Multi-criteria decision making in the management of humanitarian operations

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Peter Tatham joined the (UK) Royal Navy as a logistics officer in 1970, and served in a variety of appointments during a career of some 35 years during which he rose to the rank of Commodore. Following his retirement from the RN, he joined the faculty of Cranfield University teaching and researching and completing his doctoral thesis which investigated the role of shared values within UK military supply networks. This work received the 2010 Emerald/EFMD prize for the year's best logistics/supply network management-related PhD. Peter joined the faculty of Griffith University in July 2010 where he continues to teach and research in commercial and humanitarian supply network management. He is the Asian and Australasian Editor of the Journal of Humanitarian Logistics and Supply Chain Management, and a member of the Editorial Board of the International Journal of Physical Distribution and Logistics Management.

1. INTRODUCTION

One of the most challenging features associated with humanitarian operations is their complexity which reflects, amongst other aspects, the multiplicity of actors and stakeholders, the challenges of the physical environment and the speed with which changes occur (Tatham and Houghton, 2010; Altay and Labonte, 2014). 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 (OM) techniques. It is, therefore, unsurprising that the literature contains a number of examples of the use of such approaches as a means of better understanding the challenges associated with the management of humanitarian supply chains (HSCs). Recent examples include the work of Lin *et al.* (2011), Overstreet, *et al.* (2011) and 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.

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. Examples include the availability of capital and humanitarian resources, the number and role of the 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 *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 that differ markedly across each of these phases.

1.1. Purpose and methodology

The overall purpose of this paper is to develop a general multi-criteria decision making framework that will support evaluation of alternatives courses of action within a humanitarian operations context. 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 paper, a robust literature review is used to ascertain the criteria that have been offered by other researchers in their evaluation of HL challenges. 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 top down structured procedure is developed with the decision goal feeding into 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, and using Saaty's (2008, p. 86) scale of comparison (Table 1) the overall or global priorities are obtained. Finally these are used to evaluate the final priorities of the alternatives at the bottom-most level.

1.2. Findings

This research defines and determines the general problem and the system characteristics relating to the humanitarian operations leading to the development of a structured decision hierarchy or framework. This framework, which differs from those currently found within the literature (e.g. Richey, 2009; Liberatore *et al.*, 2014), can be used in every phase of the disaster and for different issues because allows the use of different priorities for different situations through the utilization of the Analytic Hierarchy Process (AHP). The importance of the application of this tool in humanitarian operations reflects its potential to support the evaluation of complex issues in a wide range of applications; moreover during the evaluation of the criteria the consistency helps the decision makers determine the appropriate relative importance. Another important feature is that the robustness of the results is easily verifiable through a sensitive analysis and this, in turn, assists in understanding how the evaluation of different criteria can condition the overall output.

In short, this research provides a set of guidelines that will assist managers in their understanding of the criteria and their impact mainly on decision making in humanitarian context and how different criteria or alternatives evaluations impact in the final result.

1.3. Outline of the paper

The paper is structured as follows: the next section reviews the relevant literature on operations management within a humanitarian logistics context. The third section introduces the hierarchical decision making process. In the sections that follow, more details are given about

the problem and the system characteristics, with a focus on the humanitarian operations life cycle, and the hierarchy structure framework, in particular as these relate to the primary, secondary and tertiary criteria. Some examples are then offered in order to explain the methods and the framework applicability. The next section presents a real application of the model with the results synthesis to determine an overall outcome. Moreover, as suggested by Saaty (1980), a sensitivity analysis is presented to evaluate the final result. The final section of the paper incorporates a discussion of the research, its conclusions and some proposed areas of further investigation.

2. 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.

The last decade has seen humanitarian operations receiving increasing attention by the researchers with further aspects continuing to be explored – see, for example, the work of Littieri *et al.* (2009), Natarajathinam *et al.* (2009), Caunhye *et al.* (2012), Kunz and Reiner (2012) and John *et al.* (2012). Within the literature of this relatively new field of research a broad range of OM aspects have been considered such as the context (Altay and Green, 2006; Van Wassenhove, 2006; Kovács and Spens, 2007), the challenges of the field as a whole (Kovács and Spens, 2009; Balcik, *et al.*, 2010), emerging trends (Apte, 2009; Kovács and Spens, 2011). However, within the literature that has been a general consensus supporting the definition of humanitarian supply chains offered by Thomas and Kopczak. These authors adjusted the Council of Supply Chain Management Professionals (CSCMP) definition of commercial logistics 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 also 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, Kovács 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 that are used in HSCs (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 researchers 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 and Turnquist, 2010; Campbell and Jones, 2011; Lodree, 2011) and supply items (Knott, 1987; Haghani and Oh, 1996; Balcik *et al.*, 2008; Nolz *et al.*, 2010).

Some of these macro level 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 with short lead times for a wide variety of supplies.
- High stakes associated with the achievement of 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 the need for a structured approach in order to improve the future operations, it is argued that whilst the linear programming approach which models aspects such as costs, time and service level is helpful, a broader multi-criteria approach that utilises different factors at different levels is necessary.

In particular and as outlined earlier, when introducing the research into 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 Kovács 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; (3) the transition; (4) a phase of support (sustainment); and (5) the final phase of dismantling (ramping down). Importantly, the work of Safran (2003) introduces the concept of cyclical approach to disaster management operations wherein the end of one disaster life cycle corresponds with the beginning of another disaster management cycle.

Figure 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 clearly indicates that 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 OM 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 would 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 explained later in the paper, 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, we 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).

On the other hand, the limitations of the AHP approach are well summarized by Ishizaka and Labib (2009), with 5 limitations being particularly relevant to the application of the presented framework:

- Problem structuring: Different structures 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 together with the authors’ experience 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 paper 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.

3. 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 *et al.*, 2009; Peng and Yu, 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, and Barman, 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 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 1), and this will be adopted within the current research.

Table 1: Saaty's scale of comparison

Intensity of Importance a_{ij}	Definition	Description
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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 from the higher level to weight 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 paper.

4. PROBLEM CONTEXT: HUMANITARIAN OPERATIONS

The main purpose of this paper is to develop a general multi-objective framework to support decision makers in their 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 (2003) which offers three phases: prevention, transition, and recovery as shown in Figure 1.

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

- A. *Prevention*: According to Murray (2005) and Kovács 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. Van Wassenhove *et al.*, 2012) with Awan and Rahman (2010, p. 23) arguing that the response has to be “speed at any cost and the first 72 hours are crucial”. 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 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”. Importantly, within the overall recovery phase, three sub-phases have been identified by Safran (2003). The first of these, 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 operation. 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 this 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.

5. 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 the 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 Figure 2 (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 centre of the image.

Figure 2: Humanitarian Operations framework

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

5.1. 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, therefore, to help decision makers

make these difficult choices through the use of a structured tool that considers different criteria in a rational way.

5.2. 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 those of 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.

5.3. 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 *et al.*, 2010, Dubey *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 United Nations agencies/non-government organisations (NGOs)) focusing on supporting the beneficiaries – 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 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.

5.4. 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 labour, 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.

6. 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 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.

6.1. Numerical Examples

The following section uses four examples of issues faced in real-life operations, with one selected from each of the three life-cycle phases discussed above. This section shows the applicability of the framework and the variance of the weights and priorities of the criteria in relation to 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 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 presented based on authors' experience/expertise.

6.1.1. Location of Local Distribution Centres in Preparedness (Prevention phase)

As Anand *et al.* (2012) note, the location of a plant such as a distribution centre is critical but, at the same time, is 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 plant, 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. 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. These pairwise comparisons are numerical examples for the utilization of the tools and the nature of

the outputs. These comparisons have been developed based on authors' experience/expertise and are aimed at demonstrating the method of application.

Table 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 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 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

6.1.2. Vehicle Routing in the Emergency (Transition phase)

Optimal vehicle routing is selected as an example of the methodology because, in the transition phase, and especially in the emergency situation, the distribution of items from the hubs or regional distribution centres 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, service level and time are considered as the predominant optimization factors (Pedraza Martinez *et al.*, 2010). Moreover, in the literature,

many examples of vehicle routing are presented which are designed around the optimization of the times and the service levels for the distribution of items. As in the previous example, the primary drivers' comparisons are shown below:

Table 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 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 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

6.1.3. 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 – the so-called ‘last mile distribution’. As Safran (2003) suggests in his model, the recovery phase is split into different sub-phases and the drivers considered are not the same in each of these. Indeed, in the first sub-phase of the restoration phase the drivers are more similar to those in the transition phase, with the major weight associated with cost. However, in the second phase of recovery (which includes rehabilitation and reconstruction), and in line with the suggestion of Awan and Rahman (2010), it is argued that efficient technical and material support are important. In this phase there is also,

as suggested by Battini *et al.* (2014), a growth of the importance of the costs in the optimal solution even if this remains less important than the time and service components.

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

Table 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 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 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

6.1.4.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 particular importance, while cost becomes more relevant, 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 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 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

Table13: 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

7. REAL CASE

In order to complete the presentation of the decision making procedure, a real humanitarian logistic distribution case study has been developed using the approach adopted in this paper 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 struck Haiti in January 2010, 222,570 people were killed, with many thousands

more being injured, and 1.5 million were left homeless. For these reasons, in order to meet the basic needs of the affected population, several assessment teams arrived and started their work. The two phases in which the problem is tested are , therefore, the transition and recovery phases.

According to Battini *et al.* (2014), in a disaster such as that in Haiti, items that have to be delivered to the vulnerable groups include 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, 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 authors consist of 3 possibilities (A, B and C). The application of the framework helps the decision makers in finding the best one through comparison of the available data, and where the data is not available it considers the lower level of criteria.

The two-vector distribution in this case presents two different solutions (see table 14):

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

- (3) 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 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 (1) and (2) B do not require coordination between the two different suppliers, even if (2) requires a low level of coordination because it uses two different vehicles. On the other hand, alternative (3) 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.

(2) is better than (1) and (3), 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 is to find the best alternative possible in the range of 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.

8. SENSITIVITY ANALYSIS: EVALUATION OF DECISION ROBUSTNESS

According to Saaty (1980, 2008), the final step of the evaluation consist of the assessment of the robustness of the results As will be demonstrated in this section of the paper.

In table 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 14 refer to the considerations mentioned previously. The best alternative is the one with the highest priority overall.

Table 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		

Table 15: Proposed weights per criteria and alternative, associated to the phases

EMERGENCY (TRANSITION 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	Resources	Infrastructures	Beneficiaries	Soc., Cult. & Pol. Factors							
		0.115	0.359	0.216	0.222	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	Resources	Infrastructures	Beneficiaries	Soc., Cult. & Pol. Factors							
		0.149	0.336	0.255	0.18	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

From table 15 in relation to the transition phase it will be appreciated that alternative (2) 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; (2) is the most agile. On the other hand, still referring to table 15, in the recovery phase, the most suitable alternative becomes alternative (3) as 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, a sensitivity analysis has been carried out in line with Saaty's (2008) advice. This analysis allows an 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 16 and provides a general evaluation of the obtained results. The model appears very robust because only in a few cases does the best alternative changes.

Table 16: Sensitive analysis associate to the Real Application in aids distribution

EMERGENCY (TRANSITION PHASE)		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]		
		Based Scenario [tab. XX]																				
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)		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]		
		Based Scenario [tab. XX]																				
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

9. CONCLUSION

A key conclusion from these results is that of underpinning 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. It is important to note the presenting the specific weights associated with real operations was not the objective of this paper; rather, the intention was to introduce and explain the framework and its applicability in the possible applications using weights that are drawn from the authors' background and experience.

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 just such an example of the decision making application and the sensitivity analysis demonstrates its robustness.

In conclusion, this study presents a framework that can support decision makers in the evaluation of a range of alternatives that can be applied to different contexts and phases.

Future research utilizing this approach should clearly 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.

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