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HUMANITARIAN LOGISTICS: INNOVATIVE METHODOLOGIES FOR HUMANITARIAN LOGISTICS MANAGEMENT

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...chasing the wind…

INTRODUZIONE

Negli ultimi decenni sono aumentati considerevolmente i disastri e le catastrofi sia naturali sia derivanti dall'uomo, con una conseguente crescita del numero delle relative operazioni umanitarie.

In questa situazione, è diventato enorme l'impiego di risorse nella catena di fornitura umanitaria, in cui, secondo la letteratura, la logistica copre fino all'ottanta per cento del totale sforzo.

Inoltre, è stata posta maggiore attenzione alle performance logistiche delle diverse organizzazioni coinvolte nelle operazioni umanitarie e grande cura nei confronti dell'efficienza e della sostenibilità degli aiuti. Efficienza e sostenibilità sono due caratteristiche fortemente legate tra loro, in particolare per quanto riguarda l'impatto sociale a lungo termine dei disastri e le successive operazioni di risposta ai bisogni delle popolazioni colpite.

É stato importante quindi riuscire a definire, monitorare e migliorare l'efficienza delle funzioni logistiche, oltre a introdurre nuovi termini per raggiungere una sostenibilità che si riferisca a tutti gli ambiti dell'operazione.

Su tale fronte, questo elaborato introduce innovativi modelli teorici per l'analisi delle performance dei sistemi logistici e sostiene, attraverso un appropriato studio della letteratura, nuovi modelli che introducono e sviluppano la sostenibilità e l'impatto sociale delle pratiche logistiche in ambiente umanitario, con esclusiva attenzione alle particolarità e alle problematiche ad esso associate.

L'elaborato si articola nelle seguenti parti:

1. Introduzione della letteratura e dei *criteri-drivers* utilizzati per la valutazione di questioni di carattere umanitario. Sviluppo dello studio del loro legame con applicazioni logistiche reali e numeriche;
2. Introduzione di modelli per la distribuzione nell'*ultimo miglio*. Discussione dello stretto legame tra flotta logistica e performance in termini di costi e soddisfazione della domanda;
3. Presentazione e sviluppo di modelli *euristici* per la distribuzione che considerino le caratteristiche tipiche umanitarie e allo stesso tempo introduzione di modelli semplici da implementare e utilizzare in casi reali;
4. Introduzione e definizione di nuove tecniche di *reverse logistics* in operazioni umanitarie, con studi provenienti dal campo, dalla letteratura e dagli aspetti che le organizzazioni stanno implementando;

5. Presentazione di un caso di reverse attuato in Italia: il *waste management* dopo il terremoto in Emila Romagna del 2012;
6. Definizione di un nuovo modello per la locazione di impianti di smaltimento e studio dell'impatto, in termini di performance, che questo può avere nelle operazioni umanitarie.

Il lavoro di tesi è stato sviluppato in stretta collaborazione con il Prof. Luk Van Wassenhove, Professore di "Technology and Operations Management" e Direttore dell'Humanitarian Research Group presso l'INSEAD Business School (Fontainebleau, France), e con il Prof. Peter Tatham, Professore di logistica umanitaria presso la Griffith University e Direttore del Dipartimento di "International Business and Asian Studies". Durante il dottorato e grazie ai periodi di ricerca all'estero, i contributi di tale ricerca sono stati portati alla pubblicazione su importanti riviste e presentati a convegni internazionali.

ABSTRACT

During the last decades, disasters and catastrophes both natural and handmade have been radically increased and it seems this way of things will continue the next years. In such this situation there has been even a growth in terms of humanitarian operations, in particular of the total humanitarian effort in terms of resources and supply chain in general. According to the literature here, the logistic impact covers up to 80% percent of the total effort.

All the organizations involved in these operations gave special attention to logistic performance, with an always crescent focus on effectiveness, efficiency and sustainability. In fact, the long term social impact that the disasters and the next operations can cause to the population and in general to the area, is well known by the researchers. For these reasons it is important to define, monitor and improve the logistic functions efficiency; moreover it is important to introduce a new sustainable way to reach the success of all the operations perspectives.

With this goal in mind, this research introduces new theoretical innovative methods to analyze the logistic systems performances and it introduces, through an appropriate and deep literature review, new models that present the sustainability and the social impact associated to the logistic practices in the humanitarian environment.

This thesis is composed by these principal sections:

- Introduction and analysis of the humanitarian literature with a focus on the different divers that usually are used for the evaluation of humanitarian operations. Moreover it presents a definition of a general decision making framework and its application.

- Introduction and definition of forward distribution models. In particular, the discussion of the tradeoff between the costs analysis and the demand satisfaction or shortage, associated to the use of different fleets and the development of innovative heuristic models for the distribution that considers typical humanitarian features.

- Introduction and definition of innovative reverse logistics practices based on what is normally used in the industrial supply chain and based on what the humanitarian organizations are implementing in the fields; as an example it is presented a real reverse logistics case, with real data and issued from an Italian case study, the Emilia Romagna earthquake (2012). Moreover, an innovative reverse logistic model for the

location of reverse plants is presented, with the study of their impact in humanitarian operations.

The present work has carried out to the publishing of several scientific contributions in relevant International Journals and Conferences, like Journal of Humanitarian Logistics and Supply Chain Management, International Journal of Service and Operations Management and International Journal of Operations and Quantitative Management.

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First of all, I would really like to thank to my research supervisor, Dr. Fabio Sgarbossa. With his valuable professional suggestions, he has been a great example, which has driven me in these three years in my research and experiences.

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A thank is also due to the people which for years have shared with me the office. My friends Alessandro, great fellow and great football player, Anna, Giorgia, Martina and Ilenia super nice colleagues. I cannot forget to thank all my research colleagues: Daria, Francesco, Maurizio, and Mauro.

A great thank goes to all my family, from my Mum Elisabetta and my Dad Stefano to my Grandma Italia, my beautiful sisters Sofia, Alice and Beatrix, and my right arm Giacomo, twin, colleague, sport mate, windsurfer and so many other things. The one thousand battles friends Beno & Zè. My cousins. My lawyer Daldo.

A special thanks to my beloved Martina. She has followed me in so many adventures and I will do the same. I have shared so many moments and trips, she has helped me infinite times, she makes me smile; she is chasing the wind with me. But this is just the beginning.

Last but not least, I would thank the surfers all around the world, promising I will join you soon guys.

Thank you all, A huge Shaka to all of you,
Umberto Peretti

Vicenza
31 January 2015

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1. Introduction

1.1. Purpose of Research

Historical data indicate that the total number of natural disasters has dramatically risen over the last ten years (Tang, 2006). According to Thomas and Kopczak (2005), they are even expected to increase another fivefold over the next 50 years, as ascribable to many different factors like global warming, population growth rate, urbanization, residential densification, economic and financial global contingencies, natural resources immoderate use and depletion, etc. Due to these reasons, offering timely and necessary aid to those in need through efficient humanitarian supply chains is a major challenge and logistics acts as a strategic role, as expressed by Trunick (2005). In fact, the goal of humanitarian operations has been defined by Tomasini and Van Wassenhove (2004) as “a successful humanitarian operation [that] mitigates the urgent needs of a population with a sustainable reduction of their vulnerability in the shortest amount of time and with the least amount of resources.” Indeed, one of the most critical tasks during the humanitarian operations, after a natural catastrophe, is to manage and execute all the logistics activities effectively and efficiently.

The present thesis has been developed starting from the consideration of the central role of logistics in the humanitarian supply chain in order to guarantee the achievements of the humanitarian operations’ goal.

For this reason the main purpose of this thesis is the definition of innovative methodologies for the humanitarian logistics management. In this research, the author has developed and introduced innovative theoretical models in order to define the factors and their dependence into the definition of the achievement of the humanitarian operations goal and in order to consider new features as sustainability and social costs in the final humanitarian operations evaluation.

In particular the thesis has these main objectives:

• Introduction and analysis of the literature with a focus on the different criteria usually used for the evaluation of humanitarian operations; definition of a decision making framework and its application on real cases.

• Introduction and definition of new last mile distribution models, discussion of the tradeoff between the costs analysis and the demand satisfaction or shortage associated to the use of different fleets.

• Definition and development of innovative heuristic models for the distribution that consider typical humanitarian features. These simple methods are easily implementable in real humanitarian operations cases and could be used by the humanitarian organizations;

• Introduction and definition of innovative reverse logistics practices based on what is normally used in the industrial supply chain and based on what the humanitarian organizations are implementing in the fields;

• Introduction of a real reverse logistics case, with data and issued: Emilia Romagna earthquake, 2012;

• Introduction of an innovative reverse logistic model for the location of revere plants, and study of their impact in humanitarian operations.

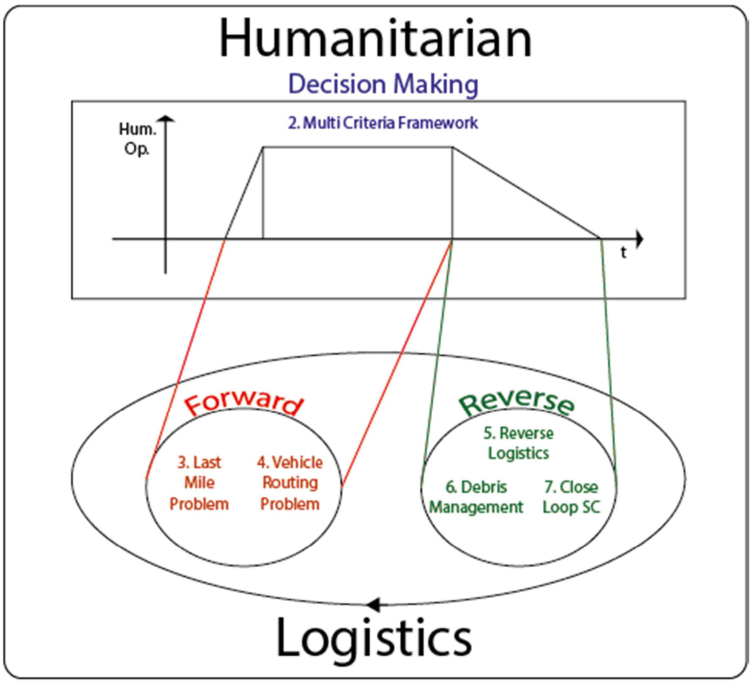


Figure 1.1: Thesis Graphic Abstract

1.2. Structure of Thesis

The present thesis has been structured in the following sections, according to the main aims of the research:

Chapter 2: The purpose of the chapter 2 is to present a general multi-criteria decision making process, to assist the evaluation of suitable alternative solutions to operations management issues in the humanitarian context, for each different phase of the life cycle. Within this chapter, humanitarian operations are described in terms of a multi-objective field that reflects service level, timing and costing as final goals, and they are composed of different life cycle phases, each of which has particular features. A structured procedure is developed and validated with some examples of its possible applications.

Thereafter, using a sensitivity analysis, it is discussed a real case. Through the study of the literature, a framework is built up and analysed to support decision makers in their evaluation of operations issues, in which the objective hierarchy is defined and are estimated the attributes of the alternatives. The given examples are just numerical illustrations of framework applications.

There is a need of additional different applications to understand how this methodology can further vary according to the parameters of the disaster in question. The impact of the research regards the support with a structured framework, of the decision makers in humanitarian operations, where usually the chaos makes difficult and critical the easiest decision. Although multi-criteria decision making topic is well suggested by some papers, there are no researches that have been focused on its application into humanitarian operations with the presentation of a hierarchy process to support the operators in making choices.

Chapter 3: The purpose of this chapter is to extend a routing model so that it may be applied to a real case study of material deliveries involved in a development operation, typical of regular humanitarian logistics, and to explore the impact of variations in available logistic assets. The introduced model is a conceptual evolution of the study recently presented. It concerns the resource allocation and vehicle routing decisions in the well-known Haitian case. Different scenarios are analyzed and a sensitivity analysis is provided. Here are considered constraints related to transportation resources in a complex environment, transportation vehicle capacities, and delivery time restrictions. This research shows how the logistic assets characteristics and their availability affect the distribution system performances, in terms of total distribution cost and shortages. The chapter 3 explores the Last Mile Distribution Problem, providing a case study to assist decision-makers in making effective and efficient distribution across the last mile. The part of research focuses upon the distribution systems management coupled with material distribution modalities.

Chapter 4: This chapter analyzes the Vehicle Routing Problem (VRP) with the particular application to the humanitarian field. The main question that differs in the application of VRP in humanitarian operations concerns the presence of Social Costs and their increase during the whole time window. These costs are defined as the sum of Logistics, linear function and Deprivation Costs, modelled as exponential functions. The suggested solutions can be used in order to achieve a good final level of Social Costs and introduce the idea of VRP Heuristic applied to the humanitarian operations.

Chapter 5: Chapter 5 introduces the use of Reverse Logistics into humanitarian operations. Whilst implementation of a broad range of Reverse Logistics (RL) practices is increasingly the norm within commercial supply chain management, they have had limited impact in the humanitarian logistics (HL) sector. The aim here is, therefore, to analyze the challenges and opportunities for the application of RL in a humanitarian logistic context.

Through a broad review of both the academic and practitioner literature, supplemented by informal discussions with senior humanitarian logisticians, the research summarizes the current state of RL within the humanitarian logistic sector, before recommending ways in which practices that are increasingly found in a commercial context could be implemented. The finding indicate that, to date, the use of commercial RL practices is extremely limited within the HL sector, but there are a number of areas where their introduction is possible in the future.

Whilst the reviews of the literature were comprehensive, further and more detailed research into the RL practices (if any) needs to be undertaken by aid agencies, in order to implement appropriate lessons and experiences across the sector as a whole. Given the overall desire of humanitarian agencies to ‘do no harm’, it will be increasingly important for such organizations to embrace RL practices in order to improve the sustainability of their disaster preparation and response activities. In light of the generally increased awareness of the need to reduce the environmental footprint, as well as improving the social and economic impacts of their supply chain activities, there is likely to be increasing pressure on aid agencies to adopt RL practices. This part of research identifies some of the potential areas in which this can be undertaken, and the associated barriers to be overcome. To date, it would appear that no academic research has been undertaken into the RL practices within the humanitarian logistic sector. To this extent, the research represents a first look at a new sub-topic within the overall HL field.

Chapter 6: In this chapter is presented a real Italian case of post-earthquake operation occurring in Northern Italy since May 2012. In particular, the purpose is to analyze the response carried on by the various organizations involved in the disaster in terms of different actors involved, number of persons and report on the post disaster waste management process. The analysis demonstrates to be complementary to the existing published literature in the field. In the second part of this work the author investigates the management of the most important waste material: the construction and demolition debris. The collected data reflect the great amount of waste generated during and after the two recent Italian earthquakes and the number of months that have been necessary to manage the debris removal process in more than 1,000 demolition sites. The Government attempts to recycle as much of the waste as possible with the aim to conserve the remaining landfill capacity.

Chapter 7: This chapter introduces for the first time the concept of the close loop supply chain (CLSC) into humanitarian operations. This has been already considered in the commercial supply chain, where the reverse flow practices have been explored. Indeed, although this topic is well suggested by some papers there are no researches that have been focused on CLSC into humanitarian operations. Since in the last years new trends have been coming out into humanitarian OM and always more importance has been giving to sustainability, this chapter wants to study and apply CLSC practices into humanitarian context in order to study the impact that it could have for the operations.

The chapter explores the CLSC topic by providing a model and studying to evaluate Regular humanitarian logistics (R-HL), where the main objective of the operation move from the reduction of population needs to a minimization of the overall impact of the disaster and of the operations. This part of research focuses on the logistic facility management coupled with material distribution modalities in the situation where the items are not just delivered using “forward channels”; it rather considers others flows that usually the humanitarian literature didn’t face yet, for instance “reverse channels” or the management of operations waste. This is because the issue of the humanitarian operations impact arose from the literature.

Constraints related to transportation resources in a complex environment, transportation vehicle capacities and delivery time restrictions are here considered, moreover different scenarios are analyzed. The proposed model optimizes resources allocation and prepositioning decisions on a number of test problems. Moreover the impact of each practice proposed is evaluated in order to understand its applicability in this particular context.

Chapter 8: This chapter reports the conclusions about the researches and the future steps.

Chapter 9: In this chapter are listed the references, divided by chapter in which they are mentioned.

1.3. Main Scientific Contribution Developed

The presented research has permitted to write and publish several scientific contributions in many important international journals during the last three years, like Journal of Humanitarian Logistics and Supply Chain Management, International Journal of Service and Operations Management and International Journal of Operations and Quantitative Management.

Some of these have been also presented and discussed by the author in several international conference, such as EurOMA, and national conferences AIDI.

Moreover, the research has also been carried out during a period of time in 2012-13 at the Humanitarian research team at INSEAD business school, in collaboration with Prof. Luk Van Wassenhove and during a period of time in 2013-14 at International Business and Asian Studies Department at Griffith University, in collaboration with Prof. Peter Tatham.

Here below the list of scientific contributions developed from this research:

INTERNATIONAL JOURNALS

BATTINI, D., PERETTI, U., PERSONA, A. AND SGARBOSSA, F. (2014), 'New last mile distribution model in relief application: the Haitian case'. JOURNAL OF HUMANITARIAN LOGISTICS AND SUPPLY CHAIN MANAGEMENT, VOL. 4, NO. 1, PP. 131-148.

PERETTI, U., THATAM P., SGARBOSSA, F., WU, Y. (2014), 'Reverse logistics in humanitarian operations: challenges and opportunities', ACCEPTED BY JOURNAL OF HUMANITARIAN LOGISTICS AND SUPPLY CHAIN MANAGEMENT.

BATTINI D, CALZAVARA M, PERETTI U, PERSONA A (2014). 'Debris management in post-earthquake operation: an Italian case study'. ACCEPTED FOR PUBLICATION AT "HUMANITARIAN OPERATIONS MANAGEMENT" SPECIAL ISSUE, IN THE INTERNATIONAL JOURNAL OF OPERATIONS AND QUANTITATIVE MANAGEMENT.

PERETTI U., PERSONA A., SGARBOSSA F., TATHAM P. (2014). 'Application of general multi-criteria framework for humanitarian logistics', ACCEPTED FOR PUBLICATION BY INTERNATIONAL JOURNAL OF SERVICES AND OPERATIONS MANAGEMENT.

PERETTI U, BATTINI D, PERSONA A, SGARBOSSA F., VAN WASSENHOVE L. (2014). 'Vehicle routing problem heuristics in humanitarian operations' SUBMITTED TO EUROPEAN JOURNAL OF OPERATIONAL RESEARCH.

TATHAM P., LOY J., PERETTI U., (2014). 'Three dimensional printing – a key tool for the humanitarian logistician?', UNDER REVIEW BY JOURNAL OF HUMANITARIAN LOGISTICS AND SUPPLY CHAIN MANAGEMENT.

BATTINI D., PERETTI U., PERSONA A., SGARBOSSA F. (2014). 'LCA for waste management in post disaster operations' SUBMITTED TO INTERNATIONAL JOURNAL OF INTEGRATED WASTE MANAGEMENT, SCIENCE AND TECHNOLOGY.

PERETTI U., BATTINI D., PERSONA A., SGARBOSSA F. (2014). 'Sustainable Humanitarian Operations: Close Loop Supply Chain', SUBMITTED TO INTERNATIONAL JOURNAL OF SERVICES AND OPERATIONS MANAGEMENT.

INTERNATIONAL CONFERENCES

TATHAM P., LOY J., PERETTI U. (2014). '3D Printing: A humanitarian logistic game changer?', PROCEEDINGS OF THE ANZAM SYMPOSIUM 2014.

BATTINI D, PERETTI U, PERSONA A, SGARBOSSA F., WASSENHOVE L. N. (2013). "Vehicle routing problem in humanitarian operations", PRESENTED AT 20TH EUROMA CONFERENCE.

AZZI A, BATTINI D, PERETTI U, PERSONA A, SGARBOSSA F. (2012). "The Haitian case: an application of a last mile distribution model in relief operations", PROCEEDINGS OF THE 5TH INTERNATIONAL CONFERENCE ON OPERATIONS AND SUPPLY CHAIN MANAGEMENT.

NATIONAL CONFERENCES

Battini D., Peretti U., Persona A., Sgarbossa F. (2014). "Close Loop Supply Chain in Humanitarian Operations". Accepted at XIX Summer School Francesco Turco (SSD Ing-Ind/17), Senigallia (An).

Battini D., Peretti U., Persona A., Sgarbossa F. (2013). "LCA in Disaster Waste Management: Emilia-Romagna Earthquake, an Italian case study". Accepted at XVIII Summer School Francesco Turco (SSD Ing-Ind/17), Senigallia (An).

Peretti U., Persona A., Sgarbossa F. (2012). "Development of a general multi-objective framework for OM in Humanitarian Logistics". Presented at XVII Summer School Francesco Turco (SSD Ing-Ind/17), Venezia (Ve).

2. Decision making in Humanitarian Operations

One of the most challenge features associated to humanitarian operations is their complexity (Tatham and Houghton, 2010; Altay and Labonte, 2014) that reflects the multiplicity of actors and stakeholders, the challenges of the physical environment and the speed with which changes occur. As a result, the evaluation of the potential operational alternatives reflects a wide range of factors, such as the impact on those affected and the speed of the response, in addition to the inevitable consideration of the financial cost of the proposed action(s).

Such a multiplicity of variables is, of course, not solely a feature of the humanitarian logistic (HL) challenge as such scenarios can be found in multiple other business contexts and which are frequently investigated through the use of operations management techniques. It is, therefore, unsurprising that the literature contains a number of examples of the use of operations management (OM) techniques as a means of better understanding the challenges associated with the management of humanitarian supply chains (HSCs). Such examples include the work of Overstreet, R. E., et al. (2011) or Caunhye *et al*., 2012. A particularly helpful feature of this research is the extent to which different parameters are taken into consideration in order to obtain the best fit of the representative models and, thereby, improve the management of such operations. Such examples include the work of Lin, *et al*. (2011).

Moreover, due to the inherent complexity of humanitarian operations, the final objective is usually hierarchical linked to several factors which may not be easily evaluated, for example the available capital and humanitarian resources, the number and role of beneficiaries, as well as cultural and social aspects. All these features impact on other elements, such as quality, agility, etc. which, as explained below, are important components that are needed to evaluate the final multi-objective goal of the operation.

Furthermore, as is evident from the literature (see, for example Tatham, P.H., et al., 2012), humanitarian operations take place across a number of phases, where each phase has its own constraints and issues. From this it is clear that the use of OM techniques must take particular account of the humanitarian operations life cycle, not least because the activities undertaken, the volumes of resources to be moved and the overall constraints differ markedly across each of these phases.

The purpose of this session is a general multi-criteria decision making framework that will support evaluation of alternatives courses of action within a humanitarian operations context. From the literature review d all the aspects and the criteria that are considered in these papers as essential in order to evaluate the issues in that specific phase have been found. From this point the framework has been built up. The central criteria are the ones most used by the literature, the ones that are seen by literature has central, while the others have been classified as secondary or tertiary for analogue reasons. The application of this framework is designed to assist the user in considering the different characteristics and the different phases of humanitarian operations life cycle. In particular, the proposed approach can support decision makers in their evaluation of the range of operations issues in which the objective hierarchy is defined and the attributes of the alternatives can be estimated.

Within this chapter, a strong literature review is carried out to find the criteria that usually are used by the literature in the evaluation of humanitarian issues. Hence humanitarian operations are described in terms of multi-objective issues and their composition of different life cycle phases, each of which has particular features. Moreover a structured procedure is developed from the top with the decision goal to the different lower levels of criteria that are linked to the alternatives. Each pair of elements at the same level is compared and a matrix of relative importance is obtained, to do this the Saaty's (2008, p. 86) scale of comparison (Table 2.1) is used then overall or global priorities are obtained. Finally these priorities are used to evaluate the final priorities of the alternatives at the bottom-most level.

This research defines and determines the general problem and the system characteristics relating to the post disasters humanitarian operations. It presents a structured decision hierarchy, the framework. This framework, differently from the ones present in the literature (Richey, R. G., 2009, Liberatore, F. et al, 2014), can be used in every phase of the disaster and for different issues because leads different priorities for different situations through the utilization of AHP. The importance of the application of this tool into humanitarian operations is associated to the possible evaluation of complex issues in a wide range of applications; moreover during the evaluation of the criteria the consistency helps the decision makers in giving the right relative importance. Another important feature is that is the robustness is easily verifiable through a sensitive analysis, this helps in understanding how different criteria evaluation can condition the overall output.

To conclude this research suggests the guidelines to understand which criteria impact mainly on decision making in humanitarian context and how different criteria or alternatives evaluations impact in the final result.

2.1. Literature review

This section contains an overview of the contributions on the use of operations management techniques that are contained within the humanitarian logistics literature. This will underline the main features of this research field, the requirements generated in recent years by the humanitarian actors and, finally, the benefits of the proposed general multi-criteria decision making process.

In the last decades Humanitarian Operations have received increasing attention by the researchers and it is still increasing in terms of investigations (Littieri, E., et al., 2009; Natarajarathinam, M., et al. 2009; Caunhye, A.M. et al., 2012, Kunz, N. and Reiner, G., 2012, John, L. et al. 2012).

Particularly in this quite new field of research many operations management aspects have been dealt with, as the context (Van Wassenhove, L.N., 2006, Kovács, G., and Spens, K. M., 2007, Altay and Green, 2006), the challenges (Kovács, G., and Spens, K. M., 2009, Balcik, B. et al. 2010), the trends (Apte, A., 2009; Kovács, G., and Spens, K.M., 2011) and many other OM features. Throughout this research the definition of humanitarian supply chains (HSCs) will be that offered by Thomas and Kopczak. These authors adjusted the Council of Supply Chain Management Professionals (CSCMP) definition of commercial supply chain management and argued that HSC management is: "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements" (Thomas and Kopczak 2005, p. 2).

The relationship between humanitarian and commercial supply chain has been widely tackled in the literature where, in particular, there is considerable discussion of the impact of unpredictability that affects both types of supply chains (see, for example, Christopher and Tatham, 2011). Other comparative discussions include the management relationships that are developed "just in case" in HSCs versus the economic transaction approach that is found in commercial supply chains (CSCs) (Kovács and Spens, 2011). Separately, Kovàcs and Spens (2007) specify a number of key features to be found in HSCs such as actors, phases and logistic processes in relief operations. Other papers investigate the challenges and the practices (Balcik et al., 2010; Kovács and Spens, 2011) and the broader similarities and differences between commercial supply chains and humanitarian ones (Beamon, 2004; Maspero and Ittmann, 2008; Holguín-Veras *et al.*, 2012). Furthermore, many papers in the literature tackle typical humanitarian issues such as the problem of allocating scarce resources to complex operations (Fieldrich et al., 2000; Van Wassenhove and Pedraza Martinez, 2012; Battini et al., 2014), scheduling activities (Barbarosoğlu et al., 2002; De Angelis et al., 2007) prepositioning (Rawls, C.G. and Turnquist, M.A., 2010; Campbell, A.M. and Jones, P.C., 2011; Lodree Jr, E. J., 2011) and supply items (Knott, 1987; Haghani and Oh, 1996; Balcik et al., 2008; Nolz et al., 2010).

Some of these macro differences are well summarized by Balcik and Beamon (2008, pp. 102) who emphasize the importance of the following features of HSCs:

• Unpredictability of demand, in terms of timing, location, type, and size.

• Suddenly-occurring demand in very large amounts and short lead times for a wide variety of supplies.

• High stakes associated with adequate and timely delivery.

• Lack of resources (supply, people, technology, transportation capacity, and money).

More specifically, some applications of multi-objective models are offered in the literature using linear programming (Tzeng *et al*., 2007; Stepanov and Smith 2009; Lin *et al*., 2011). However, reflecting on the recommendation of Chandes and Paché (2010) who emphasize that a structured approach is necessary in order to improve the future operations, it is argued that the linear program approach which models aspects such as costs, time and service level is helpful, a broader multi-criteria approach that utilise different factors at different levels is necessary.

In particular and as outlined earlier, when researching humanitarian operations, it is clear that a specific focus should be directed towards the life cycle. Thus, many authors including Long (1997), Nisha de Silva (2001), Cottrill (2002) and Kovàcs and Spens (2007), Kovács and Tatham (2009) argue that a humanitarian operation has to be seen as a set of phases that jointly constitute the life cycle. Typically, such models reflect a number of phases that vary from the three macro-phases offered by Kovács and Spens (2007): (1) a preparation phase; (2) the transition phase and (3) the reconstruction phase, to alternative models which suggest a greater number of phases. Thus, Charles *et al*. (2007) offer a model that consists of (1) a first phase of preparedness, then when a disaster hits an area; (2) the ramping up (Tomasini and Van Wassenhove, 2004); (3) the transition (4) a phase of support (sustainment); and (5) the final phase of dismantling (ramping down). Safran, P. (2003) instead introduces the concept of cycle associated to the disaster management operations, where a disaster life cycle ending corresponds to the beginning of another disaster management cycle.

Figure 2.1: Humanitarian Operations Lifecycle. Safran, P. (2003).

The introduction of the life cycle is important as it helps to emphasise the different circumstances that it is possible to find in each phase. Indeed, each phase has its own distinct issues and for this reason each has a different route by which it can be improved. This point is reinforced by Van Wassenhove and Pedraza Martinez (2012, p. 309) who note that "different phases are likely to be managed by different parties with distinct objectives". Furthermore the cyclical nature of the preparation – response – reconstruction –preparation phases in which the management actions taken in each specific event are informed by the success and/or failure or the previous iteration is an important driver of behaviour.

From the analysis of literature, it is clear that an approach that is both systematic and general should be adopted in order to assist researchers and practitioners in resolving the sort of operations management issues that typically arise, but that these approaches should be framed by consideration of the humanitarian preparation and response life cycle. Moreover, it is argued that a hierarchical approach could simplify these complex decision-making problems through consideration of both quantitative and qualitative factors in the evaluation of the final solution set. For these reasons, a multi-criteria decision making process based on AHP has been developed and, as will be demonstrated later in the thesis, its application in a real case study has demonstrated the validity of the methodology. AHP has been selected because it "is a very useful technique in solving complex decision problems. By applying this methodology, I can identify several qualitative and quantitative criteria, examine the competing and conflicting objectives among them, and assess their relative importance in order to make trade-offs and to determine priorities among them for making good decisions” (Tummala *et al*., 1997, p. 272).

The limitations of the AHP approach are well summarized by Ishizaka and Labib (2009), in particular among them 5 limitations have been considered for the application of the presented framework:

- Problem structuring: Different structure may lead to a different final ranking.
- Pairwise comparisons: Comparisons are recorded in a positive reciprocal matrix. In special cases a non-reciprocal matrices can be used, and such non-reciprocal matrices are then treated similarly to traditional matrices. In this respect the alternative use of Expert Choice does not offer the possibility of being non-reciprocal.
- Judgment scales: The use of verbal comparisons is intuitively appealing, user-friendly and more common in our everyday lives than numbers. It may also allow some ambiguity in non-trivial comparisons. To derive priorities, the verbal comparisons must be converted into numerical ones. In Saaty’s AHP methodology the verbal statements are converted into integers from one to nine. Among all the proposed scales, the linear scale with the integers one to nine and their reciprocals has been used most frequently across a range of applications.
- Consistency: Expert Choice uses the consistency ratio. However, this consistency ratio has been criticized because it allows contradictory judgments in matrices or rejects reasonable
- Sensitivity analysis: The sensitivity analysis in Expert Choice varies the weights of the criteria as input data. However, sensitivity analysis is a fundamental process in the decision with AHP.

As discussed above, the many different characteristics considered in this kind of operations lead to the use of a multi-criteria approach and, therefore, a key component of the approach is to evaluate the weight of each of the hierarchical factors. This will be achieved through inspection of the literature in order to achieve a final global goal. The weight of these elements and the goals will change according to both the operation itself and the phase of the humanitarian operation life cycle in which the problem is being considered.

One of the key aspects of the thesis is the potential for some of the features of a humanitarian supply chain to be used as performance measures, for example: number of beneficiaries, the level of damage (infrastructure) and the quantity of donations (capital, human resources) or the time required (time, cost) to reach the beneficiaries.

2.2. Decision making in humanitarian operations management

The decision making in humanitarian operations has been always seen as a tricky issue and the research in this context has been already suggested (Benini, A., et al., 2009; Peng, Y. & Yu, L., 2014). The high complexity associated with humanitarian operations argues for the use of AHP which is particularly applicable as a technique for solving complex and critical decision problems (Rao Tummala *et al*., 1997, Das, D. & Barman, D. 2010). In particular AHP is considered a reliable method (Triantaphyllou and Mann, 1995) that allows the use of both tangible and intangible measures with respect to the numerous objectives (Wei *et al*. 2005) as well as having a wide range of applications in operations management (Vaidya and Kumar, 2006, Subramanian and Ramanathan, 2012).

To better explain the developed decision making process and using the methodology of Saaty (1980, 2008), the following steps should be followed:

1 PROBLEM CONTEXT: Define and determine the problem and the system characteristics, relating to the phase of life cycle and analyzed operations.

2 FRAMEWORK STRUCTURE: Structure the decision hierarchy (framework) from the top with the goal of the decision, then the objectives from a broad perspective (cost, time, service level), through the lower levels (criteria). These criteria are linked at the end to the alternatives.

3 CRITERIA PAIRWISE COMPARISON: Compare each pair of elements at the same level and obtain a matrix of relative importance in comparisons. Each element at an upper level is used to compare the elements at the level immediately below it. Saaty (2008, p. 86) goes on to propose a scale of comparison (Table 2.1), and this will be adopted within the current research.

Table 2.1: Saaty's scale of comparison

Intensity of Importance a_{ij}	Definition	Description
1	Equal Importance	Two alternatives contribute equally to the same goal
3	Weak Importance	On the basis of experience and evaluation one alternative is slightly preferred to the other
5	Strong Importance	On the basis of experience and evaluation one alternative is favored strongly over the other
7	Very Strong Importance	One alternative is favored strongly over the other; it is demonstrated in practice.
9	Absolute Importance	The evidence on the basis of which one alternative is favored of the highest possible order of an affirmation
2,4,6,8	Intermediate values	Used to interpolate between adjacent scale values
Mutual and Not null values	If an alternative i compared to alternative j assumes a reported value, then the alternative j will assume a mutual value if compared to alternative i	

Use the priorities to weigh the priorities at the level immediately below. Complete this for every element. Then, for each element at the level below, add its weighed values and obtain its overall or global priority.

4 ALTERNATIVES EVALUATION: Using the same pairwise comparison process, define the final priorities of the alternatives at the bottom-most level. Then synthesize these results to determine an overall outcome.

5 SENSITIVITY ANALYSIS: Analyze the sensitivity to changes in judgment.

The details of each step of the decision-making process presented above will be explained in the next sections of the thesis.

2.3. Problem context: humanitarian operations

The main purpose of this chapter is to develop a general multi-objective framework to support decision makers into the evaluation of alternative solutions for typical humanitarian operations issues. As discussed earlier, this investigation reflects the operations life cycle using the formulation offered by Safran, P. (2003) which offers three phases: prevention, transition, and recovery. These are depicted in Figure 2.1.

As outlined earlier, each phase has different features, in particular:

A. *Prevention*: According to Murray (2005) and Kovàcs and Spens (2007), donations tend to rise after a disaster (not least due to the press coverage that surrounds the event), however, this is often too late to influence the preparation activities that would, in turn, lead to greater logistic efficiency and/or effectiveness (Tatham and Pettit, 2010). Thus, when considering this phase of the problem, it is important to recognise that achievement of efficient/effective preparations will potentially result in considerable cost savings at a later stage – unfortunately donors (especially governments) do not like having to pay such 'insurance premiums' to cover for an eventuality that may never take place. Nevertheless, such aspects must be factored into the problem. So whilst Balcik and Beamon (2008) research the facility location problem by considering just transportation costs and plant costs, Taylor (2012) goes further by exploring ways to improve the responsiveness of humanitarian organizations by, for example, prepositioning items in regional hubs, and through improving inter-agency coordination. Indeed, to improve responsiveness, some authors (e.g. Hale and Moberg, 2005; Kapucu *et al*., 2007) suggest that it is necessary to find a location that optimizes the reaction time to ensure a positive impact on the humanitarian supply chain lead time.

B. *Transition (Disaster Response)*: This is the most critical phase as evidenced by the views of many authors and as exemplified by Kovács and Spens (2007, p.104) who argue that "the main problem areas of the transition phase lie in coordinating supply, the unpredictability of demand, and the last-mile problem of transporting necessary items to disaster victims". Similarly, Pedraza Martinez *et al*. (2010, p. 17) underline the importance of the response operations in order "to maximize demand coverage while minimizing time of response". By the same token, Van Wassenhove and Pedraza Martinez (2012, p. 309), suggest that the "successful response implies quickly building a supply chain". Furthermore, in the disaster response phase cost is not considered the most important driver of the supply chain because greater attention is paid to life-saving activities (McCoy, 2008). With this in mind, Balcik *et al*. (2008) suggest the utilization of a penalty cost associated with suffering and loss of lives that has to be minimized in order to find an optimal solution to the distribution of "first necessity" items. Regarding this phase, the importance of reaching the people who need relief support in less than 72 hours (3 days) has been underlined by many authors (e.g. Awan and Rahman, 2010; Van Wassenhove *et al*., 2012). Indeed, the response has to be "speed at any cost and the first

72 hours are crucial" (Awan and Rahman, 2010, p. 23). Moreover, according to Russell *et al*. (1995, p. 745) "during this 72-hour period, the normal flow of goods and services will be disrupted; emergency personnel will be overwhelmed and unable to respond to every need". These quotes are very significant because they point out a crucial constraint that must be incorporated into the model, namely the time window in which the humanitarian organizations have to reach the beneficiaries. According to Van Wassenhove *et al*. (2012), the most important operational objectives for the transition phase are the maximization of the demand fulfilment and the minimization of the response times. Hence, maximizing the access to the local population is key to the delivery urgently required food and non-food items within the shortest possible response time.

C. *Recovery (support)*: recovery is the phase that reflects the stabilization of the situation after the initial hit of the disaster and before commencement of the re-build. According to Thomas (2002, p. 61), "during this phase the nature of the operation and logistics requirements can change with the time and operational conditions but the basic processes and structure remain in place".

Within the overall recovery phases three sub-phases have been identified by Safran (2003). The first part of the restoration phase, which occurs just after the transition phase, is that in which regional and international actors continue the process of delivering aid to the beneficiaries – an activity that started in the transition phase (Lamont, 2005) and in which the distribution of "first necessity" items takes place (Balcik *et al*., 2008; Battini *et al*., 2014). It will be seen, therefore, that the driver of behaviour in this sub-phase is that of the effectiveness of the operations. This can be compared and contrasted with the second sub-phase that described by Kovács and Spens (2007) as the rehabilitation phase in which, according to Maon *et al*. (2009) the most important goal is "efficient technical and material support" in other words, the focus is on the efficiency of the operation. The reconstruction phase reflects the ramping down in the life span of a disaster, and is "when assets are gradually reduced and withdrawn from the area to be redeployed elsewhere" (Maspero and Ittmann, 2008, p. 176). It is important to note that "the ramp down phase 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" (Maspero and Ittmann, 2008, p. 176). According to Van Wassenhove (2006, p.480), in the last phase it is fundamental to "start looking to buy the same goods locally", in other words, part of the dismantling phase reflects the need to provide financial support so that markets will start to re-build.

2.4. Humanitarian operations management framework structure

As discussed in the literature review, a number of authors have used linear programming approaches in order to propose the best allocation of the scarce resources that are present in humanitarian operations. In particular, Tzeng *et al*. (2007) summarize the problem by means of three objective functions that have to be considered jointly, namely: minimization of total cost, minimization of time factors, and maximization of satisfaction level (otherwise known as the service level).

However, as outlined earlier, due to the hierarchical structure of humanitarian operations management issues, this research uses AHP following the approach of Saaty (1977). This theory, widely used in a broad range of applications (see, for example: Triantaphyllou and Mann (1995) - engineering; Al-Harbi (2001) – project management), is "a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" (Saaty, 2008, p. 83). The tool allows the evaluation of issues through consideration of different features, and it facilitates the search for the best alternatives in a range of possible solutions. The resultant framework used in this research has been developed by analyzing the existing literature about humanitarian operations and, in particular, that relating to performance measures and their possible utilization in tools such as the multi-objective models that have already been described in the literature.

The parameters used are split into different levels – primary, secondary and tertiary drivers – in order to support the decision process and to allow better achievement of the final objective.

In the figure below, the framework is presented with the three levels of considered elements (from the edge to the center) with the optimization point, i.e. the goal, at the center of the image.

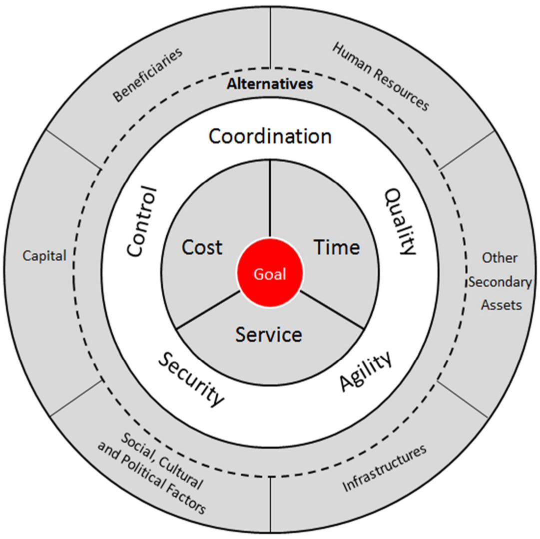


Figure 2.2: Humanitarian Operations framework

In the next subsections, this model is decomposed and the rationale for the choice of drivers is presented, based on the previous contributions, in order to clarify the structure of the framework and the hierarchy decision process.

2.4.1. Goal

In complex operations such as HSCs, organizations have to evaluate the best alternative in a set of different opportunities. The goal of the framework is help the decision makers make these difficult choices thorough the use of a structured tool that considers different criteria.

2.4.2. Primary Criteria

Following on from the discussion in previous paragraphs, it will be appreciated that there three central drivers for the management of a supply chain, namely: cost, time and service level. Within the commercial supply chain literature, costs include items such as warehouse costs, distribution costs, personnel costs, etc (Barbarosoğlu *et al*., 2002; De Angelis *et al*., 2007). Time is normally considered to reflect the responsiveness (Hale and Moberg, 2005; Kapucu *et al*., 2007) associated with the operation, while the service level is the percentage of people satisfied (Tzeng *et al*., 2007).

In the humanitarian supply chain literature, the same factors are usually applied in operations management models (such as Van Wassenhove, 2006; Kovács and Spens, 2007). Moreover, costs, time and service level are typically present both in single-objective models (Knott, 1987; Barbarosoğlu and Arda, 2004; Özdamar *et al*., 2004) and in multi-objective models (Tzeng *et al*., 2007; Balcik *et al*., 2008; Vitoriano *et al*., 2010; Lin *et al*., 2011; Battini *et al*., 2014) in order to optimize the operations. These three criteria will, therefore, be considered as the central drivers of the framework.

2.4.3. Secondary Criteria

During an operation, in addition to costs, time and service level, it is important to consider other drivers due to the complexity of the operation. Another important driver is *agility* (Charles, A., et al., 2010, Dubey, R. et al. 2014) which is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets (Christopher, 2000). Moreover, *coordination* is an important driver, as indicated by Balcik *et al*. (2010) and Tatham and Pettit (2010); in fact during many operations (especially the larger ones) there is a massive influx of aid agencies (both governmental agencies and NGOs) focusing on relief after disasters – for example, Altay and Labonte (2014) indicate that some 2,000 aid agencies were present in Haiti in the aftermath of the 2010 Haiti earthquake. Furthermore, Van Wassenhove (2006) considers different kinds of coordination according to the phase (coordination by command, coordination by consensus, and coordination by default). Van Wassenhove and Tomasini (2009) discuss the importance of *security* using the historical example of the situation of Serbian-controlled Bosnia in 1993 in which humanitarian operations were severely constrained – indeed, a more recent (2014) example would be that of the humanitarian challenges in Syria. Another driver considered is *quality*. Indeed, according to Dufour *et al*. (2004), the experience of humanitarian crises during the 1990s, notably in Rwanda (1994), led to increasing awareness among aid agencies that "Il ne suffit pas de faire le bien, il faut le bien faire" (according to French Enlightenment philosopher Denis Diderot: "It is not enough to do good, it must be done well"). Hence, some quality tools, such as the Sphere Project handbook (Humanitarian Charter and Minimum Standards in Disaster Response), or the alternative Quality Project, are being employed by humanitarian organizations in order to "improve the quality of assistance provided to people affected by disasters, and to enhance the accountability of the humanitarian system in disaster response" (Sphere Handbook, 2003, p. 2). According to the definition of Thomas and Mizushima (2005), the last aspect that has to be considered is that of *control* throughout the area interested by the operation in order to achieve the required security and quality factors.

2.4.4. Tertiary Criteria

In the literature, Richardson et al. (2010) and Richardson and de Leeuw (2012) present some factors that are used in order to locate inventories before disasters. These factors are simplified in the framework to: available capital (funds), resources (e.g. available labor, vehicles, tents, etc.), infrastructure (e.g. utilities, IT services, etc.), beneficiaries (people affected by the disaster), social, cultural and political factors (e.g. state governability, corruption, etc. (Whybark, 2007; Rodon *et al*. 2012) and other secondary assets (all the other factors that can be present in the area and are not included in the previous sections). These drivers are strictly linked to the set of possible alternatives.

2.5. Criteria pairwise comparison

As discussed earlier, the drivers and criteria used in this research relate to three different levels which influence the achievement of the goal and relate to the particularities of the system. The outermost level of Figure 2.2 refers to the basic factors that have to be considered as criteria in the first part of the decision-making process. These factors are humanitarian resources, beneficiaries, available capital, social, cultural and political factors, infrastructures and other secondary assets.

The second step focuses on five key qualitative elements: these aspects are quality, agility, security, control and coordination. The last step of this methodology is the optimization of the three core factors considered in almost all the humanitarian papers (cost, time, service level).

In using this model, it is important to explain that the goal can still be achieved even when all the drivers cannot be taken into consideration. Thus, in this scenario, if one of the primary drivers cannot be evaluated, the secondary ones are taken. Similarly, the tertiary drivers are considered if it is not possible to assess both the previous ones.

2.6. Numerical Examples

The following section uses three examples of issues faced in real-life operations, with one selected from three of the different life-cycle phases. This section shows the applicability of the framework and the variance of the weights and priorities of the criteria in function of the phase in which the framework is applied.

These examples are: *location of local distribution centers in preparedness (Prevention phase)*, *vehicle routing in the emergency (Transition phase)*, *vehicle routing in rehabilitation (Recovery phase)* and *dismantling operations in reconstruction (Recovery phase).* These examples were selected in order to explain how different issues are dealt with, and how the same issue is often present in different phases of the life cycle – but with different weightings for the secondary and tertiary criteria.

The examples are used to demonstrate numerically how the framework should be used and how the weightings associated with each criterion will vary in relation to both the issue and the phase of the life cycle under consideration. This is important because, if the framework is to be applied in a real context, all the assets involved in the operation and the particular case of application have to be considered.

In the matrices below, the priority is the weight associated with the factor (the sum of the priorities is 1), while the scale is expressed in the same way as in Saaty’s work (Table 2.1). In the examples, the scale of comparisons is a discrete scale between 1 (not important) to 9 (extremely important) and these numbers have been made up based on authors’ experience/expertise.

2.6.1. Location of Local Distribution Centers in Preparedness (Prevention phase)

As Anand, G., et al. (2012) the location of a plant can be very critical e subject to different drivers. According to Beamon and Kotleba (2006) and Richardson and de Leeuw (2012), when considering preparedness in which the main objective is the prepositioning of a plant, the key features that have to be optimized are (1) the costs of the plant: in particular, the fixed cost associated with the physical construction and (2) the variable cost associated with the shipment needed to deliver the items. In this phase, it is important to understand how time and service are linked to the responsiveness of the supply chain and, consequently to the location of the plants, but also (at a secondary level) with respect to cost.

In the example below, the application of the framework reflects the three different levels of Figure 2.2. The first level is the pairwise comparison in relation to the primary drivers, the second in relation to the secondary drivers and the third in relation to the tertiary drivers' comparison. These pairwise comparisons are numerical examples for the utilization of the tools and the nature of the outputs. These comparisons have been made up based on author' experience/expertise just to demonstrate the method of application.

Table 2.2: Primary drivers' comparison and priorities

	Priority	Pairwise comparison	Cost	Time	Service
Cost	0.683	Cost	1	4	5
Time	0.117	Time	1/4	1	2
Service	0.200	Service	1/5	1/2	1

Table 2.3: Secondary drivers' comparison in time branch and priorities

	Priority	Pairwise comparison	Agility	Control	Coordination	Quality	Security
Agility	0.189	Agility	1	1/2	1/3	2	2
Control	0.168	Control	2	1	1/2	2	1/3
Coordination	0.304	Coordination	3	2	1	3	1
Quality	0.076	Quality	1/2	1/2	1/3	1	1/4
Security	0.263	Security	1/2	3	1	4	1

Table 2.4: Tertiary drivers' comparisons in coordination branch and priorities

	Priority	Pairwise comparison	Beneficiaries	Capital	Infrastructures	Resources	Social, Cultural and Political factors
Beneficiaries	0.242	Beneficiaries	1	3	2	1	1/2
Capital	0.137	Capital	1/3	1	1	1/2	1
Infrastructures	0.120	Infrastructures	1/2	1	1	1/2	1/2
Resources	0.240	Resources	1	2	2	1	1
Social, Cultural and Political factors	0.260	Social, Cultural and Political factors	2	1	2	1	1

2.6.2. Vehicle Routing in the Emergency (Transition phase)

Optimal vehicle routing is selected as an example of the methodology because, in the transition phase, especially in the emergency situation, the distribution of items from the hubs to the beneficiaries is an important issue for the humanitarian operators to manage.

As explained in the previous paragraphs, the uncertainty associated with the demand combined with the operational impact of the particular environment and the time driver all make the transition phase the most critical one. In this phase, the service level and the time are considered as the predominant factors in phase optimization (Pedraza Martinez *et al*., 2010). Moreover, in the literature, many cases of vehicle routing are presented in order to optimize the times and the service level in the items' distribution. As in the previous example, primary drivers' comparisons are shown below:

Table 2.5: Primary drivers' comparison and priorities

	Priority	Pairwise comparison	Cost	Time	Service
Cost	0.079	Cost	1	1/7	1/5
Time	0.487	Time	7	1	1
Service	0.435	Service	5	1	1

Table 2.6: Secondary drivers' comparison in time branch and priorities

	Priority	Pairwise comparison	Agility	Control	Coordination	Quality	Security
Agility	0.359	Agility	1	5	4	3	1
Control	0.079	Control	1/5	1	1/3	2	1/5
Coordination	0.140	Coordination	1/4	3	1	2	1/3
Quality	0.074	Quality	1/3	1/2	1/2	1	1/4
Security	0.347	Security	1	5	3	4	1

Table 2.7: Tertiary drivers' comparisons in coordination branch and priorities

	Priority	Pairwise comparison	Beneficiaries	Capital	Infrastructures	Resources	Social, Cultural and Political factors
Beneficiaries	0.222	Beneficiaries	1	3	1	1/2	2
Capital	0.115	Capital	1/3	1	1/2	1/3	2
Infrastructures	0.216	Infrastructures	1	2	1	1/2	3
Resources	0.359	Resources	2	3	2	1	3
Social, Cultural and Political factors	0.087	Social, Cultural and Political factors	1/2	1/2	1/3	1/3	1

2.6.3. Vehicle Routing in Rehabilitation (Recovery phase)

In the literature, one of the most relevant problems faced in the recovery phase is the distribution of items from the hubs to the beneficiaries. As Safran, P. (2003) suggests in his model, the recovery phase is split into different sub-phases and the drivers considered are not the same. Indeed, in a first sub-phase, concerning the restoration, the drivers found are more similar to those in the transition phase, with a major weight associated with cost. In the second phase of recovery, including rehabilitation and reconstruction, however, and in line with the suggestion of Awan and Rahman (2010) that efficient technical and material support is important. In this phase there is a growth of the importance of the costs in the optimal solution, as suggested by Battini *et al*. (2014), even if it remains less important than time and Service.

The application below is placed in the second phase of recovery (rehabilitation).

Table 2.8: Primary drivers' comparison and priorities

	Priority	Pairwise comparison	Cost	Time	Service
Cost	0.169	Cost	1	1/2	1/3
Time	0.387	Time	2	1	1
Service	0.443	Service	3	1	1

Table 2.9: Secondary drivers' comparison in time branch and priorities

	Priority	Pairwise comparison	Agility	Control	Coordination	Quality	Security
Agility	0.276	Agility	1	4	3	2	1/2
Control	0.090	Control	1/4	1	1/3	2	1/4
Coordination	0.154	Coordination	1/3	3	1	2	1/3
Quality	0.084	Quality	1/2	1/2	1/2	1	1/4
Security	0.397	Security	2	4	3	3	1

Table 2.10: Tertiary drivers' comparisons in coordination branch and priorities

	Priority	Pairwise comparison	Beneficiaries	Capital	Infrastructures	Resources	Social, Cultural and Political factors
Beneficiaries	0.180	Beneficiaries	1	2	1/2	1/2	2
Capital	0.150	Capital	1/2	1	1/2	1/2	3
Infrastructures	0.255	Infrastructures	2	2	1	1/2	3
Resources	0.336	Resources	2	2	2	1	3
Social, Cultural and Political factors	0.080	Social, Cultural and Political factors	1/2	1/3	1/3	1/3	1

2.6.4. Dismantling Operations in Reconstruction (Recovery phase).

The *reconstruction* operations, such as dismantling, concern the conclusion of the relief operations, i.e. "when organizations start pulling out" (Van Wassenhove, 2006, p.484). During this phase the items owned by agencies (e. g. trucks and radios) are moved to other areas that need support; hence, the scale of the disaster enters the ramping down phase. In this phase, the time and service do not have focal importance, while cost becomes more important, as in the preparedness stage. Moreover, the focus is placed more on security, quality and control, while agility and coordination do not have the same level of importance as in the "high-scale disaster" phases.

These results are summarized in the following tables.

Table 2.11: Primary drivers' comparison and priorities

	Priority	Pairwise comparison	Cost	Time	Service
Cost	0.625	Cost	1	3	4
Time	0.137	Time	1/3	1	2
Service	0.238	Service	1/4	1/2	1

Table 2.12: Secondary drivers' comparison in time branch and priorities

	Priority	Pairwise comparison	Agility	Control	Coordination	Quality	Security
Agility	0.075	Agility	1	1/4	1/3	1/2	1/3
Control	0.208	Control	4	1	1	2	1/3
Coordination	0.168	Coordination	3	1	1	1	1/3
Quality	0.133	Quality	2	1/2	1	1	1/3
Security	0.417	Security	3	3	3	3	1

Table 2.13: Tertiary drivers' comparisons in coordination branch and priorities

	Priority	Pairwise comparison	Beneficiaries	Capital	Infrastructures	Resources	Social, Cultural and Political factors
Beneficiaries	0.109	Beneficiaries	1	1/2	1/2	1/2	1/2
Capital	0.283	Capital	2	1	2	2	1
Infrastructures	0.163	Infrastructures	2	1/2	1	1	1/2
Resources	0.163	Resources	2	1/2	1	1	1/2
Social, Cultural and Political factors	0.283	Social, Cultural and Political factors	2	1	2	2	1

2.7. Real case application

In order to complete the presentation of the decision making procedure, a real aids distribution case study has been developed using the approach adopted in this chapter to demonstrate a real example of the evaluation of alternatives. The case is that of the earthquake that struck Haiti in January 2010 (Battini *et al.*, 2014).

According to the United Nations' Secretary-General's report (United Nation, 2010), in the earthquake that hit Haiti, January 2010, 222,570 people were killed, many thousands were injured or permanently disabled, and 1.5 million were left homeless. For these reasons, in order to meet the basic needs of the affected population, after the earthquake hit Haiti, several assessment teams arrived and started their work. The two phases in which the problem is tested are the transition and recovery phases.

According to Battini *et al*. (2014), in a disaster such as that in Haiti, items have to be delivered to the vulnerable groups, including tents, blankets, tarpaulins, jerry cans, mosquito nets, food and hygiene kits, as well as more cumbersome objects like kitchens and other materials for reconstruction. For this reason, the attention has been focused on the vehicle routing problem (VRP) in aid distribution operations. According to Laporte (1992, p. 345), the VRP can be described "as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers subject to side constraints". The typical objective of the VRP is either the minimization of costs and time or the maximization of the service level. The aid distribution operation that is the subject of this case has been studied in the two different life-cycle phases, transition and recovery ones, because the objective function and the importance of each driver change.

Using the data from Battini *et al*. (2014), the research investigates the distribution using two different agencies: one for hygiene kits (item 1) and the other one for food (item 2); or a co-transportation approach in which the same agency supplies all the items to the beneficiaries. In this case the alternatives presented by the author consist in 3 possibilities (A, B and C). The application of the framework helps the decision makers in finding the best one just comparing the available data and where the data is missing it considers the lower level of criteria.

The two-vector distribution in this case presents two different solutions (see table 2.14):

A. 4 trucks and 0 helicopters for item 1 (supplied by vector A), 3 trucks and 0 helicopters for item 2 (supplied by vector B);
B. 4 trucks and 1 helicopter for item 1 (supplied by vector A), 3 trucks and 1 helicopter for item 2 (supplied by vector B).

Meanwhile, one-vector distribution concerns:

C. 7 trucks and 0 helicopters for item 1 and 2 in co-transportation (supplied jointly by vector A and B).

Then, the problem is analyzed by means of a variation in the primary drivers as presented in table 2.14.

Two of these primary criteria (cost and service) are sourced from the VRP application of Battini *et al*. (2014). For the time driver, the secondary drivers need to be evaluated because these will impact the primary driver. Thus, the need for inter-agency coordination leads to possible delays in terms of dependence on different suppliers and as a result the final time depends on the slowest supplier, while it is independent of the chosen transportation modality. Thus, alternatives A and B do not require coordination between the two different suppliers, even if B requires a low level of coordination because it uses two different vehicles. On the other hand, alternative C does need coordination between the two suppliers and it can, therefore, lead to delays in terms of delivery times. The secondary criteria of control, security and quality are the same for all the alternatives, whilst for the assessment of alternatives based on the agility driver, an evaluation of the tertiary criteria is needed.

B is better than A and C, because it has more resources and infrastructure, making the solution more agile. The other tertiary drivers do not vary. As described before, agility and coordination have a positive effect on time.

The objective of the methodology application is finding the best alternative possible in the available distribution opportunities, considering not just one phase but the evolution of the problem during the time frame of the operation. The choice of the best alternative is carried out with pairwise comparisons of the different criteria.

Table 2.14: Features associated to the different alternatives.

Alternatives		Primary Criteria			Secondary Criteria					Tertiary Criteria				
Code	Description	Cost	Time	Service	Agility	Coordination	Control	Security	Quality	Capital	Resources	Infrastructures	Beneficiaries	Soc., Cult. & Pol. Factors
A	4 trucks and 0 helicopters for item 1 3 trucks and 0 helicopters for item 2	€ 2328.45 [1295.10 for item 1 + 1033.35 for item 2]		98.97% for item 1 and 91 % for item 2		no coordination is needed					7 trucks are available	traditional and rural roads		
B	4 trucks and 1 helicopters for item 1 3 trucks and 1 helicopters for item 2	€ 6744.45 [2906.10 for item 1 + 3838.35 for item 2]	derived from secondary and tertiary criteria	100% for item 1 and 100 % for item 2	derived from tertiary criteria	no coordination is needed	invariable in alternatives	invariable in alternatives	invariable in alternatives	invariable in alternatives	7 trucks and 2 helicopters are available	traditional and rural roads + landing zone	invariable in alternatives	invariable in alternatives
C	7 trucks and 0 helicopters for item 1 and 2 in co-transportation	€ 2463.75 [item 1 and 2 in co-transportation]		100% for item 1 and 100 % for item 2		coordination in the item's management is necessary					7 trucks are available	traditional and rural roads		

2.8. Sensitivity analysis: evaluation of decision robustness

According to Saaty (1980, 2008) the final step of the evaluation consist in the assessment of the robustness of the results. To achieve this last information this section is presented.

In table 2.15, the values of the different drivers are proposed. The values associated with the criteria are developed by the application of the framework structure and pairwise comparisons, while the ones associated with the alternatives from table 2.14 refer to the considerations mentioned before. The best alternative is the one with the highest priority overall.

From table 2.15, in the transition phase, it is possible to understand that alternative B is the most suitable in this particular application because, even though it has the highest cost, it allows a high level of service. Time is studied with the secondary drivers. Within the secondary drivers, agility is linked to the tertiary criteria; B is the most agile.

On the other hand, still referring to table 2.15, in the recovery phase, the most suitable alternative becomes alternative C; indeed, the costs gain in importance in relation to the transition phase.

In order to evaluate the robustness of the analysis and of the subjective framework evaluations and comparisons, as Saaty (2008) suggests, a sensitivity analysis has been carried out. This analysis allows the understanding of whether the alternative changes when the priorities' values change. It considers the parameters that differ from one alternative to another as relationships between different criteria and between the criteria and the alternatives.

The sensitivity analysis is summarized in table 2.16 and suggests a general evaluation of the obtained results. The model appears very robust because only in a few cases does the best alternative changes.

Table 2.15: Proposed weights per criteria and alternative, associated to the phases

EMERGENCY (TRANSISTION PHASE)													
Criteria	primary criteria	Cost 0.078	Time 0.487									Service 0.435	**Overall Priorities**
	secondary criteria		Agility 0.359					Coordination 0.141	Control 0.079	Security 0.347	Quality 0.074		
	tertiary criteria		Capital 0.115	Resources 0.359	Infrastructures 0.216	Beneficiaries 0.222	Soc., Cult. & Pol. Factors 0.088						
Alternatives	Alternative A	0.466	0.333	0.250	0.250	0.333	0.333	0.429	0.333	0.333	0.333	0.200	**0.284**
	Alternative B	0.101	0.333	0.500	0.500	0.333	0.333	0.429	0.333	0.333	0.333	0.400	**0.367**
	Alternative C	0.433	0.333	0.250	0.250	0.333	0.333	0.142	0.333	0.333	0.333	0.400	**0.348**

REHABILITATION (RECOVERY PHASE)													
Criteria	primary criteria	Cost 0.169	Time 0.388									Service 0.443	**Overall Priorities**
	secondary criteria		Agility 0.276					Coordination 0.154	Control 0.09	Security 0.397	Quality 0.083		
	tertiary criteria		Capital 0.149	Resources 0.336	Infrastructures 0.255	Beneficiaries 0.18	Soc., Cult. & Pol. Factors 0.08						
Alternatives	Alternative A	0.466	0.333	0.250	0.250	0.333	0.333	0.429	0.333	0.333	0.333	0.200	**0.297**
	Alternative B	0.101	0.333	0.500	0.500	0.333	0.333	0.429	0.333	0.333	0.333	0.400	**0.340**
	Alternative C	0.433	0.333	0.250	0.250	0.333	0.333	0.142	0.333	0.333	0.333	0.400	**0.363**

Table 2.16: Sensitive analysis associate to the Real Application in aids distribution

EMERGENCY (TRANSISTION PHASE)

	Based Scenario [tab. XX]	Scenarios A primary criteria [Cost, Time, Service]			Scenarios B secondary criteria [Agility, Coordination, Control, Security, Quality]			Scenarios C secondary criteria [Capital, Resources, Infrastructures, Beneficiaries, Soc.Cult.&Pol. Factors]			Scenarios D Priorities of Alternatives based on COST [Alt A, Alt B, Alt C]			Scenarios E Priorities of Alternatives based on COORDINATION [Alt A, Alt B, Alt C]			Scenarios F Priorities of Alternatives based on RESOURCES [Alt A, Alt B, Alt C]			Scenarios G Priorities of Alternatives based on INFRASTRUCTURES [Alt A, Alt B, Alt C]		
		[0.05, 0.5, 0.45]	[0.1, 0.47, 0.43]	[0.15, 0.45, 0.4]	[0.3, 0.2, 0.07, 0.36, 0.074]	[0.4, 0.1, 0.079, 0.347, 0.074]	[0.5, 0.05, 0.04, 0.34, 0.074]	[0.12, 0.3, 0.25, 0.23, 0.1]	[0.11, 0.4, 0.2, 0.21, 0.08]	[0.1, 0.5, 0.15, 0.18, 0.07]	[0.5, 0.05, 0.45]	[0.45, 0.15, 0.4]	[0.42, 0.2, 0.38]	[0.35, 0.35, 0.3]	[0.4, 0.4, 0.2]	[0.45, 0.45, 0.1]	[0.3, 0.4, 0.3]	[0.2, 0.6, 0.2]	[0.15, 0.7, 0.15]	[0.3, 0.4, 0.3]	[0.2, 0.6, 0.2]	[0.15, 0.7, 0.15]
Alternative A	0.284	0.278	0.287	0.298	0.289	0.281	0.277	0.284	0.283	0.283	0.286	0.283	0.280	0.278	0.282	0.285	0.287	0.281	0.277	0.286	0.282	0.280
Alternative B	**0.367**	**0.376**	**0.361**	0.347	**0.368**	**0.367**	**0.370**	**0.367**	**0.368**	**0.370**	**0.363**	**0.371**	**0.375**	**0.362**	**0.365**	**0.369**	**0.361**	**0.374**	**0.380**	**0.364**	**0.371**	**0.375**
Alternative C	0.348	0.346	0.351	**0.355**	0.345	0.351	0.354	0.349	0.348	0.347	0.350	0.346	0.344	0.359	0.352	0.346	0.352	0.345	0.342	0.350	0.347	0.345

REHABILITATION (RECOVERY PHASE)

	Based Scenario [tab. XX]	Scenarios A primary criteria [Cost, Time, Service]			Scenarios B secondary criteria [Agility, Coordination, Control, Security, Quality]			Scenarios C secondary criteria [Capital, Resources, Infrastructures, Beneficiaries, Soc.Cult.&Pol. Factors]			Scenarios D Priorities of Alternatives based on COST [Alt A, Alt B, Alt C]			Scenarios E Priorities of Alternatives based on COORDINATION [Alt A, Alt B, Alt C]			Scenarios F Priorities of Alternatives based on RESOURCES [Alt A, Alt B, Alt C]			Scenarios G Priorities of Alternatives based on INFRASTRUCTURES [Alt A, Alt B, Alt C]		
		[0.1, 0.42, 0.48]	[0.2, 0.37, 0.43]	[0.3, 0.32, 0.38]	[0.2, 0.25, 0.09, 0.38, 0.08]	[0.3, 0.15, 0.09, 0.38, 0.08]	[0.4, 0.12, 0.06, 0.36, 0.06]	[0.15, 0.25, 0.33, 0.18, 0.09]	[0.15, 0.3, 0.27, 0.18, 0.09]	[0.14, 0.4, 0.2, 0.17, 0.09]	[0.5, 0.05, 0.45]	[0.45, 0.15, 0.4]	[0.42, 0.2, 0.38]	[0.35, 0.35, 0.3]	[0.4, 0.4, 0.2]	[0.45, 0.45, 0.1]	[0.3, 0.4, 0.3]	[0.2, 0.6, 0.2]	[0.15, 0.7, 0.15]	[0.3, 0.4, 0.3]	[0.2, 0.6, 0.2]	[0.15, 0.7, 0.15]
Alternative A	0.297	0.283	0.303	0.323	0.302	0.296	0.293	0.297	0.297	0.297	0.303	0.294	0.289	0.292	0.295	0.298	0.299	0.295	0.293	0.298	0.296	0.294
Alternative B	0.340	**0.360**	0.331	0.302	0.340	0.341	0.343	0.340	0.339	0.340	0.331	0.348	0.357	0.335	0.338	0.341	0.336	0.343	0.347	0.337	0.343	0.345
Alternative C	**0.363**	0.357	**0.366**	**0.375**	**0.357**	**0.363**	**0.363**	**0.363**	**0.363**	**0.363**	**0.366**	**0.357**	**0.354**	**0.372**	**0.366**	**0.360**	**0.365**	**0.361**	**0.359**	**0.364**	**0.362**	**0.360**

A key impact of these results is to underpin the perspective that leads us to consider the whole operation as a continuum in which the priority associated with each driver changes in relation to the life-cycle phase. These results emphasize the importance of a general hierarchical framework that could help in standardizing the factors involved in the decision process and realizing the priority associated with the particular event. Presenting the specific weights associated with real operations was not the objective of this study; rather, the intention was to introduce and explain the framework and its applicability in the possible applications.

The further intention is to assist the reader in understanding how the weighting changes in relation to the issue and the phase considered. In doing so, it is recognized that moving from one case to another can lead to different results, and that these may depend on the decision makers involved in the multi-criteria decision. The real case provides an example of the decision making application and the sensitivity analysis demonstrates its robustness.

3. Last mile distribution problem in Humanitarian Operations

Transportation is a key element of delivery and in many NGOs, UN agencies, and other humanitarian organizations, vehicle fleets represent the second largest overhead cost after staff expenses (Disparte, 2007). Hence, in this complex environment a growth in terms of efficiency has not just to be seen as cost saving but also as a service level increase and therefore a better performance in terms of social costs as suggested by the literature.

The particular "humanitarian environment" makes logistics a challenging field. Humanitarian logistics has the challenge of allocating scarce resources to complex operations in the most efficient way (Van Wassenhove and Pedraza Martinez, 2012), while considering invisible and/or qualitative factors (Van Wassenhove, 2006), under severe restrictions and random and imprecise information (Barbarosoglu and Arda, 2004). As previously mentioned, notable attention has been paid to the distribution problems, where traditional approaches fail due to all the particularities of humanitarian operations. Indeed, in the last mile distribution problems, not just economic factors, but also social factors are significant in the relief operations, where the purpose "is to rapidly provide the appropriate emergency supplies to people affected by natural and manmade disasters so as to minimize human suffering and death" (Balcik et al., 2008).

The main objective of the research concerns the development and application of a modified last mile distribution model to a real case study, starting from the collection of data and estimation of item demands, as well as real application of the model, and finally carrying out a sensitivity study of logistic costs and percentage of shortage varying the fleet, its capacity, and the introduction of co-transportation modality. The applied model is a conceptual evolution of the one developed by Balcik et al. (2008), whose author reported only a simple numerical example.

First, the improved model is proposed in order to study the logistic costs in function of the available vehicles, with no shortage permitted. The second part covers an important analyzed variable: the possibility of co-transportation, seen as "different conveyers/suppliers transport their goods in only one truck" (Hageback and Segerstedt, 2004). This kind of distribution has often been highlighted by the humanitarian experts in conferences and interviews as contributing to improved performance of operations at the same time. The last part deals with the situation of shortage in function of limited capacity of fleet, in order to understand how the service is related to the logistic systems.

3.1. Literature review

In this section I introduce both the main humanitarian topics and the relevant literature in order to highlight how humanitarian operations supporting the planning and execution of the disaster relief constitute a relatively new field (Kovàcs and Spens, 2007).

According to Van Wassenhove (2006), in humanitarian operations there are many areas that can be successfully explored by academics and in operations research. All of these areas can be associated with the supply chain management topic and it is possible to find more sub topics, which are specific to improvement of the humanitarian supply chain performances. Some examples of these issues, as suggested by VanWassenhove (2006), are the last mile problem, the partnership between humanitarian and private sector together with the project management, risk management, systems and technology design and optimization, process standardization, performance measurement and control.

At the same time, as widely suggested in the literature, the humanitarian operation can be considered as having different stages, each of which has its own objectives (Kovàcs and Spens, 2007; Charles, 2010; Peretti, 2011). If I consider the characterization by Holguı`n-Veras et al. (2012), where the humanitarian operation is split into regular humanitarian logistics (R-HL) and post-disaster humanitarian logistics, the author presents the main differences between these two phases and the commercial logistics. According to this research, it has been decided to place the examination in the development phase of the operation, namely in the R-HL. This choice has been made because the post-disaster phase is considered too messy, and so it is not possible to have clear data about it. These data are fundamental for the application of the model below. In fact, in the literature, the high difficulty of acquiring reliable data has been underlined (Van Wassenhove and Pedraza Martinez, 2012) in the slogan "data is the beast" (Lee, 2010).

The present research examines the last mile problem and, in particular, the fleet management, coupled with material distribution modalities, is studied. In the scientific literature, the last mile problem is widely faced in order to improve performances because "inefficient deliveries in this last mile of supply chain have led numerous business collapses as well as a substantial increase in delivery costs" (Boyer et al., 2009). For this reason in 2009, Taubenböck et al. present an interdisciplinary approach for the last mile preparation for a potential disaster while Van Hentenryck et al. (2010), always in last mile, face the single commodity allocation problem for disaster recovery. This work focusses on the transportation because it is considered as a cornerstone of last mile distribution problem, as Balcik et al. present in 2008. Field vehicles are used to transport humanitarian staff, aid items, and materials in an environment where no vehicles means no aid (Van Wassenhove and Pedraza Martinez, 2012). In a complex environment, usually under conditions requiring the allocation of scarce resources (Altay and Green, 2006), according to Stapleton et al. (2009), “the potential saving from implementing operations research models can be used in improving the social welfare of populations need,” so minimizing human suffering and the loss of lives. At the same time, when considering the importance of transportation, which is seen as an important key to reduce the social, economic, and environmental impacts (Berkoune et al., 2012), it is possible to understand how the last mile problem faces both the economic and social problems associated with the situation after disasters.

There are some models associated with distribution in humanitarian operations. Knott (1987) considered the last mile delivery of food items from a distribution center to a number of camps. Haghani and Oh (1996) introduced a multi-commodity and multi-modal network flow in the discussion, while Barbarosoglu et al. (2002) decomposed the problem hierarchically into two sub-problems, focusing on a deterministic single period model to optimize helicopter distribution. In 2004 Barbarosoglu and Arda adopted a stochastic multi-objective single-period model with an example of its application using data from a real earthquake in Turkey in 1999. Finally, in 2008 Balcik et al. developed a model that considered different relief items with different demand characterizations and criticality of supplies in resource allocation. Further, they considered the complexity of the environment and the uncertainty of the humanitarian operations. Other authors can be found in the literature review by Caunhye et al. (2012), who consider the optimization models about relief distribution.

The model applied in this script optimizes resource allocation and vehicle routing decisions in a real case, the well-known Haitian case, on a number of test problems.

3.2. Modified last mile distribution models

Typically, last mile distribution problem concerns the study of distribution in the last part of the supply chain. In this particular situation, the most important goal is to improve the performances in order to supply the aid to the beneficiaries without inefficiencies, due to the high cost of unsatisfied demand (Balcik et al. 2008; Taubenböck et al., 2009).

Known the amount of demand, the available route networks and the different transportation modalities, the problem is to define the most convenient distribution plan, meant as relief supply allocation, vehicle delivery scheduling, and vehicle routing, as defined by Balcik et al. (2008). For more details, the readers could see the explanation included in Balcik et al. (2008).

The two models applied in this research are a conceptual evolution of the mixed integer model recently developed by Balcik et al. (2008). The aim of these models was to develop an efficient resource allocation mechanism that minimizes suffering, while achieving equity in relief aid distribution among affected areas.

In this present work, it has been modified in order to maximize the beneficiaries and minimize transportation costs, by optimizing resource allocation and vehicle routing decisions.

The main differences of the two models from the one proposed by Balcik et al. (2008) are the following constraints:

1. No shortage is accepted (present in the first model below).
2. Limited Resources Capacity (present in the second model below).

Moreover, Balcik et al. (2008) reported only a simple numerical example. In comparison, this chapter aims to apply a mathematical model using real assessed data from the Haitian case study.

The purpose of the evolution of the model is to optimize material deliveries involved in a real relief operation, considering also co-transportation modalities with different costs, capacities, and routes are considered.

The first model considers the possibility of delivering aid using two kinds of vehicles, trucks, and helicopters that have different costs and transportation times. The zero shortage condition is a model constraint, and the cost of the fleet is expressed in function of the kind of vehicle applied during the relief operation. Then, I explore the impact of variations in available logistics assets, modifying the objective function and relative constraints.

In the next stage, the second model includes a different objective function to minimizing the shortage. Indeed, the aim is to maximize the level of service to people receiving aid from the organization, by varying the number and type of vehicles used.

3.2.1. Models Formulation

Sets

T set of days *t* in the planning horizon; length of the planning horizon

K set of trucks *k*

R^k set of routes r^k for trucks *k*

H set of helicopters *h*

R^h set of routes r^h for helicopters *h*

E set of demand types *e*: $E = \{1,2\}$

N set of all demand locations *i*

N_{r^k} set of demand locations *i* visited on route $r^k \in R^k$

N_{r^h} set of demand locations *i* visited on route $r^h \in R^h$

Routing parameters

$C_{r^k k}$ cost of route r^k for truck $k \in K$

$C_{r^h h}$ cost of route r^h for helicopter $h \in H$

q_k capacity of truck $k \in K$ (amount of demand)

q_h capacity of helicopter $h \in H$ (amount of demand)

$T_{r^k k}$ duration of route $r^k \in R^k$ for truck $k \in K$

$T_{r^h h}$ duration of route $r^h \in R^h$ for helicopter $h \in H$

M_k available time of truck $k \in K$

M_h available time of helicopter $h \in H$

Demand parameters

d_{it}^e demand of type e at location $i \in N$ on day $t \in T$ (amount of demand per day)

P_{it}^e priority index of $e \in E$ relief supplies to deliver to location $i \in N$ on day $t \in T$

ak_t^e amount of type $e \in E$ relief supplies arriving to the truck LDC (Local Distribution Center) at the beginning of day $t \in T$

ah_t^e amount of type $e \in E$ relief supplies arriving to the helicopter LDC at the beginning of day $t \in T$

Routing decision variables

$$x_{r^k kt} = \begin{cases} 1 \; if \; route \; r^k \in R^k \; is \; used \; by \; truck \; k \in K \; on \; day \; t \in T \\ 0 \; otherwise \end{cases}$$

$$x_{r^h ht} = \begin{cases} 1 \; if \; route \; r^h \in R^h \; is \; used \; by \; helicopter \; h \in H \\ on \; day \; t \in T \\ 0 \; otherwise \end{cases}$$

$$N_{ir^k} = \begin{cases} 1 \; if \; location \; i \in N \; is \; visited \; by \; a \; truck \; during \\ the \; route \; r^k \in R^k \\ 0 \; otherwise \end{cases}$$

$$N_{ir^k} = \begin{cases} 1 \ if \ location \ i \in \ N \ is \ visited \ by \ a \ helicopter \ during \\ \qquad the \ route \ r^h \ \in \ R^h \\ 0 \ otherwise \end{cases}$$

Delivery decision variables

$Y^e_{itkr^k}$ amount of demand of type $e \in E$ delivered to location $i \in N_r$ on day $t \in T$ by vehicle $k \in K$ via route $r^k \in R^k$

$Y^e_{ithr^h}$ amount of demand of type $e \in E$ delivered to location $i \in N_{rh}$ on day $t \in T$ by helicopter $h \in H$ via route $r^h \in R^h$

$S^{\,e}_{it}$ percentage of unsatisfied type e demand at location $i \in N$ by day $t \in T$

3.3. Minimal theoretic number of vehicles

As discussed in the previous sections, the number of available vehicles is one of the most important aspects to consider when seeking to satisfy all the demand points without incurring a shortage.

Since the accuracy and the availability of data about demand, LDC, and locations are very low, it is useful to estimate the minimal number of vehicles based on assessed data at the beginning of the study, in order to design the correct dimension of vehicles fleet.

I introduce a simple formulation to assess the minimal theoretical number of vehicles using the following simple estimated parameters:

- d^e_{it} demand of each type of item;
- $\overline{T_{r^k}}$ the average route in time for trucks;
- $\overline{T_{r^h}}$ the average route in time for helicopters;

Typically, the managers of humanitarian organizations estimate the first parameter by multiplying the expected beneficiaries of each analyzed location and per capita consumption of each item.

As regards route data, they are assessed studying the road and air network composed of the positions of beneficiaries' locations and LDCs.

After assessing these parameters in the first phase of the last mile distribution problem, the minimal theoretical number of vehicles is computed as follows:

$$\widetilde{Z_{kt}} = \left\lceil \frac{\sum_e \sum_i d_{it}^e}{\frac{M_k}{T_{r^k k}} \cdot q_k} \right\rceil \qquad [1]$$

$$\widetilde{Z_{ht}} = \left\lceil \frac{\sum_e \sum_i d_{it}^e}{\frac{M_h}{T_{r^h h}} \cdot q_h} \right\rceil \qquad [2]$$

These formulas assist in making an estimation of the number of vehicles, both trucks [1] and helicopters [2] that are necessary to satisfy the entire demand.

3.4. Last mile distribution model under no-shortage constraint

The formulation of the first problem model is:

$$FO = \min\left(\sum_{r^k \in R^k} \sum_{k \in \mathrm{K}} \sum_{t \in \mathrm{T}} C_{r^k k} x_{r^k kt} + \sum_{r^h \in R^h} \sum_{h \in \mathrm{H}} \sum_{t \in \mathrm{T}} C_{r^h h} x_{r^h ht} \right) \qquad [3]$$

Constraints:

$$\sum_{i \in \mathrm{N}} \sum_{e \in \mathrm{E}} S_{it}^e = 0 \qquad \forall t \in T \qquad [4]$$

$$S_{it}^e = d_{it}^e - Y_{it}^e \qquad \forall i \in N, t \in T, e \in E \qquad [5]$$

$$Y_{it}^e = \sum_{r^k \in R^k} \sum_{k \in \mathrm{K}} Y_{itkr^k}^e x_{r^k kt} N_{ir^k} + \sum_{r^h \in R^h} \sum_{h \in \mathrm{H}} Y_{ithr^h}^e x_{r^h ht} N_{ir^h} \qquad \forall i \in N, t \in T, e \in E \qquad [6]$$

$$Y_{tkr^k} = \sum_{e \in \mathrm{E}} \sum_{i \in \mathrm{N}} Y_{itkr^k}^e x_{r^k kt} N_{ir^k} \leq q_k \qquad \forall t \in T, k \in K, r^k \in R^k \qquad [7]$$

$$Y_{thr^h} = \sum_{e \in \mathrm{E}} \sum_{i \in \mathrm{N}} Y_{ithr^h}^e x_{r^h ht} N_{ir^h} \leq q_h \qquad \forall t \in T, h \in H, r^h \in R^h \qquad [8]$$

$$\sum_{r^k \in R^k} x_{r^k kt} T_{r^k k} \leq M_k \qquad \forall k \in K \qquad [9]$$

$$\sum_{r^h \in R^h} x_{r^h ht} T_{r^h h} \leq M_h \qquad \forall h \in H \qquad [10]$$

$$\sum_{r^k \in R^k} \sum_{i \in \mathrm{N}} \sum_{k \in \mathrm{K}} \sum_{t \in \mathrm{T}} Y_{itkr^k}^e \leq \sum_{t \in \mathrm{T}} ak_t^e \qquad \forall e \in E \qquad [11]$$

$$\sum_{r^h \in R^h} \sum_{i \in \mathrm{N}} \sum_{h \in \mathrm{H}} \sum_{t \in \mathrm{T}} Y_{ithr^h}^e \leq \sum_{t \in \mathrm{T}} ah_t^e \qquad \forall e \in E \qquad [12]$$

$Y_{itkr^k}^e \geq 0$ $\forall i \in N, t \in T, k \in K, r^k \in R^k, e \in E$ [13]

$Y_{ithr^h}^e \geq 0$ $\forall i \in N, t \in T, k \in K, r^h \in R^h, e \in E$ [14]

$x_{r^k kt} \in \{0,1\}$ $\forall r^k \in R^k, k \in K, t \in T$ [15]

$x_{r^h ht} \in \{0,1\}$ $\forall r^h \in R^h, h \in H, t \in T$ [16]

The objective function [3] minimizes costs associated with trucks and helicopters and considers both a truck and helicopter delivery.

The assumptions of the problem are based on the model introduced by Balcik et al. (2008), who consider the typical routing problem constraints in the humanitarian field.

In more detail, the first constraint [4] means that the unsatisfied demand has to be zero. This constraint allows to be studied at this stage just the costs and not the shortage variation.

Constraint [5] finds the amount of unsatisfied demand and it implies that the demand of a location is completely satisfied by the delivered amount expressed by the next constraint [6] that indicated the number of items *e* delivered location *i* on day *t*.

Constraints [7] and [8] consider the capacity limit for trucks and helicopters, while [9] and [10] concern the available time in the time window for both of the vehicles, and M_k and M_h are the number of minutes available in the day for each kind of transportation mode. Constraints [11] and [12] are the number of items present in truck and helicopter LDCs. Constraints [13] and [14] are non-negativity constraints, while [15] and [16] define the binary routing variable.

3.5. Model under limited resource capacity constraint

The aim of this part of the research is to study the model behavior in the presence of limited resource capacity in humanitarian logistics operations, so to understand the variation of the shortage and the relative cost for all the *e* items considered in the whole planning horizon in function of the number of the available trucks and helicopters, calculated in the range of values assessed using formulas [1] and [2].

In this case the objective function changes as follows:

$FO = min \sum_{e \in \mathrm{E}} \sum_{i \in \mathrm{N}} \sum_{t \in \mathrm{T}} P_{it}^e S_{it}^e$ [17]

it is subjected to almost all the constraints seen in the previous part, without considering the constraint number [4], but with one more constrain indicated as follows:

$0 \le S_{it}^{e} \le d_{it}^{e} \qquad \forall i \in N, t \in T, e \in E$ [18]

The constrain [18] suggests that the level of shortage can vary from 0, in the case that every beneficiary is satisfied, and the demand of the item *e* at the node *i* at the time *t*.

3.6. The Haitian Case

According to the United Nations Secretary-General report, which was published on September 2, 2011, the earthquake that hit Haiti in January 2010, measuring 7.2 on the Richter scale, affected almost 3.5 million people. It has been estimated by the Government of Haiti that the earthquake killed 222,570 and injured another 300,572 people. At least 188,383 houses were badly damaged and 105,000 were destroyed by the earthquake. Almost 60 percent of the Government and administrative buildings, 80 percent of schools in Port-au-Prince, and 60 percent of schools in the South and West Departments were destroyed or damaged. The total related loss has been estimated at $7.8 billion, more than 120% of Haiti's 2009 gross domestic product.

For these reasons, in order to meet the basic needs of the affected population, after the earthquake hit Haiti, several relief teams arrived and started their work. United Nations agencies, for example, as well as the International Federation of the Red Cross and Red Crescent Society started to prepare the deployment of teams and humanitarian assistance.

The organizations that will be considered in this article are WFP and UNICEF, while most of the data used come from WFP documents (WFP Operation documents – Haiti) or interviews with WFP's operators. The WFP is a United Nations agency that is focused on food planning and food deliveries to nutritionally vulnerable groups. Indeed, it is the leader of the food cluster, the logistic cluster, and the Emergency Telecommunications cluster. UNICEF, instead, is the leader of the Education, Water Sanitation Hygiene, and Nutrition clusters (for more information about the cluster see Jahre and Jensen, 2010 and the United Nation website). For both the United Nations organizations the overall objective is to "save lives and protect livelihoods in emergencies" in their own fields.

In a disaster such as that in Haiti there are many items that have to be delivered to the vulnerable groups, including tents, blankets, tarpaulins, jerry cans, mosquito nets, food, and hygiene kits, as well as more cumbersome ones like kitchens and other materials for reconstruction. Here, hygiene kits (called "item1") and food (called "item2") will be taken into consideration (they are homogeneous items for shape and size). This choice has been supported by the documents analysis and by the fact that they are provided by two different organizations: UNICEF supplies hygiene kits, while WFP delivers food consumption. Thus, it is possible to understand what should happen when they are provided at the same time with a good level of coordination between organizations.

As argued by Balcik et al. (2008), during the relief operations there are some features that can bring more problems than during commercial distribution. These characteristics are “the unavailability/scarcity of resources (time, supplies, personnel, vehicles, transportation, and communication infrastructure) and the high stakes associated with delivering supplies (suffering and/or loss of life)”. If I consider this, according to the official United Nations document, even before the earthquake, the transport infrastructure was very poor, it is easy to understand how challenging the delivery of relief items to beneficiaries can be.

3.6.1. Data

One of the most important issues in the humanitarian field concerns the data. Usually, they are incomplete, scarce or completely missing. Typically, the severity of lack of data is higher in the post disaster phase than in the development phase. For this reason, I place the research in the regular humanitarian logistics (R-HL) stage.

The case study is based on data present in documents received by the WFP association (World Food Program), and data present on the logistic cluster website and derived from one-to-one interviews with WFP operators in Italy and WFP logistics operators in Haiti. This research uses data on the demand for two kinds of item and the features of the considered vehicles (truck and helicopter) used in the distribution. Furthermore, it uses information about the aid distribution in Haiti.

The Republic of Haiti is a Caribbean country and it is divided into 10 departments for reasons of administration. This case is focused on the south-east department, whose capital is Jacmel, one of the areas most affected by the earthquake. Two independent kinds of LDC have been considered: the LCD for the trucks is in Jacmel, while the helicopter one, for emergency flight, is situated in Port au Prince. The municipalities – and the respective districts – considered as demand points, are Bainet (A), La Vallèe (B), Trouin (C), and Côtes-de-Fer (D). The situation and data are presented in figure 3.1 and table 3.1.

Figure 3.1: Truck depot and demand points in south-east department in Haiti.

Table 3.1: Input Data (A-Bainet, B-La Vallèe, C-Trouin, D-Côtes-de-Fer)

	Demands [kg]		Matrix of distances for trucks [km]					Matrix of distances for helicopters [km]				
	D1	D2	LDC_k	A	B	C	D	LDC_h	A	B	C	D
LDC_k	-	-	-	45	16	41	79	-	-	-	-	-
LDC_h	-	-	-	-	-	-	-	-	66	52	43	86
A	40183	24243	45	-	46	73	34	66	-	14	24	24
B	22710	13701	16	46	-	44	80	52	14	-	10	66
C	16878	10183	41	73	44	-	107	43	24	10	-	43
D	11167	6737	79	34	80	107	-	86	24	66	43	-
Total	90.937	54.863										

Following the two-phase approach introduced by Balcik et al. (2008), in the first phase all available routes are defined for each kind of vehicle, considering the hypothesis of a four nodes distribution (figure 3.1). All the routes are known a priori and are based on road network data.

Afterwards, the expected sets of vehicles, for each kind, have been estimated using formulas [1] and [2]. For example, using formula [1] with demand of 90.937 kg for item 1 and 54.863 kg for item 2, average route for trucks equal to 334 minutes (it considers load and download time), M_k minutes in a day equal to 647 minutes (480 minutes plus half of the average route), and capacity of vehicles is 10,000 kg, the minimal theoretical number of vehicles respectively for item 1 is equal to $\lceil 4.69 \rceil = 5$, for item 2 is $\lceil 2.83 \rceil = 3$.

For helicopters, the average route is equal to 150 minutes and M_h minutes in a day equal to 555 minutes (480 minutes plus half of the average route), while in this case capacity of vehicles is 3,000 kg. Then, the minimal theoretical number of vehicles respectively for item 1 is equal to $\lceil 8.19 \rceil = 9$, for item 2 is $\lceil 4.94 \rceil = 5$.

In the case of co-transportation strategy, the minimal numbers of vehicle are respectively equal to $\lceil 7.52 \rceil = 8$ for trucks and $\lceil 13.13 \rceil = 14$ for helicopters.

This number gives an idea of the number of vehicles for the routing problem without the need for accurate detailed data. It could be possible to consider even the probability to use each route, seen in function of the needs per each node, in order to perform more effectively the results of the formula.

Finally, in the first phase, the costs associated with each kind of vehicle are estimated by several interviews as 1.50 €/km for the trucks, and 10 €/km for the helicopters.

Continuing the two-phase approach, starting from the list of candidate routes and the related travel times, the available number of vehicles, and the associated cost, in the second stage the modified models introduced in the previous section have been applied considering the items demands of each location, the volume capacity, and the available time for each vehicle under no shortage constraints.

3.6.2. Application to the Haitian case

The application of the model under no-shortage constraint has underlined that, with an average speed of 50 Km/h, the optimal solution to deliver the item 1 is performed by 5 trucks and 0 helicopters with 1.532,25 $€/day$ of total cost, while to deliver item 2 the optimal solution is 4 trucks and 0 helicopters with 1.270,5 $€/day$ of total cost (figure 3.2 and figure 3.3). The model is solved using GAMS/Cplex on a PC equipped with an Intel CORE i3processor and Windows 7. The following section shows the graphics of the solutions in function of the available vehicles where the cost arises with the variation of number of available trucks and helicopters, considering always a zero percent of shortage, because the two kinds of vehicles have different costs per km. In this application, it is possible to note that the most important data are regarding the distribution of the demand, calculated from official documents and the distribution of the population in the disaster area, the position of the depots, taken from official documents and maps, the types of vehicle delivered in this kind of situation, and all the available routes for the vehicles.

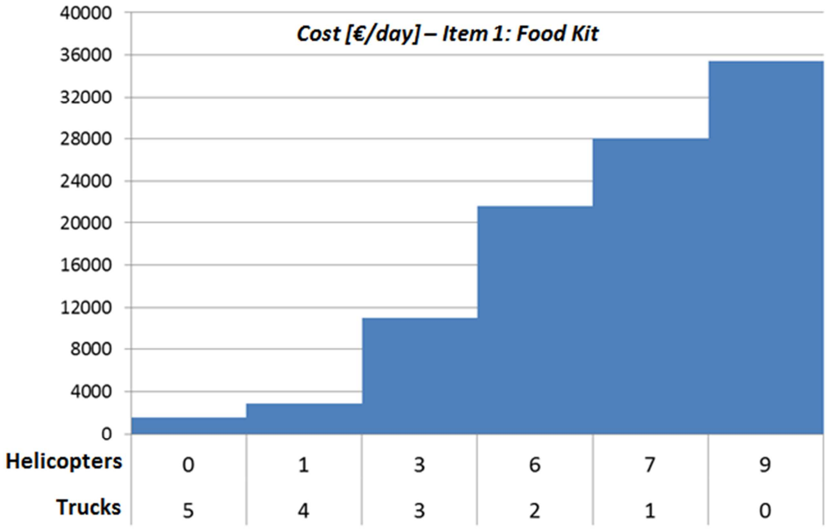


Figure 3.2: Food distribution cost increases in function of the type of available vehicle.

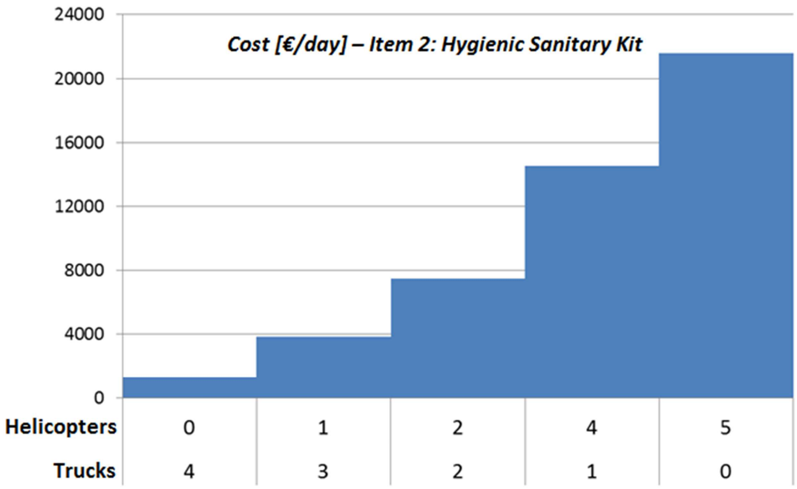


Figure 3: Hygienic-Sanitary Kits distribution cost increases in function of the type of available vehicle.

Figures 3.2 and 3.3 show two examples, for different items, of the increase in costs relative to the types of vehicle used. The increase is not always linear because in some situations the organization needs to use more helicopters to satisfy the lack of an available truck. The first column of each example considers that the delivery is done with trucks; it shows how many trucks should be used to cover the demand. The number of trucks decreases, while the number of helicopters increases. This means a non-linear growth per truck decrease.

3.6.3. *Impact of co-transportation*

According to the answers received from some logistics experts in Haiti, usually the distribution of different products is made separately by the organizations that are employed, as leaders of the clusters, for example, in the distribution of those kinds of products. Therefore, in this case, as previously explained, UNICEF supplies hygiene kits while WFP delivers food. In this section I focus on the co-transportation of both food and hygiene kits. The results are presented in figure 3.4.

The graphic shows that it is possible to use just seven trucks with 2463.75 of total cost to deliver both the products, while if I consider two different transportations, it requires nine trucks with 2802.75 of total cost (these data come from the previous example).

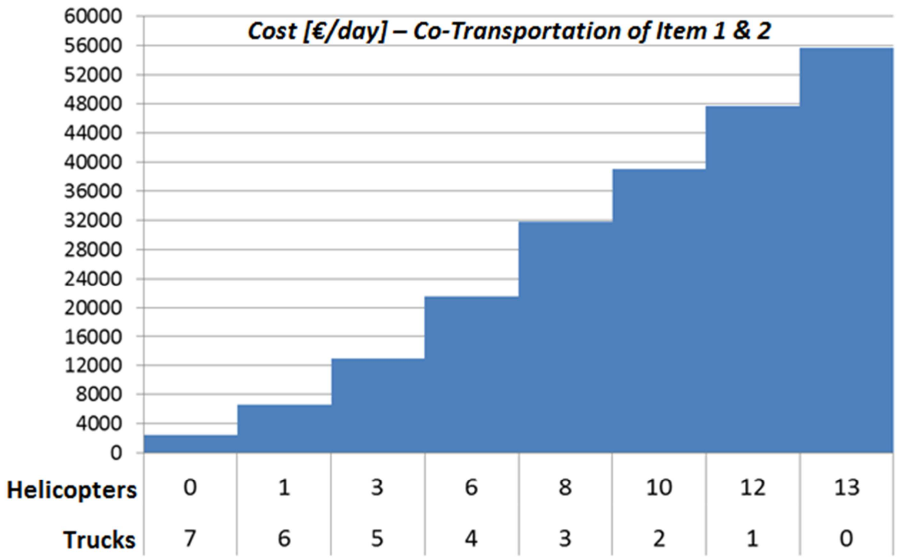


Figure 3.4: Co-transportation cost increases in function of the type of available vehicle.

This result leads to a consideration of the co-transportation in order to have a higher level of cost performance even if, as suggested by Rodríguez et al. (2007), there are some other factors that can limit the co-transportation. According to Rodríguez et al. (2007), these factors can be the volume, weight, shape, and fragility of the items and should be checked. On the other hand, the benefits concern the minimization of "transportation costs and increase delivery service" (Hageback, C., Segerstedt, A., 2004.). These results are obtained from the model in terms of reduction of costs and a higher performance in service level. Indeed, the total cost of co-transportation is lower than the sum of two different transportation ones and the total number of needed vehicles is lower. This means it is possible to have a higher level of service with the same size of fleet.

3.6.4. Impact of limited resource capacity

In this case, the application of the model under limited capacity constraints allows noting how the total cost and the shortage can change in function of the number of available trucks and helicopters. Figure 3.5 and figure 3.6 concern Food and Hygiene Kits respectively.

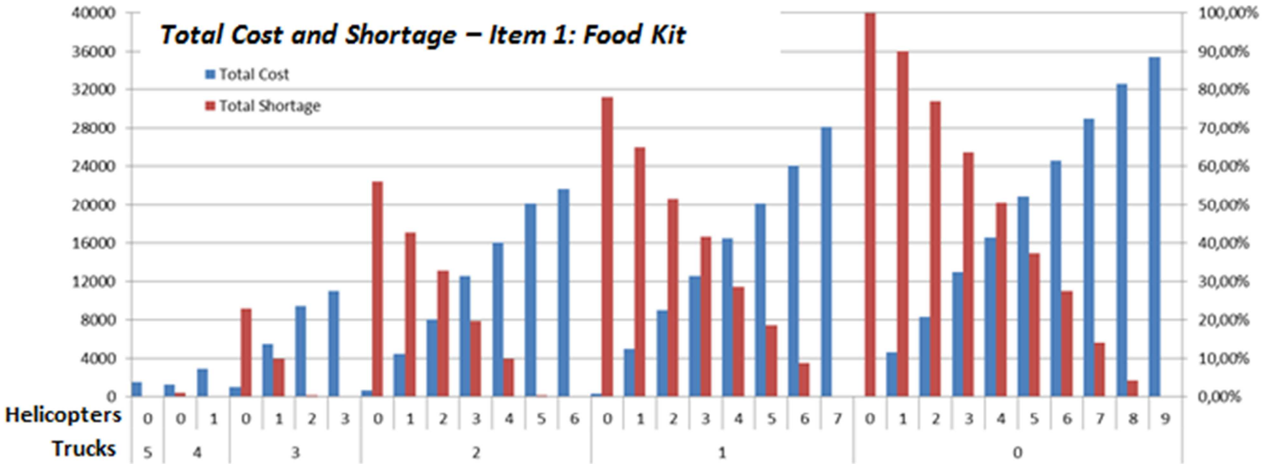


Figure 3.5: Variation of cost in function of the type of available vehicle for Food Kit.

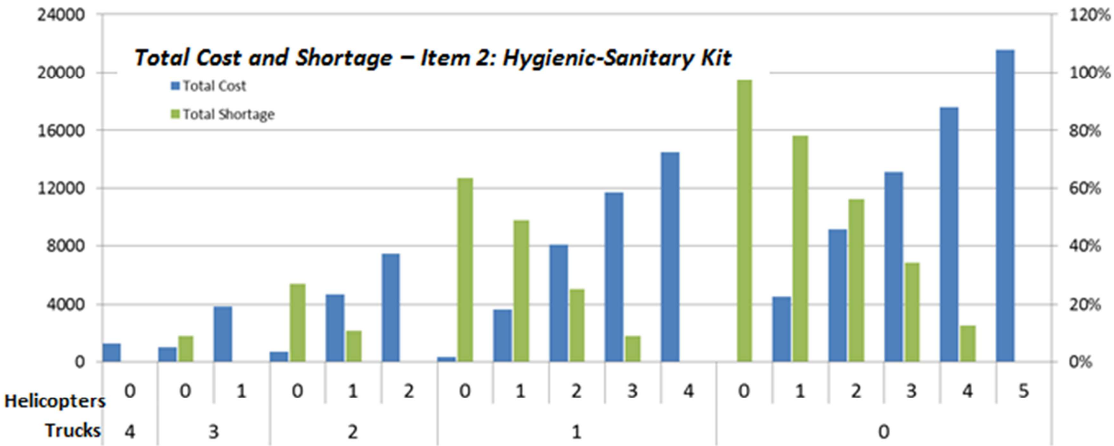


Figure 3.6: Variation of cost in function of the type of available vehicle for Hygienic-Sanitary Kits.

These graphics give us an idea of the marginal costs associated with a service level reduction. Moreover, it suggests what the best option can be in terms of costs, considering the same level of shortage. According to some interviewed humanitarian operators, if just cost considerations are made, the best result is achieved using trucks, since the humanitarian organizations usually work under economic constraints. But in some cases, it could be useful to consider helicopters, when the distance or the accessibility to the location requires too much time or if it is not reachable by road. Furthermore, the graphics in figure 3.5 and figure 3.6 show the impact of the logistic system and of the fleet on the shortage.

The variables in these two figures (3.5 and 3.6) are the number of available vehicles. The number of vehicle varies from the maximum number of trucks to zero, defined using formula [1]. Moreover, in each section of the pictures the number of available helicopters varies from zero to the maximum number of necessary helicopters needed to satisfy all the demands, using formula [2]. These variations help the reader to understand how the shortage and the costs vary in function of the available fleet.

3.7. Last mile in humanitarian logistics: a discussion on results

According to Kovàcs and Spens (2007), the research field of humanitarian logistics is relatively new, which, as Van Wassenhove and Pedraza Martinez (2012) underline, faces problems that have been successfully studied in the past. The purpose of the present work was to investigate the last mile distribution problem by providing an analytical model and a case study to assist relief decision makers in effective and efficient distribution across the last mile. Initially, the first introduced analytical model is an extension of the model developed by Balcik et al. (2008). It was modified to consider the distribution problem relating on the variation of outputs, no-shortage constraint, and cost in function of the number and type of vehicles in the fleet. Then, the basic approach composed of two phases introduced by the Balcik et al. (2008) model was used. In the first phase, the required data were collected and estimated, such as the demands, the route network, and the theoretical number of vehicles. In the second phase, the extended model was applied under no-shortage constraint. Finally, relaxing this last restriction, the limited capacity of vehicles and its impact was studied using the second model above introduced.

The results obtained show that the fleet costs increase not linearly in function of the number of helicopters an organization needs to satisfy the lack of trucks. Furthermore, the research reveals that the variation in available fleet affects shortage and costs. These models can be applied in real operations in order to show how much can be saved in function of the considered vehicle typology and then the service level, defined as shortage. This leads to understand what the best way would be in processing the distribution with the lowest level of cost and which could be the implication in terms of cost and shortage in conditions of limited resources capacity.

Moreover, this research computed the performance of the delivery system when a co-distribution of different kinds of products is applied. These levels of performance are the same as those suggested by Rodrìguez et al. (2007) and Hageback and Segerstedt (2004). The kinds of products considered in this case study are homogeneous in dimension and shape. Moreover, additional considerations, such as the presence of standard and modular packaging systems or the collaboration between humanitarian clusters, should be included and further discussed to determine the real feasibility of a co-transportation.

4. Vehicle routing problem heuristics in humanitarian operations

Vehicle Routing Problem (VRP), a subject widely discussed in the literature, is the processing of logistic costs in order to achieve a distribution goal with the minimum level of costs or the highest level of saving. The many approaches consider logistic costs, seen as costs, distances or times, as the critical factors that should be minimised to achieve a target level of performance. These methodologies can be applied in the humanitarian or private sectors (Van Wassenhove, 2006), of course considering the differences between the two fields.

In humanitarian operations not only costs should be considered (Oloruntoba, 2005, Kovàcs and Spens, 2007). Indeed, some other aspects should be studied (Huang, M., et al. 2012). This particularity is well-introduced by Holguín-Veras et al. (2012), who present and develop the differences between Commercial (C-L) and Humanitarian logistics (HL, both Regular and Post-Disaster ones). Moreover, in this chapter particular humanitarian features, such as social costs, defined as the sum of logistics costs (LC) and deprivation costs (DC), are presented and the real goal of the objective function underlined.

The main problems arising in the literature concerning the process are the non-linearity of the deprivation function, the inadequacy of minimising just unmet demand and using hard constraint limitations associated with some models, as argued in Holguín-Veras et al. (2013).

Since social costs are the sum of deprivation and logistics cost, the objective of this research is to introduce two heuristics in order to consider these costs as a function of the capacity level. In fact, it is well known that for high levels of capacity (example > 100%) the traditional VRP solving approach can be used with the goal of minimising the logistics costs. On the other hand, for low levels of capacity, it is important to consider deprivation costs, due to their exponential function. It is logical to assert the presence of a middle region of capacity where the two costs can be compared and have to be considered jointly. The final objective of the research is to understand how to weigh them in this limited capacity region.

The first heuristic introduces the prioritisation parameter, called Δ_i, which considers just deprivation costs and its growth if the node is served or not. This allows understanding which node has to be supplied. From this first solution procedure, I define the middle region, where the deprivation and logistic costs are comparable.

Then, for this middle region, the second heuristic combines logistic costs and deprivation costs during the prioritisation thanks to the introduction of a smoothing variable "$\propto$".

This variable helps explain how the prioritisation can vary in function of the available capacity level and what the achieved final level of cost is (for delivered and undelivered items) for each type of prioritisation. The application will show the most suitable value of ∝ that minimises the total social costs as a function of the capacity level.
Finally, different deprivation cost functions are analysed in order to generalise the results and to give helpful guidelines in choosing a suitable ∝ value.

4.1. Literature review

In the last decades the humanitarian context has been discussed in the literature by many authors (Van Wassenhove, 2006, Kovàcs and Spens, 2007, Galindo & Batta, 2013) who have introduced the subject, explained the features and challenges and presented some case studies (Gatignon et al. 2010, Pedraza-Martinez, 2011, Green, et al., 2013). In this particular environment, a relatively new research field, some traditional supply chain issues have been analysed, for example, facility location (Balcik and Beamon, 2008, Campbell, and Jones, 2011) and vehicle routing problems (Cambpell, et al., 2008, Naji-Azimi, et al. 2012, Wohlgemuth, et al., 2012, Battini, et al, 2014). Furthermore, the problems of allocating scarce resources to complex operations (Barbarosoglu, et al., 2002, Van Wassenhove and Pedraza Martinez, 2010, Battini et al. 2014), scheduling activities (De Angelis et al., 2007) and item supply (Knott, 1987, Haghani and Oh, 1996, Balcik et al., 2008, Nolz et al., 2010) have been dealt. The purpose of these researches is "to rapidly provide the appropriate emergency supplies to people affected by natural and manmade disasters so as to minimize human suffering and death" (Balcik et al., 2008). This definition underlines how some specific characteristics have to be considered in these particular environments, such as social aspects (Tatham and Houghton, 2011). According to Holguín-Veras et al. (2013), the developed models present some limitations (hard constraints, constant penalty models and variable penalty models) that do not permit treating the problem in the best possible way. Moreover, Holguin-Veras et al. (2013) introduce the problem of item distribution considering deprivation as an exponential cost jointly with logistic costs associated with the distribution plan.
According to Laporte (1992), the VRP can be described "as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers subject to side constraints". The literature about VRP is broad (Clarke and Wright, 1964, Fisher and Jaikumar, 1981, Laporte, 1992 and Toth and Vigo, 2002) and presents many variations of the problem even if the basic components are almost fixed (Fisher and Jaikumar, 1981). These variations consider different features of the problem,

from CVRP (Capacitated VRP, Baldacci et al. 2012, Marinakis, 2012) to VRPTW (VRP with Time Windows, Gendreau et al. 2008, Qureshi et al., 2012) passing through TDVRP (Time-dependent VRP, Polimeni & Vitetta, 2013, Lecluyse et al., 2013) and MDVRP (Multi-depot VRP, Aras et al. 2011, Salhi et al., 2013) and many others different typologies (Lin et al., 2014).

Further this classification the methodologies can be summarised in two main areas: linear-integer programmes and heuristics. While the first type of methods is usually presented for simple models application, the literature suggests many heuristics to find good solutions for more complex problems, like in the non-humanitarian literature have been closest neighbor, savings or extra-milia heuristics. Moreover, heuristics can consider specific features of the problem and, at the same time, yield quality solutions “within short computational time” (Hamedi et al, 2012). The savings (Clarke and Wright, 1964), the sweep (Wren and Holliday, 1972) and the general assignment problem approach (Fisher and Jaikumar, 1981) are just some examples of these heuristics.

This chapter aims to present some simple heuristics to face VRP into humanitarian operations, where simple tools are needed and where some constraints lead to consider particular costs into the decision making process.

4.1.1. Objective of the research

An important issue in humanitarian operations is the capacity to make a decision quickly in a complex environment that continuously changes and where typical industrial tools (e.g. linear programming or other optimisation methods) are hard to apply. Another motivation is the impossibility to make apply a complex tool by on field personnel while simple instruments could be very useful and could really improve the response. For these reasons, I decided to focus the research on simple tools, heuristics for delivery prioritisation which are flexible and can fit the complex humanitarian operations environment. In particular, these tools include the possibility of a dynamic network that can change in terms of quantity and location of demands points, a short computational time with the possibility of providing good solutions and the consideration of limited available capacity with the consequences of shortages. The importance of these heuristics is that they do not explode in terms of complexity once the network increases in size and complexity.

The objective of this research is to propose some heuristics for the VRP in a humanitarian context, i.e. to consider social costs composed of logistic and deprivation costs, as a function of the distribution system capacity level. An analysis of the ratio between deprivation and logistic costs in the delivery process is carried out to understand which proportion of deprivation and logistic costs, i.e. which value of $\propto$ performs better in terms of cost minimisation. In the analysis different scenarios are presented, in particular two different layouts and diverse deprivation functions.

The proposed solution finds a tradeoff between different costs and studies these costs not just as they are now (greedy) but it ponders the growth these could have if I decide to deliver or not. This has remarkable improvements compared to others simple algorithmic because allows to consider deprivation costs, linked to people suffering, in a contest, humanitarian operations, where standard supply chain costs cannot effectively be used.

4.2. Model

According to Solomon (1987), "the vehicle routing problem (VRP) involves the design of a set of minimum-cost vehicle routes, originating and terminating at a central depot, for a fleet of vehicles that services a set of customers with known demand".

The model is formed a typical humanitarian operations model, where the distribution center in the area hit by the disaster is the LDC (Local distribution center) and there are nodes that have to be served by the different trucks. In this situation typically the area hit by the disaster, under a lack of distribution capacity, is split into different sub areas where each vehicle works alone and has its nodes to serve. The difference between this problem and the standard VRP is due to the costs. The two main costs considered in VRP applied to humanitarian operations are the traditional logistic costs and the deprivation costs, related to the lateness associated with delivering to a node. These costs are presented by Holguín-Veras et al. (2012) and they are seen as the social costs that should be considered in order to achieve the humanitarian operations goal. While the traditional logistic costs have been widely presented in the literature, quantification of the deprivation costs associated with aid distribution is a relatively new problem feature.

An important assumption is made considering that in some regions of total available capacity it is not useful to apply the heuristics. Indeed, when the available capacity is enough to satisfy all demand in one period the maximum time of deprivation will be the distribution window, so one day. In this situation deprivation cost will be rather low compared with logistic costs and it should not be considered in the prioritization process. This allows simplifying the problem and using typical heuristics presented in the literature that consider just logistic costs. On the other hand, if the available capacity is less than the demand the deprivation cost will increase and so has to be taken into account.

Thus, the step before the presentation of the heuristics is the introduction of the notations and function used in the model.

4.2.1. Notation

δ_i is the time of deprivation for node i, which in this case is the deprivation from water. In this chapter no limit value of the deprivation cost function is considered.

C and D are the constant values presented by Holguín-Veras et al. (2012) in the exponential function, $C = 1.5031$ and $D = 0.1172$. These values change in function of the missing items, in this example water;

T_{0i} is the time of deprivation at the node i in the current instant; after each step of the heuristic it changes in function of how much is delivered.

t_{ji} is the time distance between the point j, where the vehicle is, and the point i, where the vehicle is going to deliver.

$\tilde{T}_i$ is the mean time to arrive to node i from the other nodes. This term is used in the delta to understand the mean necessary route to leave the point and return in it ($2 * \tilde{T}_i$). This term is considered because usually if a point cannot be served in a round it will be considered just next and so this value studies the increase of cost in the situation of leaving the node, serve another node and come back to serve this node again.

Θ_{it} is a value that translates the percentage of items delivered of the total needs in i. It is the percentage of decrease of the deprivation time (and so in cost) used in the deprivation cost function.

$\propto$ [0:1]: smoothing variable. This variable changes the weight associated with deprivation (benefits and costs) and logistic costs.

LC_{it} : logistic cost to deliver at the node i at the time t.

K: transportation cost per hour has been taken as the value suggested by Holguin-Veras and Brom (2008) of 55 $/h. This cost considers typical logistic direct costs, as fuel and personnel.

LDC is the Local Distribution Centre that stores and distributes emergency relief items to a number of demand nodes.

Δ_i is the prioritisation parameter of the first heuristic, called Δ_i, this considers just deprivation costs to know which node has to be supplied.

$\propto$ is the smoothing variable introduced in the second heuristic that combines logistic costs and deprivation costs into the prioritisation process and study the radio between these.

4.2.2. Function

In this research the deprivation function is taken from the research proposed by Holguìn-Veras et al. (2013) and it is “estimated with data collected about willingness to pay for water”. This function is a non-linear function that better represents the levels of deprivation:

$$f(\delta_i) = e^{(1,5031+0,1172*\delta_i)} - e^{(1,5031)}$$

4.2.3. Time Window

According to Josè Holguìn-Veras et al. (2013), the logistics costs usually “take place in a single time period”, while “opportunity costs of those individuals who did not receive aid […] are likely to accrue in future time periods”. For this reason, if the objective is the study of the costs associated with the level of suffering, it is important not to consider just a single period for the model, but rather a multi-period in order to achieve the right level of the deprivations and their change in the whole time window. The time window that has been considered is a multi-day time window of 20 days. Days start at 8 am and end at 6 pm, when night falls. It is important to note how delivering all day long is not possible in humanitarian operations where personnel safety is fundamental. For this reason, the delivery plan suggested is a continuous window of 10 hours, from 8 am to 6 pm, during which deliveries are made without any stop. This has clearly an implication on social cost because not serving a point in the “today” trip will require “tomorrow” trip with a delay that hits the deprivation costs.

4.3. Heuristics

The first heuristic proposed is focused on the low available capacity region where the high level of deprivation costs leads to their consideration only in the prioritization process. The identification of a middle region where logistic and social costs coexist leads to the second heuristic in which total social costs are studied jointly.

4.3.1. 1° HEURISTIC: deprivation cost minimization for low distribution capacity level.

The first heuristic uses the prioritization based on the highest level of deprivation cost during the humanitarian operations for each served location i at the time *t*, called Δ_{it}. For this reason, the choice of the next node for distribution is made considering how deprivation cost increases during the next period, taking into account the possibility of delivering now, in T_{0i}, or waiting to deliver, from the current instant 0 to the next instant 1. This first problem, by assumption, does not consider logistic costs.

The Δ_{it} considers what happens if the items are delivered to node *i* now or after a while (2*$\tilde{T}_i$) in terms of ratio between the missed deprivation benefits DB_{it} (deprivation if not delivered at node i) and deprivation costs DC_{it} (deprivation costs if items are supplied). In this case, after delivery, it is possible to know where the highest marginal level of suffering will be.

The parameter is defined as follows:

$$\Delta_{it} = \Theta_{it} * DB_{it}/DC_{it} = \Theta_{it} * (LS_{1i} - LS_{0i})/\left(LS_{1i,H} - LS_{0i,H}\right)$$

The ratio's upper term DB_{it} (deprivation benefits) is related to how the levels of suffering increase if no items are delivered at node *i*. It is indicated with letter "A" in figure 4.1 and considered as the social benefit associated with the delivery (the avoided social cost):

$LS_{0i} = e^{C+D*T_{1i}} - e^{C}$ → $T_{1i} = T_{0i} + t_{ji}$

$LS_{1i} = e^{C+D*T_{2i}} - e^{C}$ → $T_{2i} = T_{0i} + t_{ji} + 2 * \tilde{T}_i$

The denominator DC_{it} evaluates how the level of suffering increases if the node i is served at current instant. This is "B" in figure 4.1, the social cost associated with the delivery:

$LS_{0i,H} = e^{C+D*T_{1i,H}} - e^{C}$ → $T_{1i,H} = T_{1i} * (1 - \Theta_{it})$

$LS_{1i,H} = e^{C+D*T_{2i,H}} - e^{C}$ → $T_{2i,H} = T_{1i,H} + 2 * \tilde{T}_i$

In the $T_{2i,H}$ the value $\tilde{T}_i$is multiplied by 2 because it assumes the possibility of delivering later the items, so the truck will go to another node and presumably it will come back.

Moreover, considering N_{it} as the level of needs in the node i at time *t* and C_{t} as the available truck capacity at instant t, Θ_{it} is:

$$\Theta_{it} = \begin{cases} \frac{\mathrm{C_t}}{\mathrm{N_{it}}} \text{ if } \mathrm{C_t} < \mathrm{N_{it}} \\ 1 \text{ if } \mathrm{C_t} \geq \mathrm{N_{it}} \end{cases}$$

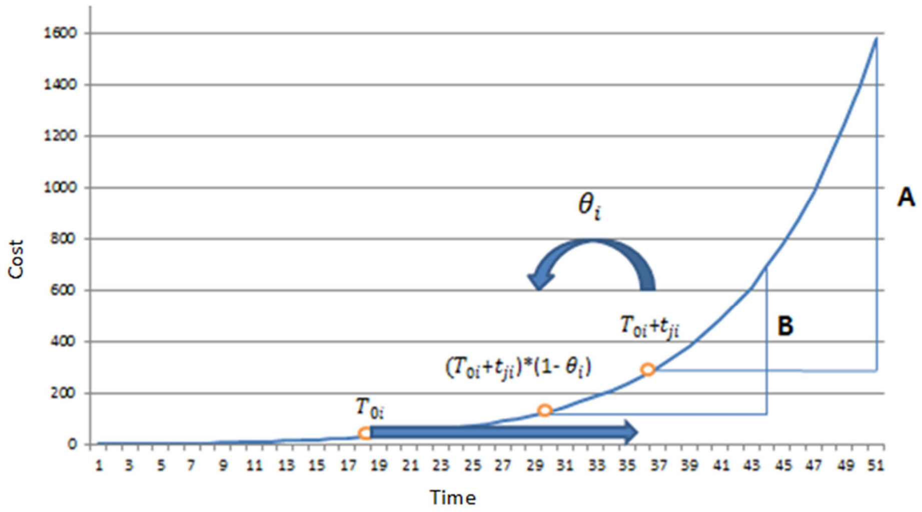


Figure 4.1: Δ_{it} calculation process.

Algorithm with one vehicle:

Step 1. Compute the Δ_{it} considering the time of deprivation (T_{0i}), the time distance between the point j, where the vehicle is, and the point i, where the vehicle is going to deliver (t_{ji}) and the percentage of items that can be delivered of the total needs in i (Θ_{it}).

Step 2. Order Δ_{it} in an increasing order and supply to the first node, the one which has the highest Δ_{it}

Step 3. If the needs at the point chosen are more than capacity, deliver all the capacity and go back to the LDC [go to step 4] otherwise return to step 1 [go on until all the items of the vehicle capacity have been delivered].

Step 4. When the vehicle is back to the LDC, available capacity=max vehicle capacity, if there is enough time and there is still “needs” go to Step 1, otherwise end.

The figure below summarizes the heuristic process.

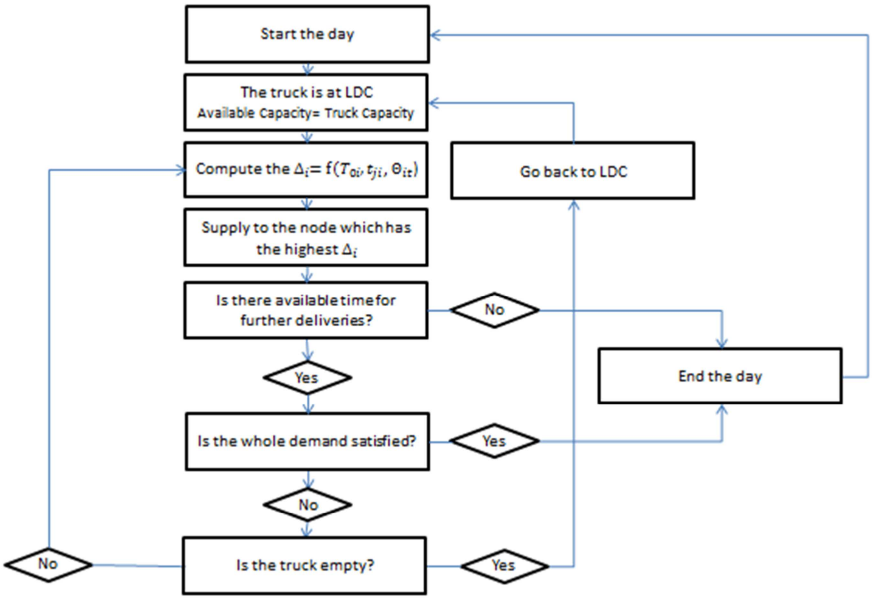


Figure 4.2: Heuristics process

This first heuristic shows the importance of the social costs and how they have to be considered in order to achieve a good level of cost considering Marginal Costs; the programme uses this organization in order to understand which node will be the next stop for the shipment.

4.3.2. Prioritization in the middle region.

In the middle capacity regions, a second heuristic is proposed in order to study how the two different costs, deprivation and logistic, have to be considered in function of the level of capacity. The deprivation benefits DB_{it} and deprivation costs DC_{it} are the same as in previous heuristic. Logistic costs (LC_{it}) are proportional to the delivery time and use K as transportation cost per hour (Holguin-Veras and Brom, 2008).

Thus, the priority value is Δ_{it2}:

$$\Delta_{it2} = \frac{\propto * \Theta_{it} * DB_{it}}{[\propto * \Theta_{it} * DC_{it} + (1 - \propto) * LC_{it}]}$$

The value of Δ_{it2} summarises the level of deprivation costs that would arise if there is no delivery at the node i, jointly with the related distribution costs (logistic). The value is seen in terms of ratio between expected benefit and cost associated with the distribution.

The results lead to consider node i in function of the percentage of the satisfied people, distance from the actual starting point, deprivation time and mean distance between i and the other nodes.

Algorithm with one vehicle:

Step 1. Compute the Δ_{it2} considering the time of deprivation (T_{0i}), the time distance between point j, where the vehicle is, and point i, where the vehicle is going to deliver (t_{ji}) and the percentage of items that can be delivered of the total needs in i (Θ_{it}). Moreover, the Logistic costs associated with the distribution are considered.

Step 2. Order Δ_{it2} in an increasing order and supply to the first node, the one which has the highest Δ_{it2}

Step 3. If the needs at the point chosen are more than capacity, deliver all the capacity and go back to the LDC [go to step 4], otherwise return to step 1 [go on until all the items of the vehicle capacity have been delivered]

Step 4. When the vehicle is back to the LDC, available capacity=max vehicle capacity, if there is enough time and there is still "needs" go to Step 1, otherwise end.

The structure is the same as that of the previous Algorithm, and just the prioritisation changes.

4.4. Test Problem

This section of the chapter presents the different characteristics of the Test problems: the layouts, the distributions of the demand and other typical distribution features as capacity and distances. The problem considers in one vehicle distribution.

4.4.1. Demand Layout

In this research, two different demand points' positions are considered; these layouts have demand nodes and so different distances. In the first, figure 4.3, the LDC (Local Distribution Centre) is in the middle of the layout, while the second layout has very different distances, starting from the nearest node A to the furthest one (H). Figure 4.4 summarizes the plan.

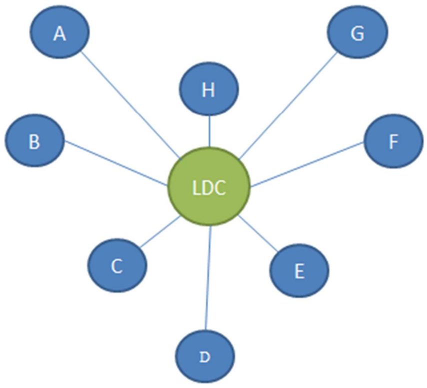


Figure 4.3: Centred layout (A_G)

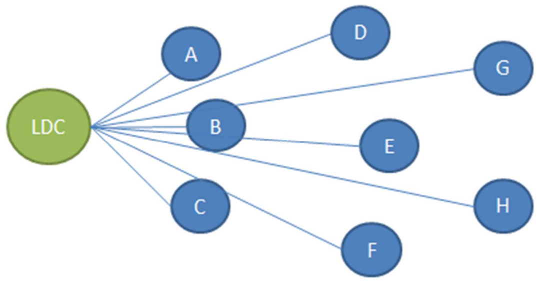


Figure 4.4: Decentred layout (A_G2)

The hypothesis is a constant demand during the entire time window. The demand pattern considered in the application and applied to the different layouts is:

A(1000)-B(2000)-C(4000)-D(5000)-E(3000)-F(2000)-G(1000)-H(4000)

The letter is the name of the node while the quantity of the population needs is between brackets.

Every beginning of the day, demand is the same; this is the case with perishable food that needs to be refilled every day. Moreover, no inventory is possible at the demand points.

Table 4.1: Centred layout and decentred layout distances [min]

	LDC	A	B	C	D	E	F	G	H
LDC	0	30	32	29	50	55	60	80	95
A	30	0	30	65	70	80	97	95	120
B	32	30	0	38	42	45	65	73	92
C	29	65	38	0	53	29	31	77	80
D	50	70	42	53	0	36	56	32	52
E	55	80	45	29	36	0	29	37	43
F	60	97	65	31	56	29	0	53	22
G	80	95	73	77	32	37	53	0	41
H	95	120	92	80	52	43	22	41	0

	LDC	A	B	C	D	E	F	G	H
LDC	0	30	32	29	55	60	62	78	82
A	30	0	50	53	72	68	32	76	32
B	32	50	0	65	58	34	72	78	72
C	29	53	65	0	54	86	42	31	81
D	55	72	58	54	0	72	83	39	72
E	60	68	34	86	72	0	73	87	43
F	62	32	72	42	83	73	0	68	55
G	78	76	78	31	39	87	68	0	92
H	82	32	72	81	72	43	55	92	0

4.4.2. Maximum available capacity regions

One important step is the definition of the capacity. The maximum available capacity considered in the models is calculated as the percentage of the items delivered on the items required, optimizing just the logistic costs. The results of the heuristics are shown in function of the maximum available capacity. This choice has been made since in humanitarian operations one of the main issues organizations have to deal with is the presence of scarce resources, which do not allow satisfying completely the demand present in the area hit by the disaster. In this particular application the range of capacities considered is from 500 to 3000 items per vehicle, with an increase of 100 after every loop.

4.5. Results

The first results obtained are associated with the application of the first heuristic, so the consideration of just social costs during the prioritization of the shipments. These results are summarized in the two graphics below (figure 4.5), where the x-axis is the maximum available capacity level, while the y-axis is the cost associated with the maximum available capacity.

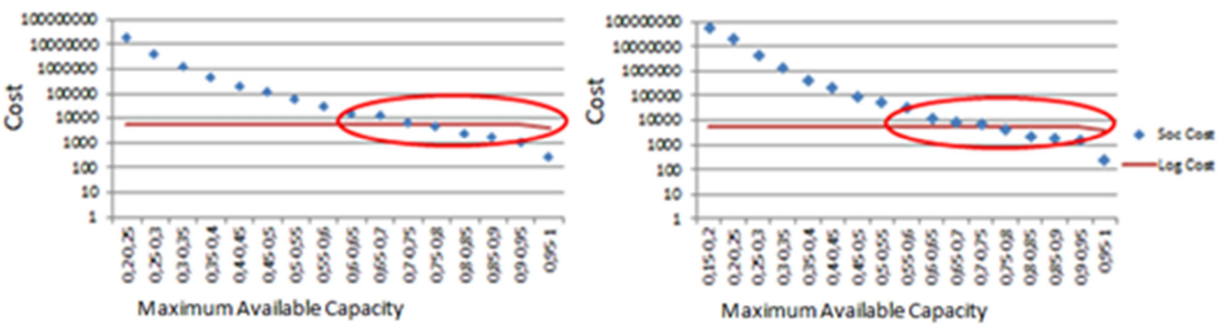


Figure 4.5: Application of the first heuristic. Scenario A_G and Scenario A_G2.

The results of the first heuristic application show how in some "capacity regions" the logistic costs have a certain weight that leads to their consideration during the distribution process. This intermediate region seems to be between 65% and 100% of the necessary capacity, where 100% is the needed capacity to deliver in one day. This result leads to reconsider the assumption of no-logistic costs contemplation.

The second heuristic is presented in order to study how the two different costs, deprivation and logistic, have to be considered. The heuristic is applied in the two different layouts, with different levels of available maximum capacity and different "$\propto$". Table 4.2 reports the average saving that is possible to obtain using the Optimal Alfa rather than other values resulting from all other Alfa. This value has been found taking the results of the heuristic per each level of capacity and per each level of Alfa, after this the author has taken the values of Alfa with the minimum total final cost.

Table 4.2: SAVING between the Total Social Cost with the Optimum Alfa and the Average Total Social Cost for relative Maximum Available Capacity.

	SAVING	
Maximum Available Capacity	Scenario A_G	Scenario A_G2
< 65%	-	-
65% - 70%	31.4%	34.6%
70% - 75%	40.3%	18.6%
75% - 80%	24.2%	4.6%
80% - 85%	2.7%	10.6%
85% - 90%	1.4%	1.2%
90% - 95%	0.4%	0.5%
95% - 100%	2.0%	0.9%
> 100%	-	-

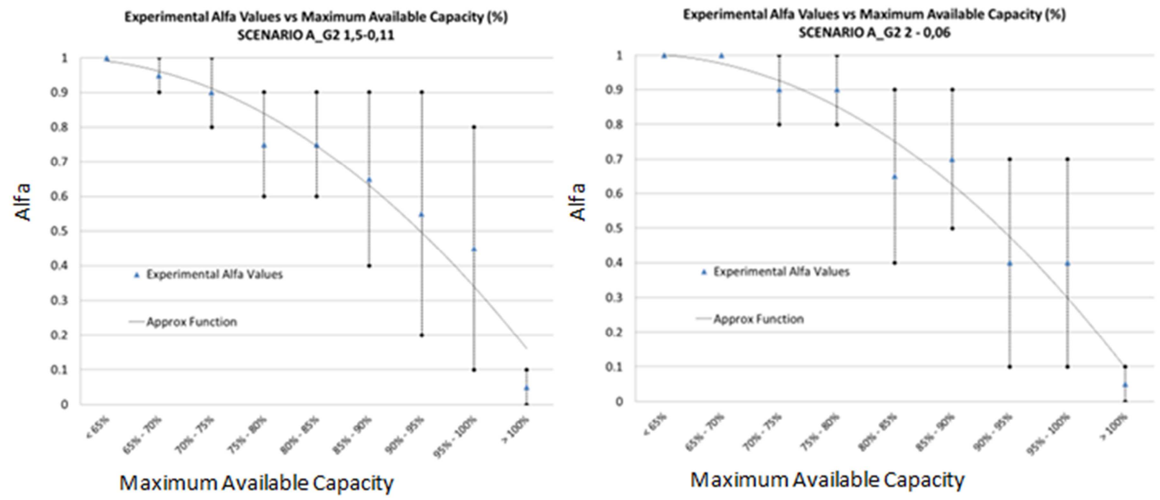


Figure 4.6: Trend of Alfa ("∝") in function of the available capacity

Figure 4.6 shows the trend associated with "∝" (y-axis) in function of the available capacity (x-axis). In the graphics "∝" approximation function is found to be the interpolation of the experimental "∝" values averages. The experimental "∝" values are the values that lead the minimum social cost obtained with certain capacity. This trend underlines the relationship between the deprivation and the logistic costs during the items distribution operation. The results show the importance of deprivation costs in situations where the available capacity is low. When the maximum available capacity is higher, it is better to use an integrated approach where both of the costs are considered.

4.6. Parametrical analysis

In this section, an analysis is carried out on what happens if the exponential function changes, whether it is different from the one proposed by the literature (Holguìn-Veras et al. 2013). In particular, the function considered is the one below with parameters of C and D.

$$f(\delta_{it}) = e^{(C+D*\delta_{it})} - e^{C}$$

With

$$C \ = \ 0.5 - 1 - 1.5$$

$$D \ = 0.01 - 0.05 - 0.09 - 0.13 - 0.17 - 0.21$$

These numerical values have been chosen in relation to the exponential function taken by the literature (Holguìn-Veras et al., 2013). In fact, the author has proposed some values estimated with "data collected about willingness to pay for water". For this reason, the numerical examples have been calibrated on hypothetical items that can have different exponential deprivation functions, but always in the range of the one proposed by the literature. The logistic cost remains the one proposed by Holguin-Veras and Brom (2008), 55 $/h.

The results obtained are summarized in the figures below (figure 4.7), where the x-axis is the Optimal Alfa associated with the maximum available capacity (y-axis). In this figure, the non-linear behavior of "$\propto$" is shown. From the different graphs, it is possible to note how the heuristic gives more importance to the exponential deprivation functions ("$\propto$" →1) instead of the linear logistic ("$\propto -1$" →0) cost when the maximum available capacity is low. This is because the deprivation functions tend to increase more rapidly. On the other hand when the maximum available capacity increases, more importance is always given to the logistic cost as long as the maximum available capacity is higher than 100%. These results are the same for different function. Indeed, they change along with the change of the supplied product and so the exponential function associated with the item. In particular, the results have a high variation when the value D (the one associated with time) varies. If the item is more critical the exponential function associated with it will rear up more quickly. This will lead the heuristic to consider more the deprivation cost than logistic cost with a higher Alfa.

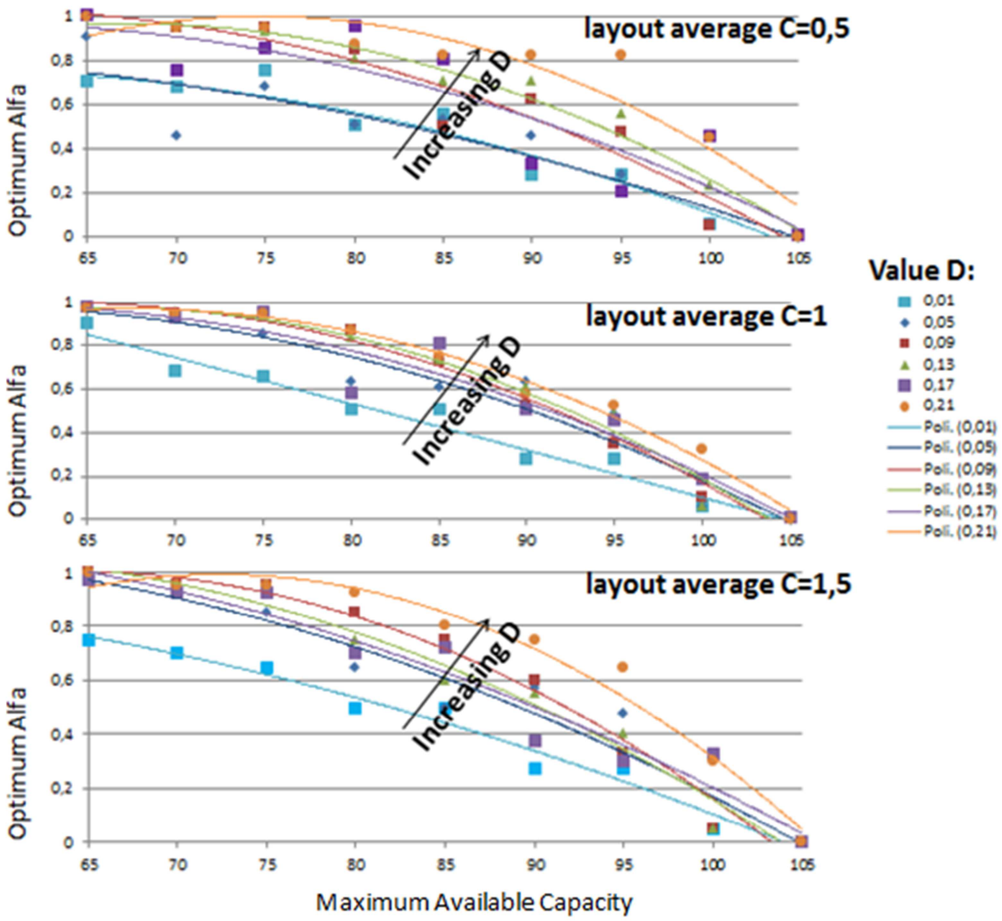


Figure 4.7: Optimal Alfa changes with different deprivation functions

4.7. Discussion of results

As demonstrated by the results, in particular figure 4.5, the performances of the heuristics depends mainly on the maximum available level of capacity. In particular, the results show this relationship. For high levels of available capacity the "∝" is low, so high importance is given to logistic costs. On the other hand, when available capacity decreases, the deprivation costs start to have greater importance ("∝" is closer to 1). The graphics in figure 4.6 show the non-linear trend of "∝" according to the integration of exponential and linear functions associated with deprivation and logistic costs. This result leads to consider the two costs differently in order to obtain a good final result in terms of deprivation and logistics efforts.

The results have been tested with different deprivation functions, in the "parametric analysis" section, changing C and D values, where C is the independent value of the exponential function, while D depends on the time variable. The achieved goal shows the importance of considering different ratios between the deprivation and social cost in function not only of the maximum available capacity (that remains a fundamental value), but also considering the item that is in the delivery, and so its deprivation function characteristics (figure 4.7).

Since the outcomes of the heuristics have underlined that the optimum "∝" is mainly determined by the D value, the one linked to the time, rather than the C value, the author has focused the study on D, which has a higher impact in the results. This is demonstrated by the graphics in figure 4.7, where the "∝" curves are similar for different C, while they change mainly with D. The logistic costs have not been changed in the examples, but the heuristics can be easily used even for different transportation vectors, as helicopters or trucks, which can have dissimilar K constant but with similar linear behavior.

In the study the different results have been obtained from hypothetical deprivation functions. These can be improved for real applications. In fact, when some other real product deprivation function is provided, it will be easy to find the "∝" curves and so apply the heuristics in other real product distribution. This is very important because once the humanitarian organizations have some data (demand points and amount, maximum available capacity and costs associated with the deprivation of the needed product and the distribution) they can upload the optimal "∝" and use the heuristics in order to achieve a good final level of social costs.

The correct "∝" allows saving in terms of costs and items deprivation. According to Stapleton et al. (2009), "the potential saving from implementing operations research models can be used in improving the social welfare of populations need." Therefore, a minimization of social costs can lead to minimizing human suffering and loss of lives, the goals of a humanitarian operation (Balcik and al., 2008).

From the first heuristic application, studying the social costs in function of the maximum available capacity, a particular region, called the "middle region", is identified, where deprivation and social costs have the same order of magnitude. In order to deal with this region the second heuristic is introduced, in which the prioritization is calculated considering the global social costs, both logistic and deprivation. Furthermore, a smoothing parameter "∝" is presented in order to understand, studying the final total cost, which should be the relationship between the two costs in function of the available level of capacity. Finally, the parameter "∝" is studied with diverse deprivation costs in order to determine how its behaviour changes in function of the different exponential values.

Generally, the saving obtained using the correct "∝"value for different maximum available capacity levels demonstrates the added value of this research for the humanitarian field. Moreover, the non-linear behaviour of the "∝" jointly with the diverse results obtained applying different functions helps understand how costs have to be considered with different products in real distribution, as a function of some factors (e.g. capacity and demand). These results could be improved using real deprivation functions. Indeed, once the parameters "$\propto$" are found for real products, they could be proposed to organisations that work in the field in order to achieve a good final level of social costs and the best ratio between deprivation and logistics costs during distribution.

The limitations of these heuristics are mainly associated with their simplicity. The author has considered just one delivered item and one vehicle. The restriction of a single item can be easily relaxed. Demand points can be split into two or more points with different deprivation functions and demands to consider two or more items with the same location. On the other hand, when more vehicles are involved in the aids distribution operations, they can be added to the heuristics process every time the previous vehicle is fully scheduled for the entire day.

This approach can be simplistic but also used jointly with other approaches like the generalized assignment problem (GAP) (Fisher and Jaikumar, 1981). In fact, once the network is defined and divided into different areas in which one vehicle will deliver, this allows simplifying the problem and using the proposed heuristic.

5. Reverse Flows in Humanitarian Operations

Humanitarian logistics (HL) is a fast growing area of international academic study with a broadening literature base and, since 2011, its dedicated outlet – the Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM). However, in common with many other emerging academic disciplines, the early years reflect the need to develop a common understanding of the core concepts, their inter-relationships and, indeed, the vocabulary and its meanings. For example, at a basic level, the challenge facing the humanitarian logistician is, arguably, the same as that in the 'for profit' world namely to align supply with demand in an efficient, effective, secure, resilient and sustainable way (Melnyk et al., 2010). Typically, however, the responsibilities of a humanitarian logistician cover the management of the whole of the supply network (purchasing through to last mile distribution), together with a range of ancillary duties such as facilities management and security. It is, thus, significantly more complex than the oversight of 'trucks and sheds' that often reflects the commercial perspective of this role (Kovács et al., 2012).

This breadth of responsibility is reflected in the frequently quoted definition of HL: "The process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements." (Thomas and Mizushima, 2005, p. 60). Indeed, it is worth reflecting that there are actually only a few thousand individuals world-wide who would lay claim to the job title of 'humanitarian logistician' (Holguín-Veras et al., 2012), and yet the annual global spend is of the order of $15Bn (Tatham and Pettit, 2010).

Importantly, however, the definition of HL quoted above only relates to the outbound flow of goods, its associated information and, by extension, services-. It will be noted that it is silent on the topic of 'reverse logistics' (RL) which, as I will expand on later, I define as: "The process of planning, implementing and controlling the efficient and cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal." (Rogers and Tibben-Lembke,1999, p. 2). This lacuna is understandable given the HL context in which the major challenge is perceived to be the effective and efficient movement of potentially lifesaving materials to those affected by a disaster or emergency, or in a developmental context (Tomasini and Van Wassenhove, 2004).

That said, there is an increasing appreciation of the importance of RL as evidenced by its appearance as a specific section within the United Nations (UN) Logistics Cluster (Log Cluster) Logistics Operational (Log Ops) Guide (Log Cluster, 2013). Moreover, it is well established that the introduction within commercial supply chains of RL best practices results in economic savings in addition to reductions of environmental impact. It is suggested, therefore, that adoption of such an approach in the humanitarian context would lead to improvements in efficiency that could then be translated into improved effectiveness of an aid agency's logistic spend.

5.1. Aim

With this introduction in mind, approximately 10 years ago, De Vore (2004, p. 6) noted that "often the reverse supply chain is overlooked, not planned for, and not used when deploying for ... humanitarian relief operations". However, as outlined above, the last decade has seen the visibility and importance of RL issues increasing in a commercial context and so the author of this research were keen to understand whether this situation has been mirrored in the changed practices in relation to HL during the intervening period. Thus, the aim of this chapter is to describe and analyse the challenges and opportunities for the application of reverse logistics practices in a humanitarian logistic context. In doing so, and particularly in light of the relative youth of HL as a field of study, the author is mindful of Stock's (1997) recommendation that business logistics, which was then in a similarly emergent state, should 'borrow' from other disciplines as a means of advancing knowledge and understanding.

5.2. Research Limitation

A further aspect of the essential scene-setting is the observation that HL frequently focuses on the ways in which the management of the supply network can be improved in a rapid onset disaster or emergency. In such a scenario, where speed is frequently the essence, it is understandable – and, indeed ethically acceptable – that actions that might improve the RL outcomes take second place, particularly if such actions have the effect of reducing the speed of response and, hence, adversely impacting those affected. However this research will particularly focus on the development context where a more measured approach is possible with the result that RL practices can potentially be embedded as part of the whole flow of goods and materials. As a result issues such as those raised by Destro and Holguín-Veras (2011) and Holguín-Veras, et al. (2014) which relate to the management of unsolicited donations that frequently challenge the logistician in the aftermath of a rapid onset event will not be considered in depth.

I intend, therefore, meeting the chapter's aim by outlining the ways in which RL is operationalised in the business context and analyzing the challenges and opportunities for employing similar practices in the preparation and response in a development context as well as to disasters/emergencies – especially those that fall into the slow onset category. To achieve this goal, the next sections of the thesis will first give an overview of the research methodology before the results of the review the literature relating to RL first in a business and, secondly, in an HL context are discussed. This latter analysis is underpinned by the results of informal discussion with HL practitioners in order to test their understanding of commercial RL concepts and their applicability. This will be followed by a section in which I develop an understanding of the challenges and opportunities for RL as part of the overall HL spectrum of activities. Finally, I will offer my view of the potential avenues for further research in relation to this topic.

5.3. Methodology

The overall research methodology is outlined below and depicted in figure 5.1 where 4 steps are highlighted, with the detailed procedures being explained in next sections. The initial step was to review the literature relating to RL within a commercial context. The rationale for this approach reflects the general perception that HL lags behind its commercial counterpart in terms of the development and implementation of new approaches and ideas. Whilst it was argued by Thomas and Kopczak (2005, p. 7) that "Today's underdeveloped state of logistics in the humanitarian sector is much like corporate logistics was 20 years ago", the author of this thesis takes a less pessimistic view evidenced by, for example, the 2006 European Supply Chain Excellence Award that was won by the International Federation of Red Cross and Red Crescent Societies (IFRC). Nevertheless, it is believed (and as will be demonstrated in the literature review that follows) that the commercial sector, driven by public and shareholder pressure, is ahead of the humanitarian sector in respect of its RL practices.

Figure 5.1: Methodology and steps of the research

Having analysed the commercial RL literature, the second step was to undertake a similar review of the humanitarian logistics literature. However, as indicated in the introduction of the chapter, the canon of literature is relatively small – for example the recent review by Leiras et al. (2014) identified just 228 papers that had been published in the last 20 years.

As a result, in step 3, this element of the review was expanded to include consideration of the annual reports of the Top 14 HL organisations extracted from Tatham and Pettit (2010, Table 5.1). Given the clear desire of humanitarian agencies to 'do no harm' it was reasoned that achievements in improved RL practice would be highlighted as a positive aspect of their work in such publications. However, as will be explained in greater detail below (Section 6), there was only limited mention of the subject and therefore a confirmatory 'deep dive' was undertaken by reviewing all of the IFRC's post-mission reports for the period January 2011-November 2013. The choice of the IFRC for this more detailed analysis was driven by a number of factors: Firstly, as indicated above, through its receipt of the European Supply Chain Excellence Award, the IFRC has clear credentials as being amongst the most innovative HL organisations within the sector. Secondly, it deals mainly in non-food items (NFI) and it is this generic range of commodities that (compared with food and medical items) is perceived to be most easily integrated into a reverse supply chain. Thirdly, the IFRC makes all of its post-mission reports available on its web site and thus, in a sector where access to data is often challenging, this represents an excellent source that was able to be searched in the same way as the academic literature relating to the commercial sector. The final stage of the review process was to undertake a number of informal discussions over the general challenge of achieving sound RL practices with a number of senior humanitarian logisticians in UK and Australia. This element of the overall research is discussed in more detail in later sections.

In the final phase, step 4, the RL challenges and opportunities were defined and analysed introducing a new classification of the items in function of their use and final destination. Several drivers and factors were highlighted and discussed.

5.4. Review of the Reverse Logistics in the Academic Literature

5.4.1. Academic Reverse Logistics literature in the "for profit" context

There is a broad swathe of literature relating to RL that has been developed over the last two decades and, inevitably, this approaches the concept from a variety of perspectives. Thus, at the relatively strategic level, Rogers and Tibben-Lembke (2001, p. 133) outline the scope of RL drawing on the then extant literature that encompassed a range of activities including:

- Remanufacturing,
- Refurbishing,
- Recycling,
- Landfill,
- Repackaging,
- Returns processing,
- Salvage.

These authors also noted that there is a clear overlap between the research in to RL and the (even) broader field of 'Green Logistics' as demonstrated in Figure 5.2.

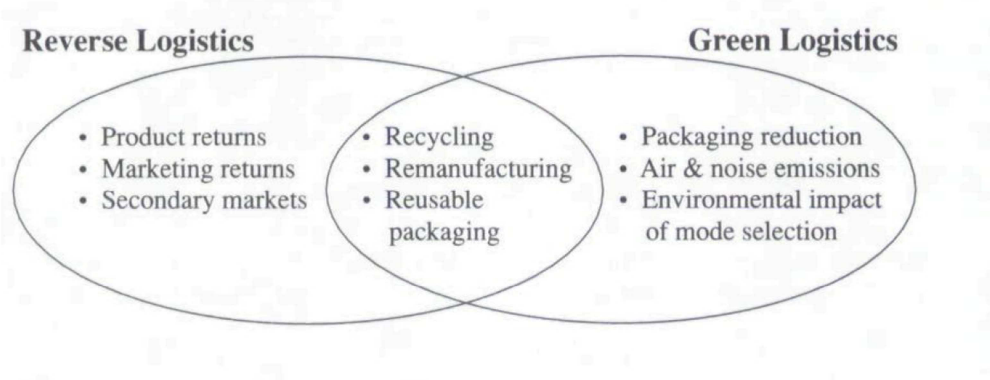


Figure 5.2: Comparison of Reverse and Green Logistics (Rogers and Tibben-Lembke, 2001, p. 131)

This overlap between these two areas is also found within the limited literature relating to RL in an HL context where, for example, the UN's Log Ops Guide has a separate section relating to Green Logistics, but in this it is noted that: "The main objective of Green Logistics is to coordinate the activities within a supply chain in such a way that beneficiary needs are met at "least cost" to the environment. *It is a principle component of reverse logistics*." (Log Cluster, 2013a) (Emphasis added). The above quote reflects the general sense of the desire amongst humanitarian agencies to 'do no harm' – be this to individuals or, as is becoming increasingly important, the environment in which they are operating. However, the research reported in this chapter is focussed on the RL component of the overall drive towards a more eco-friendly approach as it is believed that the use of commercial RL techniques has the potential to improve the efficiency and effectiveness of a humanitarian agency's actions in a development/slow onset situation (as well as, potentially, in a rapid onset disaster context). In doing so, I am following the lead of a number of authors including Kovács and Spens (2007) and Swanson and Smith (2013) who suggest that the humanitarian response can benefit from lessons identified and best practice in commercial logistics.

Separately, Tibben-Lembke and Rogers (2002) compared and contrasted the forward and reverse logistic practices in a retail environment; whilst other authors have considered a more detailed sub-set of the overall RL challenge. Thus, Atasu and Cetinkaya (2006) discuss the ways in which the process can be optimised in order to allow for efficient remanufacturing, whilst Blackburn *et al*. (2004) consider the issues surrounding the decision to adopt reuse, recycling and remanufacturing alternatives for a given product. Other significant contributions include Fleischmann *et al*. (1997), Bloemhof-Ruwaard *et al*. (1999) and Lee *et al*. (2008) who focus on channels, location, routing problems; whilst Teunter *et al*. (2000), Minner (2001) and Dobos (2003) discuss the impact of RL on inventory through the study of costs, products and policies. In considering the opportunity to reuse the returned product “as is” or after minor repairs Srivastava (2007, 2008) researches yet another dimension of the RL concept; whilst Hazen *et al*. (2012) have identified seven components that should be considered when deciding which RL approach to adopt, together with a decision making framework.

Given the ambit of the potential RL field that can be deduced from the above small sample of the literature, it is clear that core to understanding it applicability in an HL context is both a definition of RL and the consequential potential activities that are in scope. In light of the genesis of the definition of HL quoted in Section 1 which clearly reflects the former Council of Logistics Management Professionals (CLMP) (and current Council of Supply Chain Management Professionals (CSCMP)) definition of logistics, I have adopted the approach of Rogers and Tibben-Lembke (1999, p. 2) who reverse the sense of the CLMP/CSCMP approach and define RL as: “The process of planning, implementing and controlling the efficient and cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal.” In adopting this definition, I note that it is broadly similar to others suggested by those researching within the field, for example Dowlatshahi (2000), and De Britos (2003).

Expanding this definition, it can be seen that it covers a broad range of activities as demonstrated by Rogers and Tibben-Lembke (2001, p. 133) in Table 5.1.

Table 5.1: Reverse Logistics Activities by Rogers and Tibben-Lembke (2001, p. 133)

Material	Reverse Logistics Activities
Products	Return to supplier Resell Sell via outlet Salvage Recondition Refurbish Remanufacture Reclaim materials Recycle Donate Landfill
Packaging	Reuse Refurbish Reclaim materials Recycle Salvage Landfill

A similar approach is offered by other authors, for example the flow diagram representation of Farahani *et al*. (2011) in figure 5.2 – albeit this does not differentiate between the product and its associated packaging. However, in the HL context, discussion of RL as it relates to packaging is perceived to be an important aspect. For example, as will be discussed further in Section 8.4, it is understood that one commercial supplier has designed the box used to transport large (family size) tents in such a way that it can subsequently be employed as the framework for a field latrine. For this reason, the typology in table 5.1 will be used as the basis for the analysis in the remainder of this chapter and, for example, the entries within table 5.1 were used as the keywords for the search of the academic and practitioner HL literature.

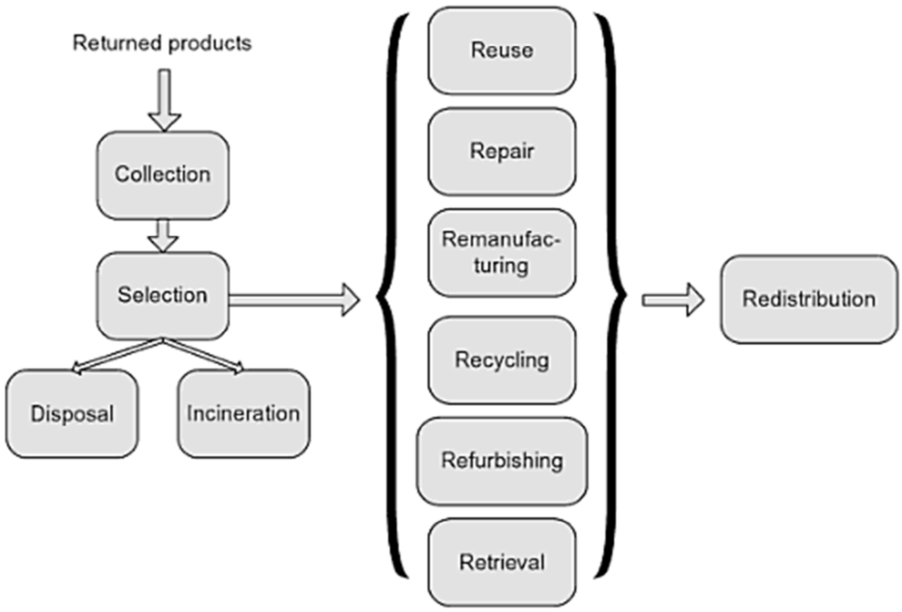


Figure 5.2: Product flow in reverse logistics (Farahani *et al*., 2011)

5.4.2. Academic Reverse Logistics literature in the "not for profit" context

In relation to the academic literature, and as noted in the introduction to this chapter, this is relatively small in volume. For example, the review by Kunz and Reiner (2012) uncovered a total 174 papers published between 1993 and 2011, of which 128 (74%) were from the last three years of their sample. This research, together with the associated literature reviews from Altay and Green (2006), Kovács and Spens (2007), Natarajathinam *et al*. (2009), Pettit and Beresford (2009), Overstreet *et al*. (2011), and Caunhye *et al*. (2012), were analysed to uncover any discussion of RL (as defined in table 5.1). This was achieved by inspection of the title, abstract and keywords of each of the papers within the sets of literature reviews, together with the titles of works noted within the informal bibliography of Tatham (2014). The result of this review shows that the management of RL in an HL context has only achieved limited attention in the academic literature.

Whilst a number of researchers (e.g. Guide *et al*., 2003; Dekker *et* al., 2004; De Vore, 2004; Hall, 2013) suggest that RL should be incorporated into the HL supply network, these authors are silent as to the mechanisms/approaches that should be adopted. On the other hand, there are some specific examples of a discussion of RL issues, albeit these are generally from a relative broad 'green logistics' perspective. Thus, Sarkis *et al*. (2012, p. 199) underline the general importance of an environmental perspective in the evolution of the humanitarian response in order to meet "a variety of pressures faced by the [responding] organization including regulatory, competitive, and community/public pressures". However Sarkis *et al*.

(2012, p. 205) also note that there are considerable internal organisational barriers that limit the application of new practices and procedures, but these authors underline the importance of future studies "to overcome the barriers and hopefully aid in greening the relief supply chains".

This paucity of consideration of RL is further emphasised by Kovács (2011, p. 258) who notes the serious environmental impact of humanitarian activities in the field and particularly that "... there is an almost total absence of reverse logistic processes". Indeed, taking this environmental theme further, researchers at INSEAD (Humanitarian Research Group, 2010) have analysed the impact of the humanitarian response in the aftermath of the 2010 Haiti earthquake, and their work underlines the enormous volume material that needs to be removed and the associated challenge facing the humanitarian logistician. The importance of green logistics in humanitarian operations is also presented by Eng-Larsson and Vega (2011) where the difficulty of achieving environmental goals without compromising the short-terms humanitarian objectives is studied. Since the humanitarian operations inevitably generate substantial amounts of waste, the research underlines the importance of adopting a green operations perspective. However, Larsson and Vega fully acknowledge that there are some clear gaps between green logistics practices and disaster relief operations, and as a result that have developed a framework of objectives that could be used to drive humanitarian actions.

Taking a somewhat different approach, Hua and Sheu (2013) develop a system that considers three different RL aspects: logistic operations, environmental protection and psychological recovery, and they propose a system that models the transport, recycling, reproduction and final disposal of debris. In a similar transport-related approach, Liberatore *et al*. (2014) consider the possibility of using some RL procedures (such as reverse flows) in the modelling of distribution problems in recovery operations.

In summary, the academic literature surrounding the potential operation of commercial RL practices is in its infancy. Thus, although there is a clear acknowledgement of the importance and relevance of this topic, but there is almost zero discussion of its operationalization.

5.5. Review of the Reverse Logistics in Non-Academic Literature and Informal Interviews

5.5.1. Annual reports review

The next element of the literature review was to consider the non-academic literature – i.e. that which is available from the publications and web-sites of humanitarian organisations (as distinct from regular academic journals). This was approached by examining the material available from the Top 14 HL organisations as noted by Tatham and Pettit (2010, table 1, p. 611). The annual reports are general documents that show not just what has been done in the last year by the organization but they are used to indicate the way the organization is going to take in the future years. The most recent annual reports (i.e. those from 2011 or 2012 – Care 2012, Crs 2012, Ifrc-rcs 2011, Msf 2011, Ocha 2012, Oxfam 2012, Save the children 2011, Undp 2012, Unfpa 2011, Unhcr 2012, Unicef 2011, Who 2012, Wfp 2011, World vision 2012) of each of these organisations were reviewed using the key words from table 5.1 as the search criteria, with the results as shown in table 5.2. In selecting the annual reports as the source, it will be recognised that they are both easily accessible and also provide a vehicle through which the organisation is able to tell its story to the wider community. Thus, such annual reports are not just focused on field operations; rather they typically expose the future direction of the organisation. It was therefore reasoned that, particularly in light of the global desire of such organisations to operate more sustainably, if RL was becoming an important feature of future operations, it was likely to be emphasised in such annual reports. However, as will be see from table 5.2, the reality is that there was almost no discussion of RL within these documents. In fact findings show that just few annual reports deal with RL practices with a focus mostly on recycling and the management of donations – which can be seen as a form of RL from the perspective of the original owner of the item - with just limited attention on landfill and reuse.

Table 2: Annual reports finding

Material	**Reverse Logistics Activities**	**UNICEF**	**WFP**	**UNHCR**	**WHO**	**UNDP**	**UNPF**	**OCHA**	**VWI**	**STC**	**CARE**	**CRS**	**MSF**	**Oxfam**	**IFRC-RCS**
Products	Return to supplier														
	Resell														
	Sell via outlet														
	Salvage														
	Recondition														
	Refurbish														
	Remanufacture														
	Reclaim materials														
	Recycl*											5		5	
	Donat*	1	1				1	1	5		2	8	14	2	7
	Landfill											1		1	
Packaging	Reuse													1	
	Refurbish														
	Reclaim materials														
	Recycl*														
	Salvage														
	Landfill														

5.5.2. Review of IFRC field reports

Given the paucity of 'hits' from the above process, a 'deep dive' was undertaken by reviewing all of the post-mission reports held on the International Federation of Red Cross and Red Crescent Societies (IFRC) data base for a three year period January 2011 to November 2013. This process led to an examination of 116 such reports which were, again, searched using the keywords from table 5.1. These reports are focused on single operations that are conducted by IFRC in different part of the world. The information is possible to have from these are more operational that in the annual reports and allow to understand what kind of practices are used in the operational fields.

Of the original number, 15 were not published in English and so were discounted from the analysis. And of the remainder, 75 (74%) had zero mention of RL. A total of 26 reports did include mention of the topic, and these are shown in table 5.3, with the specific details of the report to be found in table 5.6.

The advantage of the 'deep dive' approach was that it was targeted at the more operational level mission reports, as distinct from the strategic level annual reports, however it will be seen that the results were broadly the same as the latter (table 5.1), with the majority of the discussion being around the area of donations and re-cycling. At the same time the on-field reports do emphasise some other reverse logistics activities such as salvage, reselling and returning items to suppliers.

Table 5.3: on-field reports finding

Material	Reverse Logistics Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Total
Products	**Return to supplier**																					3						**3**
	Resell											1		1								3						**5**
	Sell via outlet																											**0**
	Salvage	2														1	2											**5**
	Recondition																											**0**
	Refurbish																											**0**
	Remanufacture																											**0**
	Reclaim materials																											**0**
	Recycle			1					1		24	10	4	2				2										**44**
	Donate		4		73	7		2	2	11				2	13				5	29	1		15	9	3	1	2	**179**
	Landfill						1				4																	**5**
Packaging	**Reuse**			1							3		1	2														**7**
	Refurbish																											**0**
	Reclaim materials																											**0**
	Recycle																											**0**
	Salvage																											**0**
	Landfill																											**0**

5.6. Informal interviews

The third part of the analysis was aimed at corroborating the results of phases 1 and 2 (figure 5.1) by conducting informal discussions with a small number of senior humanitarian logisticians based in the UK and Australia in order to understand their personal perspective, and their perception of the perspective of their organisation. The respondents were selected through a 'snowball' sampling approach that utilised the network of contacts already known to the author of this thesis and consisted of a total of 6 individuals – five from international NGOs and 1 from a UN agency.

The discussions were conducted on a semi-structured basis using the following script as the guide:

1. What does the concept of 'Reverse Logistics' mean to you?
2. To what extent is this perspective shared by your organisation?
3. More broadly, how do think the Reverse Logistics concept could be implemented into humanitarian operations:
    a. In the context of rapid onset disasters?
    b. In the context of slow onset disasters/development activities?
4. Are there any specific commodities to which reverse logistics can particularly be applied?
5. To the extent that the organisation does engage in reverse logistics, is this carried out in house, or is it outsourced?
6. Does the organization engage in any recycling practices? If so, to what commodities does this apply and how is it undertaken?

The responses from this small sample supported the findings from the literature review. For example, the head of logistics for a major international NGO indicated that "they did not engage in any form of RL". Similarly, whilst the head of logistics for another major international NGO fully accepted that RL was an area on which his organisation needs to focus in the future, "it was not currently on their agenda". In particular, he emphasised the division of responsibility between the programmes and logistics teams, with the role of the latter being that of meeting the former's requirements as efficiently and effectively as possible. Thus, he indicated that it would be for the relevant programme's team to make create a requirement for the movement of items out of the affected area, he noted that in his experience, this had yet to happen.

A further observation from the head of logistics for another NGO was that, in effect, they treated items brought into the country as donations to the affected population and, hence, they did not make any specific arrangements for their subsequent re-use etc as this was a matter for those who had received the donations. A further challenge highlighted was the need to comply with the importation regulations with a given country. For example, these might allow NGOs to bring items into a country free of any import duties, but that these might be levied retrospectively if material was subsequently ‘exported’.

In summary, it will be seen from the above analysis of the literature that, whilst RL is recognised as a process that should, in an ideal world, form part of the HL preparation and response to a disaster/complex emergency, in reality it has received little attention in either the academic or practitioner literature and, indeed, amongst the small sample of practitioners with whom this subject was discussed. With this in mind, the next section of the thesis will consider the various activities that are in scope (figure 5.2), and the ways in which they might be operationalised by humanitarian logisticians.

5.7. Humanitarian Reverse Logistic Challenges and Opportunities

In considering the potential for RL in an HL context, it is relevant to recognise that there is a broad spectrum of materiel that is procured, transported and distributed by the humanitarian logistician. This is generally categorised as:

a. Food Items (FI). Items such as rice, flour, nutrition bars, etc.

b. Non-Food Items (NFI). Items such as tents, blankets, tarpaulins, etc.

c. Medical Items (MI). Items such as drugs and medical equipment.

to which, in this context, should be added an additional category of:

d. Agency Owned Items (AOI). Items such as trucks and radios that belong to the responding agency.

Whilst in theory, all of the approaches to RL offered in table 5.1 could be applied to each of the above categories, a brief reflection on the reality HL and its current maturity would clearly indicate that not all of the commercial concepts are applicable. In particular, it is important to distinguish between (a) those items that have not been used, (b) those that have been used and (c) packaging. Whilst each of these categories has a potential residual value, table 5.4 offers an overview of the areas where the opportunities for the use of RL would appear to be most favourable. It will be noted that noting that this table broadly aligns with the extent to which RL is discussed in the academic and practitioner literature.

Table 5.4: RL practices applicable in Humanitarian field

Type of Items	Practices
Items that have not been used:	Return up the supply chain
	Donate
Items that have been used:	Re-use
	Refurbish/Recondition
	Salvage/Recycle
	Donate
	Landfill
Packaging:	Re-use
	Landfill
	Recycle

The challenges and opportunities will now be discussed, first in relation to a number of general issues, and then using the categorisation within Column 1 of table5. 4.

5.7.1. General Challenges and Opportunities

As indicated in the earlier part of this chapter, the whole area of RL in a humanitarian context has yet to achieve the traction that it is increasingly enjoying in the 'for profit' environment. In a sense, this is entirely understandable. Given the absence of a profit motive (and associated shareholder pressure) to drive behaviour, and also in the face of a challenging funding situation that has worsened since the Global Financial Crisis, it is clearly difficult for aid agencies to justify the expenditure of the additional resources that would be necessary to manage RL operations over and above the demands of the life-saving outbound network. Put simply, the current view is that the scarce resources that are available would be better spent on disaster relief.

However there are many opportunities for the application of RL practices in this field. At one level improved management of the supply chain, and the associated improved matching of demand and supply, would help ensure that the right products are, indeed, delivered to the right place at the right time. In doing so, wastage – and hence the need to even consider the RL challenge would be – avoided (as would the impact of under-provision). One example might be the use of 3D printing technologies that have the potential to deliver ‘logistics postponement’ – in other words the manufacture of a item of equipment only when the demand has crystallised. However, discussion of ways in which the outbound supply network could be improved is beyond the scope of this research. Furthermore the broader application of “green thinking”, be this in the guise of improved vehicle operation, improved procurement practices of the substitution of information for inventory are also beyond the scope of this chapter which is focussed on ways the generic practices outlined in table 5.1 and, in particular, the sub-set in table 5.4.

That said, and reflecting on the suggestion that agencies feel that scarse resources are best spent on direct developmental and/or disaster response activities, it is arguably the donor mindset that needs to change – be this institutional or governmental donors, or members of the general public. In other words, until and unless the imperative to operate in a more sustainable way becomes part of the ‘normal way of doing business’, it is clear that agencies will struggle in the development and/or operation of similar reverse logistics approaches that are increasingly found in the commercial context. In reflecting on this challenge, it will also be appreciated that the cost of implementing a broad range of RL policies does (in the same way as for the outbound leg), not just consist of the transport and storage costs, but also those related to the management of the associated information. These costs are unlikely to be trivial given both the challenging nature of the physical environment (for example, the potential damage to pre-existing communications infrastructure), but will also reflect the time lag between the supply of a given item or commodity and any decision to return any surplus back up the supply network.

5.7.2. Items that have not been used

Turning to the groupings in table 5.4, items that have not been used for the designated or planned project can potentially be made available in two different ways. Firstly, they could be shipped back up the supply chain to, for example, a warehouse in the affected country, to a regional warehouse, or even to the supplier. Alternatively, they could be donated to the affected country. The main drivers for the choice of action in this scenario would appear to be (a) the item’s residual value; and (b) the cost of returning the item back up the supply chain. In this respect, the determination of ‘cost’ would include both the actual expenditure involved in the process of taking an item back up the supply chain, as well as softer aspects such as the potential for adverse publicity if unwanted items are left in the country.

However, there will also be a number of other factors that may influence such a decision. For example, the government of an affected country may be more than happy to waive any import taxes for incoming relief goods, but it is understood that some countries will retrospectively impose taxes on good that are taken back out. A second challenge is that, in the case of complex emergencies, agencies may have to resort to unconventional means of importing relief goods in order to avoid them being impounded by one faction or another in a confrontation. In this situation, and in the unlikely scenario that they are not needed, any attempt to move them back up the supply chain would cause considerable difficulties and is, thus, unlikely to be contemplated. A further issue relates to, in particular, food items and consumable medical items. Attempts to re-cycle these are clearly challenging as the aid agency would need to be able to guarantee to any future recipient that they have been correctly stored and that they are safe to be sent to a new location for use.

Finally, it must be recognised that some aid agencies follow a policy in which goods are donated to the recipients and, thus, the concept of taking goods back up the supply network is not contemplated. In short, the poor benefit to cost ratio for the return of the majority of new items makes this an unattractive option, and thus the option of local donation is likely to be adopted. As an aside, although from a commercial perspective this can be seen as a 'reverse logistic' process, this is arguably not the case in the humanitarian scenario where it can be seen as a variant on the original purpose of the supply chain which was to deliver material to the beneficiaries. Nevertheless, and notwithstanding the arguments against the return of unused goods back up the supply network, there is, in principle, no reason why such an approach should not be adopted. For example, the policies of aid agencies could be amended to reflect the potential for return of goods and their subsequent use in a more pressing scenario. Similarly, it may prove possible to negotiate with governments so that they, too, accept that other countries may be in greater needs of items that are surplus to requirements in their own country. By the same token, the return of medicines and foodstuffs could be achieved in a safe and secure way – however, as indicated earlier – all of these approaches would require a greater focus on the importance of the RL supply chain than is currently the case.

5.7.3. Items that have been used

In principle, the same arguments discussed above will apply to items that have already been used. Therefore, as before, the hard and soft benefit to cost ratio is likely to be the key determinant. That said, in the case of Agency Owned Items (such as trucks and radios), the default setting is likely to be that of returning the items for re-use in another operation (after any necessary repair or refurbishment). A similar approach may be used for other expensive items – for example, the Italian Civil Protection organisation uses a particular type of tent that is valued at some 10,000 Euros and so such items are also likely to be returned for subsequent re-use. More broadly, and unlike the commercial scenario, the volume of material that is returned back up the supply chain is likely to be small and, furthermore, the volume that requires refurbishing and/or reconditioning is also likely to be extremely low, making the unit cost of such activities high.

The practice of salvaging or re-cycling materials is one of the few areas that are mentioned in the study of the operational reports. In particular IFRC encourages "the use of salvaged materials" (IFRC, 2011, pp. 32) and their reports underline the extent to which families in developing countries can make use of such materials. However, there is clearly potential for both negative publicity here as well as a real danger of injury or illness being caused by inappropriate salvaging techniques. This could, in part, be mitigated by the introduction of appropriate contractual arrangements whereby, in addition to using a 3rd party organisation to manage and operate the outbound supply chain, it is theoretically entirely possible for aid agencies to let contracts with appropriately qualified and experienced companies who can operate as their agents in the salvaging/recycling of materials. Once again, however, this would require a considerable change of mind set amongst many parties including national governments, donors, recipients, as well as the agencies themselves before such an approach is likely to gain traction.

As indicated earlier, the donation of used items is a well understood and well used practice within the sector, and indeed is the major subject that was uncovered in the literature review. Clearly there is a double benefit here in that the aid agency is making a contribution to the population of the affected country, whilst at the same time it is avoiding the potential costs of alternative scenarios such as returning the item up the supply chain or ensuring an appropriate means of its final disposal. However, even the donating of material to those affected by a disaster has potential challenges in that some items may not be serviceable after their initial period of use and may, therefore, cause unintentional illness or injury. The question then becomes one of assessing the implicit risks of a donation policy which, in turn, will consume scare manpower and financial resources.

Within the RL literature, disposal of products into landfill is seen as the ultimate fall-back position – i.e. the one to be adopted when there are no other alternatives available that will capture the residual value in a cost-effective way. Given the potential for negative publicity and also mindful of the general sustainability orientation of aid agencies, there is a considerable focus within the literature on achieving appropriate practices in this regard. However, the literature is also clear that one of the main challenges for these activities is that of engaging with the disposal practices adopted within the affected community and, where appropriate, attempting to reduce the environmental impact of poor practices. As in the case of the return of unused or used good up the supply network, it is entirely feasible for aid agencies to engage local or international contractors to undertake the waste disposal in an appropriate and sustainable way – although it is fully recognised that such an approach would not only be extremely costly in cash terms, it would also run counter to the prevailing cultural norms in many countries.

5.7.4. Packaging

The issue of the appropriate disposal or recycling of packaging materials is one of the most challenging facing the aid organisations as demonstrated by the work of the INSEAD Humanitarian Research Group (2010) who noted that some 7 million bottles of water were donated by North American companies to Haiti during the first two months after the 2010 earthquake. Interestingly, and notwithstanding the clear potential environmental impact of such packaging, there is relatively limited discussion of this subject within either the academic or the practitioner literature. It is suggested that this is an area on which agencies should focus in the future as being one which would have clear benefit in terms of both practice as well as from a publicity perspective. On the one hand, the issues around the proper disposal of such packaging are broadly the same as those relating to used products as discussed above. Thus, there is the potential, at cost, to become stricter in ensuring that the disposal actions are appropriate and do not cause further environmental or other damage.

As an alternative, a number of companies across the globe have developed packaging that is re-usable, or can be used for a secondary purpose. As an example, the 'Clip-Lok' company has developed a wooden box, the primary use for which is to transport large tents (such as food halls). However, it is designed in such a way that it can subsequently be converted as the basis for a field latrine. It is suggested that similar initiatives can potentially be developed and, thereby, reduce both the inflow of relief items as well as reducing the volume of material that would otherwise require disposal. That said, it is recognised that, in addition to the cost of development of such multi-use packaging, there is a cost associated with educating the final users who may view such packaging as having some form of residual value (such as an alternative source of fuel), and who may, therefore, be reluctant to embrace its return up the supply chain or conversion to another use.

Table 5.5: Humanitarian Reverse Logistic Challenges and Opportunities summary

Type of Items	Examples	Practices	Drivers & Factors	Challenges
Items that have not been used:	Medicines, Food items, Hygienic kits,	Return up the supply chain Donate	Residual Value & Cost of returning Government Policies (import-export taxes) Poor benefit of cost ratio	Guarantee correct, safe and secure transportation way Negotiate with government and make acceptable the transportation to other countries with greater needs. Avoid Negative Publicity
Items that have been used:	Trucks, Radios, Tents, Expensive Items	Re-use Refurbish/Recondition Salvage/Recycle Donate Landfill	Residual Value & Cost of returning Requirement in other emergencies	Avoid illness and injuries caused by inappropriate re-use or reconditioning High unitary cost of refurbishing/reconditioning Use of 3rd party organisations for managing the reverse flow, that requires a change in mind set of governments, donors, recipients Education of people about best practices for landfill
Packaging:	Bottles, Wooden boxes, cardboard boxes	Re-use Landfill Recycle	Great Impact of packaging low value of items high number of used items	Make the packaging reusable as packaging or for other uses Education of people to reuse the packaging or conversion to other uses Education of people about best practices for landfill or recycling

5.8. Discussion

The aim of this part of research was to describe and analyse the challenges and opportunities for the application of commercial reverse logistics practices in a humanitarian logistic context. In doing so, it has sought to understand the current state of RL practices within the HL field, and the extent to which commercial approaches can be brought to bear. Unfortunately, it is clear from the above analysis that there remains a considerable gulf between current and developing commercial practice and that found in a development context or in the aftermath of a disaster or emergency. At one level, this is entirely understandable. In essence, and in light of their exceedingly taught budgets and the increase in the numbers of beneficiaries needing assistance, it is totally unsurprising that aid agencies see the outbound supply chain as their priority. However, this situation broadly reflects that scenario of commercial supply chains prior to, say, the turn of the millennium. However, since then there has been a sea change in thinking, driven by both the pressure of public opinion as well as recognition that RL need not necessarily be a huge drain on resources. Indeed, with the increase in the use of the internet as a sales medium, the easy return of unwanted purchased is now an essential element of many business propositions.

Table 5.6: IFCR database available at https://www.ifrc.org/en/publications-and-reports/evaluations/

Type	Date of the report	Title of the report	URL (accessed 22 October 2014)
Cluster evaluation	31Oct2013	Review of the Fiji Shelter Cluster in Response to Tropical Cyclone Evan	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-51074&catid=38&loccode=SP
Final evaluation	01Sep2011	Pilot project: Building sustainable local capacity in the branches of the Burundi Red Cross Society	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=372&catid=55&loccode=SP164BI
Case study/research	01 Jan 2011	Bringing people back home The long path of a successful reconstruction programme in Peru	https://www.ifrc.org/en/publications-and-reports/evaluations/?c=&co=&fm=1&fy=2011&mo=&mr=1&r=&ti=in%20peru&tm=11&ty=&tyr=2013&z=
Evaluation Report	09 Jul 2013	Americas Club 25 Evaluation Report	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-45335&catid=39&loccode=SP2
Review	10Apr2011	Asia Pacific Zone Review of the Red Cross Red Crescent Disaster Response Capacity	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=428&catid=28&loccode=SP3
Survey	13Sep2013	Beneficiary Satisfaction Surveys: Emergency Operations 2012 Jamaica and Dominican Republic	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-47957&catid=28,%20202&loccode=SP249DO,%20SP249JM
Final evaluation	20Mar2013	Comoros Flash Floods Emergency Appeal Evaluation	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-40000&catid=13,%2030,%2039,%2053&loccode=SP164KM
Final evaluation	15Aug2013	Water, Sanitation and Hygiene Promotion: Final Evaluation -Haiti Earthquake Operation	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-46644&catid=53&loccode=SP249HT
Final evaluation	17Oct2012	Global Organizational Development: Building sustainable local capacity in the branches of the Ghana Red Cross	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-33115&catid=54,%2055&loccode=SP161GH
Case study/research	30Oct2013	Green Response, case studies of Haiti and El Salvador Operation	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-50829&catid=78&loccode=SP243SV,%20SP249HT
Final evaluation	30Oct2013	Haiti - Lessons Learned & Best Shelter Practices	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-61816&catid=9,%2038&loccode=SP249HT
Final evaluation	13Aug2013	Informe final de Lecciones aprendidas en Inundaciones y Deslizamientos - Bolivia 2011	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-46521&catid=13,%2016,%2028&loccode=SP246BO
Review	20Apr2011	A Review of the IFRC-led Shelter Cluster Haiti 2010	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=346&catid=9,%2038&loccode=SP249HT
Final evaluation	06Aug2013	IDRL in Haiti: A Study on the Legal Framework for the Facilitation and Regulation of International Disaster Response in Haiti	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-50093&catid=77&loccode=SP249HT
Cluster evaluation	01Jan2011	Shelter Cluster Review: 2009 Indonesia Earthquake	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=334&catid=9,%2038&loccode=SP351ID

Cluster evaluation	01Jan2011	Shelter Cluster Review 2009 West Sumatra Earthquake	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=344&catid=9,%2038&loccode=SP351ID
Cluster evaluation	08Dec2011	An Evaluation of the Haiti Earthquake 2010 - Meeting Shelter Needs: Issues, Achievements and Constraints	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=419&catid=9,%2038&loccode=SP249HT
Case study/research	05Aug2013	Annual ISD Report	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-51162&catid=56&loccode=SP
Review	01Jun2012	Preparing for and Responding to Large Scale Disasters in High Income Countries: Findings and Lessons Learned from the Japanese Red Cross Society’s Response to the Great East Japan Earthquake and Tsunami	https://www.ifrc.org/docs/Evaluations/Evaluations%202012/AsiaPacific/JPTsunamiEarthquake12_report.pdf
Case study/research	01Jan2011	Community Disaster Response Teams in Action Saint Lucia, 2010	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=383&catid=29&loccode=SP249LC
Review	15Oct2013	Zambia Floods MDRZM008 DREF Review	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-49906&catid=13,%2028,%2031&loccode=SP163ZM
Survey	29Mar2013	Survey on ICT capacity in National Societies	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-51046&catid=56&loccode=SP
Real-time evaluation	20 Jan 2011	Pakistan: Management Response to the RTE of the IFRC Pakistan Floods Operation 2010	https://www.ifrc.org/docs/Evaluations/Evaluations2011/Asia%20Pacific/2010%20PakistanFloods.RTE/Management%20Response%20to%20Pakistan%20Floods%20-%20final_28Feb2011.pdf
Mid-term evaluation	29Nov2011	Pakistan Floods 2010: Evaluation of the Relief Phase of the Red Cross Red Crescent Monsoon Flash Floods Operation	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=404&catid=13&loccode=SP352PK
Mid-term evaluation, Review	17Oct2013	Evaluation of the Somali Red Crescent Drought Response Operation 2011	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=-50063&catid=8&loccode=SP164SO
Final evaluation	08Nov2011	Vanuatu:Cyclone Vania Dref Evaluation	https://www.ifrc.org/Templates/Public/Pages/EvaluationDatabasePrint.aspx?a=395&catid=23&loccode=SP355VU

6. Debris management in post-earthquake operation: an Italian case study

During the last decades, according the literature (Thomas & Kopczak 2005; Tang, 2006) there have been an increasing number of disasters and this trend will continue in the course of the next years. This has led and will lead to an increase in terms of the humanitarian organisation effort. This effort has been widely studied in terms of resource allocation in the operations (Barbarosoglu et al., 2002), aids distribution (Brown & Vassiliou,1993; Balcik, 2008) coordination between the organisations (Kovacs & Spens, 2007) and humanitarian context (Van Wassenhove, 2006), to give just some examples, while little research has been carried out concerning the managing of the disaster's products (e. g. Poon et al., 2001). This study considers some earthquakes that hit Italy in recent years in order to understand the response from the Italian organisations to these disasters. In particular the research is focused on debris management. Debris management is an important issue that is emerging in an environment where sustainability is increasingly important (Moskal et al. 2008). The importance of sustainability in this circumstance has to be seen as the possibility for the population to restart their lives as soon as possible, jointly with the minimisation of the impacts that the operations can cause. For this reason effective strategic and operational guidelines are essential. In particular in countries that are considered as the first world the focus isot just in food deliveries or health support rather on what should be done in order to restart the supply chain as it was before the disaster.

Disaster waste management is a well-recognised problem for humanitarian operations (Brown, 2012), it is important in all the operations that concern areas where the recovery of materials could be useful for the entire community. According to Blakely (2007) there are two different phases concerning debris management. The first phase, in the post-disaster situation, is more focused on 'cleaning' the area hit by the disaster. By 'cleaning' the author means removing debris from the critical routes to allow the transit of the vehicles. On the other hand, the second phase is a long-term operation and concerns the removal of debris and reconstruction of the area.

Experience shows that disaster waste cannot be managed by standard disposal options but often requires an ad hoc manner. However, from a logistic flow management point of view, a substantial improvement could be made in future response efforts. Moreover reducing and recycling these materials enables saving of landfill space, reducing the environmental impact of producing new materials, creating jobs, and can reduce, overall, the building project expenses through avoiding purchase/disposal costs.

As recently discussed in the literature, an overwhelming amount of waste is normally left after a disaster (Brown, 2012). Earthquakes, in particular, generate shock waves and displace the ground along fault lines. These seismic forces can bring down buildings in a localised area and damage buildings and other structures in a far wider area. Earthquake waste includes construction and demolition materials consisting of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges (Brown et al., 2011). This kind of waste often contains bulky, heavy materials, such as concrete, wood, metals, glass, and salvaged building components. Moreover, it is always necessary to clean and separate different waste materials coming from the same place and manage the mixed waste that is not separable.

In this chapter, post-disaster management operations are analysed with particular attention on debris management as the combination of processes, strategies and actors. The aim of this chapter is to present an accurate picture of what happened during a genuine Italian case study in the post-disaster phase when faced with thousands of tons of debris produced by the earthquake, and what post-disaster waste management strategies and challenges were identified from these post-disaster operations. Here the application of a case study analysis is provided with the main purpose to offer to the reader a collection of real data in terms of waste flow quantities, transportation distances and number of demolition points and landfills. The chapter offers for the first time a waste management process description with the subdivision in tasks: this set of data and information could be used by the readers in a wide range of domains in which information is incomplete, in modelling future waste management processes or in validating present analytical models.

6.1. Literature review

The papers on humanitarian operations dealt with the definition of the humanitarian field (Van Wassenhove, 2006; Kovács & Spens, 2007; Maspero & Ittmann, 2008; Apte, 2010) and with the challenges (Beamon, 2004: Oloruntoba, 2005: Thomas & Kopczak, 2007) and the context (Gustavsson, 2003: Kovács et al., 2009) with which the organisations involved usually have to be familiar. In particular the different actors involved (Kovács & Spens, 2007, Baumann, 2008), the operational space (Tomasini & Van Wassenhove, 2004; Van Wassenhove, 2006), the training needs (Allen et al., 2013) and the different needs of the population (Delgado et al., 2013; Battini et al., 2014) meant this operation was highly critical from a management point of view. In fact the coordination between different organisations

(Balcik et al., 2010; Jahre & Jensen, 2010; Akhtar et al., 2012), the presence of unsolicited donations (PAHO, 2001; Stapleton et al, 2010), the different bottlenecks present in the supply chain (Destro & Holguín-Veras, 2011) and the lack of quality real-time data (Kovács & Spens, 2007) are just some examples of what the operators had to tackle, and on what the researchers have focused in this study.

In this particular context this research focused on one important issue that can, in some circumstances, be critical to the operation immediately post the disaster: waste management. Specifically, its application in post-disaster operations, hence in critical situations, 'when a disaster strikes, especially in densely populated areas, huge amounts of construction waste and other kinds of wastes are suddenly produced, demanding immediate attention' (Lauritzen, 1998).

Waste management is a topic broadly dealt with in the literature (Pires et al., 2011; Wilson, 2007). It considers the management associated with a wide range of refuses such as solid waste (Metin et al., 2003; Manaf et al., 2009) radioactive waste (Holdren, 1992) toxic waste (Derrington, 1988) or construction demolition debris waste (Lee et al., 2006). All these typologies of waste streams generated by a disaster have been classified recently by Brown et al. (2011). In particular the authors proposed a classification that was focused on three main areas: Planning, Waste Characterisation and Treating Waste. Planning considers the difference between waste management in developed (Boyle, 2000) and in developing countries (Wilson et al. 2006; Manga et al., 2008; Karunasena et al., 2012; Guerrero et al., 2013); the waste characterisation, considers the features associated with scrap of a particular composition (as introduced above) and quantity. Moreover Brown et al. (2011) categorised the different options for treating waste such as recycling, temporary staging sites and disposal. Brown et al. (2011) presented a qualitative specification of waste management activities without talking the question of the environmental impact of different strategies. This classification is very helpful because it summarises all the aspects that this chapter deals with: planning in a developed country, debris flows and debris management flow (treating waste) that will be introduced in the next paragraphs.

6.2. Case study and methodology

This chapter aims to report the findings from post-disaster waste management strategies and challenges identified from the post-earthquake operations in Emilia Romagna. Data was gathered through interviews with government and non-government organisations, at national and local level, that were involved in post-disaster debris operations. In particular the organisations that were involved in debris collection and landfill management are considered in this research. Moreover specialised websites were accessed to get data about the actors and the beneficiaries involved in the debris operations (Protezione Civile Italiana: www.protezionecivile.gov.it, Regione Emiglia Romagna: www.regione.emilia-romagna.it).

On 20th May 2012, at 04:03:52 Italian time, a shock of magnitude 5.9 occurred with its epicentre approximately 36 km north of the city of Bologna, between Finale Emilia and San Felice sul Panaro (figure 6.1), following a foreshock that had occurred 2 hours earlier. This first shock was followed by others shocks, in fact on 29th May 2012 a second shock, magnitude 5.8, with its epicentre in Medolla, hit the same area (Tertulliani et al., 2012) with more than thirty aftershocks over the next 20 days. The area suffered a high level of damage in particular the municipalities of Camposanto, Carpi, Cavezzo, Concordia, Medolla, Mirandola, Novi, San Felice Sul Panaro, San Possidonio, San Prosepro and Soliera.

The considered earthquakes caused twenty-seven fatalities, more than 350 wounded and a high level of damage in terms of homeless (estimated at 450,000) and unliveable buildings. One of the main problems faced by the Italian authorities was the debris management associated with the destroyed buildings. Indeed, the large quantity of waste materials present in the cities made them dangerous, preventing citizens from carrying on with their everyday lives (Bonomi & Casazza, 2013).

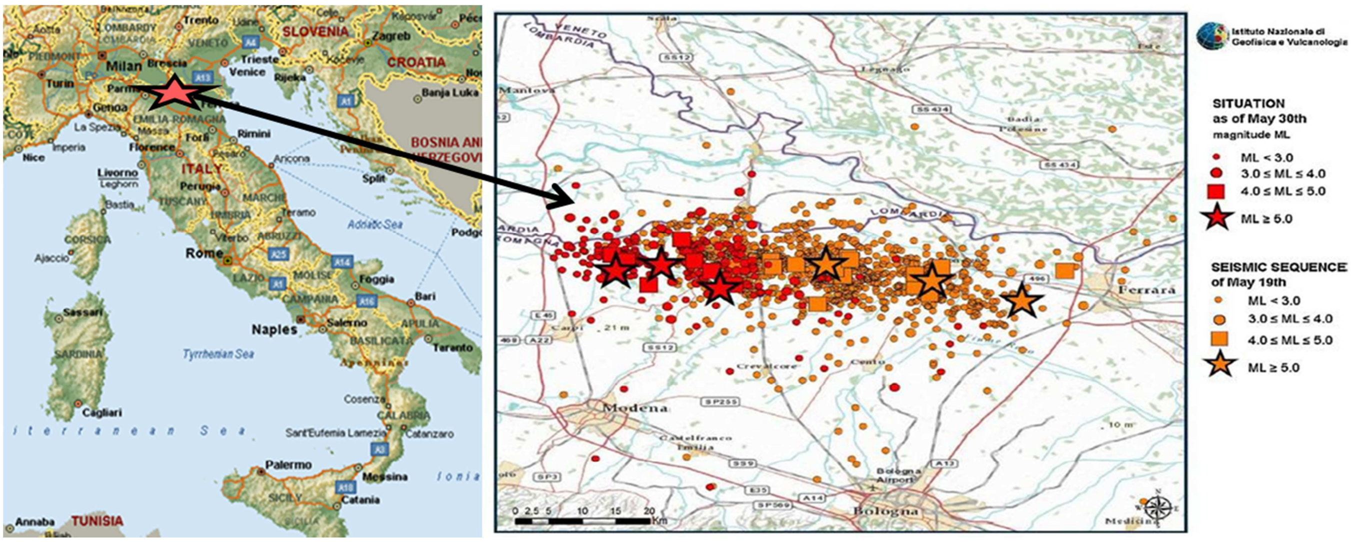
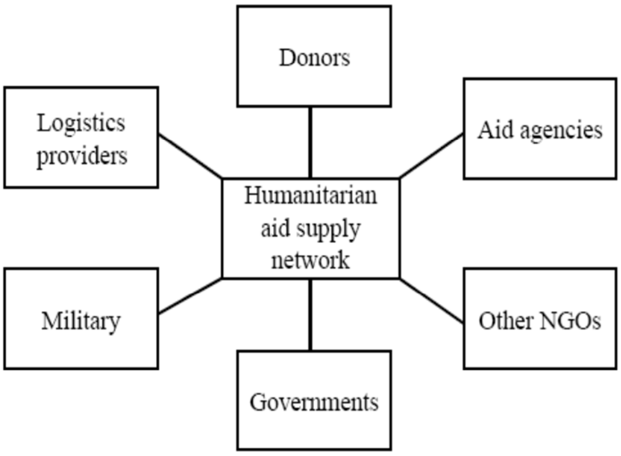


Figure 6.1: Emilia Romagna earthquake epicenter

In the area hit by the disaster thirty-two refugee camps were placed but the municipalities also made available hotels, gyms and schools in order to satisfy the first wave of people who had lost their homes. Six Emilia Romagna civil protection teams were employed in order to verify essential camp services such as electricity, drainage, hydraulic and hygiene systems (http://www.regione.emilia-romagna.it/terremoto/notizie?b_start:int=520).

6.2.1. Actors involved

According to Kovács and Spens (2007) in a humanitarian aid operation many actors are employed that have to collaborate and be coordinated in order to achieve the goal of meeting the needs of the beneficiaries. These are presented in figure 6.2.



Actors	**Operators**	**Vehicles**
Firemans	695	304
Army	334	60
Italian Police	357	136
Traffic corps	144	46
Italian Finance Police	48	16
Forest Service	59	29
Red Cross	239	97
Department of Civil Protection	82	-
Volunteers of Civil Protection	1316	-
Total	**3274**	**688**

Figure 6.2: Actors in the humanitarian aid supply network according to literature (Kovacs & Spens, 2007) on the left and list of actors involved in the Italian case study on July 25, 2012 (source: www.protezionecivile.gov.it) on the right.

The literature underlines how coordination between these organisations can be challenging (Kovács & Spens, 2009) and that it is an issue that typically has to be managed (Kovacs & Spens, 2007). Various actors were involved in the post-earthquake management activities in Emilia Romagna, that differed from the cases presented in literature, from a directional board to more operational roles.

After the first event, on 22th May 2012, the Italian Council of Ministers declared a state of emergency for a duration of 60 days in the Modena, Ferrara, Bologna and Mantova provinces. On 30th May the state of emergency was extended to the Reggio Emilia and Rovigo provinces. The chief of operations for this first phase of response was given to the Italian civil protection department chief.

This leadership changed on 2nd August 2012, when the responsibility passed to the ER region's president. This transfer reflected the transition to a second phase (http://www.protezionecivile.gov.it/jcms/it/terremoto_emilia_2012.wp) of the disaster and the end of the most critical response phase. This passage is the one presented in literature by Kovacs and Spens, (2007) and Blakely, (2007), where the transition from response to reconstruction is underlined. The life span fits the one proposed by Charles, (2010), in fact the duration of immediate response and support phases was almost three months (see figure 6.3). From the 25 of August 2012 the emergency camps started to be progressively closed and about 2 months later, by the end of October, all fifty-two camps were closed and new containes were installed.

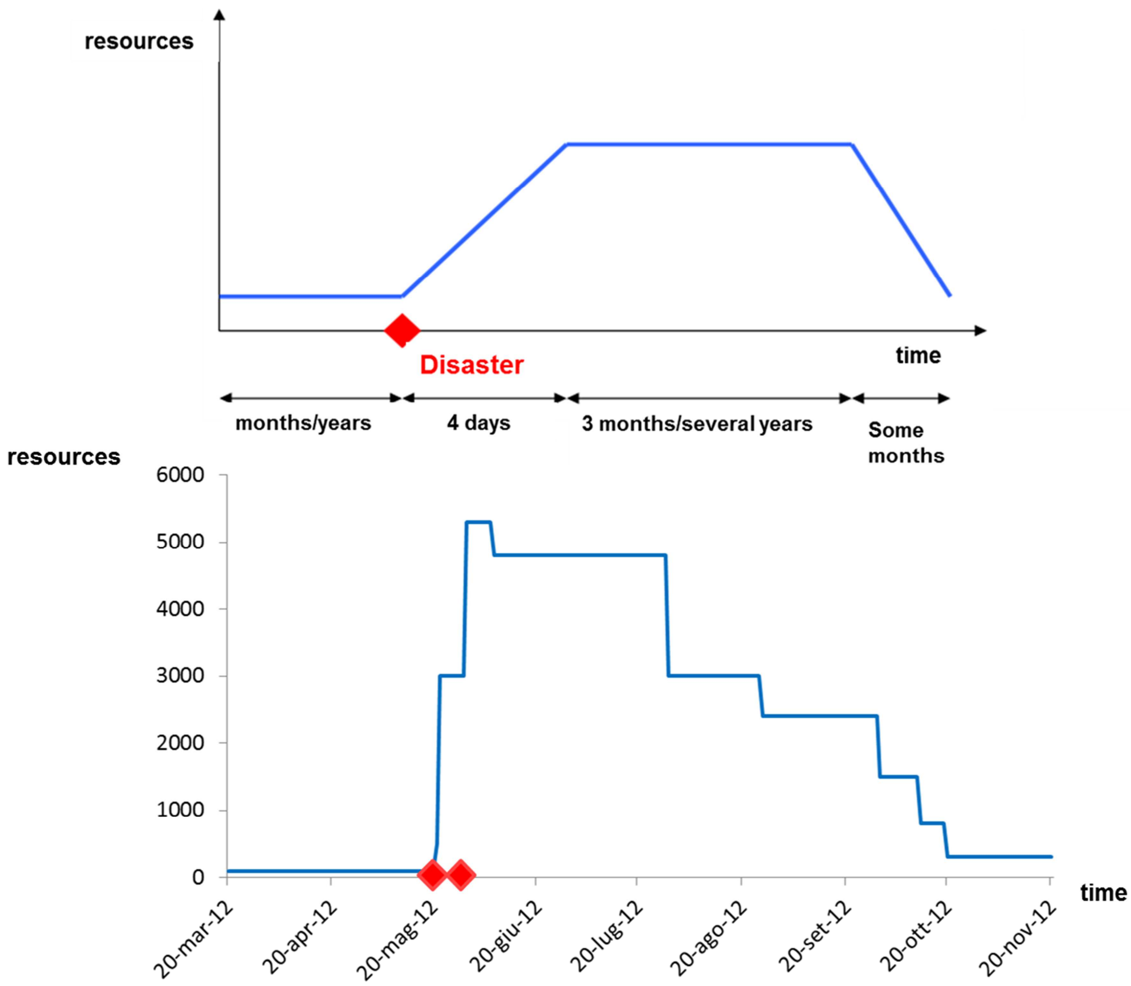


Figure 6.3: Resources versus time according to literature (Charles, 2010) above, and number of operators involved versus time following the two Italian earthquakes below (elaborated from www.protezionecivile.gov.it)

The actors involved in the Emilia Romagna post-disaster operations were different, with diverse assignments engaged at different times within the operation's timespan. The first actor to arrive in the area was the central Italy civil protection department chief, jointly with some experts. They arrived to carry out a general inspection immediately after the disaster hit the area. Moreover they discussed with the Emilia Romagna region president and with the regional civil protection chief a first situation point. From this first step the main aids and national support were planned. In particular teams of technicians and vehicles were sent to the area for an evaluation of the damage and to collect seismic data. In the first 48 hours after the disaster about 5,300 persons needed assistance and about 3,000 operators provided first aid.

In function of the previous collection of data were sent sanitary modules from four Italian regions and five regional mobile columns of the civil protection Voluntary Service were immediately employed in the area. These columns are independent departments within regional civil protection, with their own vehicles, volunteers and tools. These civil protection departments are coordinated by the central Italy civil protection department. They are deployed in construction and management of refugee camps and in helping the locals with maintenance and support operations. Further independent volunteer groups and associations are engaged in order to assist the population with different duties. During operations the national police are active in public security and preventing incidents of profiteering.

After the second earthquake on May 29, 2012 the number of persons involved in the assistance rose to a maximum of 5,300 operators contemporary involved in helping about 16,000 persons needing assistance.

In figure 6.4 the major kinds of waste managed after the earthquake are depicted and classified in two distinct categories: direct and indirect waste. House and building debris represents the majority of the waste and for this reason in the next paragraph I will investigate them in detail. The waste management operations were carried out by different actors. All the activities were led by the local waste management public agency, which also coordinated private service and logistic providers, national fire corps, the military and national association of volunteer surveyors for civil protection (A.Ge.Pro.). The military and the national fire corps were engaged in assistance activities for the population, moreover, with the A.Ge.Pro., they were employed to verify the buildings. Similar to what happened in Abruzzo (Brown et al., 2010) activities were carried out by the national fire corps. Furthermore the military and the national fire corps were employed in removing debris. This final operation was carried out with the help of local waste management organisations that are usually responsible for waste management operations, before and after the earthquake. These organisations followed the debris process that is presented in the next section.

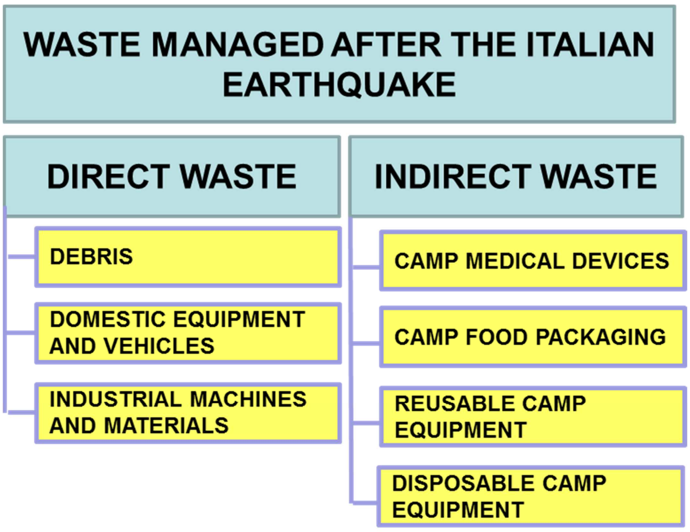


Figure 6.4: Classification of the waste typologies managed after the Emilia Romagna earthquake (elaborated from www.protezionecivile.gov.it)

6.2.2. Debris management operations

In the area under study, about 39,000 buildings were inspected after the earthquakes in order to evaluate their liveability. A specific evaluation card (called an Aedes card) is used to evaluate the damage; this is a standard tool used on public and private buildings that have reported damage in order to have a standardised evaluation carried out. The tool forecasts six different categories of damage, summarised in the table below (table 6.1).

Table 6.1: Aedes categories of damage (from: www.protezionecivile.gov.it)

Category	Classification	Features
A	Building Liveable	The building can be used entirely without hazard for the residents
B	Building Temporarily Unliveable (entirely or partially) but liveable after some minor repairs	The building is temporarily unliveable, but needs some minor repairs to be used entirely without hazard for the residents
C	Building Partially Unliveable	Some parts of the building present a high level of hazard for the residents
D	Building Temporarily Unliveable, needs re-inspection	The judgment of liveability is uncertain. A more in depth inspection is needed, until then, the building is not liveable

E,F	Building Unliveable	A building is not liveable due to structural damage, not structural and geotechnical risk (E). Otherwise it is not liveable due to grave external risk (F), even without any significant damage to the building If (E) the reparations need a project by technician in order to reinstate or reinforce the load-bearing capacity of the building. If (F) the buildings are subjected to external factors, other unsafe buildings

The results showed that 36% of the buildings were immediately liveable, 18% were temporarily or partially unliveable, 36% were not fit for habitation while the remaining 5% was not liveable due to external precarious elements (there were some external elements that were not fixed that could have affected the building).

6.3. Debris management process

The process presented in this paragraph is the waste management process utilised for the post-disaster debris in the municipalities hit by the two earthquakes. These municipalities are located close to the earthquake epicentres and are the ones that suffered the highest level of damage (depicted in figures 6.5 and 6.6). The process outlined is the product of a study of local organisations' practices in waste management, which were supported by interviews undertaken by the authors and data collected by government agencies.

The processed materials were debris from private and industrial buildings (destroyed building, classes 'E' and 'F'). The total amount of this flow was the total that had originated directly from the two close-together earthquakes and by all subsequent demolitions: the total quantity of waste materials managed in the area reached about 410,000 tons by the beginning of August 2013 and about 500,000 tons by the end of 2013 (including the Ferrara province).

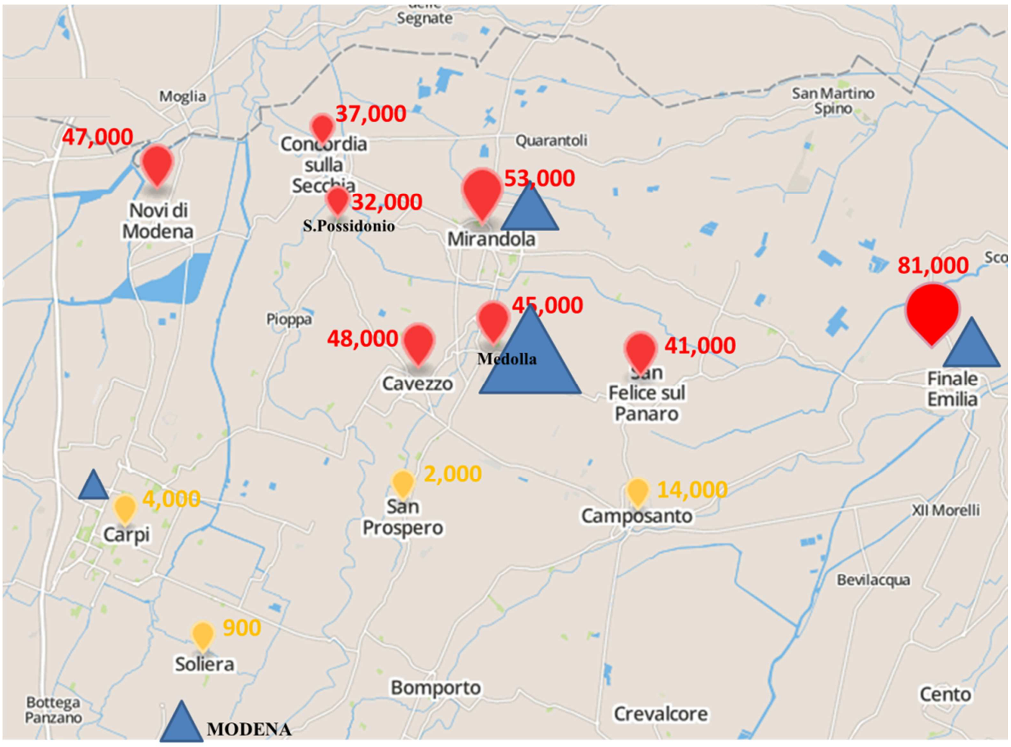


Figure 6.5: Amount of debris (in tons) collected and transported from the municipalities hit by the two earthquakes to the five landfills (blue triangles). Elaborated from: www.regione.emilia-romagna.it.

During the period before the earthquake these landfills were used to process municipal solid waste from the bordering localities. Hence the landfills used in debris operations were not started ex-novo rather the organizations used infrastructures already in place.

Figure 6.6: Building demolition sites and landfills' position (white squares) in the area hit by the earthquake.

Some definitions used in the next sections:

- Intermediate Landfills (deposits): are the five considered landfills that were considered which are situated in the disaster area. These were not the final locations for the debris, indeed the materials were eventually taken to the final landfills to be covered, once the authorities had chosen the sites.
- Final Landfills: the final debris locations. They were chosen by the authorities and are the landfills that needed the final covering.
- Waste treatment (debris grinding machines): the materials were treated in order to obtain a more homogenous material to cover the landfill.
- Waste selection: the materials that could be selected and taken off quickly (wood, metals, plastic, cables,...) were sorted from the residual materials that went on to the main process.

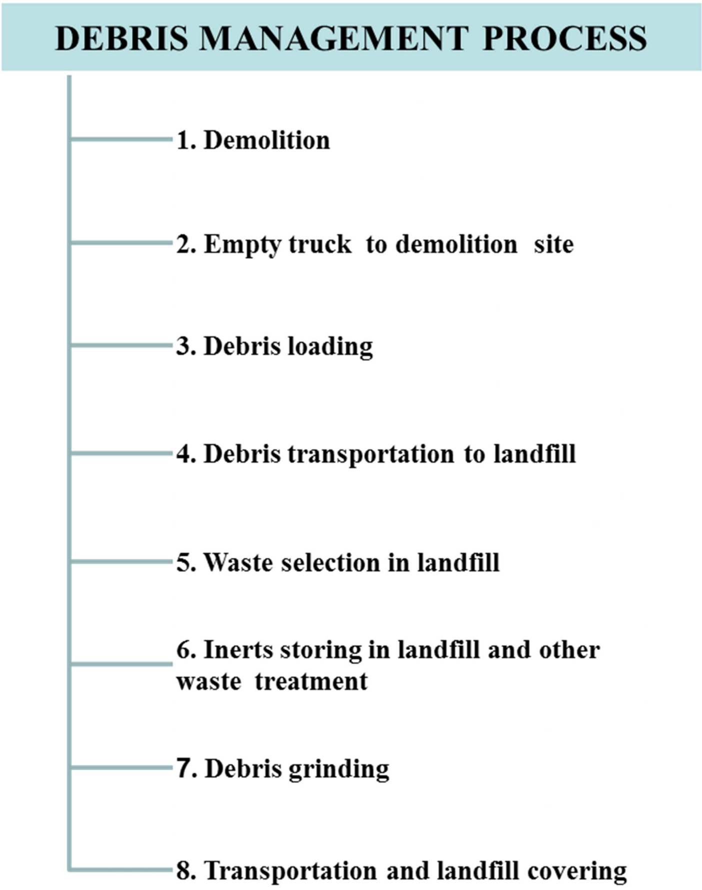


Figure 6.7: Debris management process subdivided into eight consecutive activities

The main process is composed of eight different phases (figure 6.7). These can be split into three macro stages: the first stage concerns the activities made in the dismantling sites (1, 2, 3, 4), the second stage of activities regards the process in the intermediate landfills (5, 6, 7) while the third and last part of the process is done at the final landfills (8).

The first phase concerns the management of all demolition sites, by purchasing demolition services from private companies. About 1,200 different demolition points were managed in the hit area in accordance with the map depicted in figure 6.7. After the demolition empty trucks were needed at the point where there was debris (2). Here the trucks were loaded by hydraulic excavators (phase 3) and went back, full of debris (phase 4), to the landfills where they were processed. One of the five landfills introduced before was associated to the area. In this first stage a macro selection was carried out by the operators, this means that all the materials that could be easily sorted were separated by type of debris; these were usually big planks or large household electrical appliances.

The intermediate landfills were not the final places where the materials were used for landfill covering. Once the trucks arrived the debris was sorted (phase 5). During the waste selection the materials that could be selected and recycled quickly (wood, metals) were sorted from the residual materials that went on to the main process.

After the materials were stored in the landfill, (phase 6) they were handled and processed by grinding machines in phase 7 inside the landfill plant. During this phase the materials have to be treated in order to have cleaner and more homogenous volumes and shapes for their final utilisation to cover the landfill. All these activities are done in what I have called ‘intermediate landfills’ (deposits) that are situated in the disaster area.

These are not always the final locations for the debris, indeed a percentage of the materials will eventually be transported to final landfills that have to be covered, once the authorities have choose the preferred places. The procedure ends with transportation to the final landfill and its covering (phase 8). Landfills for the final debris locations are chosen by the authorities and are the landfills that need the covering.

6.4. Debris management issues

The post-disaster debris management process described is not yet complete. According to Bonomi and Casazza (2013) just half of the process has been completed (figure 6.8) because there is uncertainty about the final use for the debris. Considering figure 6.8, the debris is currently waiting in the intermediate landfills. There are two main problems associated with this uncertain situation: the landfill’s congestion and the high costs in terms of transportation associated with further handling of the debris from the intermediate landfills to their final destination.

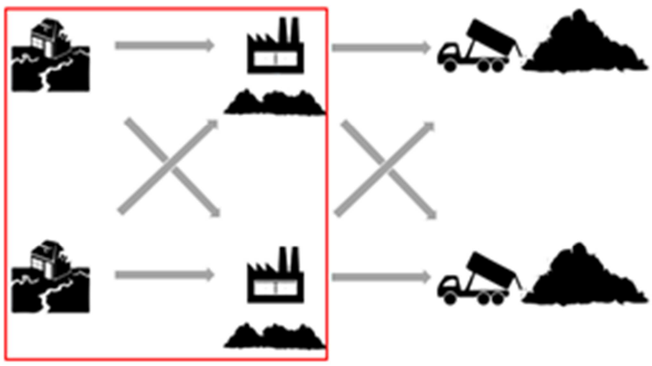


Figure 6.8: Debris operations process situation in the Italian case study

According to Bonomi and Casazza (2013) two other alternatives in term of final use could been considered in addition to the covering process, finally leading to three alternative possibilities:

- use the collected debris to cap decommissioned landfills (i.e. the covering process);

- use the collected debris as raw materials to build road floors and new parking areas;
- use the collected debris to build the foundations of a new national highway.

The main problem associated with the last two options regards the presence of 'dirty' materials (e.g. plastics and wood) in the debris that cannot be used as construction materials, moreover the lead time for the highway's construction is not definite, there is no final project for it, and could therefore have a long lead time.

For these reasons the option of using the processed debris to cover the landfill is the most probable. The real issue associated with this choice regards the impact of the transportation. Indeed it can vary if I consider it as a function of the distance from the intermediate landfill to the final one. This is the most variable datum (Battini et al., 2013) and it has to be taken in consideration when making the final decision about the debris. Indeed if the distribution of the landfills that have to be covered are within one area this solution could be good in terms of emissions; on the other hand, if the final landfills are far from the damaged areas the solution starts to be critical. This response is interesting because the concentration of landfills to be covered is not close to the earthquake area (Bonomi& Casazza, 2013). This problem in terms of transportation to the final locations has not yet been taken into consideration by the organisations and it will be able to have a higher impact than if they were considered before.

The second issue concerns congestion of the landfills. The four considered landfills are usually used to store and process the municipal's solid waste from the central-north province of the area. The huge amount of debris in these places has led to the landfill being in a state of congestion; this needs to be considered in the total debris management lead time to reduce its impact.

In figure 6.9 the timetable for demolition process management is presented. The data was collected through direct interviews and documents available from the websites of the municipalities in the Emilia Romagna region.

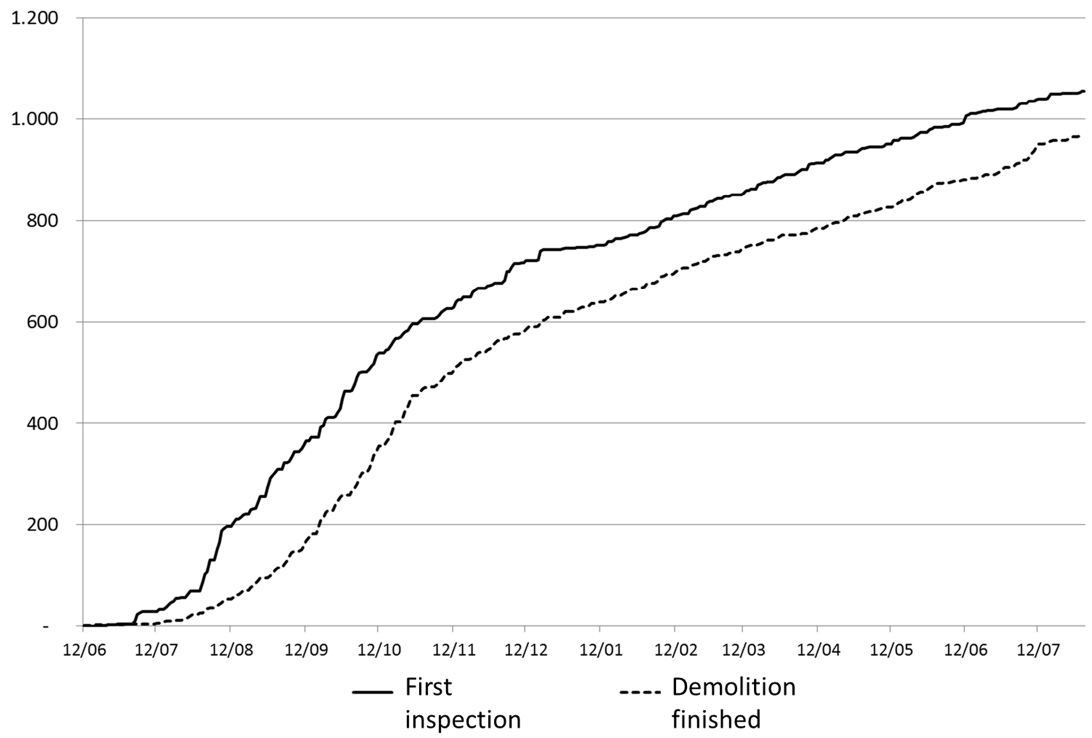


Figure 9: The 'S' curve of the building demolition activity after the earthquakes from June 2012 to July 2013 (source: elaborated from the municipalities' websites)

The graphic in figure 6.9 shows the lead time that exists between dispatching the demolition sites listed by the municipality and the closure of the demolition sites after the debris was been processed.

The case study presented here can easily be compared with the other recent Italian Earthquake that happened in Abruzzo (in the city of Aquila during2009), presented by Brown et al., (2010a) and Brown et al., (2010b). Despite this earthquake having similarities with Emilia Romagna, there are some issues that were faced differently.

In the Emilia Romagna earthquake the sorting was done after the debris collection and transportation to landfill, unlike in the Abruzzo earthquake (Bonomi& Casazza, 2013) where the lead time in terms of collection was significantly longer because the waste selection and differentiation was operated directly by each demolition site. The Emilia Romagna approach led to an improvement in terms of reducing the amount of debris in the area hit by the disaster, assuring the practicality of the streets in a shorter time. Moreover, figure 6.9 shows a good lead time for the demolition sites' operations. In fact in this first phase of the process, from the start of the demolition process (presentation of the demolition sites list by the municipality) to the closure of the demolition site, took just one month with a total waiting time of two months from the first inspection of the building to its final demolition. The distance between the intermediate landfills and the final ones should be considered in order to minimise the total social impact, humanitarian objective (Tatham & Houghton, 2011; Holguín-Veras et al., 2012). This issue has to be dealt with in order to minimise its possible social and environmental impact. Finally, the author recommend future research in this field capable of efficiently coupling the Life Cycle Assessment techniques with the economic analysis in order to choose which of the waste management alternative solutions should be adopted to reduce costs and environmental impact at once.

6.5. Case Study Conclusion

In recent years, many earthquakes have hit the Italian territory and some of them have produced high levels of damage – earthquakes were the strongest for the populations in Abruzzo and Emilia Romagna. In this new era of seismic hazard new strategies for management have to be carried out in order to respond more effectively to the disasters. In this optics this part of the study aimed to explore what had been done in Italian debris management operations and what has to be improved for future operations in order to minimise the social impacts that the long-term presence of debris in the disaster area.

In this Emilia Romagna post-earthquake situation the author has underlined an important issue that is that the transport of the processed debris from the intermediate landfills to the final covering has not yet been done, and is not yet even planned. This is due to the uncertainty associated with the final use of the materials. The impact of this final stage is high (both in terms of costs and carbon emissions generated during transportation) and it is important for the evaluation of the whole process. Since the main humanitarian operation's goal is the minimisation of social and environmental implications (Tatham & Houghton, 2011) that arise after a disaster, the final use of the debris has to be considered before the collecting of the debris from the area in order to minimise the environmental impact on the area.

7. Close Loop Supply Chain in Humanitarian Operations

Tomasini and Van Wassenhove (2004) define the humanitarian operations goal as "a successful humanitarian operation- that – mitigates the urgent needs of a population with a sustainable reduction of their vulnerability in the shortest amount of time and with the least amount of resources". So the most important humanitarian operations objective is to deliver the essential supplies and help to beneficiaries, people who need to be supported into the disaster area. In this contest the literature underlines how logistic operations affect almost the 80 percent of the humanitarian operations effort (Van Wassenhove, L.N., 2006), becoming one of the most important factors in the operations. Transportation is a key element of delivery and in many NGOs, UN agencies and other humanitarian organizations; vehicle fleet management represent the second largest overhead cost after staff expenses (Disparte, 2007). In humanitarian operations the typical "commercial supply chain" challenges of allocating scarce resources in an efficient way (Van Wassenhove and Pedraza Martinez, 2012) as to be contextualized in complex operations furthermore according to Van Wassenhove (2006) these operators have to consider many different factors that can be invisible or/and ambiguous, that can have interactions and can increase and often they are associated to new phenomena. Another important issue concerns the random and imprecise information about the scope, timing and resource requirements of the disaster prior to the event, this according to Barbarosoglu and Arda (2004) affects the decision making process and leads to the unpredictability and uncertainty due by the complex environment associated to the disaster. Furthermore into the humanitarian operations are related to the qualitative factors, indeed not just economic factors are important rather social factors have to be considered during the logistics operations.

At the same time as is presented in the literature review some researchers suggest the importance of improving operations performances taking in consideration that some improvements are usually used in commercial supply chain and so applying these to humanitarian contest changing, of course, the field of application and so their features to fit the new environment. As has been proposed by the literature, which will be discussed later on the chapter, CLSC is seen as one of the possible improvements not just to minimize cost rather to increase operations sustainability and the opportunity to reuse items in other operations without buying or remanufacturing (Rajapakshe et al., 2013) more items than is necessary. In literature this argument is considered as Green supply chain (Olugu &Wong, 2011, Kim et al., 2014).

For these reasons these research explores the possibility to apply CLSC practices into humanitarian operations by providing a model and studying the impact it can have in the Regular humanitarian logistic (R-HL) operations where the main objective of the operation switches from the reduction of population needs to a minimization of the overall disaster and operations impact. In particular the research is focused on logistic facility management in the situation of using reverse logistics practices. Moreover the model considers typical humanitarian RL features as items interested by the reverse flows (Peretti et al., 2014) or humanitarian distribution structure.

This research aims to explore the impact in terms of costs and performances of using CLSC practices into humanitarian contest. This study has been suggested by the literature that is showing the growing importance of the humanitarian operations impacts. For this reason typical commercial CLSC practices, as recycling or reusing, are introduced in a model to optimize resources allocation and prepositioning decisions not just to minimize the overall costs rather to show the possibility to minimize the overall environmental impact.

7.1. Literature Review

In the last decades Humanitarian Operations have received increasing attention by the researchers and it is still increasing in terms of investigations (Caunhye, A.M. et al., 2012, Kunz, N. and Reiner, G., 2012, Dubey et al. 2014). Since the logistics has seen as one of the most important operations in terms of efforts (“Since disaster relief is about 80% logistics”, Van Wassenhove, L.N., 2006), many typical Commercial logistic aspects have been investigate both in what have been called Regular humanitarian logistics (R-HL) and Post-disaster humanitarian logistics (PD-HL) (Holguín-Veras, J. et al., 2012). In particular transportation issues have been extensively studied (Caunhye, A.M. et al., 2012) touching problems as last mile distribution (Balcik, B., et al, 2008, Battini, D., et al., 2014), resources allocation (Barbarogosġlu, G., and Arda, Y., 2004, Campbell & Jones, 2010) or fleet management (Pedraza-Martinez, A.J., et al. 2011). In the well-structured humanitarian operations literature (Tatham, P., 2013) the “forward channels” (Fleischmann, M. et al, 1997) of the supply chain have received a high attention while “the reverse flows” not.

For these reasons in this research the author wants to analyze the possible implication of introducing a Close Loop Supply Chain point of view into humanitarian operations. These practices have been already applied in the commercial context e well studied by its literature, but its application in humanitarian field has never dealt with before. In fact although Kovacs

G. and Spens, K. M. (2011) establish the inclusion of reverse flows "is yet to be researched in the humanitarian context" and although Van Wassenhove (2006) considers the possibility of "Material flows, which represent physical product flows from suppliers to customers as well as reverse flows for product returns, servicing and recycling", no real researches focused in this specific issue has been found in the literature (Caunhye, A.M. et al., 2012, Kunz, N. and Reiner, G., 2012, Tatham, P., 2013).

In the literature there have been just some investigations that propose the application of the RL methods into the humanitarian logistics. In 2004 De Vore underlines that "often the reverse supply chain is overlooked, not planned for, and not used when deploying for aerospace expeditionary force rotations, contingencies, wars, sustainment operations, and humanitarian relief operations". In 2013 Hall, M. suggests some alternative views that could be included in humanitarian logistics. Among these alternatives, owned by the private sector, Hall comprises the "reverse logistics capacities" and underlines the possibility to involve the close loop supply chain (Guide & Van Wassenhove, 2003, Dekker et al, 2004). At the same time the academics focus on RL in order to achieve what has been called green humanitarian logistics (Christopher, MG and Tatham, PH, 2011). Especially concerning the environmental impact of the activities on the field where "non-degradable materials in the field have further environmental implications" and where there is practically the total absence of reverse logistics processes. In this way an article presented by Humanitarian research group at INSEAD investigates the humanitarian response and in particular analyzes the environmental impact of the humanitarian response in the post 2010 Haiti earthquake operations, with a focus on the impacts of some items (e. g. water bottles). Furthermore Eng-Larsson, F., and Vega, D. (2011) study the tradeoff in humanitarian field between achieving the green logistics without compromising the short-terms humanitarian objectives.

The problem of greening the humanitarian operations has been underlined by Kovacs, G. and Spens K. M. (2011) and Srivastava, S.K. (2007). Kovacs, G. and Spens K. M. (2011) in particular in the 11th chapter ("A study of the barriers to greening the relief supply chain" by Sarkis, J., Kovacs, G. and Spens K. M) present the importance of an environmental point of view in the evolution of the humanitarian response in order to fit "a variety of pressures faced by the organization including regulatory, competitive, and community/public pressures" even if there are some barriers that have to be passed. According to Kovacs, G. and Spens K. M. (2011) these barriers that don't allow the application of some new practices and procedures into humanitarian context, but the authors underline the importance of future studies "to overcome the barriers and hopefully aid in greening the relief supply chains". On the other hand Srivastava, S.K. (2008) considers and presents the possibility reverse flows in order to achieve the greening supply chain goal. From the commercial supply chain literature, in particular according to Guide & Van Wassenhove (2003, p. 3) the Close Loop Supply chains in commercial SC "include traditional forward supply-chain activities and the additional activities of the reverse supply chain", where the forward activities are typical industrial process while, according to Dowlatshahi (2000) the *reverse channels are the "process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing, or disposal."* This process has to be incorporated in a RL system where the *"supply chain that has been redesigned to manage the flow of products or parts destined for remanufacturing, recycling or disposal and to use resource effectively"*. The RL has been widely dealt with in the literature (Fleischmann et al., 1997, Mahapatar et al. 2013) and usually it faces three main areas of interest: the distribution planning, inventory control and production planning. The RL distribution (Bloemhof-Ruwaard, et al. 1999, Lee, D.-H. et al., 2008) is focused on channels, location, routing problems. Inventory, instead, considers the possibility of returned modules or spare parts in order to be re installed in new products (Teunter, R. H., et al. 2000, Minner , S., 2001, Dobos, I., 2003). At the end, the RL in production is focused on the opportunity to reuse the returned product "as is" or after minor repairs (Srivastava, S.K. 2007, Srivastava, S.K. 2008). The literature presents different possibilities that can belong to different reutilizations of the products, the return flows. A good exhaustive example of the Forms of Return Flows is summarized by Farahani et al. (2011), where once that the products return they are subjected to a selection and after different solutions are available. The main activities after the selection can include two main possibilities: the redistribution and the waste management. The waste management is considered when "a firm has decided that it is no longer of value to reuse, upgrade, or recover materials from a specific product, the product then becomes waste" (Hazen, B. T. et al., 2012) and the activities that are associated to this are disposal and incineration. On the other hand, for the redistribution, the options for the process include different levels of re-elaborating, from a low level of re-elaboration (reuse "as is") to a recycling level, where the operation is not focused on retaining the functionality of used products or parts (Bloemhof-Ruwaard, J. M. et al. 1999). The literature (Ferrer, 1997, Bloemhof-Ruwaard, J. M. et al. 1999) divided the discarded products into three graduations: product recovery, parts recovery and material recovery. The first considers products or packages that could be directly reused or that need just a quick inspection or cleaning, the second graduation (Remanufacturing) contemplates the products that can be disassembled and which components can be reused for new products but the identity of the products is preserved, the third and last degree (Recycling) is focused on the reutilization of the disassemble products parts without maintaining the functionality of the former product. This classification of the post-selection activities is similarly proposed by Hazen, B. T. et al (2012) with the addiction of waste management.

In general in the commercial supply chain all the products that have a strategic cost, products that can increase the overall quality or the customer service, products that can have environmental consequences or that are interested by legislative concerns can be considered as interesting by reverse flow practices. The products usually involved in RL can be various, according to Stock, J. R. (2001) the items that come back and require reverse logistics processing may include product returns, product recalls, end-of-lease equipment, old/obsolete items being replaced, packaging materials and myriad other items.

An important issue is due by the barriers that can make difficult the application of CLSC practices in commercial SC as there are some others, as presented above, that can make it even more difficult in humanitarian SC. As it proposed by Rogers, D. S. and Tibben-Lembke, R. (2001) these barriers are: the importance of RL relative to other issues, company policies, lack of systems, competitive issues, management inattention, personnel resources, financial resources and legal issues.

As it is suggested by the commercial literature review one of the area that can be influence the CLSC regards the distribution planning and the costs that can arise with the reverse flows. In this study the topic considered is the facility location and the minimization of costs in the situation where reverse flows are applied. In humanitarian literature many researches explore the prepositioning of facility to better perform during humanitarian crisis (just few examples are Drezner et al., 2006, Balcik & Beamon, 2008, Doerner et al., 2009, Dõyen, et al. 2011) but no one introduce the presence of the reverse flows. Taking into account all of the features that are raised up in the literature review and barriers this study wants to explore a facility location in the situation of CLSC model and its application in humanitarian operations context considering some features usually present in the field.

7.2. Model

The model is a Close Loop SC model that considers humanitarian features and proposes the presence of reverse flows in order to understand when is possible to implement reverse flows and whether these applications can lead to improvements in terms of supply chain cost and their applicability in humanitarian field. The layout of the distribution structure is shown in the figure below.

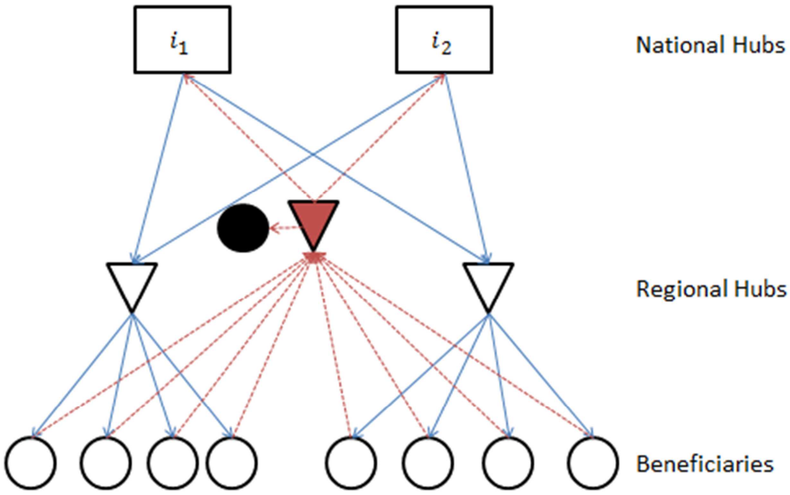


Figure 7.1: Distribution structure

The main reverse after the selection activities considered, as it is suggested by the literature, include two main possibilities: the redistribution and the waste management. In the first case the items return back to the national hub while in the second case they go to the disposal. The product considered are the ones suggested by (Peretti et al., 2014):

1. Those items that have not been used;
2. Those that have been used;
3. Packaging.

In the model these products are E = {1, 2, 3}. These products have different minimum disposal fraction (γ_e) because they have different features and different possibilities of being reused.

Index set:

I set of potential National Hubs i location

J set of potential Regional Hubs j location

D set of disposal options d location

L set of disassembly options l location

E set of demand types e: E = {1, 2, 3}

N set of all demand locations n

K set of beneficiary locations in disposer and reuse market k

The model:

$$FO = \min\left(\sum SC + \sum RC + \sum DC + \sum PnS + \sum PnR + \sum FI + \sum FJ + \sum FDs + \sum FD \right)$$

SC: Supply cost

RC: Reverse Cost

DC: Disposal Cost

PnS: Penalty Cost for not Supplying

PnR: Penalty Cost for not Collecting (Reversing). This considers the savage it is possible to achieve with reuse etc.

FI: Fixed cost to open a National Hub

FJ: Fixed cost to open a Regional Hub

FDs: Fixed cost to open a Disassembly point

FD: Fixed cost to open a Disposal point

Variables

X_{ijke}^{f}= fraction of product e demand of beneficiary k to be served from national hub i and regional hub j

X_{klie}^{r}= fraction of product e returns from beneficiary k via disassembly point l to national hub i

X_{klde}^{r}= fraction of product e returns from beneficiary k via disassembly point l to disposal point d

U_{ke}= fraction of unsatisfied demand of beneficiary k [=0]

W_{ke}= fraction of uncollected demand of beneficiary k

Y_i = indicator opening national hub i

Y_j = indicator opening regional hub j

Y_l = indicator opening disassembly point l

Y_d = indicator opening disposal point d

Costs

C_{ijke}^{f}= unit variable cost of satisfy product e demand of beneficiary k to from national hub i and regional hub j

C^r_{klie}= unit variable cost of product e returns from beneficiary k via disassembly point l to national hub i

C^r_{klde}= unit variable cost of disposing product e returns from beneficiary k via disassembly point l to disposal point d

P^s_{ke}= unit penalty cost for not serving product e demand of beneficiary k

P^c_{ke}= unit penalty cost for not collecting product e returns from beneficiary k

F_i= fixed cost for opening national hub i

F_j= fixed cost for opening regional hub j

F_l= fixed cost for opening disassembly point l

F_d= fixed cost for opening disposal point d

Parameters

d_{ke} = product e demand from beneficiary k in reuse market

r_{ke} = product e returns from beneficiary k in disposer market

γ_e= minimum disposal fraction per e product (different categories of product lead to different percentage of disposal)

$$FO = \min \left(\begin{array}{c} \sum X^f_{ijke} C^f_{ijke} d_{ke} + \sum X^r_{klie} C^r_{klie} r_{ke} + \sum X^r_{klde} C^r_{klde} + \\ \sum U_{ke} P^s_{ke} d_{ke} + \sum W_{ke} P^c_{ke} r_{ke} + \sum_i Y_i F_i + \\ \sum_j Y_j F_j + \sum_l Y_l F_l + \sum_d Y_d F_d \end{array} \right)$$

Subject to

$$\sum_i \sum_j X^f_{ijke} = 1 - U_{ke}$$

The fraction of the supplied product is equal to the satisfied demand for the product e at the customer k

$$\sum_l \left(\sum_i X^r_{klie} + \sum_d X^r_{klde} \right) = 1 - W_{ke}$$

The fraction of the returned products is equal to the satisfied collection for the product e at the customer k

$$\gamma_e(\sum_i X^r_{klie} + \sum_d X^r_{klde}) \leq \sum_d X^r_{klde}$$

The disposing products are at least a γ fraction of all the returned products.

$$\sum_k \sum_l r_{ke} X^r_{klie} \leq \sum_j \sum_k d_{ke} X^f_{ijke}$$

The total amount of shipped products is mayor than the returned items flow

$$\sum_k \sum_e \sum_j X^f_{ijke} \leq Y_i$$

$$\sum_k \sum_e \sum_i X^f_{ijke} \leq Y_j$$

$$\sum_k \sum_e (\sum_i X^r_{klie} + \sum_d X^r_{klde}) \leq Y_l$$

The total amount of shipped products managed is less than the plant capacities.

$$Y_j, Y_l, Y_d \vee \{0,1\}$$

$$0 \leq X^f_{ijke}, X^r_{klie}, X^r_{klde}, U_{ke}, W_{ke} \leq 1$$

Each variable domain

7.3. Model Discussion

The proposed model is innovative because it has never been used in literature. Usually the humanitarian literature applies forward channels to study typical humanitarian issues, as distribution or prepositioning. With this model the author wants to introduce a typical industrial supply chain approach to humanitarian context. In particular in the model to better preposition the plants is introduced the possibility to have reverse flows with typical humanitarian features considered, while the phase of the disaster in which the logistics model is applied is the regular humanitarian operations phase.

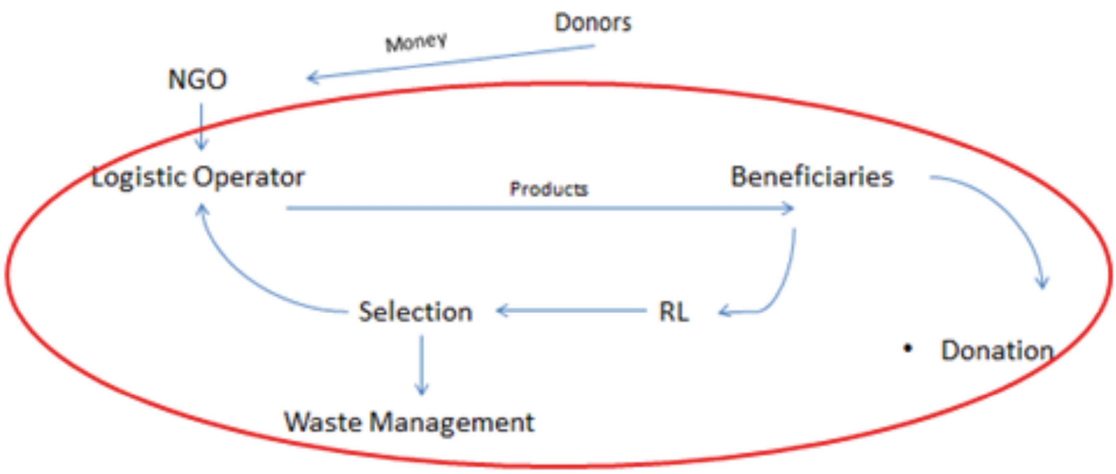


Figure 7.2: Typical humanitarian flows

As introduced in the figure above (Figure 7.2) typically a humanitarian supply chain is financed by the donors, public and private ones, that allow the NGO's to set up the distributions, the specific countries programs or others activities. Concerning the distribution the activities are usually outsourced to logistic operators. These operators follow the NGO's directives and distribute the items to the beneficiaries. Nowadays once the items are supplied the organizations don't consider the possible return of them, just some radio equipment or vehicles are subjected to return in order to be reused in others humanitarian programs. The model in this research applies this possibility to all the items and to the packaging usually let into the area to be considered in reverse flows in order to be reused or disposed.

Further the typical humanitarian supply chain, presented above (figure 7.1), with national and regional hubs, the model considers other humanitarian operations features. According to the literature Peretti et al. (2014) there could be mainly three types of item that could be involved. In particular, it is important to distinguish between (a) those items that have not been used, (b) those that have been used and (c) packaging. Each of these categories has a potential residual value, and could have the opportunities in the reverse flows. These different products have been considered in the model (E = 1, 2, 3) with different features and different γ_e= minimum disposal fraction per product. The different features have been translated in the model with some different items characteristics:

-penalty cost for not collecting

-disposal cost

-transportation cost

-disposal and disassembly operations costs

Moreover the humanitarian literature widely presents the importance delivery items in the area hit by the disaster and underlines the primary importance to satisfy beneficiaries' needs before thinking about the others features of the supply chain. In the model proposed the importance of the forward is underlined, indeed the study of the reverse flows starts just once the forward flows are completely satisfied. In some situations can happen that forward distribution can have lower impact in terms of supply chain management, as can happen less rarely, in this case it is possible to change a bit the model giving penalty costs to unsatisfied demand. This situation is presented in the mathematical section of the model where the fraction of unsatisfied beneficiaries demand $U_{ke}$is fixed as 0. The model show whether or not is economic to consider the reverse flows, the costs are the translation of sustainability, and where has to be put the disassembly point in the case of reverse.

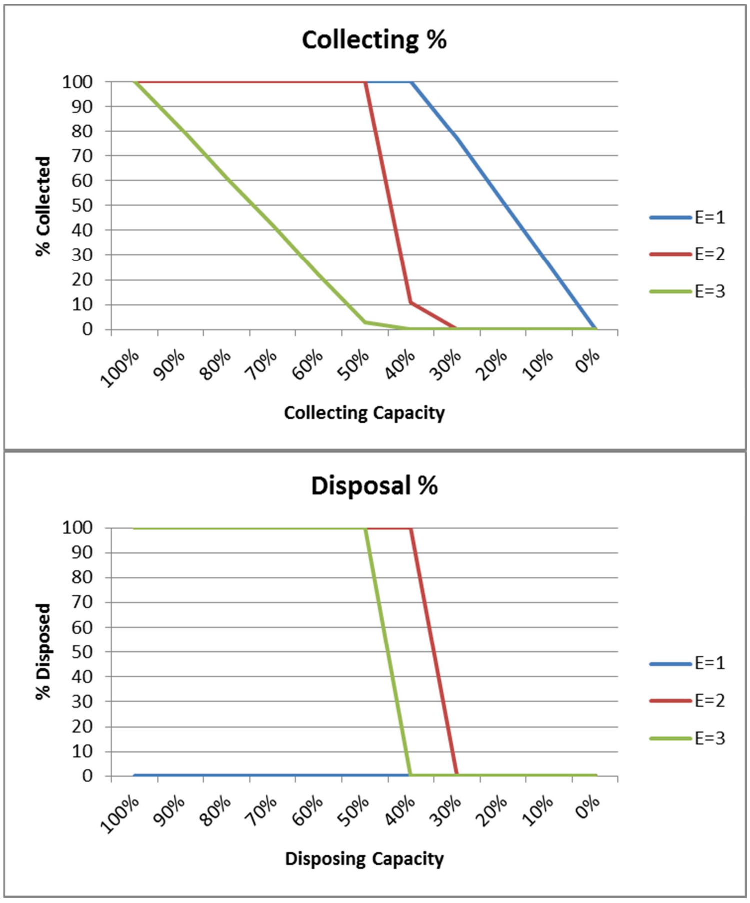


Figure 7.3: percentage of collected and disposal items in function of the reverse available capacity

The application of the model that has been carried out considering the features presented above, in particular the different items and the primary importance of forward flows, in a contest of CLSC in humanitarian field. The results are about the optimization of the reverse logistics. It has been assumed that the disposal capacity is infinite while the reverse available capacity is the variable. In the figure above the results have been found passing from a 100% to a 0% of reverse available capacity per item.

The figure 7.3 shows that different items, with different penalty cost for not reversing and with different, have different priority of return to National Hub to be reused. In particular items E=1, the ones that have not been used, are pushed to return to the national hub and never disposed. This situation translates the great opportunity to reuse them. On the other hand packaging (E=3) is the first product that is let in the area, however with a cost.

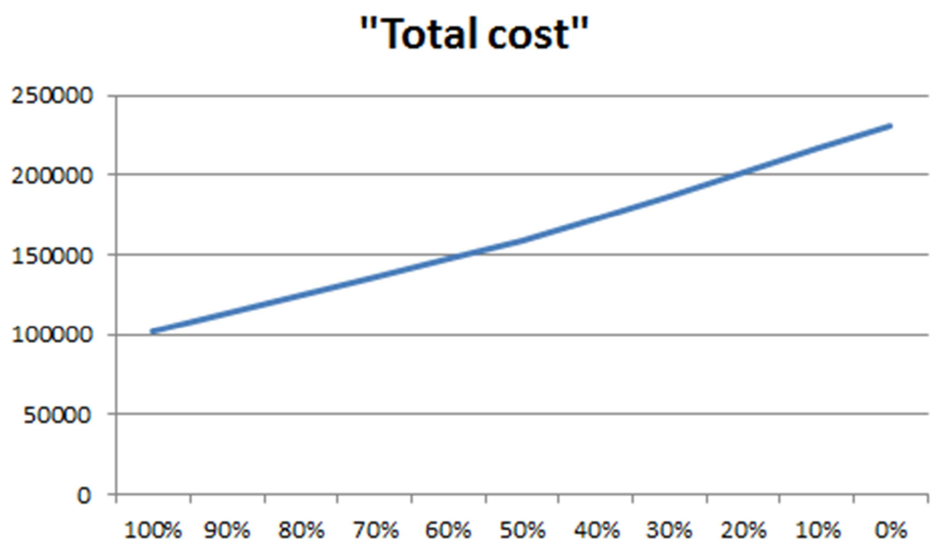


Figure 7.4: Total cost for not reversing

In the figure 7.4 are presented the total cost that can grow up in the case of not reversing. This cost is due by the un-sustainability of the operations and can be minimize considering CLSC and not just a forward one.

8. Conclusions and Future Research

As discussed in the thesis introduction, during the last decades disasters and catastrophes, both natural and man-made, have been radically increased and it seems it will continue during the next years; millions of people around the world are affected annually by disaster phenomena and are, therefore, in need of assistance. This situation underlines the importance of research in the humanitarian field and represents a small step in responding to Van Wassenhove's (2006) call to academics to contribute to the improvement of humanitarian operations. With this thesis the author wants to explore some humanitarian logistics aspects, with a focus on the application of some innovative aspects, such as reverse flows and heuristics with social costs, into the humanitarian field that could translate the growing importance of sustainability in this particular world.

In particular the thesis has these main objectives:

- Introduction and analysis of the literature with a focus on the different criteria usually used for the evaluation of humanitarian operations, definition a decision making framework and its application on real case;

- Introduction and definition of forward distribution models, discussion about humanitarian logistic aspects tradeoff such as the cost analysis versus demand satisfaction and between typical logistic costs versus deprivation costs;

- Introduction and definition of innovative reverse logistics practices based on what is normally used in the industrial supply chain and based on what the humanitarian organizations are implementing in the fields.

The second chapter develops a decision making framework. Here the problems have been split into different hierarchical sub-problems in order to compare the available alternatives and their features in each phase of the operation. The results present a procedure that can support decision makers in their evaluation of operations issues where the attributes of the alternatives are estimated.

In conclusion, the second chapter presents a broad literature review and introduces a framework that can support decision makers in the evaluation of the range of alternatives and that can be applied to different contexts and phases. Future research that utilizes this approach should be undertaken in order to understand how this methodology can further vary according to the parameters of the disaster in question and the implications for humanitarian logistics practitioners of using this framework. Furthermore, it is important to underline how the results of the applications can change just by modifying the weights of the criteria and therefore understanding which are the most appropriate.

The third chapter introduces new distribution models: linear programming models. These explore the Last Mile Distribution Problem by providing a case study to assist decision-makers in making effective and efficient distribution across the last mile. The research focuses upon the distribution systems management coupled with material distribution modalities. Moreover, these models concern the resource allocation and vehicle routing decisions in the well-known Haitian case, with a sensitivity analysis to study the impact of different fleets. The results of this chapter show a not linear increase of fleet costs in function of the number of helicopters an organization needs to satisfy the lack of trucks. This is due by the different costs and capacity of different kind of fleets, and reveals the different fleets' impact in terms of shortage and costs. In conclusion, the chapter analyzes the performance of the delivery system when a co-distribution of different kinds of products is applied. As conclusion and improvements in terms of research, these models are very useful because they can be easily applied in real operations to support the decision makers about what are the best fleet solutions and their impact in the operations performance, defined as costs and shortage. This leads to understand which can be the best way in processing the distribution with the lowest level of cost and which could be the implication in terms of cost and shortage in conditions of limited resources capacity.

The fourth chapter presents a couple of heuristics that can be easily implementable in real humanitarian operations cases and could be used by the humanitarian organizations. In particular these heuristics regard VRP into humanitarian operations. Here can be considered not only logistic costs, but also other aspects, such as those well-introduced in Holguín-Veras et al. (2012) and described as social costs. Thus, the objective of this research is the development and application of heuristics that can solve the VRP in humanitarian context considering the social costs, defined as the sum of logistic and deprivation costs. A new concept of prioritization is introduced, which considers the future evolution of deprivation costs, in function of the distance, the needs at node and the capacity of the vehicle. The results obtained underline the exponential behavior of the deprivation costs and arise in function of the available capacity. These heuristics have sensible improvements in terms of results compared to others simple algorithmic; indeed the use of deprivation costs allows the vehicle to consider not just close nodes. However it finds a trade-off on different costs and it studies these costs not just as they are now but it ponders the growth these could have if we decide to deliver or not. This has notable implication in a field where standard supply chain costs cannot be used.

Chapter 5 has explored the use of Reverse Logistics into humanitarian operations. In particular it has analysed the challenges and opportunities for the application of RL in a humanitarian logistic context through a broad review of both the academic and practitioner literature, supplemented by informal discussions with senior humanitarian logisticians. This section has demonstrated that the reverse logistics concept has started to become a suitable topic into humanitarian field. The finding indicate that, to date, the use of commercial RL practices is extremely limited within the HL sector, but there are a number of areas where their introduction is possible in the future. This part of the study has clearly demonstrated that there are relatively few examples of RL being undertaken in the HL environment. This represents something of a ‘green field’ opportunity for organisations to introduce such practices and, indeed, they use these as a ‘selling point’ in respect of their increasingly competitive funding situation. However, it is also clear that further detailed research is needed to establish the ways in which commercial RL practices can be introduced with the support of host governments, aid agencies, donors and, most importantly of all, the affected populations.

Sixth chapter investigates the management of the most important waste material, the construction and demolition debris, studying a real reverse logistics case, Emilia Romagna earthquake in 2012. The data reflect the great amount of waste generated during and after the two recent Italian earthquakes in more than 1,000 demolition sites. This chapter contributes to the existing literature by providing two reality-based timelines of a disaster both in terms of resources involved and demolition activities. This analysis demonstrates how a huge amount of debris the operations dealt with and the effort involved in order to re-establish the situation as it was before the disaster. From this point the author has investigated the operations to find out how the recovery was done by the organisations involved in the process. Afterwards have been presented different solutions for the future utilisation of the debris; moreover these have been analysed to identify potential issues that could affect operations.

Chapter 8 introduces for the first time the concept of close loop supply chain (CLSC) into humanitarian operations. The objective of this part of research was to complete the previous chapters developing a prepositioning model that could consider reverse flows to support long terms humanitarian operations. This model has been applied in a situation where humanitarian operators are focalized on supply items and where the organizations, as gathered from recent researches, are giving always more importance to the humanitarian operations sustainability, in terms of environmental impact and from an economical point of view. In humanitarian operations generally social costs have to be considered to reduce population needs. Usually these costs are applied in forward logistics researches into post disaster operations. With this study the author has presented the importance of consider the whole operation, so the substance of include reverse logistics into the operations and the impact these practices can have. In fact, the reverse channels start to have an important role in dismantling operations, when the urgency of response is lower. The application of the model shows the results in terms of costs these practices can lead. This cost is the translation of having a more sustainable operation.

In conclusion, the thesis has investigated the importance of sustainability in humanitarian operations. It shows the two different sides of logistics, upstream and downstream.

In the first part the research is focused on humanitarian aids distribution, the forward channels, and proposes new models to improve this operation under humanitarian operations constraints. In the second part of the thesis reverse flows are introduced to improve the long term operations sustainability.

With this the author wanted to introduce a new point of view, not just focused on what is typically performed by the organizations. Indeed, besides the typical relief operations goals, the author wanted to look forward into a more sustainable point of view, where the humanitarian operations will be organized not just to supply items into the area hit by the disaster rather than to include typical reverse practices.

The innovations of this research has been well demonstrated and its applications on humanitarian field have been deeply investigated, well highlighting the great benefits of the models introduced. Several future steps have been introduced in order to continue the research activity in this important field. In particular the models application to real cases could be interesting to further understand and improve sustainable operations. These applications together with this research will be able to present the fundamental role of having sustainable humanitarian operations rather than just humanitarian operations.

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