13.50	8.1	5.4	13.50	8.1	5.4	13.50	8.7	4.8	13.50	54	10.6
Same quantity to site A	0.25	8.25	5.5	13.75	8.25	5.5	13.75	8.25	5.5	13.75	8.25	4.5	12.75	54	10.75
Reaching the depot at T	0.67	9.50	6.33	15.83	9.5	6.33	15.83	9.5	6.33	15.83	4.50	2	6.50	54	12
Latest time permitted	1	10.5	7	17.50	10.5	7	17.50	10.5	7	17.50	1.5	0	1.50	54	13

The following findings are identified for this initial case of abundant supplies. The deprivation cost will be equal to $\gamma = 3 * \Gamma(1) + 2 * \Gamma(1.5)$. The idle time ranges between 0 and 1 so that the number of trips holds. All trips, except the last one, preserve the proportional property for the quantity distributed between site A and B according to their ratio of consumption. As the idle time increases, more supplies shift from the last trip and are split equally among the previous three trips. Reduction of supplies in the last trip will continue until site B receives no supplies; this is a point where the value of the idle time represents the latest travel time permitted for the truck to travel and which the four trips are sustained.

Figure 3.23 illustrates graphically the calculations recorded in Table 3.1. A four-leaf diagram is adopted where each leaf displays one trip sequence at a time and continues to the next trip starting from the upper right quadrant clockwise to the upper left. The numerical value in the box next to each trip represents the arrival time of the vehicle at the depot before any idle time is imposed. Each of the six leaf diagrams represent the vehicle trip series under different idle time values. Six values of idle time were applied and are presented graphically.

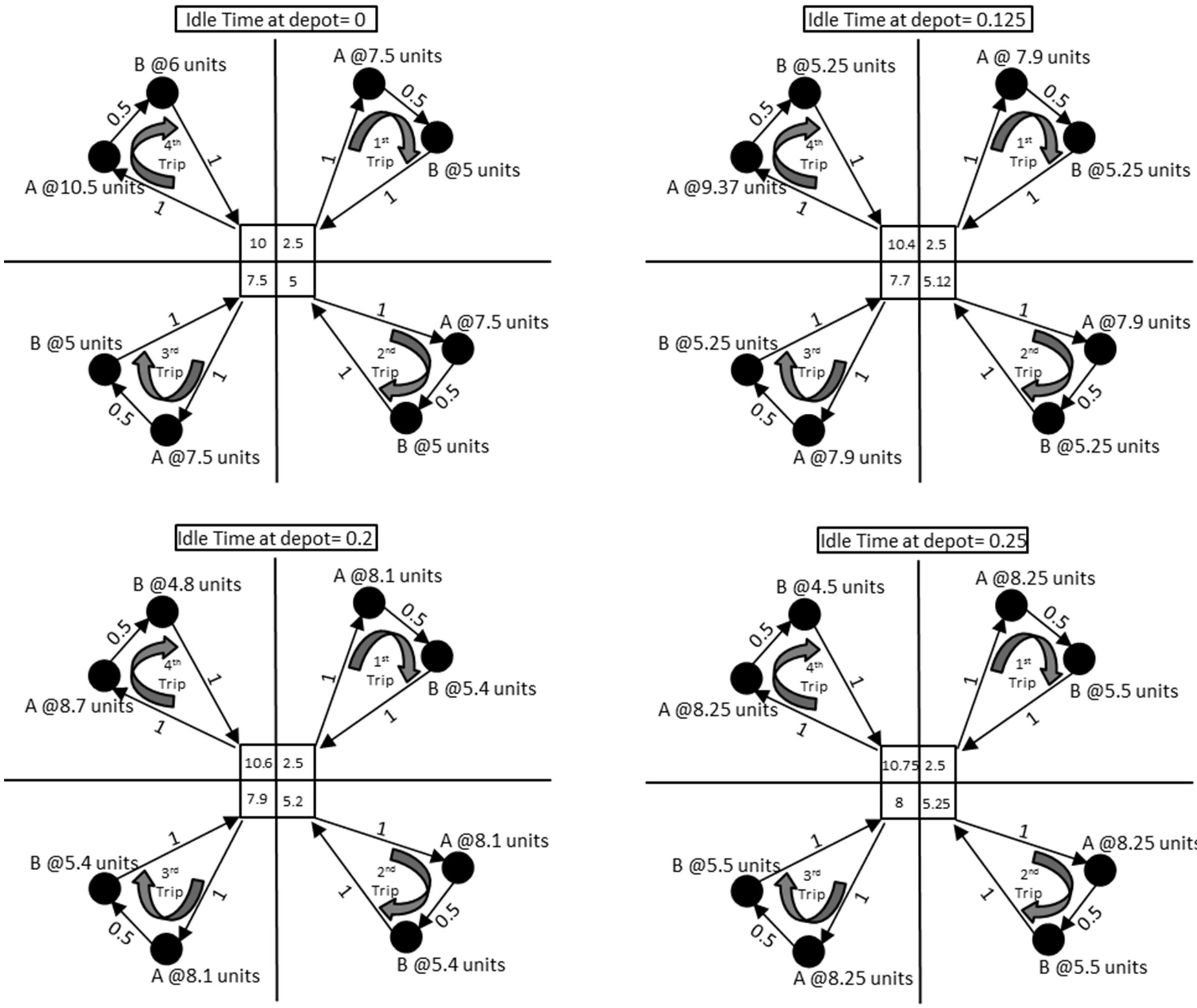


Figure 3.23. Four-leaf diagram to represent vehicle trips under different idle time values

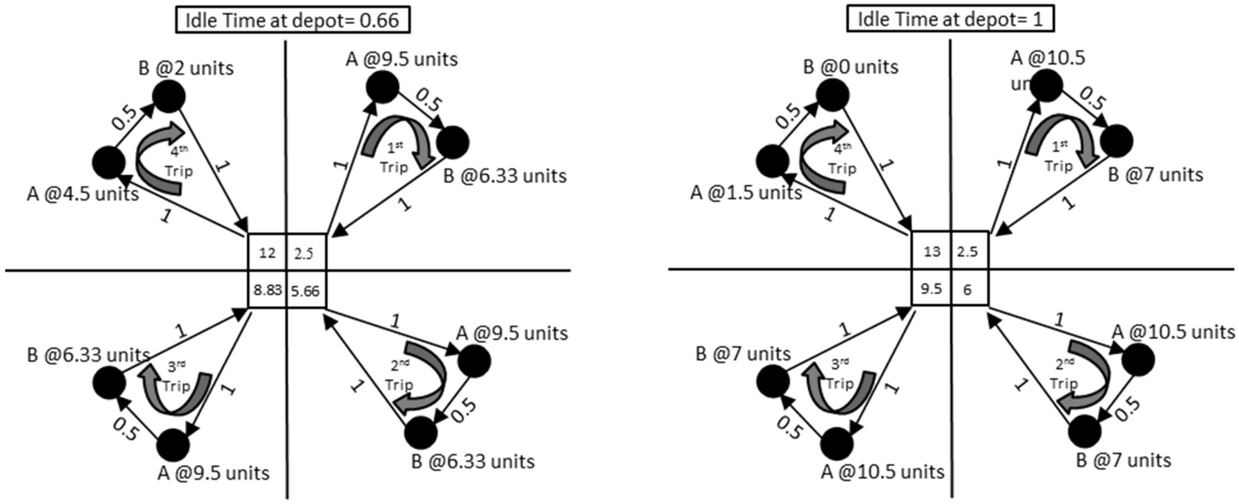


Figure 3.23. Four-leaf diagram to represent vehicle trips under different idle time values (continued)

Figure 3.24 is another illustrative presentation of Table 3.1; however, the emphasis here is to highlight the movement of a vehicle and its consecutive stopover at sites along the x-axis while tracing consumption levels of each site on the y-axis. It visualizes how the idle time increases will induce more supplies to be shifted from the last trip and split equally among the previous three trips.

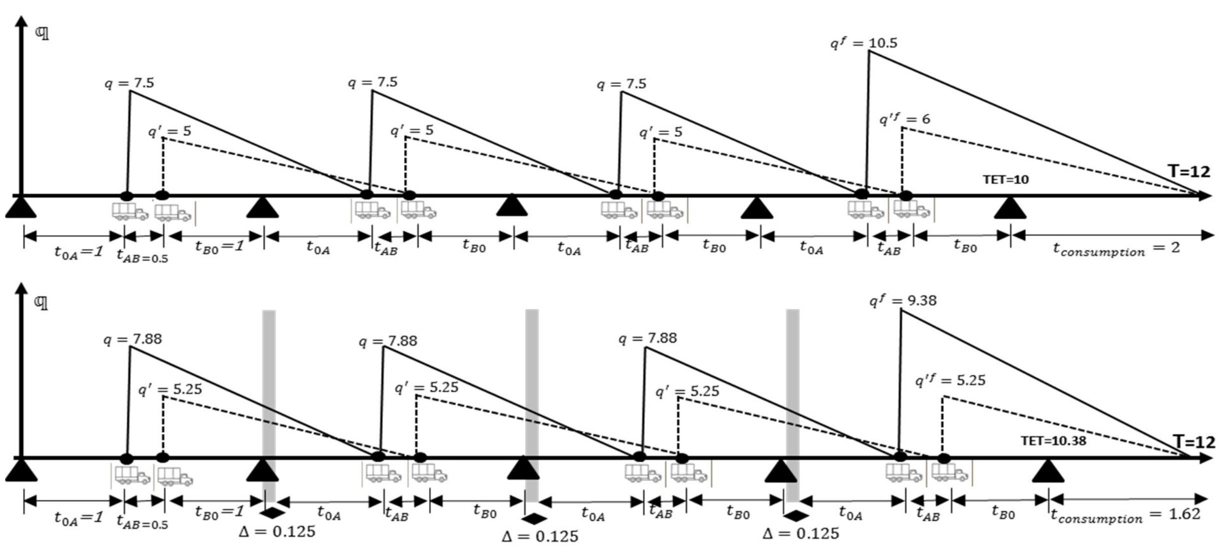


Figure 3.24. Duality of variation in idle time and shift in supplies from the last trip

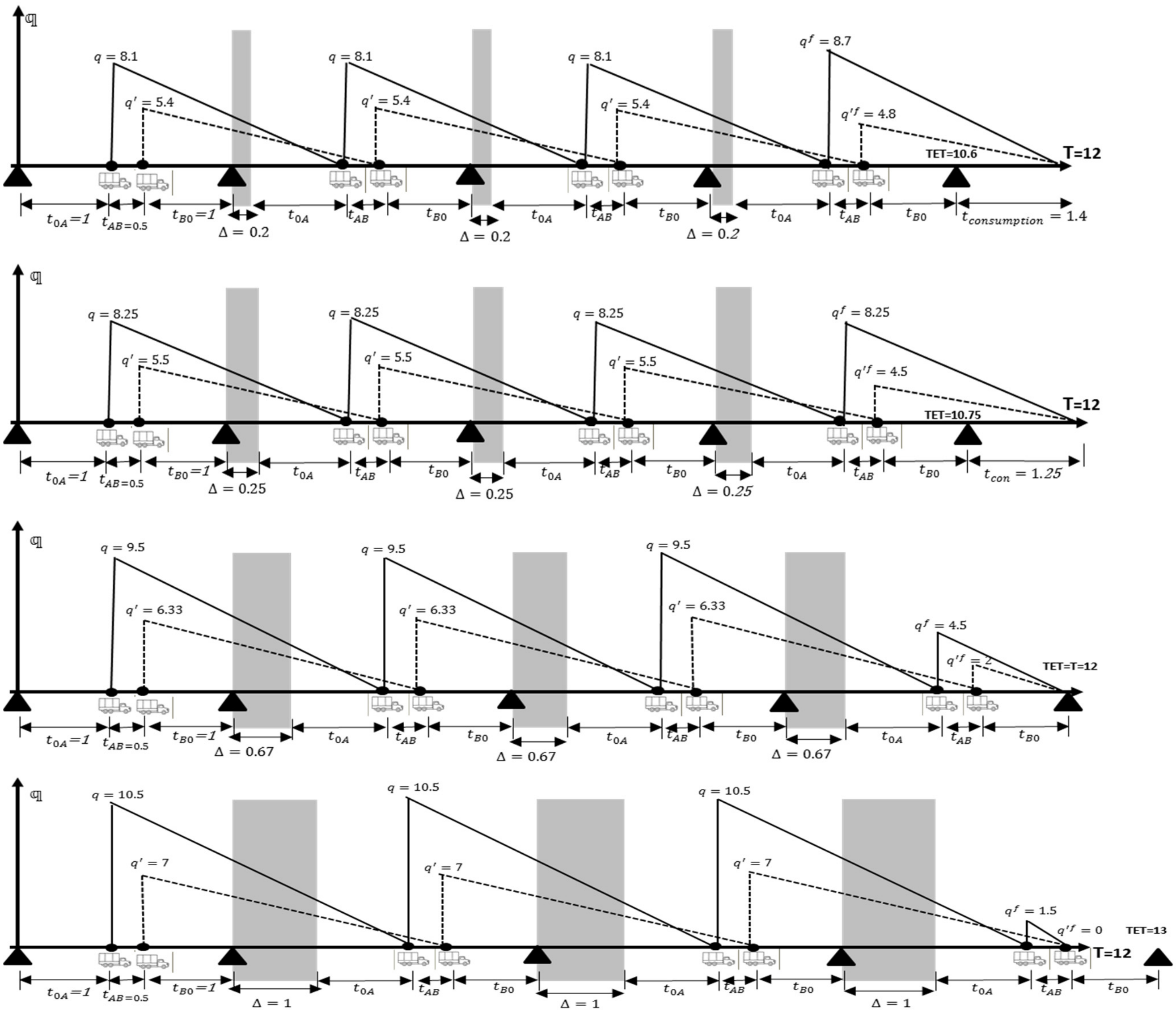


Figure 3.24. Duality of variation in idle time and shift in supplies from the last trip (continued)

Exceeding the idle time limit of one will reduce the total number of trips and increase the vehicle load per trip as illustrated in Table 3.2 for values $\Delta = 1.5$ *and* $\Delta = 2.5$ to reach a one trip delivery.

Table 3.2. Variation in idle time and its impact on number of trips

Frequency of Trips	Idle time (hrs.)	Trip 1 load (units)			Trip 2 load (units)			Trip 3 load (units)			Trip 4 load (units)			Total Qty. (units)	Truck End Time (hrs.)
		A	B	Subtotal	A	B	Subtotal	A	B	Subtotal	A	B	Subtotal		
3 Trips	1.5	12	8	20.00	12	8	20.00	9	5	14.00	-	-	0.00	54	10.5
2 Trips	2.5	15	10	25.00	18	11	29.00	-	-	0.00	-	-	0.00	54	7.5
1 Trip	N/A	33	21	54.00	-	-	0.00	-	-	0.00	-	-	0.00	54	2.5

As a generalized result in the case of allocating enough resources, the deprivation cost value is based on the initial deprivation time occurred by a truck traveling from the depot to each site during its first trip. Also, as long as the idle time is spread over the entire planning horizon, there are many combinations to allocate supplies among sites while preserving the minimum deprivation cost. Among these combinations, three broad allocation schemes will be identified: (1) when a truck will be in continuous operation, (2) when a truck makes a stopover at the depot and deliver a non-zero load to any site in the last trip, and (3) when a truck makes fewer or more trips. Hence, idle time can be used as a tool to alter the number of trips or to balance the loads across trips or to identify the appropriate vehicle type to be used while maintaining the same deprivation cost in this configuration. In applying the cube maximization strategy to the example problem, a vehicle with 13.5 units of capacity and an idle time of 0.2 hours would be appropriate while scheduling four equal load deliveries.

3.5. Mathematical Model for Single Route Resource Allocation

This section will elaborate more on what has been discussed so far about idle time with the allocation of resources if shortages occur. Initially, it has been shown that delaying the vehicle from departing the depot will just redistribute the vehicle load among trips to match the modified tour length. The proportionality rule will be sustained and no rise incurred to the deprivation time; and hence, no impact on the overall deprivation cost. In connection to this, reaching the lowest deprivation cost would necessitate that deprivation time, other than in the initial period, be split equally among trips performed. Moreover, it has been recognized that quantities allocated per site will be of the same size for all trips except the last one performed. Hence, understanding the behavior of the first and last delivery in a cyclical distribution schedule would simplify the problem. This section will extend the discussion on how the resources are allocated among sites visited in the same trip if supply shortages are experienced at the depot. The strategic goal is to determine how much to deliver to each site per trip so that the total deprivation cost is minimized.

Formulating a mathematical model holding these characteristics mentioned above would allow reaching an initial allocation solution while relaxing the problem using a single vehicle continuously roving with unlimited capacity and a fixed sequence in visiting all sites. This model is built upon the key insight of the previous work done by Pèrez (2011) with two modifications that were discussed in section 3.4.2. First, the first trip will start immediately at t=0 without any delay imposed, a justifiable action as an initial response call for relief efforts. Second, the model considers allocation quantities to vary by demand site per trip.

3.5.1. Assumptions and Simplifications

Some assumptions and simplifications are made in order to make the resulting model useful for the characteristics of the operation and users.

- The planning horizon ***T*** denoted the total consumption period provisioned for each beneficiary.
- All sites begin operating at the same time *t*=0 and end at T.
- The depot begins operating at *t*=0 and can end operating before reaching T.
- Each site has a known geographical location and must be visited at least once in the entire planning horizon.
- There is a limited supply in the depot.
- Supplies delivered to sites are to be consumed before ***T***. No leftover exists beyond ***T***.
- Shortages experienced by any site is regarded as lost and won't be accounted for in the next delivery.

- The consumption rate $\boldsymbol{u}$ is a constant and deterministic rate over the planning horizon. Assume that $\boldsymbol{u}$ is equal to one, i.e., one package is required to sustain a beneficiary for one unit of time.
- The theoretical total quantity demanded at various sites can be correctly estimated before the beginning of the planning horizon. It is based on the number of beneficiaries at a site and the consumption rate $\boldsymbol{u}$. Demand is assumed unchanged during all planning time periods.
- It is assumed that the deprivation cost function has been previously quantified and properly calibrated. Deprivation cost is assumed to be uniform for beneficiaries across all sites.
- Unlimited numbers of identical vehicles are used to transport supplies.
- Each and every demand site is assigned to exactly one vehicle.
- The traveling time between depot and sites is deterministic.
- The time spent at the depot or at a site $\boldsymbol{i}$ to load or unload a vehicle is ignored.
- Vehicles are assumed to operate continuously, with no limits on trip length or duration. A vehicle is driven by multiple drivers; a frequent practice in humanitarian operations.
- Each site can be visited more than one time during the planning horizon. The delivered quantity should be large enough to serve all beneficiaries in a site for at least one period of time.
- The optimal quantity delivered to a site is when this site reaches its zero stock level and coincides with a vehicle visiting the site.

Based on the aforementioned framework and postulations, a single route allocation problem will be formulated and preceded by defining its notation in the following section.

3.5.2. Mathematical Notation

3.5.2.1. Parameters

T= Planning Horizon

E= Initial inventory available at depot

P_i= Population at demand site ***i***

u= Consumption rate

ɵ= Number of time periods satisfied by a full serving of supplies

L_i= Demand rate of site i per time unit. $L_i = u.p_i$

Q= Vehicle capacity

τ= Tour travel time

$\hat{\tau}_{0i}$= Travel time along the tour between depot and the demand site ***i***

δ_i^0= Initial deprivation time experienced by the beneficiaries at demand site ***i***. Such duration is fixed and equal to the travel time taken between the depot and site ***i***.

3.5.2.2. Decision Variables

h= Number of trips to be performed

q_i^*= Amount of supplies per shipment to demand site ***i*** except for the last trip

q_i^f= Amount of supplies to demand site ***i*** in the final trip

δ_i^*= Average deprivation time experienced by the beneficiaries at demand node ***i*** during deprivation time periods ***1***,…,***h***

γ_i= Deprivation cost for demand point ***i***

3.5.3. Mathematical Model

The mathematical model to minimize total deprivation costs experienced at each demand site over $\boldsymbol{T}$ is:

$$DPV(E)\text{: Minimize} \quad \sum_{i \epsilon N} \gamma_i \tag{Eq. 3.17}$$

Subject to

- The deprivation cost would be minimized by splitting the deprivation time in $\boldsymbol{h}$ equal deprivation periods

$$\delta_i^* \geq \frac{1}{h}.\left(T - \delta_i^0 - \frac{(h-1).q_i^* + q_i^f}{u.P_i}\right) \quad \forall i \in N \tag{Eq. 3.18}$$

- Define the total deprivation costs experienced at each site

$$\gamma_i \geq P_i.\left(\Gamma(\delta_i^0) + h.\Gamma(\delta_i^*)\right) \quad \forall i \in N \tag{Eq. 3.19}$$

- Any delivery to a site should be large enough to meet the needs of all its beneficiaries for at least e periods of time. This will prevent partial deliveries from creating time-expanded network.

$$q_i^* \geq \text{e}.u.P_i \quad \forall i \in N \tag{Eq. 3.20}$$

- Define an upper bound for deliveries based on the supply inventory available at depot

$$\sum_{i \epsilon N} \left((h-1).q_i^* + q_i^f\right) \leq E \tag{Eq. 3.21}$$

- Define an upper bound for deliveries per trip based on the maximum vehicle capacity

$$\sum_{i \epsilon N} q_i^* \leq Q \quad \forall i \in N \tag{Eq. 3.22}$$

- Define an upper bound for last trip delivery based on the maximum vehicle capacity

$$\sum_{i \epsilon N} q_i^f \leq Q \quad \forall i \in N \tag{Eq. 3.23}$$

- Define a time frame for total deprivation and consumption periods on the time horizon $\boldsymbol{T}$

$$\delta_i^0 + h.\delta_i^* + \frac{(h-1).q_i^* + q_i^f}{u.P_i} = T \quad \forall i \in N \qquad \text{(Eq. 3.24)}$$

- Define a time frame for deprivation and consumption period over a single trip

$$\delta_i^* + \frac{q_i^*}{u.P_i} = \tau \quad \forall i \in N \qquad \text{(Eq. 3.25)}$$

- Number of trips must be integer and requiring at least a single delivery to each site

$$h \geq 1\, , integer \quad \forall i \in N \qquad \text{(Eq. 3.26)}$$

- All deprivation costs of sites must be non-negative

$$\gamma_i \geq 0 \quad \forall i \in N \qquad \text{(Eq. 3.27)}$$

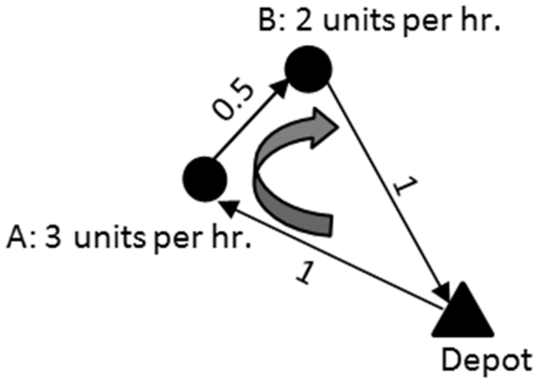
- All delivered quantities to sites must be non-negative

$$q_i^* \geq 0 \;\; ; \;\; q_i^f \geq 0 \quad \forall i \in N \qquad \text{(Eq. 3.28)}$$

Solving this mixed integer formulation model will determine the optimal number of trips, the quantity of supplies, and the timing of deliveries to each demand site that minimizes total deprivation costs over a planning horizon $\boldsymbol{T}$. However, several non-linear constraints are generally making this problem more difficult to solve. The following two demand sites example were solved using Frontline Solver add-in with Microsoft Excel for non-linear mathematical optimization, e.g., MINLP.

3.5.4. Illustrative Example

Consider the same network structure adopted in previous examples. Sites A and B need 3 and 2 units per hour, respectively. Assume that the consumption period $\boldsymbol{T}$=12. Let $\boldsymbol{\lambda}$ be the level of services which is the percentage obtained in dividing the initial amount of supplies available at the depot by the total theoretical demand from sites. Ten service levels are used in this example: 100%, 90%, 80%…, 20%, 10% as shown in Figure 3.25 below.



λ	Available Supplies
100%	60
90%	54
80%	48
70%	42
60%	36
50%	30
40%	24
30%	18
20%	12
10%	6

Figure 3.25. Two nodes transportation network for allocating resources on various $\boldsymbol{\lambda}$

Consider a deprivation cost function mentioned in subchapter 3.3 and introduced by Holguin-Veras et al. (2011). The deprivation time $\boldsymbol{\delta}$ produced by the lack of water since the prior water consumption could be formulated by the time function $\Gamma(\delta) = e^{1.5031+0.1172*\delta} - e^{1.5031}$.

When $\boldsymbol{\lambda}$=100%, even though the theoretical demand is 60 units, still site A is expected to receive 36 units reduced by 3 units lost in the first hour. Similarly, site B is expected to receive 24 units reduced by 3 units lost in the first 1.5 hours.

Set the idle time to zero, $\boldsymbol{\Delta}$=0. The truck travel end time is at 10 hours after performing four trips. The repeated consumption/deprivation cycle for both sites is 2.5 hours while the final cycle duration varies; 3.5 hours to site A and 3 hours to site B. The metric total deprivation per person-hr. represents the accumulated deprivation time experienced by an individual during the planning horizon $\boldsymbol{T}$.

The output from solving this model is provided in Table 3.3. Each service level is considered separately and the outputs are provided in sub-tables.

Table 3.3. Effect of service level on resource allocation for a two node network

λ=100% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	7.50	10.50	33.00	1.00	0.00	1.00	0.56	0.00	1.68	3.50
B	5.00	6.00	21.00	1.50	0.00	1.50	0.86	0.00	1.73	3.00
Total	**12.50**	**16.50**	**54.00**	-	-	-	-	-	**3.41**	-
Ratio	**1.50**	**1.75**	**1.57**	-	-	**0.67**	-	-	-	-

λ=90% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	7.50	10.50	33.00	1.00	0.00	1.00	0.56	0.00	1.68	3.50
B	5.00	6.00	21.00	1.50	0.00	1.50	0.86	0.00	1.73	3.00
Total	**12.50**	**16.50**	**54.00**	-	-	-	-	-	**3.41**	-
Ratio	**1.50**	**1.75**	**1.57**	-	-	**0.67**	-	-	-	-

λ=80% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	6.60	9.60	29.41	1.00	0.30	2.20	0.56	0.16	3.61	3.50
B	4.40	5.40	18.59	1.50	0.30	2.71	0.86	0.16	3.02	3.00
Total	**11.00**	**15.00**	**48.00**	-	-	-	-	-	**6.63**	-
Ratio	**1.50**	**1.78**	**1.58**	-	-	**0.81**	-	-	-	-

λ=70% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	5.70	8.70	25.80	1.00	0.60	3.40	0.56	0.33	5.61	3.50
B	3.80	4.80	16.20	1.50	0.60	3.90	0.86	0.33	4.35	3.00
Total	**9.50**	**13.50**	**42.00**	-	-	-	-	-	**9.96**	-
Ratio	**1.50**	**1.81**	**1.59**	-	-	**0.87**	-	-	-	-

λ=60% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	4.80	7.80	22.20	1.00	0.90	4.60	0.56	0.50	7.68	3.50
B	3.20	4.20	13.80	1.50	0.90	5.10	0.86	0.50	5.74	3.00
Total	**8.00**	**12.00**	**36.00**	-	-	-	-	-	**13.42**	-
Ratio	**1.50**	**1.86**	**1.61**	-	-	**0.90**	-	-	-	-

Table 3.3. Effect of service level on resource allocation for a two node network (continued)

λ=50% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	3.90	6.90	18.60	1.00	1.20	5.80	0.56	0.68	9.83	3.50
B	2.60	3.60	11.40	1.50	1.20	6.30	0.86	0.68	7.17	3.00
Total	**6.50**	**10.50**	**30.00**	**-**	**-**	**-**	**-**	**-**	**17.00**	**-**
Ratio	**1.50**	**1.92**	**1.63**	**-**	**-**	**0.92**	**-**	**-**	**-**	**-**

λ=40% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	3.00	6.00	15.00	1.00	1.50	7.00	0.56	0.86	12.06	3.50
B	2.00	3.00	9.00	1.50	1.50	7.50	0.86	0.86	8.65	3.00
Total	**5.00**	**9.00**	**24.00**	**-**	**-**	**-**	**-**	**-**	**20.71**	**-**
Ratio	**1.50**	**2.00**	**1.67**	**-**	**-**	**0.93**	**-**	**-**	**-**	**-**

λ=30% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	2.10	5.10	11.41	1.00	1.80	8.20	0.56	1.06	14.36	3.50
B	1.40	2.40	6.59	1.50	1.80	8.70	0.86	1.06	10.19	3.00
Total	**3.50**	**7.50**	**18.00**	**-**	**-**	**-**	**3.41**	**5.28**	**24.55**	**-**
Ratio	**1.50**	**2.13**	**1.73**	**-**	**-**	**0.94**	**-**	**-**	**-**	**-**

λ=20% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	1.20	4.20	7.80	1.00	2.10	9.40	0.56	1.26	16.75	3.50
B	0.80	1.80	4.20	1.50	2.10	9.90	0.86	1.26	11.78	3.00
Total	**2.00**	**6.00**	**12.00**	**-**	**-**	**-**	**-**	**-**	**28.52**	**-**
Ratio	**1.50**	**2.33**	**1.86**	**-**	**-**	**0.95**	**-**	**-**	**-**	**-**

λ=10% , Δ=0, Four deliveries, Truck arrives to depot at 10 Hrs., Repeated cycle duration 2.5 Hrs.										
Site	q^*	q^f	Total Delivered	δ^0 (Hrs.)	δ^* (Hrs.)	Total Depriv. (person-hr)	$\Gamma(\delta^0)$	$\Gamma(\delta^*)$	Total Depriv. Cost γ	Final Cycle duration (Hrs.)
A	0.30	3.30	4.21	1.00	2.40	10.60	0.56	1.46	19.21	3.50
B	0.20	1.20	1.79	1.50	2.40	11.10	0.86	1.46	13.43	3.00
Total	**0.50**	**4.50**	**6.00**	**-**	**-**	**-**	**-**	**-**	**32.64**	**-**
Ratio	**1.52**	**2.76**	**2.35**	**-**	**-**	**0.95**	**-**	**-**	**-**	**-**

Figure 3.26 is another illustrative presentation of Table 3.3; however, the emphasis here is to highlight the movement of a vehicle and its consecutive stopover at sites along the x-axis while tracing the exponential trend of deprivation cost for each site on the y-axis. It visualizes how the decrease in service level will reduce the allocation per site in each trip and how the deprivation time is split equally among them during the planning horizon ***T***.

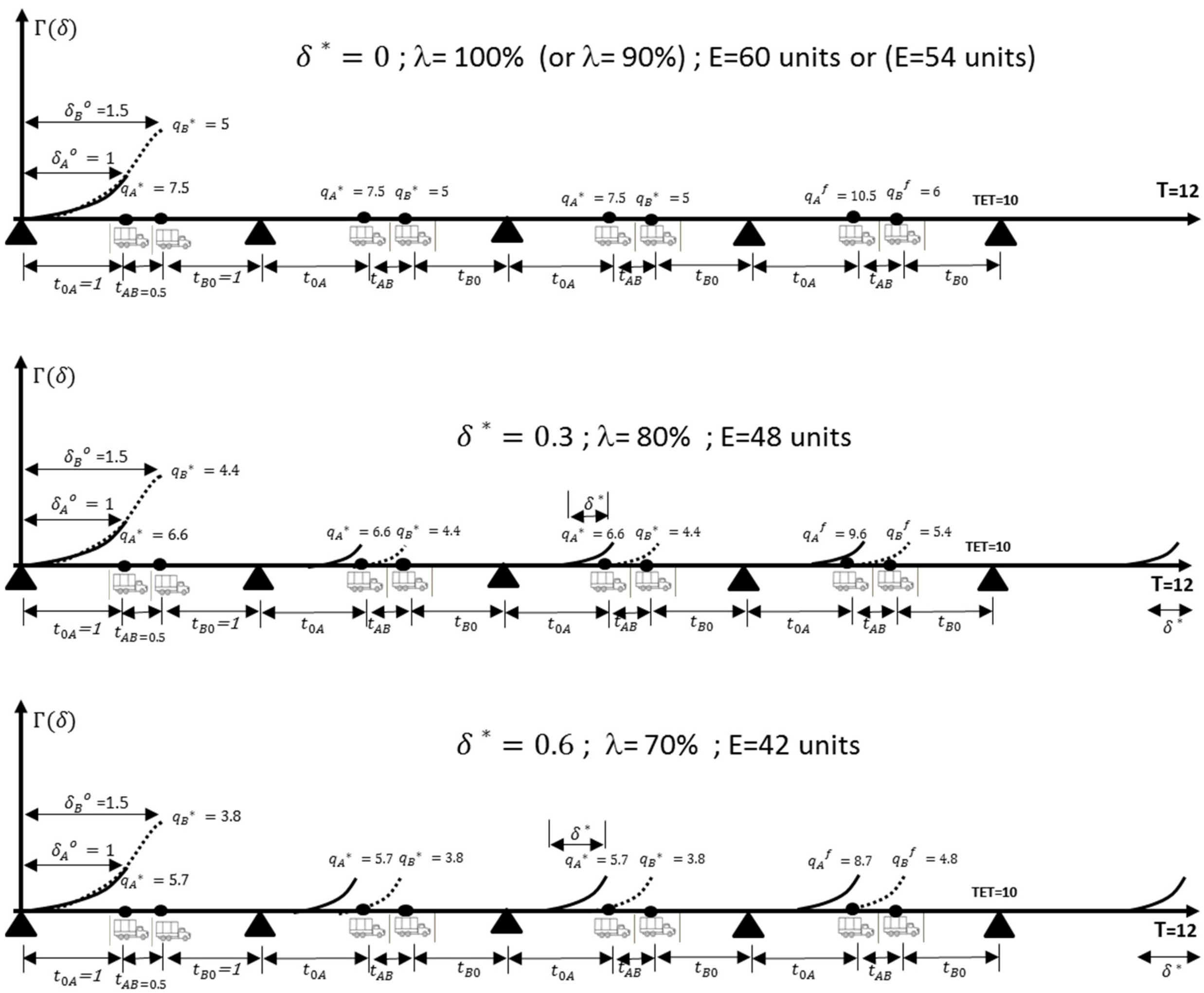


Figure 3.26. Effect of service level on resource allocation and deprivation cost for a two node network

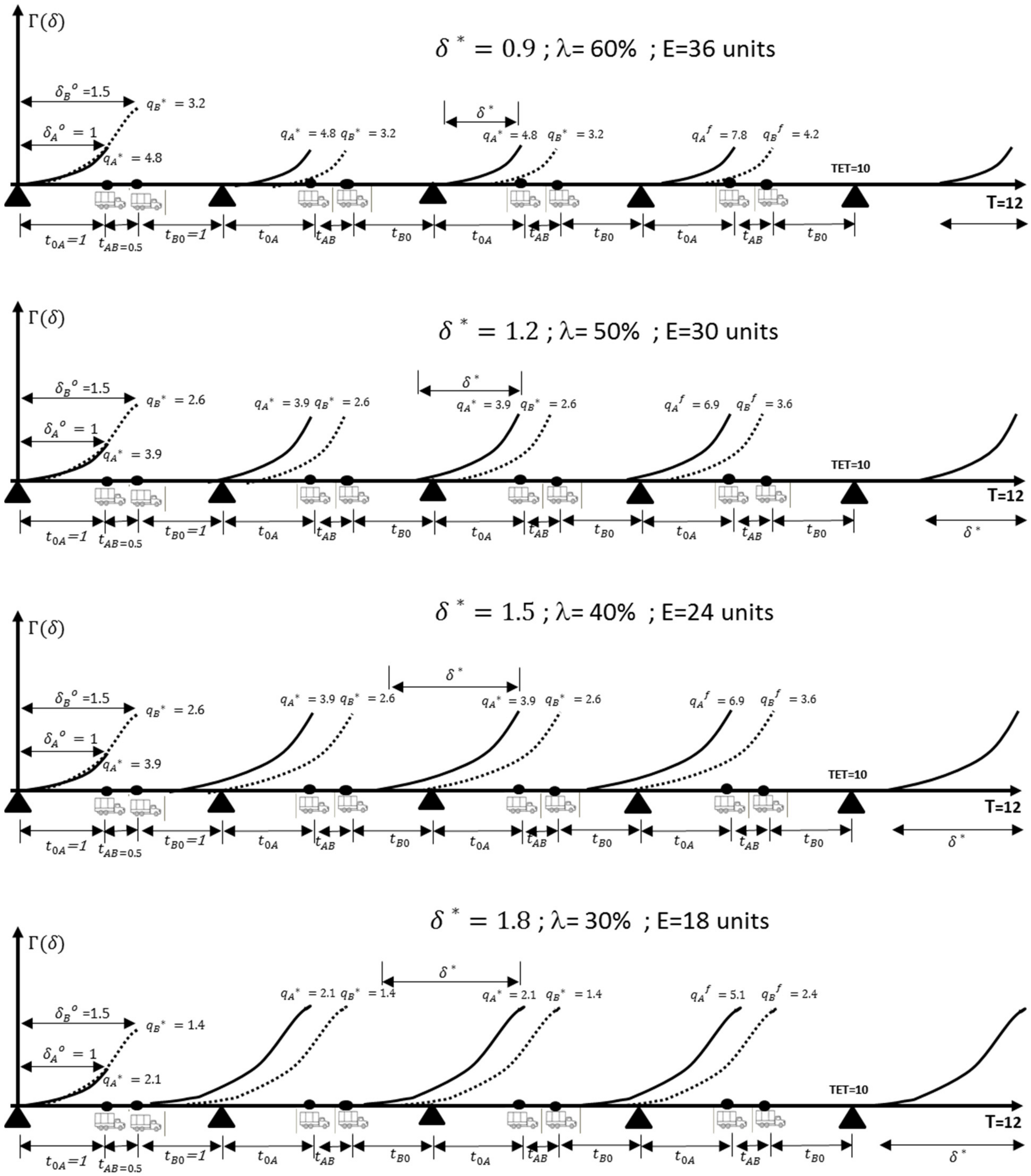


Figure 3.26. Effect of service level on resource allocation and deprivation cost for a two node network (continued)

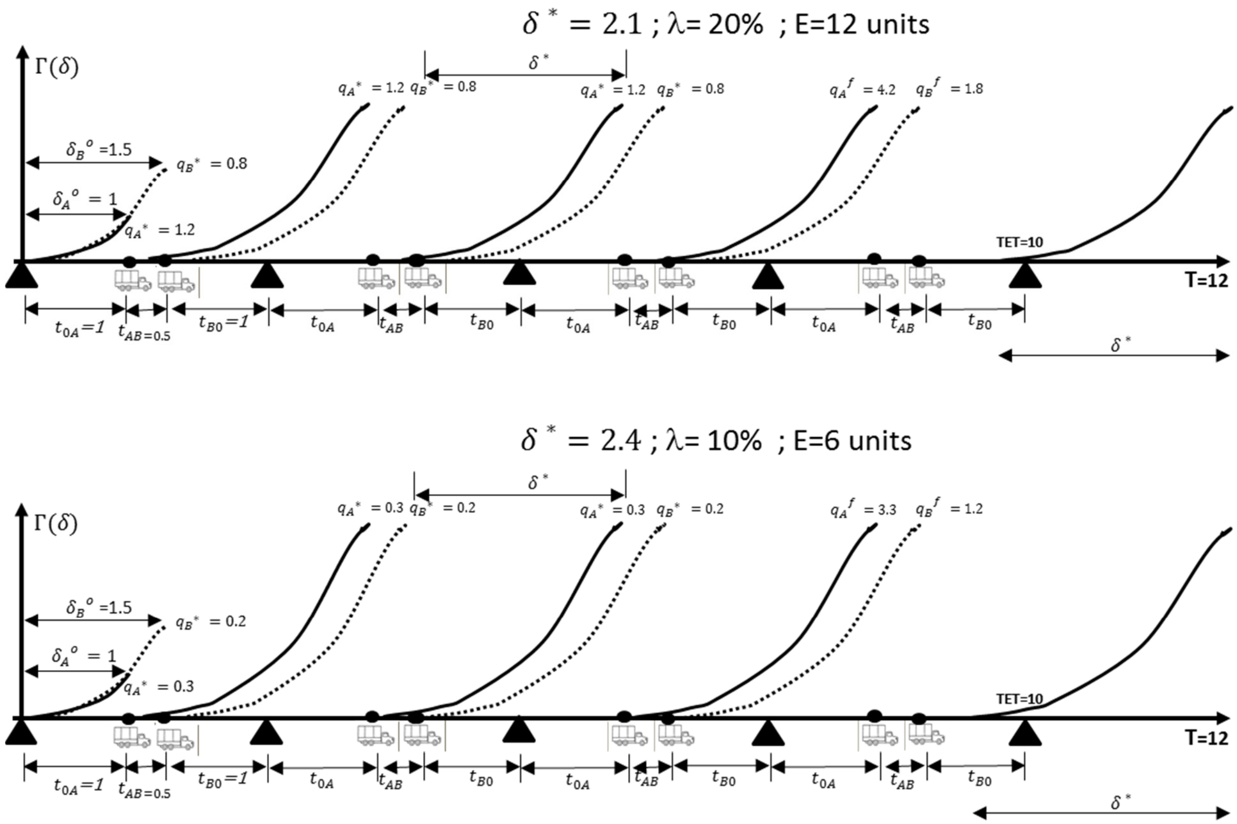


Figure 3.26. Effect of service level on resource allocation and deprivation cost for a two node network (continued)

The following findings are identified when supply shortages exist at the depot. The lower and upper bound for the deprivation cost are 3.41 and 69.33, respectively. As expected, the deprivation cost is rising as the shortage increases. Similar to the abundant resources case, all trips, except the last one, preserve the proportionality property as the quantity distributed between site A and B is proportional to their ratio of consumption. This ratio seamlessly holds for λ>10% and, to a large extent, for extreme scarcity in supplies of λ=10% or less. At a 30% service level, the delivery to site B wasn't large enough to meet the needs of all its beneficiaries for at least one period of time. Demand rate for site B is 2 units per unit time; whereas, it has been allocated 1.4 units or lower for $\lambda \leq$ 30%. To overcome this shortfall, either the number of trips are to be reduced by one or the equation (Eq. 3.20) in the model constraint $q_i^* \geq$ $e.u.P_i \quad \forall i \in N$ is relaxed so that a solution to the model is reached.

The deprivation time experienced by a beneficiary at either node is equally spaced between consecutive deliveries and sustained under various service levels. The lower the service level, the higher the deprivation time would be until reaching the trip length value of 2.5 hours. This can be generalized if the number of trips is reduced to three, two, or one. The results are summarized Table 3.4.

Table 3.4. Effect of service level and number of trips on deprivation time and deprivation cost

λ	**Four Trips** δ*	**Three Trips** δ*	**Two Trips** δ*	**One Trip** δ*
100%	0.00	0.00	0.00	0.00
90%	0.00	0.00	0.00	0.00
80%	0.30	0.40	0.60	1.20
70%	0.60	0.80	1.20	2.40
60%	0.90	1.20	1.80	-
50%	1.20	1.60	2.40	-
40%	1.50	2.00	-	-
30%	1.80	2.40	-	-
20%	2.10	-	-	-
10%	2.40	-	-	-
0%	-	-	-	-

λ	**Four Trips** γ	**Three Trips** γ	**Two Trips** γ	**One Trip** γ
100%	3.41	3.41	3.41	3.41
90%	3.41	3.41	3.41	3.41
80%	6.63	6.65	6.69	6.81
70%	9.96	10.04	10.20	10.72
60%	13.42	13.60	13.98	-
50%	17.00	17.33	18.03	-
40%	20.71	21.24	-	-
30%	24.55	25.33	-	-
20%	28.52	-	-	-
10%	32.64	-	-	-
0%	69.33	-	-	-

Finally, Table 3.5 reveals that for any given service level, the total deprivation time experienced by each beneficiary is unchanged regardless of the number of trips performed or which site the beneficiary is being served from. However, as the service level declines, the deprivation differences among beneficiaries would decrease, creating a propensity of equal treatment in deprivation durations.

Table 3.5. Effect of service level and number of trips on deprivation time per person-hrs.

λ	Four Trips Total Depriv. (person-hr)		Three Trips Total Depriv. (person-hr)		Two Trips Total Depriv. (person-hr)		One Trip Total Depriv. (person-hr)	
	A	B	A	B	A	B	A	B
100%	1.00	1.50	1.00	1.50	1.00	1.50	1.00	1.50
90%	1.00	1.50	1.00	1.50	1.00	1.50	1.00	1.50
80%	2.20	2.70	2.20	2.70	2.20	2.70	2.20	2.70
70%	3.40	3.90	3.40	3.90	3.40	3.90	3.40	3.90
60%	4.60	5.10	4.60	5.10	4.60	5.10	-	-
50%	5.80	6.30	5.80	6.30	5.80	6.30	-	-
40%	7.00	7.50	7.00	7.50	-	-	-	-
30%	8.20	8.70	8.20	8.70	-	-	-	-
20%	9.40	9.90	-	-	-	-	-	-
10%	10.60	11.10	-	-	-	-	-	-
0%	12.00	12.00	-	-	-	-	-	-

3.5.5. Implications of Idle Time on Allocation Structure

Referring to the fundamental idea that even though the initial deprivation period may seem to distort the distribution system, setting equal deprivation time in subsequent deliveries, with or without idle time, will restore the system back to balance. It is just that the load is being shifted among the trips. Hence, the concept of idle time will exhibit the same previous properties while experiencing a supply shortage. Specific results, which still hold as we incorporate or increase the idle time, are summarized as follows:

- Idle time has no impact on either deprivation time per person-hour; recurrent deprivation time δ^*; total deprivation cost γ; individual site deprivation cost; total quantities delivered to each site; or the proportionality ratio.
- Increase in idle time will shift loads from the last trip and split them equally among the previous trips.
- An increase in idle time extends the length of the recurrent delivery cycles while diminishing the length of the final cycle.
- An increasing the idle time prolongs the truck end time to reach the depot.

Idle time can be a tool to scale the loads across trips to meet truck capacity, to pursue a truck reaching ***T*** in its final trip, or deliver the same quantity to a specific site in all trips performed. Such a scale is unaffected by varying the service level. For example, an idle time of 0.2 hours creates equal loads in trips regardless of the service level. Of course, the amount of the load will change, but the loads are still equal in each trip.

<u>*Example*</u>: Consider the previous network structure presented again in Figure 3.27. Sites A and B needs 3 and 2 units per hour, respectively. Assume that the consumption period ***T***=12.

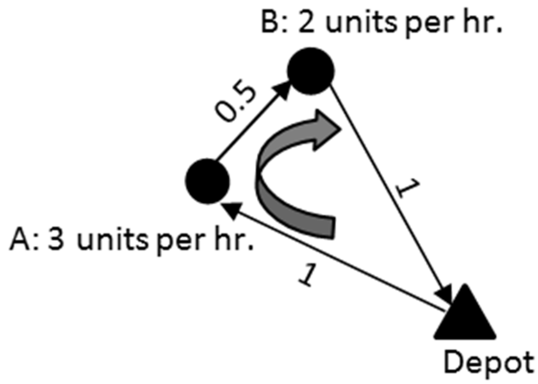


Figure 3.27. Two nodes transportation network for examining idle time effect on network

For illustrative purposes, we will consider Δ=0.2 with λ= 100%, λ= 70%, and λ=30%. Other idle time values and percentages will follow the same logic of analysis.

As mentioned in an earlier example presented in section 3.4.4, incorporating an idle time of 0.2 hours prior to each vehicle departure (aside from the initial trip) would create a balanced truckload; that is, $(q_A^* + q_B^*) = \left(q_A^f + q_B^f\right)$. This equality is preserved for any service level used. For example, referring to Figure 3.28, an idle time of 0.2 creates equal truckloads of 13.5 units, 10.5 units, and 4.5 units for service levels 100%, 70%, and 30%, respectively.

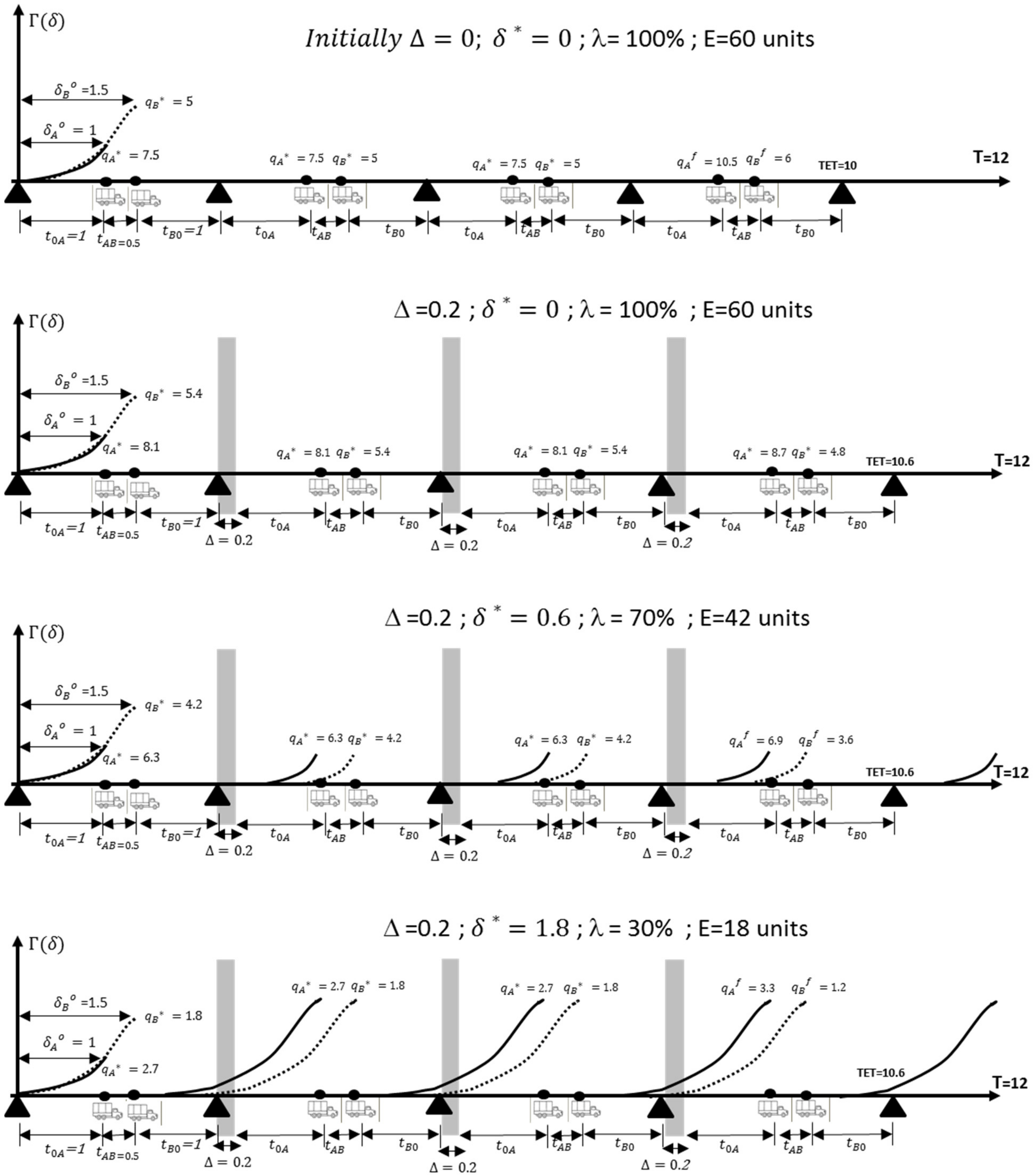


Figure 3.28. Effect of service level and idle time on truck load

Table 3.6 shows that for the same service level considered, whether it was 70% or 30% in this example or any other percentages, the idle time has no impact on deprivation time per person-hour, recurrent deprivation time δ^*, total deprivation cost γ, individual site deprivation cost, total quantities delivered to each site, or proportionality ratio. Exceptionally, the deprivation time and cost properties hold in the range of the same number of trips performed.

Table 3.6. Variation in idle time within same service level and its impact on network metrics

λ=70% equivalent to E=42 units											
Δ	Number of possible trips	Quantity delivered to site A	Quantity delivered to site B	Total Quantity Delivered	Proportion-ality A to B except last trip	δ^* (Hrs.)	Total Depriv. Cost γ	Total Depriv. Cost for A γ_A	Total Depriv. Cost for B γ_B	Total Depriv. (person-hr) for site A	Total Depriv. (person-hr) for site B
0.00	**4**	26	16	42	1.5	0.6	9.97	5.61	4.35	3.4	3.9
0.125	**4**	26	16	42	1.5	0.6	9.97	5.61	4.35	3.4	3.9
0.20	**4**	26	16	42	1.5	0.6	9.97	5.61	4.36	3.4	3.9
0.25	**4**	26	16	42	1.5	0.6	9.97	5.61	4.36	3.4	3.9
0.67	**3**	26	16	42	1.5	0.8	10.04	5.66	4.39	3.4	3.9
1.0	**3**	26	16	42	1.5	0.8	10.04	5.66	4.39	3.4	3.9
1.5	**3**	26	16	42	1.5	0.8	10.04	5.66	4.39	3.4	3.9
2.0	**2**	26	16	42	1.5	1.2	10.2	5.76	4.45	3.4	3.9
2.5	**2**	26	16	42	1.5	1.2	10.2	5.76	4.45	3.4	3.9
3.5	**2**	26	16	42	1.5	1.2	10.2	5.76	4.45	3.4	3.9
λ=30% equivalent to E=18 units											
Δ	Number of possible trips	Quantity delivered to site A	Quantity delivered to site B	Total Quantity Delivered	Proportion-ality A to B except last trip	δ^* (Hrs.)	Total Depriv. Cost γ	Total Depriv. Cost for A γ_A	Total Depriv. Cost for B γ_B	Total Depriv. (person-hr) for site A	Total Depriv. (person-hr) for site B
0.00	**4**	11	7	18	1.5	1.8	24.55	14.36	10.19	8.2	8.7
0.125	**4**	11	7	18	1.5	1.8	24.55	14.36	10.19	8.2	8.7
0.20	**4**	11	7	18	1.5	1.8	24.55	14.36	10.19	8.2	8.7
0.25	**4**	11	7	18	1.5	1.8	24.55	14.36	10.19	8.2	8.7
0.67	**3**	11	7	18	1.5	2.4	25.33	14.83	10.5	8.2	8.7
1.0	**3**	11	7	18	1.5	2.4	25.33	14.83	10.5	8.2	8.7
1.5	**3**	11	7	18	1.5	2.4	25.33	14.83	10.5	8.2	8.7
2.0	**2**	11	7	18	1.5	3.6	27.03	15.84	11.18	8.2	8.7
2.5	**2**	11	7	18	1.5	3.6	27.03	15.85	11.18	8.2	8.7
3.5	**2**	11	7	18	1.5	3.6	27.03	15.85	11.18	8.2	8.7

3.5.6. Summary

As a generalized result for a single route resource allocation with shortages in supplies, scheduling cyclical deliveries to sites would be an appropriate strategy in a multi-period distribution plan. Setting equal deprivation time experienced by any beneficiary before each visit to the site would be an approach to widespread equity in the distribution system. The cycle length is composed of deprivation time and consumption time. It is applied equally to all sites, with the exception of the last trip, to match it with the total duration of trips performed. As the amount of supplies at the depot is reduced, deprivation time would stretch out to account for such shortages until reaching a tour length where the same number of deliveries wouldn't be feasible anymore and the number of trips required would be reduced incrementally. The quantity distributed between sites is proportional to their ratio of consumption with the exception of the last delivery. For any given service level, the total deprivation time experienced by each beneficiary is unchanged regardless of the number of trips performed. As the service level declines, the deprivation time differences among beneficiaries would decrease creating a propensity of equal treatment in severe shortages.

Incorporating an idle time on vehicle departures exhibits similar results whether there are enough supplies or a shortage at the depot. Also, idle time has no impact on either deprivation time per person-hour, recurrent deprivation time δ^*, total deprivation cost γ, individual site deprivation cost, total quantities delivered to each site, or the proportionality ratio. Finally, idle time can be used as a tool to scale the loads across trips to meet truck capacity, the truck reaching $\boldsymbol{T}$ in its final trip, or delivering the same quantity to a specific site in all trips performed. Such a scale is unaffected by varying the service level.

CHAPTER 4. MODEL FOR MULTIPLE ROUTE RESOURCE ALLOCATION

This chapter will expand the allocation problem to consider multiple routes. It will determine for each vehicle which sites it serves, which site to visit first, and how much to allocate to it before going to the next site. This would be regarded as an integrated routing and allocation problem (RAP). As previously mentioned, visiting sites in loops will simplify the problem because it only requires identifying the first trip sequence for each vehicle, as other trips will be repetitive in sequence and the same quantity is delivered per site except in the last trip. Deprivation and consumption times would be calculated based on sites' arrival times in the first tour. Even with such simplification, it is not an obvious problem to solve. This is mainly because the demand rate of each site plays a role in determining the direction in which the vehicle travels from one site to another and not just the physical distance of sites from the depot. In addition, the given level of shortages at the depot will also influence its direction.

The following model is proposed, which is an extension of the allocation problem discussed in sub-chapter 3.5 to incorporate the vehicle routing part. The objective is to minimize the maximum deprivation cost incurred at the cluster level if supplies to beneficiaries in that cluster are delayed. Transportation costs incurred by providing the needed assistance to the affected areas are considered a secondary objective in this model.

4.1. Mathematical Notation

4.1.1. Parameters

T= Planning Horizon

N= Set of sites $\{1, \dots, n\}$. Let $\{0\}\ and\ \{n+1\}$ be two copies of the depot.

$$N' = \text{Set of sites } \{1, \dots n\} \cup \{0\} \cup \{n+1\}$$

A= Set of arcs linking sites together. $A = \{(i,j): i,j \in N', i < j\}$

E= Initial inventory available at depot

V= Number of vehicles available

P_i= Population at demand site ***i***

u= Consumption rate

Θ= Number of time periods satisfied by a full serving of supplies

L_i= Demand rate of site i per time unit. $L_i = u.p_i$

Q= Vehicle capacity

ω= Cost of vehicle per unit time

τ= Tour travel time

τ_{ij}= Travel time required to traverse arc $(i, j) \in A$. It is assumed that travel times are symmetric and satisfy the triangle inequality.

σ_v = The sequence of the sites vehicle ***v*** visit

ξ= Positive number

M= Large positive number

4.1.2. <u>Decision Variables</u>

h^v= Number of trips to be performed

q_i^*= Amount of supplies per shipment to demand site ***i*** except for the last trip

q_i^f= Amount of supplies to demand site ***i*** in the final trip

δ_i^*= Average deprivation time experienced at demand site ***i*** during deprivation time periods ***1***,…,***h***

γ_i= Deprivation cost for demand site ***i***

t_i^v= Travel time took between the depot and site ***i***. It is the initial deprivation time experienced by at demand site ***i***.

τ^v= Tour travel time. $\tau^v = t_{n+1}^v - t_0^v$

x_{ij}^v= Binary variable equal to 1 if and only if vehicle ***v*** traverses arc ***(i,j)*** from ***i*** to ***j***.

4.2. Mathematical Model

The mathematical model to minimize the maximum deprivation costs experienced by sites over ***T*** together with minimizing transportation costs reduced their impact on the model by ξ is:

$$\textbf{\textit{Minimize}} \quad \sum_{i \in N} \gamma_i + \xi . \sum_{v \in V} \omega . \tau^v . h^v \qquad \text{(Eq. 4.1)}$$

Subject to

- The deprivation cost would be minimized by splitting the deprivation time in ***h*** equal deprivation periods

$$\delta_i^* \geq \frac{1}{h^v} . \left(T - t_i^v - \frac{(h^v - 1) . q_i^* + q_i^f}{u . P_i} \right) \quad \forall i \in \sigma_v \qquad \text{(Eq. 4.2)}$$

- Define the total deprivation costs at the sites

$$\gamma_i \geq P_i . \left(\Gamma(t_i^v) + h^v . \Gamma(\delta_i^*) \right) \quad \forall i \in \sigma_v \qquad \text{(Eq. 4.3)}$$

- Any delivery to a site should be large enough to meet the needs of all its beneficiaries for at least ϴ periods of time. This will prevent partial deliveries from creating a time-expanded network.

$$q_i^* \geq ϴ . u . P_i \quad \forall i \in N \qquad \text{(Eq. 4.4)}$$

- Define an upper bound for deliveries based on the supply inventory available at depot

$$\sum_{v \in V} \sum_{i \in N} \left((h^v - 1) . q_i^* + q_i^f \right) \leq E \qquad \text{(Eq. 4.5)}$$

- Ensure that the total deliveries per trip does not exceed the vehicle capacity

$$\sum_{i \epsilon N} \sum_{j \epsilon N'} q_i^* . x_{ij}^v \leq Q \quad \forall v \in V \tag{Eq. 4.6}$$

- Ensure that the last trip delivery does not exceed the vehicle capacity

$$\sum_{i \epsilon N} \sum_{j \epsilon N'} q_i^f . x_{ij}^v \leq Q \quad \forall v \in V \tag{Eq. 4.7}$$

- Define a time frame for total deprivation and consumption periods on the time horizon T

$$t_i^v + h^v . \delta_i^* + \frac{(h^v - 1).q_i^* + q_i^f}{u.P_i} = T \quad \forall i \in N, v \in V \tag{Eq. 4.8}$$

- Define a time frame for deprivation and consumption period over a single trip

$$\delta_i^* + \frac{q_i^*}{u.P_i} = \tau^v \quad \forall i \in \sigma_v \tag{Eq. 4.9}$$

- Arrival time to site i must be equal to or greater than its direct travel time from depot

$$t_i^v \geq \tau_{ij} \quad \forall i \in N, v \in V \tag{Eq. 4.10}$$

- Flow conservation equation

$$\sum_{i \epsilon N'} x_{ij}^v = \sum_{i \epsilon N'} x_{ji}^v \quad \forall j \in N, v \in V \tag{Eq. 4.11}$$

- Each site is served once by only one vehicle

$$\sum_{v \epsilon V} \sum_{j \epsilon N'} x_{ij}^v = 1 \quad \forall i \in N \tag{Eq. 4.12}$$

- Ensure that each trip starts at the depot

$$\sum_{j \epsilon N'} x_{0j}^v = 1 \quad \forall\, v \in V \tag{Eq. 4.13}$$

- Ensure that each trip ends at the depot

$$\sum_{i \epsilon N'} x_{i,n+1}^v = 1 \quad \forall\, v \in V \tag{Eq. 4.14}$$

- Ensure that if site j is served after site i by vehicle v, then $t_j^v \geq t_i^v$, plus the travel time τ_{ij}

$$\left(t_i^v + \tau_{ij}\right). x_{ij}^v - t_j^v \leq \left(1 - x_{ij}^v\right). M \quad \forall i \in N' \backslash \{n+1\}, j \in N', v \in V \tag{Eq. 4.15}$$

- Number of trips must be integer and require at least a single delivery to each site

$$h^v \geq 1 \text{ , } integer \quad \forall v \in V \tag{Eq. 4.16}$$

- All deprivation costs of sites must be non-negative

$$\gamma_i \geq 0 \quad \forall i \in N \qquad \text{(Eq. 4.17)}$$

- All delivered quantities to sites must be non-negative

$$q_i^* \geq 0 \; ; \; q_i^f \geq 0 \quad \forall i \in N \qquad \text{(Eq. 4.18)}$$

- All arrival times to sites must be non-negative

$$t_i^v \geq 0 \;\; \forall i \in N, v \in V \qquad \text{(Eq. 4.19)}$$

- Binary variable equal to 1 if and only if vehicle v visited site j after site i

$$x_{ij}^v \in \{0,1\} \;\; \forall i \in N', j \in N', v \in V \qquad \text{(Eq. 4.20)}$$

4.3. Illustrative Example

Consider the network structure given in Figure 4.1. Assume that the values represent the demand and location of each site.

Sites	Demand (units)	X	Y
0	0	0	0
1	1	1	13
2	20	10	25
3	3	25	31
4	20	7	3
5	5	20	3

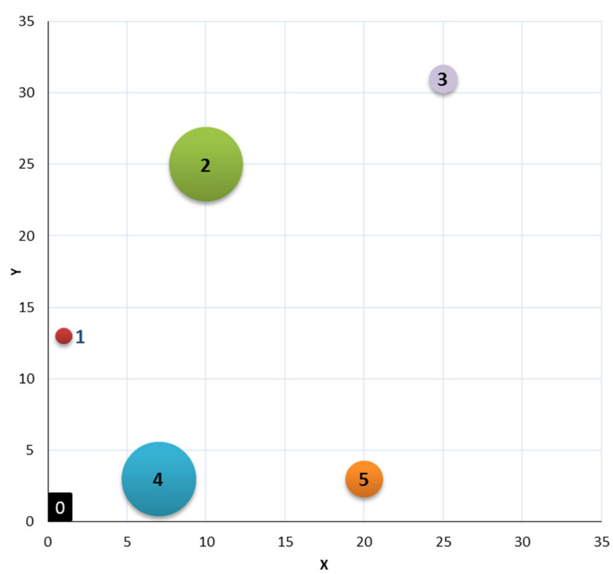


Figure 4.1. Five node network structure

The time matrix is calculated to find the time taken to travel from site ***i*** to site ***j*** (Table 4.1).

Table 4.1. Time matrix for the five node network

TIME MATRIX	0	1	2	3	4	5
0	**-**	**2.61**	**5.39**	**7.96**	**1.52**	**4.04**
1	**-**	**-**	**3.00**	**6.00**	**2.33**	**4.29**
2	**-**	**-**	**-**	**3.23**	**4.44**	**4.83**
3	**-**	**-**	**-**	**-**	**6.66**	**5.69**
4	**-**	**-**	**-**	**-**	**-**	**2.60**
5	**-**	**-**	**-**	**-**	**-**	**-**

Assume that the consumption period $\boldsymbol{T}$=100 and the previous deprivation cost function is used in this example. One vehicle is available with no restrictions on capacity.

Suppose initially there are abundant supplies at the depot. Given the distance matrix in Table 3.7, the TSP path is 0-1-2-3-5-4-0 with a duration of 18.65 hours, the minimum amount of time in which the vehicle can return to the depot. If this path is followed clockwise, the total deprivation cost value is 790.7. The anti-clockwise deprivation cost would have a value of 410.76. The TSP path, which minimizes the initial deprivation times at the sites, is 0-4-1-2-3-5-0 with a duration of 19.82 hours. This route has a total deprivation cost value of 282.12. The anti-clockwise deprivation cost would have a value of 1,066.69. Implications of these preliminary figures point out that the clockwise and anti-clockwise path of the same route impact the deprivation cost. Next, we will show that the TSP route might not be always the best fit while considering deprivation cost.

Table 4.2 provides the optimal solutions for service levels ranging from 100% to 15%. Note that the path which minimizes the initial deprivation times is not the same path that minimizes deprivation costs. Note also that the optimal path changes when the service level goes from 65% to 60% and again when the service level goes from 20% to 15%. The optimal path when considering deprivation cost turns out to be dynamic based on the level of resources available at the depot for distribution.

Table 4.2. Impact of service level on route direction

λ	Route	Depriv. Cost	h	τ	δ*	Total q_1	Total q_2	Total q_3	Total q_4	Total q_5
100%	0-4-5-2-3-1-0	274.92	4	20.8	0	82	1,821	263	1,970	479
90%	0-4-5-2-3-1-0	389.97	4	20.8	1.05	78	1,737	251	1,886	458
80%	0-4-5-2-3-1-0	729.41	4	20.8	3.54	68	1,537	221	1,686	408
70%	0-4-5-2-3-1-0	1,184.44	4	20.8	6.05	58	1,337	191	1,486	358
65%	0-4-5-2-3-1-0	1,466.70	4	20.8	7.30	53	1,237	176	1,386	333
60%	0-4-5-3-2-1-0	1,681.38	5	18.7	6.54	51	1,085	172	1,315	316
50%	0-4-5-3-2-1-0	2,308.24	5	18.7	8.54	41	885	142	1,115	266
40%	0-4-5-3-2-1-0	3,101.42	5	18.7	10.57	37	683	112	913	215
30%	0-4-5-3-2-1-0	4,110.12	5	18.7	12.79	37	504	79	691	160
20%	0-4-5-3-2-1-0	6,952.76	4	18.7	18.18	11	285	52	515	116
15%	0-1-4-2-3-5-0	9,385.60	4	22.4	Varies	37	504	37	136	21

4.4. Heuristics for RAP

The RAP is a hard combinatorial optimization problem and only relatively small instances can be solved to optimality. This is due to the fact that it is an extension of the VRP problem which is itself NP-hard. Since exact approaches are in general inadequate, a heuristic is used to solve the RAP model. Therefore, it is of benefit to develop simple heuristics that can construct good feasible solutions. A solution would produce a schedule for each vehicle with a starting time to depart from the depot on each trip, specified sites to visit, and a quantity to deliver to each site on that trip.

The overall approach can be seen in Figure 4.2. This approach constructs a solution by separating the RAP into two sub-problems: routing and allocation. The routing first-cluster second technique will be applied and followed by solving the allocation sub-problem for each route that has been found. An iterative improvement algorithm will be applied to the solution to shift resources among clusters to reduce the overall deprivation cost. This approach will be discussed in detail next.

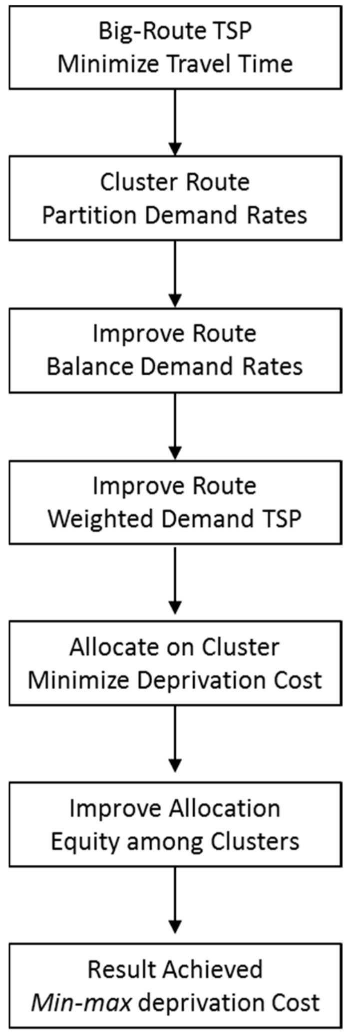


Figure 4.2. Structure of proposed heuristics

4.4.1. <u>Routing Problem</u>

The routing sub-problem creates routes for each vehicle by assigning sites to each vehicle and determining the order in which they are visited. The RAP differs from traditional a VRP because the objective is to minimize the deprivation cost and not to minimize total travel time. It is desirable in RAP to create routes with short travel times as this will reduce the deprivation cost. At the same time, clusters have balanced aggregate demand rates among them. This will allow each vehicle to be able to distribute supplies to the sites while considering the vehicle's capacity.

With a route first-cluster second method, a tour is created through all of the sites using TSP, and then the sites (and the route) are divided into a desired number of partitions equivalent to the number of available vehicles to form clusters. Each cluster holds sites adding up to and not exceeding the average demand rates calculated as $\overline{L} = \frac{\sum_{i \in N} L_i}{V}$ where $L_i = u.p_i$ is the demand rate of site $\boldsymbol{i}$ per time unit.

The initial construction of clusters may produce varying aggregated demand rates among clusters because the decision of including an ending site in a route is a strict yes or no answer. The site not satisfying the partition criteria will be included as a starting point for its vehicle in the next cluster. That will potentially increase the number of vehicles needed. In order to have balanced clusters as much as possible, an improvement algorithm will be used to reduce such variation.

This improvement algorithm strives to make the clusters' demand rates as similar as possible by minimizing the range of cluster demand rates. This algorithm begins with calculating each cluster's demand rates. In each iteration, the algorithm examines the cluster with a maximum and minimum demand rate and considers moving sites at the beginning (or end) of one route to the previous (or next) vehicle's route. If the potential move decreases the range of cluster demand rates, then the clusters are updated to reflect this change. This continues until no further improvement can be made. Of course, this type of local search may not find the smallest possible range, but it mitigates reaching a situation of capacity overflow in vehicles. Note that each cluster consists of demand points that were adjacent on the original TSP. The pseudo code, along with the notation, is provided below:

R_v : The aggregate demand rate covered by vehicle $\boldsymbol{v}$ deployed in a cluster. $R_v = \sum_{i \in \sigma_v} L_i$

l_v : First site visited by vehicle $\boldsymbol{v}$.

m_v : Last site visited by vehicle $\boldsymbol{v}$.

σ_v : Route assigned to vehicle $\boldsymbol{v}$. $\sigma_v = \{l_v , \dots , m_v\}$

REPEAT

CALCULATE $R_1, \dots , R_v$

$F = max\{R_1, \dots , R_v\} - min\{R_1, \dots , R_v\}$

$v_{max} = argmax\{R_1, \dots , R_v\}$

$v_{min} = argmin\{R_1, \dots , R_v\}$

$\sigma'_{v_{max}-1} = \sigma_{v_{max}-1} \cup \{l_{v_{max}}\}$

$\sigma'_{v_{max}} = \sigma_{v_{max}} \backslash \{l_{v_{max}}\}$

CALCULATE $R'_1, \dots , R'_v$

IF $max\{R'_1, \dots , R'_v\} - min\{R'_1, \dots , R'_v\} < max\{R_1, \dots , R_v\} - min\{R_1, \dots , R_v\}$

$\sigma_{v_{max}-1} = \sigma'_{v_{max}-1}$

$\sigma_{v_{max}} = \sigma'_{v_{max}}$

$R_{v_{max}-1} = R'_{v_{max}-1}$

$R_{v_{max}} = R'_{v_{max}}$

END

$\sigma'_{v_{max}+1} = \{m_{v_{max}}\} \cup \sigma_{v_{max}+1}$

$\sigma'_{v_{max}} = \sigma_{v_{max}} \backslash \{m_{v_{max}}\}$

CALCULATE $R'_1, \dots , R'_v$

IF $max\{R'_1, \dots , R'_v\} - min\{R'_1, \dots , R'_v\} < max\{R_1, \dots , R_v\} - min\{R_1, \dots , R_v\}$

$\sigma_{v_{max}} = \sigma'_{v_{max}}$

$\sigma_{v_{max}+1} = \sigma'_{v_{max}+1}$

$R_{v_{max}} = R'_{v_{max}}$

$R_{v_{max}+1} = R'_{v_{max}+1}$

END

$\sigma'_{v_{min}} = \{m_{v_{min}}\} \cup \sigma_{v_{min}}$

$\sigma'_{v_{min}} = \sigma_{v_{min}-1} \backslash \{m_{v_{min}-1}\}$

CALCULATE $R'_1, \dots, R'_v$

IF $max\{R'_1, \dots, R'_v\} - min\{R'_1, \dots, R'_v\} < max\{R_1, \dots, R_v\} - min\{R_1, \dots, R_v\}$

$\sigma_{v_{min}-1} = \sigma'_{v_{min}-1}$

$\sigma_{v_{min}} = \sigma'_{v_{min}}$

$R_{v_{min}-1} = R'_{v_{min}-1}$

$R_{v_{min}} = R'_{v_{min}}$

END

$\sigma'_{v_{min}} = \sigma_{v_{min}} \cup \{l_{v_{min}+1}\}$

$\sigma'_{v_{min}+1} = \sigma_{v_{min}+1} \backslash \{l_{v_{min}+1}\}$

CALCULATE $R'_1, \dots, R'_v$

IF $max\{R'_1, \dots, R'_v\} - min\{R'_1, \dots, R'_v\} < max\{R_1, \dots, R_v\} - min\{R_1, \dots, R_v\}$

$\sigma_{v_{min}} = \sigma'_{v_{min}}$

$\sigma_{v_{min}+1} = \sigma'_{v_{min}+1}$

$R_{v_{min}} = R'_{v_{min}}$

$R_{v_{min}+1} = R'_{v_{min}+1}$

END

$F' = max\{R_1, \dots, R_v\} - min\{R_1, \dots, R_v\}$

UNTIL $F = F'$

It is important to note that these initial clusters consider only the demand rates of sites with their sequence determined by TSP. However, the sites in each cluster won't necessarily be preserved in the sequence specified in the TSP. For instance, visiting sites with low demand rates last in sequence would reduce deprivation cost; the same is true for visiting high demand rate sites first. Also, to start visiting dense sites in an anti-clockwise sequence might be better than visiting them clockwise even though both routes have same time duration. Hence it is necessary first to decide on the sequence the sites are visited by each vehicle. For that purpose, a modified TSP is proposed to consider demand rates in determining vehicle tours in each cluster separately.

The idea behind modifying the TSP originated from the fact that tour time and demand rates are determining factors in the deprivation cost equation. Incorporating idle time won't affect the total deprivation cost of a tour as long as the same number of trips is executed. In other words, if the tour length marginally deviates from the TSP original tour and visits high demand nodes earlier in the tour while preserving the number of trips, then deprivation cost would be reduced at the cluster level. Moreover, the idle time case that is recommended in our study is the balanced truck load trips. Hence, the objective function of the TSP is replaced with an objective of maximizing idle time. This allows a truck to deliver equal loads in each trip while keeping the same TSP constraints (Eq. 3.2 thru Eq. 3.7) and would yield better routes when solving the allocation phase later on. The objective function would be:

$$\textbf{Maximize } \boldsymbol{\Delta} = \frac{1}{h}\left\{T - h.\tau - \tau + \frac{p_1(\tau-\tau_{01})+p_2(\tau-\tau_{02})+\cdots p_n(\tau-\tau_{0n})}{(p_1+p_2+\cdots p_n)}\right\} \qquad \text{(Eq. 4.1)}$$

Subject to

(Eq. 3.2 thru Eq. 3.7)

The duration of a route may still vary widely, which will have implications on allocation and on the deprivation cost. The initial allocation will be done on the sequence found by the modified TSP.

4.4.2. <u>Allocation Problem</u>

An allocation will specify the quantities to be delivered to each site as well as the departure time for each vehicle and how many trips it performs. The clusters are entitled with a proportional share of the supplies available at the depot for distribution among their sites during construction of the routes. The sites will hold such proportionality except in the last scheduled trip as previously pointed out.

Using the sequence provided in the modified TSP output, it is possible to determine how many trips the vehicle will perform to service the sites assigned to it, what time each trip will start, and what quantity to deliver in each trip. Let τ_v be the tour length of vehicle $\boldsymbol{v}$ and ∂_v be the quantity delivered by vehicle $\boldsymbol{v}$ in each trip. Assume that $\frac{R_v}{\sum_{i \in N} L_i} \geq \frac{T.Q}{\tau_v}$ in order to meet vehicle capacity and have a feasible solution. Then the number of trips performed by vehicle $\boldsymbol{v}$ is $h_v = \left\lfloor \frac{T}{\tau_v} \right\rfloor$ and the quantity assigned to a vehicle to deliver in each trip is $\partial_v = \frac{1}{h} . \left(\frac{R_v}{\sum_{i \in N} L_i} . E \right)$. Each site $i \in \sigma_v$ will be allocated the same quantity $q^*_{vhi} = \frac{L_i}{R_v} . \partial_v$ in each trip.

The initial deprivation time for a site $i \in \sigma_v$ is t_i^v and the recurrent deprivation time $\delta_i^* = \frac{1}{h_v} . \left(T - t_i^v - \frac{h_v . q^*_{vhi}}{L_i} \right)$. The initial allocation scheme to clusters may produce varying deprivation cost levels across clusters. In order to experience balanced deprivation cost in clusters as much as possible, an improvement algorithm will be used to reduce this variation. This improvement algorithm strives to make the clusters' deprivation cost as similar as possible by iteratively shifting supplies from a low deprivation cost cluster to a high level one.

This improvement algorithm begins with calculating each cluster's deprivation cost rates. In each iteration, the algorithm examines two clusters with the maximum and minimum deprivation costs, and considers moving quantities incrementally by one from the cluster with the low deprivation cost to the cluster with the high cost. If the shift in supplies decreases the difference between clusters' deprivation cost, then the clusters' quantities are updated to reflect this change. Another incremental quantity shift will be performed to the same two clusters until no further improvement can be made. When that condition is reached, once again the two clusters with the maximum and minimum costs will be taken and the allocation process will start all over again. Note that in consecutive iterations, it is possible that one or both of the same clusters are selected. This type of local search may not find the smallest possible range, but it mitigates reaching a situation of high variation in deprivation cost across clusters. The pseudo code is provided below:

Step 1: Generate Initial Allocation quantity list $\{q_1, \ldots, q_v\}$ indexed by the vehicle serving cluster $\{1, \ldots, v\}$ and using proportionality rule to obtain $q_1 = \frac{P_1}{P}.E, \ldots, q_v = \frac{P_v}{P}.E$

Step 2: Calculate the deprivation cost for each cluster separately by solving the allocation model $DPV(q_v)$ presented in section 3.5.3 to obtain $\gamma_1, \ldots, \gamma_v$

Step 3: Re-index the clusters according to the values of deprivation cost from lowest to highest. $Clusters = \{C_{min}, \ldots, C_{max}\}\ such\ that\ \gamma_{C_{min}} \le \cdots \le \gamma_{C_{max}}$.

Step 4: Let $a_v, and\ b_v$ denote the cluster number assigned to $C_{min}\ and\ C_{max}$

Step 5: Calculate $F = \gamma_{c_{max}} - \gamma_{c_{min}}$

Step 6: **IF** $|F| \le \varepsilon$

Step 7: **THEN** no re-allocation is possible between clusters. Go to **STEP 24**

Step 8: $Initialize\ Z^{best} = F;\ t = 0;\ t' = 0; maximum\ iterative =\ q_{C_{min}}$

Step 9: **REPEAT**

Step 10: $q_{C'_{max}} = q_{C_{max}} + 1$ and calculate $DPV(q_{C'_{max}})$

Step 11: $q_{C'_{min}} = q_{C_{min}} - 1$ and calculate $DPV(q_{C'_{min}})$

Step 12: Calculate $Z^t = \gamma_{C'_{max}} - \gamma_{C'_{min}}$

Step 13: $t = t + 1$

Step 14: **IF** $Z^t < Z^{best}$

Step 15: **THEN** $q_{C_{max}} = q_{C'_{max}} and\ q_{C_{min}} = q_{C'_{min}}$

Step 16: **ELSE** $Z^{best} = Z^t$

Step 17: **UNTIL** $\Omega^t = |Z^t - Z^{best}| \le \varepsilon\ or\ t > maximum\ iteration$

Step 18: $q_{b_v} = q_{C'_{max}} and\ q_{a_v} = q_{C'_{min}}$

Step 19: Update the allocated quantities list to reflect quantity changes

Step 20: $t' = t' + 1$

Step 21: **IF** $t' > v!\ and\ t' > maximum\ iteration$

Step 22: **THEN** improvement reached. Go to **STEP 24**

Step 23: **ELSE** go to **STEP 2**

Step 24: **END**

The flow chart for this heuristic is shown below (Figure 4.3):

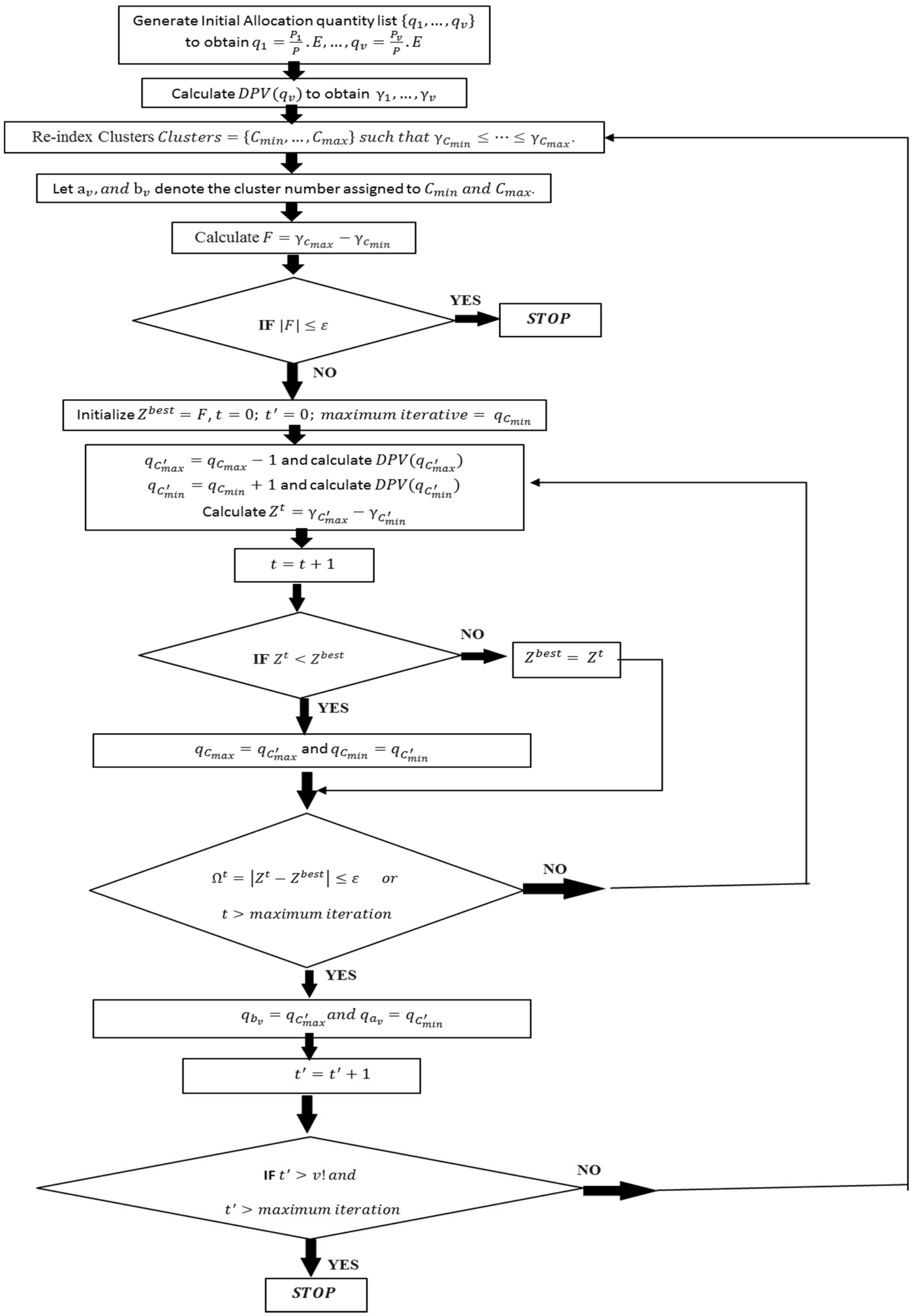


Figure 4.3. Flow chart diagram for allocation of supplies among and within clusters

CHAPTER 5. RESULTS AND ANALYSIS

In this chapter, the concept of bankruptcy rules will be applied while deciding on distribution to demand sites' Non-Food Items (NFIs) in a one-time period. The concept of deprivation cost will be applied to distribute consumable packages in a multi period setting. The exemplary case of the United Nations Relief and Works Agency (UNRWA's) Lebanon field office in the effort to distribute relief supplies to Palestinian refugees fleeing from Syria is discussed in more detail.

5.1. Implementation of Bankruptcy Rules: Allocation of NFIs for Syrian Refugees

The United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA) has provided basic services, such as education and health, to Palestine refugees in Syria, Jordan, Lebanon, the West Bank, and Gaza for over 63 years. The Agency has also responded to the urgent needs of Palestine refugees with emergency assistance in times of conflict and extreme hardship. The current Syrian crisis, however, is the largest challenge the Agency has faced since its original task to assist Palestine refugees after their original dispossession and dispersion throughout the region in 1948.

The civil war in Syria has produced what is currently the largest refugee crisis of the last 20 years, with a reported 1.7 million Syrians in neighboring countries and a further 4.5 million displaced people inside Syria (UNRWA, 2013). Palestine refugees account for approximately 100,000 of the refugees from Syria, where they had enjoyed relative stability and security. The majority of Palestine refugees from Syria have fled to Jordan and Lebanon, while a small number have reached Gaza. Within Syria, it is thought that close to half of the Palestine refugee community is displaced, with roughly 232,000 displaced people in April 2013. By the end of 2013, it was expected that some 80,000 Palestine refugees from Syria (PRS) will be in Lebanon, 10,000 in Jordan, and 1,350 in Gaza. By 14 February 2014, 15,028 PRS families were recorded with the UNRWA Lebanon Field Office (Figure 5.1).

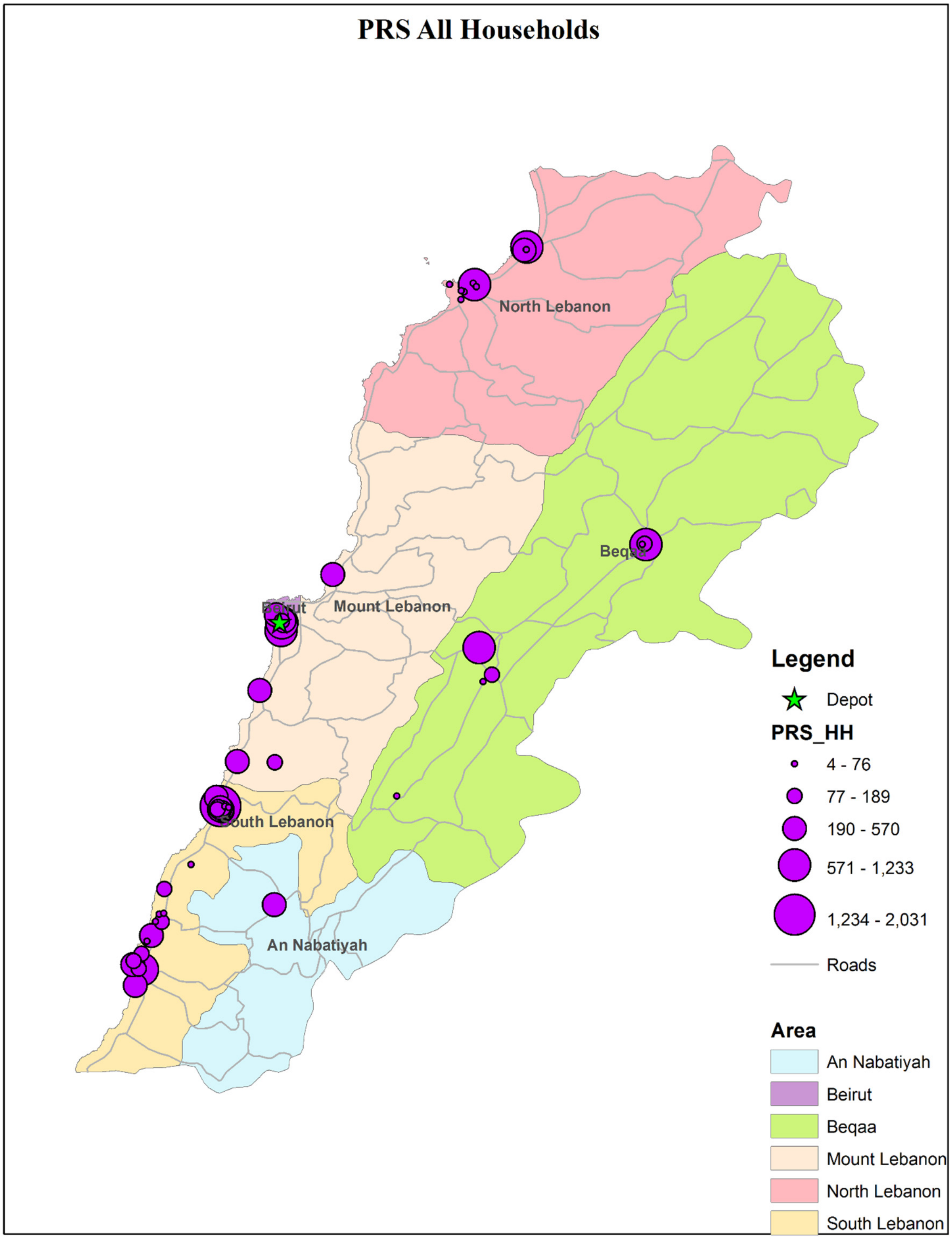


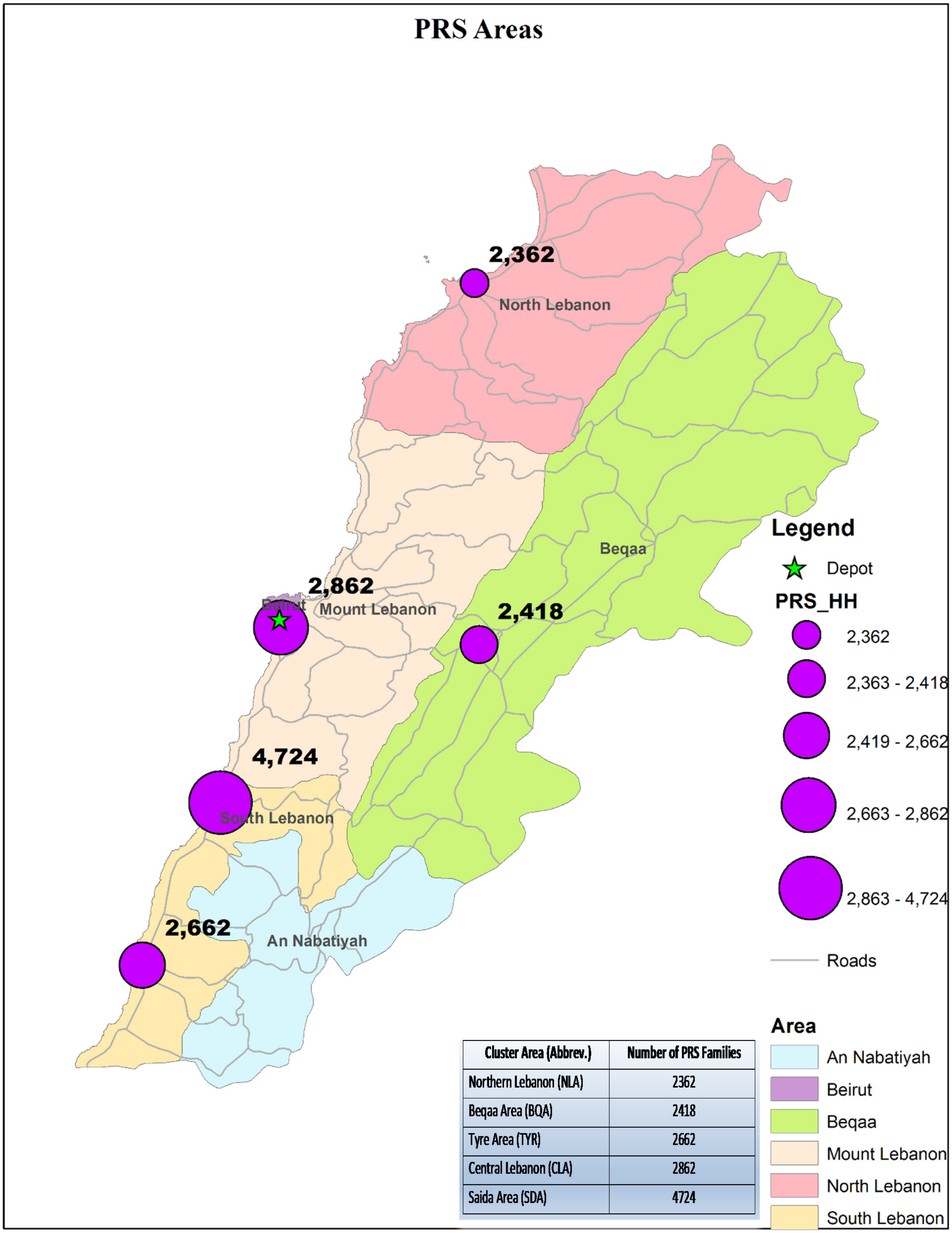
Figure 5.1. Geographical dispersion of PRS families in Lebanon

The UNRWA is working to address the continued and emerging emergency needs of Palestine refugees, including through cash and food assistance, emergency shelter support, emergency health, education, and the provision of essential non-food items within and outside Syria.

5.1.1. Emergency Non-Food Item Assistance to PRS in Lebanon

Non-food items are vital to the health and well-being of refugees. Many refugees have left their homes and are displaced either within Syria or in neighboring countries. Items including mattresses, blankets, jerry cans, and children's clothes are critical in enabling them to meet their basic needs and live with dignity. The distribution of NFI kits has also encouraged PRS registration for those who have moved outside of Syria.

UNRWA's Lebanon Field Office aimed to distribute NFI kits to 4,500 families out of 15,028 families geographically clustered in five regional areas (UNRWA, 2014). Details about cluster locations and number of PRS families displaced across Lebanon are shown in Figure 5.2 below:



Cluster Area (Abbrev.)	Number of PRS Families
Northern Lebanon (NLA)	2362
Beqaa Area (BQA)	2418
Tyre Area (TYR)	2662
Central Lebanon (CLA)	2862
Saida Area (SDA)	4724

Figure 5.2. Geographical dispersion of PRS families in Lebanon per area

5.1.2. Allocation Results

We consider the distribution of 4,500 NFI kits to 15,028 families and compute the outcome according to ten bankruptcy rules previously discussed. The outcomes are given in Table 5.1. In this table, the rows correspond to the areas with their respective claim, while the columns correspond to the different rules applied.

Table 5.1. Results of allocation rules based on 4,500 NFI sets

		ALLOCATION RULE									
Demand Point	**Demand**	**P**	**AP**	**CEA**	**CEL**	**TAL**	**CE**	**Pin**	**RTAL**	**MO**	**RA**
Northern Lebanon (NLA)	2,362	707	718	900	256	900	900	900	578	472	750
Beqaa Area (BQA)	2,418	724	735	900	312	900	900	900	606	486	764
Tyre Area (TYR)	2,662	797	809	900	556	900	900	900	728	568	825
Central Lebanon (CLA)	2,862	857	870	900	756	900	900	900	828	668	875
Saida Area (SDA)	4,724	1,415	1,368	900	2,618	900	900	900	1,759	2,306	1,285

To select the best rule for allocation is not easy because each rule has either merit of operational convenience or fairness. In addition, the choice of allocation schemes for NFI sets should depend on an agreement by all participants considering the above-mentioned features.

Since the total needs of NFIs in four out of five clusters are nearly identical in number of families, then the allocated NFIs to these areas would be consistently the same quantity and, thus, such a setup won't reveal the distinct properties that each rule holds. Still, realistically, the proportionality rule can be recommended in this circumstance as it exhibits neutrality and more fairness than the other rules.

5.1.3. Comparison of Rules Results

Figure 5.3 shows results of NFI distribution using various bankruptcy rules under six scenarios: 100%, 80%, 60%, 50%, 30%, and 10% of the ratio of initial inventory available at the central depot to total demands from areas. In the application of the proportion rule, NFI distribution is performed proportionally within the NFI claim of each area. This result is similar to the application of the AP and RA rules where NFIs are allocated almost proportionally among areas. In the application of the CEA and CE rules, equal NFI quantities are allocated to all areas in a serious shortage of 3,000 kits or more, whereas in the application of the TAL and Pin rules, NFIs are allocated to all areas almost proportionally within claims in small to medium supply shortages. On the other hand, in serious supply shortages of 11,000 kits or more, NFIs are allocated to all areas evenly. Results from applying the CEL, MO, and RTAL rules reveal that NFIs are allocated almost proportionally among areas, whereby the one claiming more NFIs still take preference over other clusters until reaching a shortage of 2,000 kits, where NFIs are allocated evenly to all clusters.

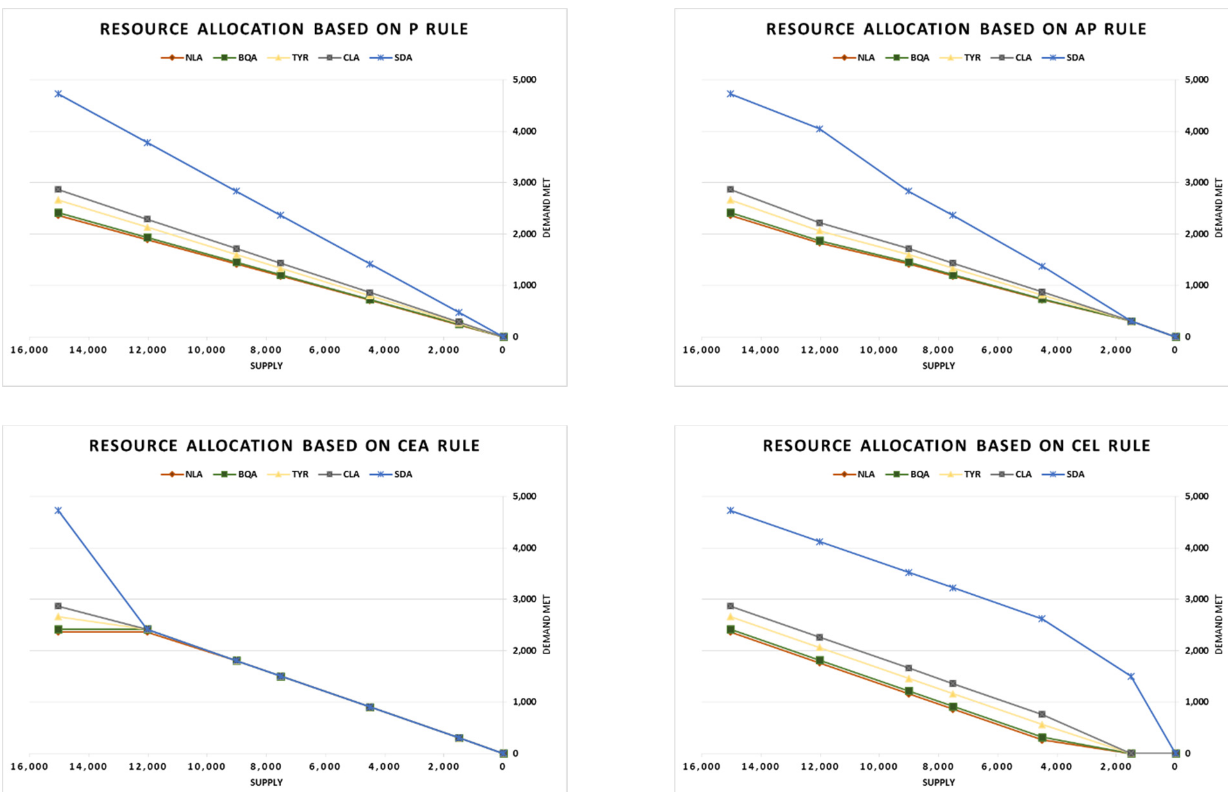


Figure 5.3. NFI allocation based on ten bankruptcy rules

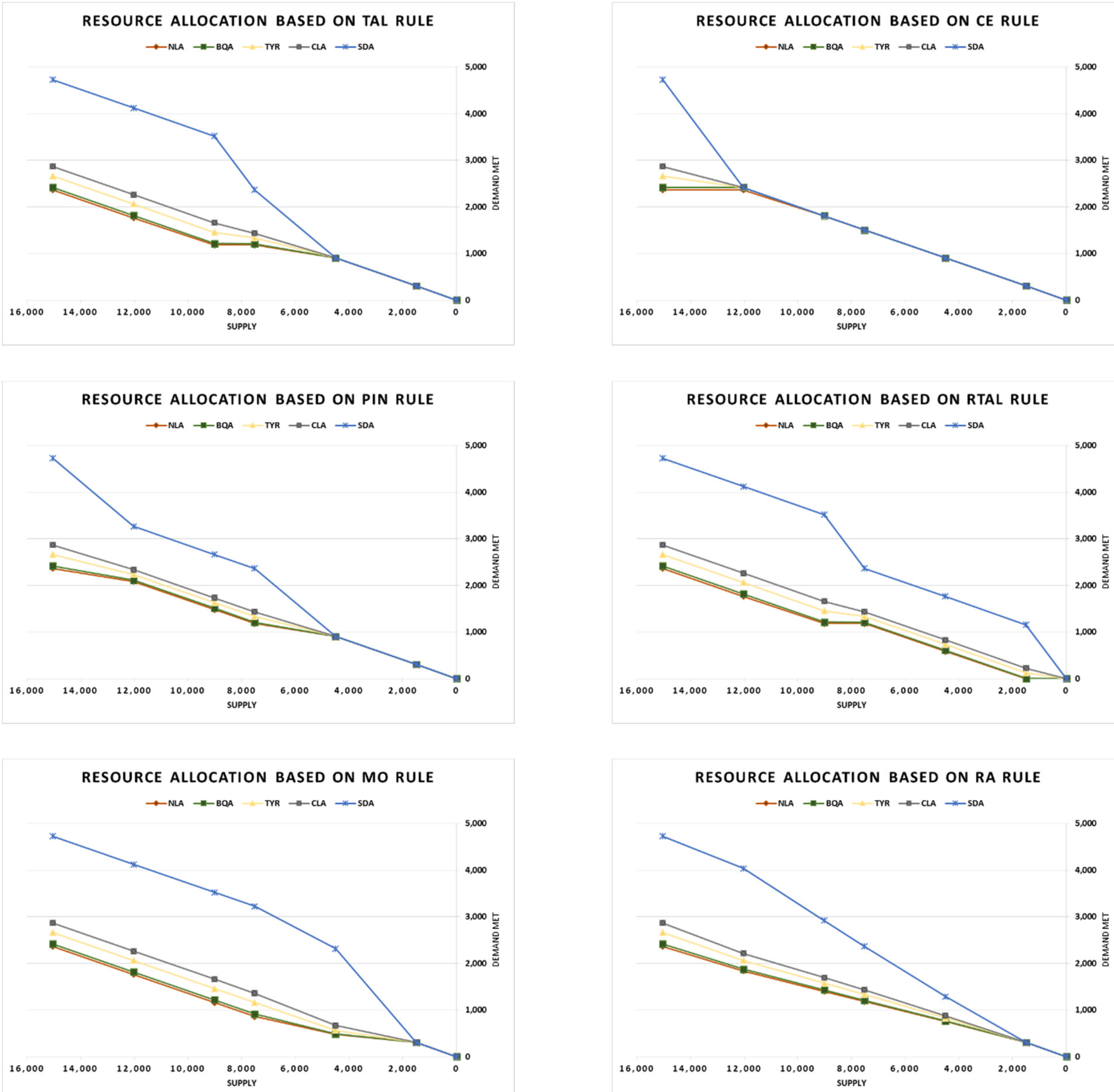


Figure 5.3. NFI allocation based on ten bankruptcy rules (continued)

5.1.4. <u>Managerial Implications and Future Strategies</u>

During the distribution of NFIs, it came to light that some NFIs were being sold to third parties for lower prices than the market price, therefore damaging the purpose behind distributing NFIs to beneficiaries. As a result, UNRWA is now considering a revised approach for the NFI provision. In the meantime, UNRWA is distributing NFI assistance to newly arriving PRS only.

UNRWA is focusing on strengthening strategic partnerships, including with Non-Governmental Organizations (NGOs) and United Nations agencies, for the distribution of basic non-food items and winterization packages (Figure 5.4). These partnerships have proven successful in the provision of assistance to a large amount of beneficiaries in a short period of time. Moreover, generous in-kind donations of NFIs were received from several organizations such as the Lebanese Ministry of Social Affairs, the Lebanese High Relief Council, and United Nations High Commissioner for Refugees (UNHCR). Still the issue of distributing NFI to target needy refugees is not resolved yet as many PRS families are now crossing the Lebanese border to get their relief share once the distribution day is announced and immediately return to Syria to continue their normal lives.

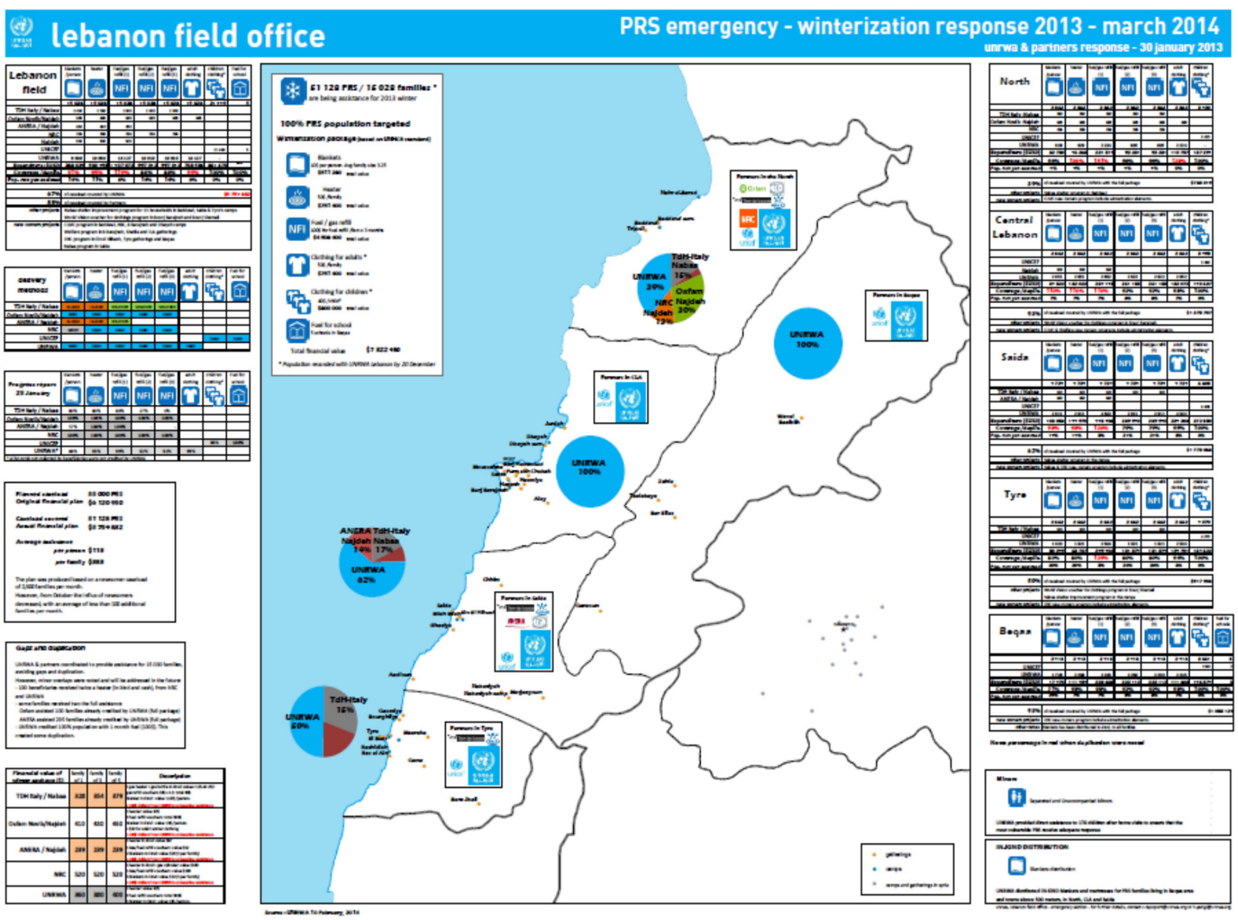


Figure 5.4. PRS winterization partnership response in March 2014 (UNRWA, 2014)

5.2. Implementation of RAP Model to Food Packages Distribution to PRS

In order to evaluate the contribution of the RAP model to establish equitable distribution and to demonstrate its applicability, a real case has been demonstrated reflecting the allocation of food packages among PRS beneficiaries. The results from solving the RAP model heuristically, along with a series of computational tests for the scenario, are presented in this sub-chapter.

The following data were obtained from a survey conducted by UNRWA Lebanon Field Office on 14 February 2014, where 15,028 PRS families were located inside one of 20 areas (Table 5.2) dispersed across Lebanon. The graphical location of the demand sites is presented in Figure (5.5).

Table 5.2. Number of PRS families per area

Area	Demand Cluster	No. of PRS Families	Total %	% per Area
TYR	BURJ SHAMALI CAMP	1,071	7.3%	40.0%
TYR	Other gatherings in TYR	965	6.6%	36.0%
TYR	RASHIDIEH CAMP	353	2.4%	13.0%
TYR	BUSS CAMP	273	1.9%	10.0%
SDA	EIN EL HILWEH CAMP	2,042	13.6%	43.0%
SDA	Saida Old City	1,382	9.2%	29.0%
SDA	Other Gathering In SDA	1,099	7.3%	23.0%
SDA	MIA MIA CAMP	201	1.3%	4.0%
NLA	BEDDAWI CAMP	1,115	7.6%	47.0%
NLA	NAHR EL BARED CAMP	904	6.1%	38.0%
NLA	Other gatherings in NLA	219	1.5%	9.0%
NLA	Tripoli City	124	0.8%	5.0%
CLA	BURJ BARAJNEH CAMP	859	5.3%	30.0%
CLA	Other gatherings in CLA	858	5.3%	30.0%
CLA	CHATILA CAMP	630	3.9%	22.0%
CLA	Sabra	515	3.2%	18.0%
BQA	Taalababaya- Saadnayel -Jalala	1,233	8.6%	51.0%
BQA	Baalbeck	846	5.9%	35.0%
BQA	Other Gatherings in BQA	218	1.5%	9.0%
BQA	WAVEL CAMP	121	0.8%	5.0%

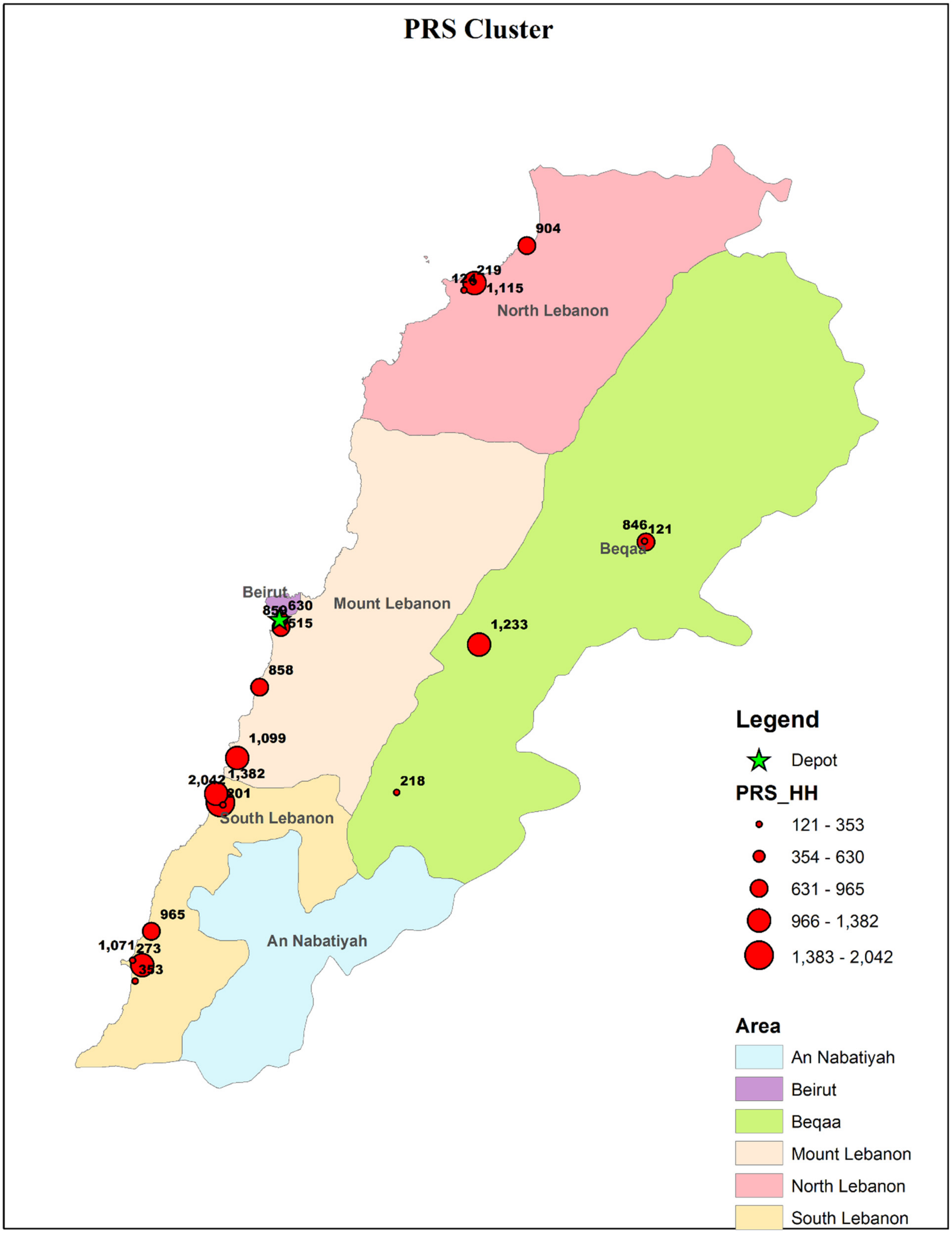


Figure 5.5. Geographical dispersion of PRS families in Lebanon per area

Assume that five trucks are available, and the capacity of a vehicle enable it to hold up to 15,000 packages. The planning horizon considered in this example is 60 hours. A 70% service level is used. The analytical steps to solve this multi-period problem heuristically will be followed as introduced in sub-chapter 4.4.

Step 1 – Big-route TSP to minimize travel time. The GIS output for the 20 sites TSP is presented in Figure 5.6.

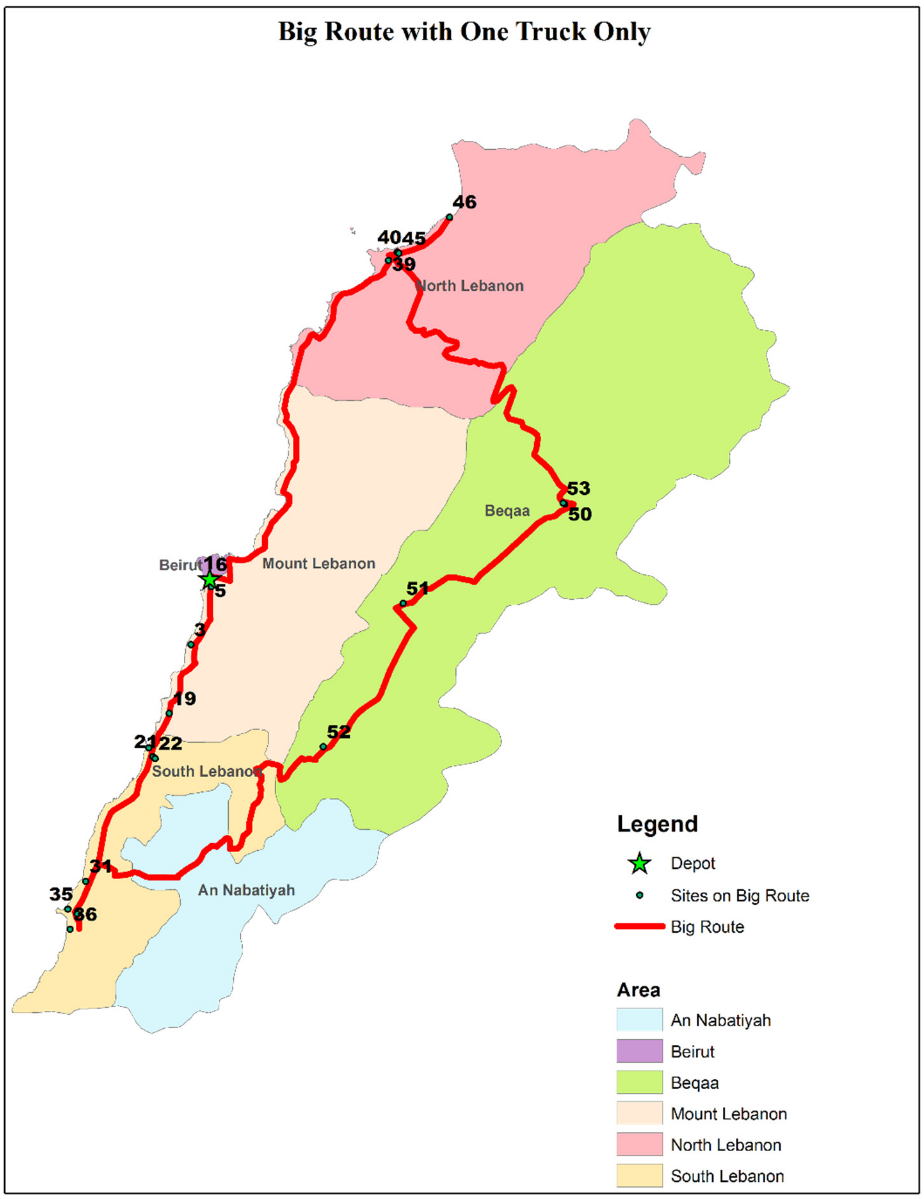


Figure 5.6. Big-route TSP for 20 demand sites

Step 2 – Cluster Route. Five clusters were formed taking into consideration the geographical dispersion of the demand sites. Each vehicle serves four demand sites in a cluster. The GIS output is shown in Figure 5.7.

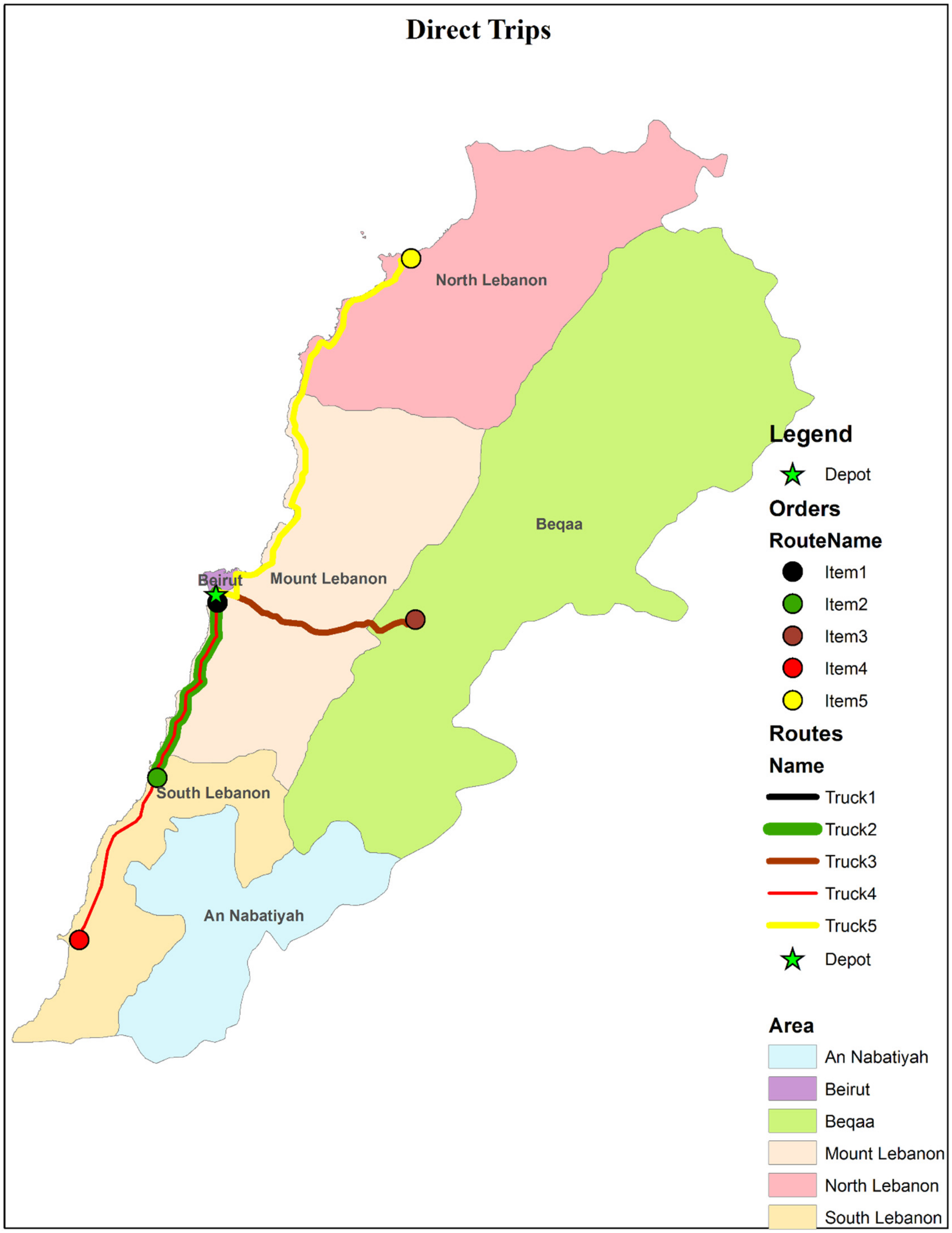


Figure 5.7. Five clusters for the 20 demand sites

Steps 3 and 4 – Improve Routing. Route improvement has been done by solving the balanced TSP on each cluster (refer to section 4.1.1). The GIS display is shown in Figure 5.8. The sequence of visiting each demand site along each route is shown in Table 5.3.

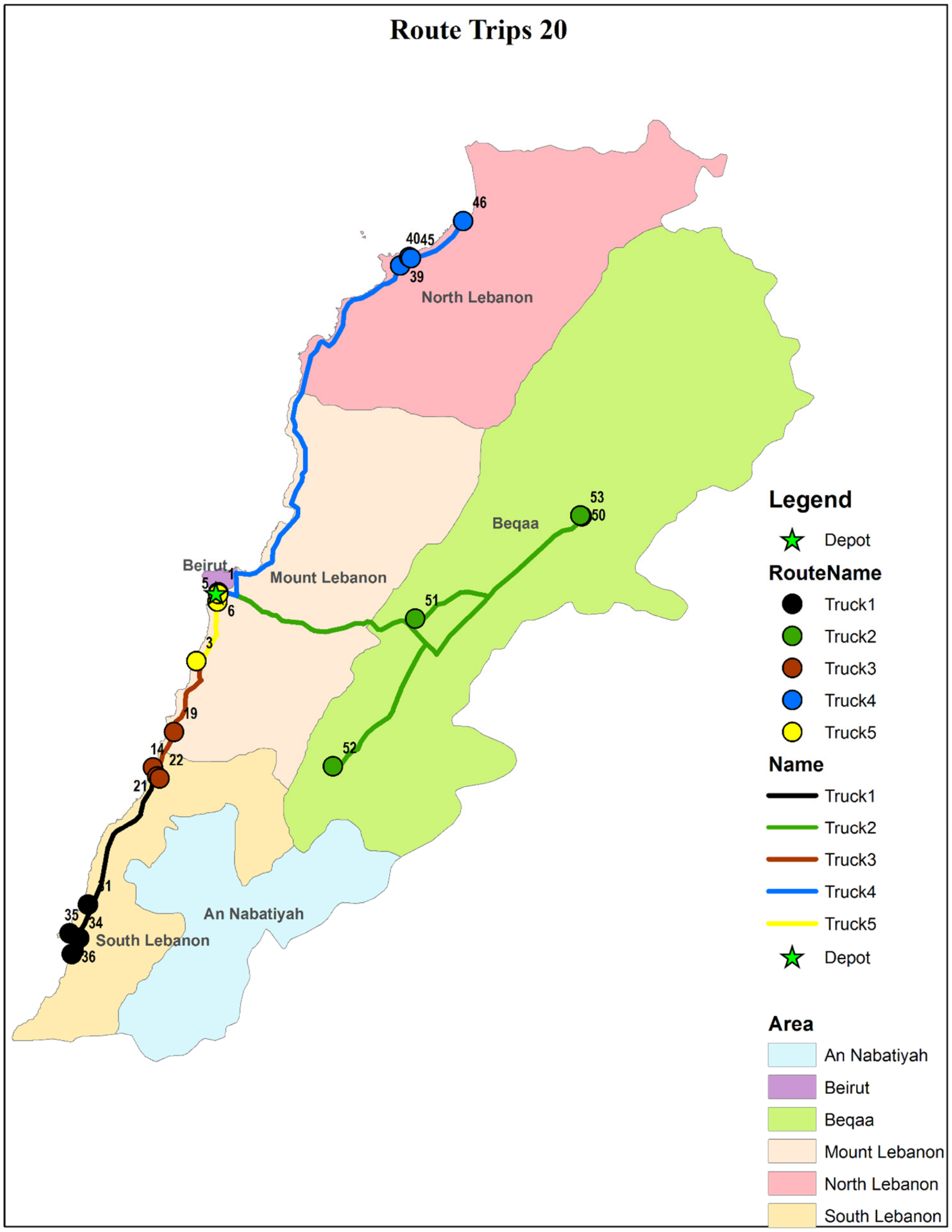


Figure 5.8. Route improvement inside each of the five clusters

Table 5.3. Improved TSP route per clustered area

ROUTE	Tour Length (Hrs.)	Area	Visiting sequence	Site Number	Demand Sites	No. of PRS Families
0-31-35-34-36-0	3.4	TYR	3	34	BURJ SHAMALI CAMP	1,071
		TYR	1	31	Other gatherings in TYR	965
		TYR	4	36	RASHIDIEH CAMP	353
		TYR	2	35	BUSS CAMP	273
0-19-14-21-22-0	2.46	SDA	3	21	EIN EL HILWEH CAMP	2,042
		SDA	2	14	Saida Old City	1,382
		SDA	1	19	Other Gathering In SDA	1,099
		SDA	4	22	MIA MIA CAMP	201
0-39-45-40-46-0	3.99	NLA	2	45	BEDDAWI CAMP	1,115
		NLA	4	46	NAHR EL BARED CAMP	904
		NLA	3	40	Other gatherings in NLA	219
		NLA	1	39	Tripoli City	124
0-1-5-3-6-0	1.86	CLA	2	5	BURJ BARAJNEH CAMP	859
		CLA	3	3	Other gatherings in CLA	858
		CLA	4	6	CHATILA CAMP	630
		CLA	1	1	Sabra	515
0-51-52-50-53-0	4.4	BQA	1	51	Taalababaya- Saadnayel -Jalala	1,233
		BQA	3	50	Baalbeck	846
		BQA	2	52	Other Gatherings in BQA	218
		BQA	4	53	WAVEL CAMP	121

Steps 5 – Allocate on Cluster. Having identified the route for each cluster, this step will treat each cluster separately while allocating the supplies. First, initialize the allocation run to minimize the deprivation cost with a service level of 100%. This initialization step identifies the number of trips to perform and the idle time to be imposed so that a balanced load for the vehicle is achieved during the trips. Output is presented in Table 5.4.

Table 5.4. Results on 100% service level

Cluster	Idle Time Δ	No. of Trips h	Vehicle Load in each trip	Tour Length	δ*	Depriv. Cost
CLA	0.105	30	5,606	1.97	0	1,477.56
SDA	0	24	11,615	2.46	0	3,028.23
TYR	0.041	17	9,150	3.44	0	2,442.18
BQA	0.092	13	10,950	4.49	0	2,439.97
NLA	0.155	14	9,788	4.14	0	2,804.83

Applying the required 70% service level across demand sites using same sequence and tours will yield the following results (Table 5.5)

Table 5.5. Results on 70% service level

Cluster	Idle Time Δ	No. of Trips h	Vehicle Load in each trip	Tour Length	δ*	Depriv. Cost
CLA	0.105	30	4,006	1.97	0.57	28,145.01
SDA	0	24	8,295	2.46	0.7	46,836.00
TYR	0.041	17	6,578	3.44	0.97	26,858.38
BQA	0.092	13	7,813	4.49	1.26	24,871.16
NLA	0.155	14	7,086	4.14	1.14	24,147.45

Steps 6 – Improve Allocation. This step strives to make the clusters' deprivation cost as similar as possible by iteratively shifting supplies from a low deprivation cost cluster to a high level one. The output result converges after six iterations and is presented in Table 5.6.

Table 5.6. Minimize the maximum deprivation time among clusters

Cluster	Idle Time Δ	No. of Trips h	Vehicle Load in each trip	Tour Length	δ*	Depriv. Cost	Depriv. Person-Hr
CLA	0.105	30	3,856	1.97	0.62	30,689.94	19.56
SDA	0	24	9,514	2.46	0.44	30,335.53	11.85
TYR	0.041	17	6,245	3.44	1.09	30,219.96	20.2
BQA	0.092	13	7,128	4.49	1.54	30,400.60	22.05
NLA	0.155	14	6,358	4.14	1.45	30,410.99	22.2

Steps 7 – Result Achieved. A summary of the allocation supplies per demand site is presented in Table 5.7. A comparison with proportional allocation is included.

Table 5.7. Final allocation of supplies per demand site

ROUTE	Tour Length (Hrs.)	No. of Trips h	Area	Site Number	Demand Sites	No. of PRS Families	Allocate by Deprivation (Packages)	Allocate by Proportionality (Packages)	% Change
0-31-35-34-36-0	3.4	17	TYR	34	BURJ SHAMALI CAMP	1,071	42,440	44,982	-6%
			TYR	31	Other gatherings in TYR	965	38,944	40,530	-4%
			TYR	36	RASHIDIEH CAMP	353	13,864	14,826	-7%
			TYR	35	BUSS CAMP	273	10,909	11,466	-5%
0-19-14-21-22-0	2.46	24	SDA	21	EIN EL HILWEH CAMP	2,042	97,849	85,764	12%
			SDA	14	Saida Old City	1,382	66,720	58,044	13%
			SDA	19	Other Gathering In SDA	1,099	53,492	46,158	14%
			SDA	22	MIA MIA CAMP	201	9,598	8,442	12%
0-39-45-40-46-0	3.99	14	NLA	45	BEDDAWI CAMP	1,115	42,314	46,830	-11%
			NLA	46	NAHR EL BARED CAMP	904	33,687	37,968	-13%
			NLA	40	Other gatherings in NLA	219	8,251	9,198	-11%
			NLA	39	Tripoli City	124	4,752	5,208	-10%
0-1-5-3-6-0	1.86	30	CLA	5	BURJ BARAJNEH CAMP	859	35,052	36,078	-3%
			CLA	3	Other gatherings in CLA	858	34,464	36,036	-5%
			CLA	6	CHATILA CAMP	630	25,064	26,460	-6%
			CLA	1	Sabra	515	21,124	21,630	-2%
0-51-52-50-53-0	4.4	13	BQA	51	Taalababaya- Saadnayel -Jalala	1,233	48,270	51,786	-7%
			BQA	50	Baalbeck	846	31,540	35,532	-13%
			BQA	52	Other Gatherings in BQA	218	8,378	9,156	-9%
			BQA	53	WAVEL CAMP	121	4,468	5,082	-14%

The following results are identified in this example to support what had been stated earlier through this study:

1. A general result reached in this example, which answers objectively three main questions raised in section 2.12.2: when to serve a site, how much to deliver, and which routes to follow. The objective of the distribution plan is equity among beneficiaries and will be measured by minimizing the maximum deprivation cost experienced in any cluster.
2. The farther the demand site from the depot, the fewer the number of trips the truck will perform, and vice versa. Even though the two clusters have approximately the same total demand, the CLA cluster is the closest to the depot, was visited 30 times; whereas, the BQA cluster is the farthest and was visited 13 times.
3. The idle time had no impact on the deprivation cost measured inside the cluster; it has been used to balance the load across trips performed. Hence, the largest load a vehicle would carry is 9,514 packages and the smallest load is 3,856 packages. The 15,000 capacity specified earlier in this example did not impact the solution. Decision makers can adjust the logistical plan according to this result. Loading the vehicle with more supplies than it is scheduled to deliver won't reduce the deprivation level experienced by beneficiaries in clusters. On the contrary, that will distort the cyclical pattern of deliveries across the entire planning horizon and extend the last deprivation time.
4. The proportionality rule is cherished in each delivery to each site, except in the last trip as mentioned earlier. The existence of such property gives the model the equity essence, and that is implemented not in a single, but multi-period fashion. The proportionality rule might be a straightforward application to any resource allocation problem on a one time

instance; however, the recurrence of deliveries and the interactions of deprivation time with consumptions makes it hard to be achieved.

5. The deprivation time between cycles is kept constant across clusters over the entire planning horizon. The initial high total deprivation cost in the SDA cluster is reduced together with the recurrent deprivation time to become 0.44 hours as shown in Table 5.6. Also, the transfer of supplies to it didn't significantly increase the deprivation time for the other four clusters.
6. The most revealing result reached is how the SDA cluster attracts supplies from the four other clusters to reduce its total deprivation cost. Proportionality in distributing supplies among clusters is proven to distort the equity objective when time and distance play a role in the distribution plan. It is still applicable to sites inside each cluster but not among clusters. The behaviors demonstrated by this model stem from its goal to alleviate the aggregate suffering experienced by beneficiaries in each cluster. Since the SDA cluster holds the largest population, it is expected that some additional supplies should be allocated to it. Use of this model provides insight in distributing supplies across clusters to maintain equity.

CHAPTER 6. SUMMARY AND FUTURE RESEARCH

6.1. Summary

Practically, one of the most critical tasks after a natural disaster is to organize and execute humanitarian relief operations effectively and efficiently while reaching an equitable outcome at the same time. The humanitarian relief operation provides essential daily living supplies to people who are isolated inside the disaster affected areas. However, due to the sudden eruption of huge demands in the initial stage of response, it becomes challenging for logistics planning authorities to target needy individuals. The concerns would be with providing an unbiased platform to make decisions about equitable distribution schedules to a set of beneficiaries during the immediate response to a disaster when there are limited resources. Therefore, developing an effective and efficient disaster relief plan that tries to treat individuals as equitably as possible was the main motivation in this research.

For this purpose, this dissertation studied a novel last mile distribution plan in the initial response phase where the key focus is the preservation of lives. A centralized-supply delivery strategy, a single central depot, and multiple known demand sites were considered. Critical resources were allocated to demand sites directly from the central depot, and all vehicles would make many trips to serve demand sites. This integration and coordination of vehicle routing and resource allocation was investigated to formulate an allocation-routing model (RAP).

The theoretical foundation of RAP is formulated as an egalitarianism model. The goal is to alleviate suffering, and resources are distributed to maximize the welfare of those in greatest need. The strategic goal is to alleviate human suffering by minimizing the response time in regard to beneficiaries' needs fulfillment and delivery delay on the route. Equity is quantified with a *min-max* objective on deprivation cost. The objective function is set to minimize the maximum deprivation of the beneficiaries so that supplies arrive in a cyclical manner while all demand sites are treated equitably. The developed model seeks to allocate supplies to clusters such that it equalizes the expected suffering in the clusters. The model's key decision variables are the sequence of the sites each vehicle visits inside a cluster, the start time at which a vehicle leaves the depot, and the quantity delivered to each site in each trip. The available critical resources would be directed to the most needy or deprived beneficiaries.

The practical discussion on the routing-allocation problem started by initially assuming that enough resources are available at the depot. It is shown that allocating supplies to sites has proliferated considerations that emerged in the vehicle routing problem even if there were only a single route. On one hand, the demand rate of each site plays a role in determining the direction the vehicle travels from one site to another and not just the physical distance of the sites from the depot. In addition, the given level of shortages at the depot will also influence its direction. On the other hand, excluding a distanced site along a route from recurrent visits will reduce the transportation cost; however, this will extend the deprivation time and have negative implications on the equitable allocation strategy. Accordingly, this stipulates that all sites are to be visited in a sequence and supplies allocated such that the total deprivation cost of the route is kept to a minimum. That means sites are to be visited in a cyclical pattern.

As a generalized result reached in this study where enough resources are allocated to sites served by a single vehicle, the value of the total deprivation costs consists of the initial deprivation time incurred as the vehicle travels from the depot to each site during its first trip. The subsequent deliveries would yield no deprivation cost. Consequently, once the timing for the first delivery is set, any additional deliveries to the site should be scheduled in the same tour sequence provided that the vehicle's capacity would meet the consumption quantities per site until the next trip. Otherwise, deprivation time would be incurred and deprivation cost could take on high values if the deprivation time is not split equally across the remaining scheduled trips. By maintaining the same tour sequence, all beneficiaries in the cluster would then experience the same deprivation interval between consecutive deliveries. Moreover, the optimal deprivation times are fairly stable for all demand nodes in a cluster when supplies are distributed in proportion to the number of beneficiaries in each node, with deviations from the optimal deprivation time occurring only during the first and last deprivation periods.

Expanding the discussion to allow for shortages in supplies at the depot, the model indicated that scheduling cyclical deliveries to sites would be an appropriate strategy in a multi-period distribution plan. Setting equal deprivation time experienced by any beneficiary before each visit to the site would provide widespread equity in the distribution system. The cycle length is composed of deprivation time and consumption time. It is applied equally to all sites, with the exception of the last trip, and matched with the total duration of trips performed. As the amount of supplies at the depot decreases, deprivation time would stretch out to account for such shortages until reaching a tour length where the same number of deliveries would no longer be feasible and the required number of trips will be reduced incrementally. The quantity distributed between sites is proportional to their ratio of consumption with the exception of the last delivery. For any given service level, the total deprivation time experienced by each beneficiary is unchanged regardless of the number of trips performed. As the service level declines, the deprivation time differences among beneficiaries would decrease, creating a propensity of equal treatment in severe shortages.

This study regards the total planning period for the routing problem separate from the consumption period used in calculating the quantities of resources required to be allocated. The latter is fixed and used to determine the total demand required by each site; whereas, the total travel time of a vehicle is flexible depending on the number of trips allowed in a certain tour sequence. That gave rise to the concept of incorporating idle time to a vehicle once it reaches the depot. It was explained and shown graphically that delaying the vehicle from departing the depot will redistribute the vehicle load among trips to match the modified tour length. The proportionality rule will be sustained and no change in the deprivation time and hence no impact on the overall deprivation cost. In connection with this, achieving the lowest deprivation cost would necessitate that deprivation time, other than in the initial period, to be split equally among trips performed. Moreover, it has been recognized that quantities allocated per site will be the same size for all trips except the last one performed. Consequently, idle time can be used as a tool to alter the number of trips or to balance the loads across trips or to identify the appropriate vehicle type to be used while maintaining the same deprivation cost in this configuration. Therefore, understanding the behavior of the first and last delivery in a cyclical distribution schedule would simplify the problem.

Incorporating an idle time on vehicle departures exhibits similar results whether there are enough supplies or a shortage of supplies at the depot. Idle time has no impact on deprivation time per person-hour, recurrent deprivation time, total deprivation cost, individual site deprivation cost, total quantities delivered to each site, or the proportionality ratio. Finally, idle time can be used as a tool to scale the loads across trips to meet truck capacity, the truck route matching with the planning horizon in its final trip, or delivering the same quantity to a specific site in all trips performed. Such a scale is unaffected by varying the service level.

The allocation problem expanded further to consider multiple routes. As previously mentioned, visiting sites in loops will simplify the problem to where the only requirement is to identify the first trip sequence for each vehicle, as other trips will be repetitive in sequence and the same quantity is delivered per site except in the last trip. Deprivation and consumption times would be calculated based on sites' arrival times in the first tour. Even with such simplification, instead of attempting to solve the RAP model as a large non-linear program due to its complexity, this study adopts a six-stage solution approach that separates the problem into two sub-problems. The routing stage will assign one vehicle per cluster and sequence sites to create routes. The allocation stage considers deprivation costs among sites in each cluster, and also introduces novel heuristic algorithms to manage the allocations on clusters in the model. The algorithms play a pivotal role in providing equitable outcomes among and within clusters. The output will determine how many trips each vehicle will make, when they will start, and the sequence sites are visited to deliver equitable quantities on each trip.

In addition to theoretical development of the RAP, real-world case studies are involved in this research to gain insights into practicability of proposed models and solution methodologies. A survey conducted by UNRWA Lebanon Field Office on 14 February 2014, where 15,028 PRS families were located inside one of 20 sites dispersed across Lebanon, is employed in this study as a scenario to analyze. Various analyses are conducted, including the application of the bankruptcy rules, to provide a more comprehensive understanding of how to organize an equitable humanitarian logistics plan in a disaster relief operation.

6.2. Future Research

This research started a new approach to deal with distribution of supplies in humanitarian logistics. Demands are considered as rates not quantities, and the distribution plan is set according to how much supplies are needed in a time frame. This frame is still bounded by the time and space of a transportation network. Absence of supplies at a site doesn't create a penalty, but deprivation and suffering.

Combining allocation-routing with other aspects of logistics would be an interesting avenue of research. We are particularly interested in solving the location-allocation-routing problem and link it to the deprivation cost concept. Another interesting problem would be to investigate problems where depot locations are stochastic. This would model real-life situations better, as a site's initial deprivation time and cost tend to depend on travel time from the depot.

The most important criticism of the allocation-routing problem is that during the initial planning horizon, the beneficiaries' demands may fluctuate and even the location of the demand sites may change. Thus these types of uncertainties merit further investigation. In such a case, a dynamic RAP would be considered that strived to preserve flexibility in an uncertain environment and is solved using a robust analysis.

On the other hand, there are a number of issues that should be developed further to the proposed RAP. Among them, incorporate an operational cost in the model and solving the combined problem analytically. Also, the routing and allocation heuristics should be implemented in a stand-alone program. It is necessary to further investigate more sophisticated techniques, including meta-heuristics, to find optimal solutions. The deprivation cost function applied in this study is based on the water utility function. Other functions need further exploration to cover various consumables as well as non-consumable items. Finally, additional approaches should be initiated to develop better clusters, and identify generalized rules on the best ways to visit demand sites along a route to reduce the total deprivation cost.

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APPENDIX. SUMMARY DIFFERENTIATING CSC AND HSC

Table A 1. Summary table differentiating between CSC and HSC

		Commercial Supply Chain	Humanitarian Supply Chain
Definition	Chain Definition	The integrated process-oriented planning and control of material, information and financial flows along the entire value chain from the customers to the raw material producer, with certain objectives such as synchronization of supply and demand, improvement of customer orientation, flexible and demand oriented production, and reduction of inventory along the value chain.	The planning and management of all activities related to material, information, financial, people, and their knowledge and skills in disaster relief for the purpose of alleviating the suffering of vulnerable people. Importantly, it also includes coordination and collaboration with partners in the supply chain.
Supply Chain Structure	Chain Features	A typical supply chain consists of a network of suppliers, manufacturers, distribution centers, retailers, customer and three types of flow: information, financial and material flow.	A typical humanitarian chain consists of donors and governments as origins of the financial flow, suppliers as origin of the material flows, beneficiaries as the recipient or destination of material flow, staff as the manpower deployed to affected areas at each intervention to implement the supply chain, and knowledge as the required skills needed to reconfigure quickly the supply chain response.
	Stakeholders	Shareholders, customer and suppliers with aligned incentives. End User = buyer = customer	Different types of stakeholders including donors, governments, military, NGOs, beneficiaries, United Nations, etc. misaligned in incentives. Beneficiary = end user ≠ buyer = donor
	Supply Chain Range	From suppliers' supplier to customers' customer	From donors and suppliers to beneficiaries
	Revenue Sources	Revenues comes from sales of goods and services to customers. Pricing defines profit margin of the company, and it is relatively static over reasonable time horizon	Aids are given free for beneficiaries and there is no revenue generation. Funding and donations comes from governments, and charitable organizations or bodies.
	Dealing with Ineffective chain member	An ineffective member in a chain has to pay for its own inefficiencies.	There is no way to punish ineffective organizations because of absence of the humanitarian logistics system final beneficiaries' voice in the performance appraisal and evaluation process. Since the affected people are not directly involved in this process, provided they are not dead, they usually cannot claim for more than their damages, which is usually paid by insurances and governments.
	Chain Flows	Referred to as the Three Bs: Boxes, Bytes, and Bucks, representing material, information, and financial flow. Commercial products.	Three Bs adding a fourth and fifth B for Bodies and Brains, representing people, and their knowledge and skills. Resources like evacuation vehicles, people, shelter, food, hygiene kits, etc.
	Financial Flow	Bilateral and known.	Unilateral (from donor to beneficiary) and uncertain.
	Information Flow	Information is accurate and its flow is generally well structured.	Information is available only after assessment and often is unreliable, incomplete or non-existent, updated every second, and mostly flow through media. Data network is non-existent or of limited visibility.
	Collaboration and Coordination	Coordination between supply chain participants that can take the forms of joint-ventures, merges, etc.	A competitive environment emerges due to the difficulties in attaining funding. This makes coordination, collaboration, and resource sharing among participants limited or even impossible. Usually there are alternate supply chains operating in parallel.
	Ethics	Commercial organizations operate in accordance with CSR to align their values and behavior with the expectations and needs of stakeholders.	Humanitarian organizations act in accordance with the principles of humanity, neutrality and impartiality.
	Professionalism	Commercial SCM is now a respected career path.	Insufficient number of professional staff unable to efficiently and effectively supervise humanitarian operations. High employee-turnover, based on voluntary staff, harsh physical and psychological environment.
	Decision Making Structure	Formal decision making structures, a small number of decision makers, standard procedures, and clearly defined roles for all players.	Decisions are highly dynamic, often informal and/or improvised.
	Supply Chain Processes	Business processes are defined as supplier and customer relationship management, demand management, order fulfillment, manufacturing flow management, product development and commercialization and returns management.	Products development, manufacturing and returns management processes are not likely to be relevant to humanitarian supply chain.
	Process Management	Processes are structured and oriented to the value chain.	Processes are structured by projects and continuous welfare programs.
	Supply Chain Lifecycle	The majority are steady state supply chain that rely on supply chain models designed for repetitious actions.	The majority are transient supply chains that rely on finite-life supply chains models that are regularly deployed in response to a specific predictable events.
	Distribution Network Configuration	Well-defined with predetermined numbers and locations for distribution. Facility location and capacity is a critical strategic decision. Important to balance efficiency and responsiveness.	Dynamic network structure due to the nature of the unknowns (locations, type and size of events, politics, and culture), and "last-mile" consideration. Facility location and capacity are operational decisions and local distribution centers are instantaneous upon disaster. Lack of security in the regions affected by the disaster.
	Distribution Network Design	The distribution network has to be designed in such a way that they get the right goods to the right place and distribute to the right people at the right time in order to minimize system-wide costs while satisfying service level requirements.	The distribution network has to be designed in such a way that they get the right goods to the right place and distribute to the right people at the right time in order to save lives, reduce suffering and the best use of donated funds.

Table A.1 Summary table differentiating between CSC and HSC (continued)

		Commercial Supply Chain	**Humanitarian Supply Chain**
Supply Chain Logistics	Uncertainties	Commercial supply chain deals with four different levels of uncertainties: General variation, foreseen, unforeseen, and chaotic uncertainty.	The humanitarian supply chains show the extremes of a trend towards more chaotic uncertainty and risk prevalent in today's global business supply chains.
	Supply Pattern	High variation in products and services where mostly are predictable.	Unpredictability of supplies since good part of the supplies are obtained in-kind or through cash donated for procurement limited products. Unsolicited in-kind donations need sorting, special packaging, prioritizing to decrease bottlenecks.
	Demand Characteristics	Demand are products, characterized by relatively stable, and predictable demand patterns. Demands occur from fixed locations in set quantities.	Demand are supplies (aids) and people, characterized by suddenness and unpredictable in terms of timing, location, type, and size. Higher demands are usually expected during the initial days of relief operations.
	Response Time	A delay in the commercial supply chain is costly in terms of productivity and/or customer satisfaction,	A delay in the humanitarian supply chain could literally mean the difference between life and death for those most severely impacted by the disaster.
	Push-Pull movement	The customer "pulls" the goods when needed, while the suppliers "pushes" the goods towards the consumer to entice them.	At initial disaster response, relief items are pushed out to affected areas as quickly as possible to rescue as many lives. Later on, the demands of relief items are much estimated and are pulled to the affected areas.
	Volume and Frequency of the Logistic Activities	Commercial logistics deals with a large and relatively steady flows of goods. Most of the delivery activities repeat an established pattern day after day, though there may be variations from the routine.	Humanitarian logistics deals with a large pulse in demand that gradually subsides. Most humanitarian logistics are dealing with once in a lifetime events and, for that reason, the element of learning and improvement by repetition is not possible.
	Earmarking of Funds on Support Activities	Support activities such as improvement of processes, installation of state-of-the-art information and communication infrastructure, operations' support with a long-term focus, and organizational learning are important areas in commercial supply chain management.	Support activities are generally thought to have a lower priority function. Logistics and other support activities such as information technologies, decision support systems and human resources tend to be given inadequate funding. This situation generally continues until a negative situation associated with this lack of funding forces precautions to be taken.
	Infrastructure	commercial supply chains are fully functioning in an environment with well-defined and reliable infrastructure.	Operations often have to be carried out in an environment with destabilized infrastructure ranging from a lack of electricity to limited transport infrastructure.
	Transportation	Transportation network design is a strategic decision. It is well established and reliable. The choice of transportation mode creates competitive advantage.	Former plans on transportation network design becomes infeasible and unreliable when the infrastructures such as roads are severely damaged in the disaster. So the former plans needs to be revised to establish reliable routes to direct transport large and dynamic volumes of critical supplies with time limitation. Often very limited choice of transportation mode.
	Equipment and Vehicles	Ordinary trucks, vehicles and fork-lifts	Lack of vehicles and robust equipment that can be mounted and demounted easily greatly restrict the capabilities of transportation in the dispatching centers.
	Information System	Well-defined, highly developed software packages are generally available and used to integrate the supply chain stages, improve coordination, increase visibility and maximize profitability.	Variable levels of enabling technology is used with few software packages are available that can record and track logistical data. Manual, non-standardized, error-prone processes are dominant. Data has to be written out onto multiple forms and keyed into multiple spreadsheets with no central and structured database or historical data on prices paid, transit times or quantities received/purchased.
	Communication System	An established network-based communication system will reduce dramatically the operational costs, boost productivity and get closer to members of the chain.	Communication systems may have been impacted and unable to fully function in an environment with destabilized infrastructures. Means of communication often reduced during relief operations (no internet access on field etc.).
	Inventory Management	Sourcing is cost-based and procurement is a strategic decision that provide competitive advantage. Chain can tolerate lead times if to obtain lower purchase prices. Usually dealing with a predetermined set of suppliers, and manufacturing sites; they are 2 or 3 on average. Supplies brought into a country have to go through the normal customs procedure. Inventory control is relatively less challenging that utilizes well-defined methods for determining inventory levels based on lead time, supply, demand and target customer service levels.	Sourcing is donation based and procurement is an immediate operational decision. Chain cannot tolerate lead times and ready to accept high purchase prices set by suppliers since it is a matter of life or death. Suppliers and/or donors are uncertain in identity and number. Clearing humanitarian aid at country port of entry needs additional step: getting the duties and taxes exemptions. Inventory control is challenging due to the high variations in lead times, supply, demands, and demand locations. Prepositioned inventories are usually insufficient.

Table A.1 Summary table differentiating between CSC and HSC (continued)

		Commercial Supply Chain	Humanitarian Supply Chain
Supply Chain Model	Objectives being pursued	Typically to produce high quality products at low cost to maximize profitability and achieve high customer satisfaction.	High stakes (often life-and-death) aims at minimizing loss of life and alleviating the suffering of vulnerable people in disasters.
	Model Formulation	Maximize profit or minimize cost	Fairness and efficiency
	Performance Measurement System	Based on standard supply chain metrics focused on resource performance measures, such as maximizing profit or minimizing costs. Reliability (fill rates, delivery performance, order fulfillment); Responsiveness (lead time), Flexibility (supply chain response times, production flexibility); cost (total cost, costs of goods sold, value-added productivity, warranty cost or returns processing cost); Assets (cash-to-cash cycle time, inventory turnouts).	Many relief operations are naturally ad-hoc and poorly structured, without effective performance measurement systems in place. The primary focus is on output performance measures, such as the time required to respond to a disaster or percentage of demand that is met. Output (total amount of disaster supplies, target fill rate achievement, average response time, minimum response time); flexibility (units of supply provided, number of different types of item provided); resources (total cost, distribution cost, cost of supplies, number of relief workers, money spent per aid recipient, donor spending per time period).
Cross Learning Possibilities	Amount of Academic Research	The field of commercial supply chain is a mature discipline with many research concepts and tools developed and successfully implemented in global organizations.	The field of humanitarian logistics is relatively new with significant research only having begun to be undertaken within the last five years.
	Learning Possibilities	Business professionals have a lot to learn from the humanitarian sector such as in agility, adaptability, alignment, volatility of demand, imbalance between supply and demand, disruptions	Humanitarian professionals have a lot to learn from the commercial sector such as in demand forecasting, inventory management, bullwhip effect, push-pull boundary, standardization, information integration, postponement, logistical restructuring, collaboration, resource sharing, and partnership