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A framework to compare OR models for humanitarian logistics

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Abstract

A multitude of OR models – mainly mathematical programs – has been published in relevant journals to support decision-making in the field of humanitarian logistics. Due to the effort that comes with their application, these models are often not adapted by practitioners in humanitarian organizations. Clearly, one part of the effort relates to the comparison process in which the decision-maker has to choose the most appropriate model out of the available OR models. In this contribution, a framework is presented that should help decision-makers in the field of humanitarian logistics to compare available OR models. Three different ways how to compare OR models are introduced: based on the decision they support, based on the decision criteria and metrics they use, and based on their underlying methodology and assumptions. To serve as an illustration, two mathematical programs for the specification of stationary warehouses for relief items are compared with the help of this framework. In the long run, this framework will guide users of a methodological toolkit for humanitarian logistics to the most appropriate OR model for their decision problem. The development of such a methodological toolkit is the overarching goal of this work-in-progress.

Keywords: Humanitarian logistics, Operations Research

1. Introduction

Disasters – whether caused by nature or human activity – are defined as serious disruptions of the functioning of society. They pose a significant, widespread threat to human life, health, property, and the environment, and can develop suddenly or slowly as a result of complex, long-term processes [1]. Between 1970 and 2010 natural disas-

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ters killed 3.3 million people, an annual average of 82,500 deaths worldwide in a typical year [2]. Besides fatalities, these events cause severe injuries, communicable diseases, damage to health facilities, damage to water supplies, damage to food supplies, and population displacements. Experience has shown that these events again cause needs for certain types of relief items in and around the affected area: severe injuries, communicable diseases, and damage to health facilities require the provision of health care items; damage to water supplies requires the provision of drinking water; lack of food requires the provision of religiously, culturally, and traditionally appropriate food; and physical displacement of population requires the provision of shelter, non-food items (e.g. clothes and bedding) and sanitation systems. Humanitarian logistics networks are used for the distribution of these relief items in the aftermath of a disaster [3].

A multitude of OR models is available to support decision-makers in the field of humanitarian logistics. Recent overviews on existing mathematical programs were given in [4] and [5]. However, as it is pointed out in [6], these models are often not adopted by relief organizations due to various reasons including sparse time, limited staff availability, and limited funding. In order to reduce organizations' effort to adopt available analytical models, the overarching goal of this work-in-progress is to develop a methodological toolkit for humanitarian logistics. With its help, practitioners should be able to find, compare, and apply available models for their particular decision problem. In order to guide users through the toolkit to the right model, a framework is needed. In the first part of this paper, the components of such a framework are presented that enables practitioners to compare available OR models. In the second part, two mathematical programs are exemplarily compared based on this framework.

2. A framework to compare OR models for humanitarian logistics

Both, commercial and humanitarian logistics processes account for the flows of goods between the nodes of a network. However, while commercial supply chains are generally permanent structures, large parts of humanitarian logistics networks can only be setup after a disaster strikes. These temporary networks, commonly consisting of temporary warehouses in bigger cities, distribution centers and drop-off points, have to be interlaced into a crisis region where transport corridors may be broken, unsafe or unsecure, where failed communication systems remove the logical links between the actors (private sector, specialized military/non-military institutions, NGOs, UN agencies), and where the locations of beneficiaries are dynamic or unknown [7].

2.1. Decisions in humanitarian logistics

The designing and running of a humanitarian logistics network comprises several decisions. In the preparedness phase the locations, capacities, relief item stocks, and suppliers of stationary warehouses need to be specified together with the types, locations, capacities, and suppliers of pre-positioned transportation vehicles and the locations of the professional workforce within the permanent network. After a disaster strikes, this permanent network is extended in the direction of the disaster location. How the network spreads into the disaster area depends on the results of the initial rapid assessments. In the assessment process, information about the specific needs, available resources, and social, cultural, and environmental characteristics of the disaster area are collected from secondary data analysis and community level assessments. The specification of the routes and schedules of community level assessment teams is one of the tasks of humanitarian logistics in the disaster response phase. Others are the locating of temporary warehouses, distribution centers, and relief item drop-off points in the disaster area, the locating of staging areas for non-priority donations, the assignment of the professional and volunteer workforce to the different nodes of the temporary network, the selection of suppliers and replenishment orders, and the specification of the type, number, load, route, and schedule of transportation vehicles [3]. In the following Table 1, those decisions that comprise the field of humanitarian logistics are outlined. These decisions can be either assigned to the disaster preparedness or the disaster response phase of the disaster management cycle. Table 1 is the first component of the framework that should enable practitioners to compare available decision support models for humanitarian logistics; a comparison based on the models' function.

Table 1. Decisions in the field of humanitarian logistics.

Decisions in the disaster preparedness phase	Decisions in the disaster response phase
Specification of…	Specification of…
• location, capacity, supplier, and stocks of stationary warehouses	• routes and schedules of community level assessment teams
• type, number, location, capacity, and supplier of pre-positioned transportation vehicles	• location, capacity, and stocks of temporary warehouses and distribution centers
• location and number of professional workforce	• location of drop-off points within the affected settlements
	• location of staging areas for non-priority donations
	• location and number of professional and volunteer workforce
	• suppliers and replenishment orders for relief items
	• types, numbers, loads, routes, and schedules of transportation vehicles

2.2. Decision criteria and metrics in humanitarian logistics

Making decisions in the field of humanitarian logistics results in a specific configuration of the permanent and temporary parts of a humanitarian logistics network. A certain configuration needs a specific amount of inputs (e.g. warehouses, vehicles, workforce, relief item stocks) and has desired and non-desired outputs, i.e. effects on beneficiaries, society, and the ecosystem. For the decision-maker who decides the configuration of a humanitarian logistics network, the various inputs and outputs of such a network are the decision criteria. It is assumed that the decision criteria used in humanitarian logistics are essentially equivalent to those used in commercial logistics: resources, delivery service, social effects, and ecological effects [8]. However, the importance of the specific criteria can differ depending on whether they are applied in a humanitarian or commercial context. This is particularly true for the sub-criterion delivery time which is generally of bigger importance in the field of humanitarian logistics than in the field of commercial logistics [9].

In order to measure the performance of a particular humanitarian logistics network's configuration in the different decision criteria, metrics are needed. Utilization metrics measure the usage of inputs reported as a ratio of the actual amount of inputs to a target value [10]. Effectiveness metrics measure the output quality reported as a ratio of the actual amount of outputs to a target value [10]. Impartiality metrics measure the difference in the effectiveness among the beneficiaries in the disaster area. As such, impartiality metrics capture the wider principle of non-discrimination which says that no one should be discriminated against on any grounds of status, including age, gender, race, color, ethnicity, sexual orientation, language, religion, disability, health status, political or other opinion, national or social origin [11]. Productivity metrics measure the transformational efficiency of a configuration as a ratio of actual outputs to actual inputs [10]. Finally, flexibility metrics measure the transformational efficiency of a configuration over time [12] reported as the amount of additional inputs necessary to adapt to changes in the demand pattern (action flexibility) or as the number of different demand patterns a network can serve without additional inputs (state flexibility) [13]. In Table 2, decision criteria and metrics used in humanitarian logistics are presented. Table 2 is the second component of the framework that should enable practitioners to compare available decision support models for humanitarian logistics; a comparison based on the models' decision criteria and metrics.

Table 2. Decision criteria and metrics used in humanitarian logistics.

Category	Criterion	Sub-criterion	Metrics
Inputs	Resources	Coordination	Utilization
		Procurement	
		Warehousing	
		Transportation	
		Handling	
		Distribution	
Outputs	Delivery service	Relief item quantity	Effectiveness, Impartiality
		Relief item quality	
		Delivery time	
		Distribution location	
		Delivery service information	
	Social effects	Workforce satisfaction	
		Workforce safety	
		Workforce diversity	
		Supplier diversity	
		Beneficiaries participation	
	Ecological effects	Air pollution	
		Climate change	
		Accidents	
Efficiency			Productivity, Flexibility

2.3. OR models for humanitarian logistics

In general, OR models are based on a specific methodology that provides a scientific approach in the process of decision-making, make specific assumptions about the real world, use specific input parameters, and have a specific complexity. [14] identified mathematical programming (23%), decision analysis (9%), and simulation (9%) as the most commonly used methodologies in the field of disaster management – a field that includes humanitarian logistics. They also list a number of unrealistic, limited, and reasonable assumptions regularly included in decision support models for disaster management. Parameters included in OR models can be distinguished into those whose definition leaves room for interpretation, and others that do not. Finally, regarding the complexity of an analytical model, a gross division is often made between those that can be solved in polynomial time and those that cannot be solved in polynomial time, no matter what algorithm is used. Table 3 contains the attributes that can be used to describe an OR model for humanitarian logistics; it is the third component of the framework that should enable practitioners to compare available decision support models for humanitarian logistics; a comparison based on the decision support models' methodology, assumptions, parameters, and complexity.

Table 3. Characteristics of decision support models.

Attribute	Specification
Methodology	Math. Programming, Decision Analysis, Simulation, Expert Systems, Soft OR
Assumptions	Unrealistic, limited, reasonable
Parameters	Scope of interpretation
Problem complexity	Polynomial, nondeterministic polynomial problem

3. Comparison of two mathematical programs for humanitarian logistics

In this section, an exemplary comparison of two decision support models is described; namely the comparison of the models developed by [15] (Balcik and Beamon, 2008) and [16] (Bozorgi-Amiri et al., 2013). Both can be assigned using Table 1 to those models that support the specification of stationary warehouses for relief items in the pre-disaster phase; both can be characterized using Table 3 as mathematical programs and as nondeterministic polynomial problems (because of their use of binary variables); and moreover both are stochastic programs and contain two types of decision variables: design and control variables. Design variables describe the location and stocks of stationary warehouses within the underlying transportation network; they cannot be adjusted by the program once a specific disaster is observed. Each possible disaster is represented by a scenario with a certain probability of occurrence, with certain demands for relief items at specific nodes of the network, and with certain transportation costs on specific arcs. The flows of relief items from warehouses to demand locations are described by control variables and depend on the values assigned to the design variables and the realization of the scenario-dependent parameters. [14] evaluate the usage of scenarios in OR models for humanitarian logistics as a limited assumption if data of previous disasters is scarce or disasters occur in a low frequency. Furthermore, [14] evaluate the usage of deterministic scenario-dependent demands for relief items and deterministic scenario-dependent transportation costs as unrealistic assumptions.

3.1. Stationary warehouse specification model of Balcik and Beamon (2008)

In the program of [15], coverage of the relief item demands in the scenarios is maximized while adhering to a maximum available budget. More precisely, their model maximizes the percentage of fulfilled demands for relief items. Each delivered relief item contributes to the value of the objective function depending on the probability of the scenarios in which it used, its general importance for the beneficiaries, and the weight assigned to the transportation time necessary for its delivery to the demand location. The available budget needs to cover procurement costs, warehouse setup costs, and transportation costs between warehouses and demand locations.

Procurement costs, warehouse setup costs, and transportation costs are utilization metrics (U) that capture the criteria procurement, warehousing, and transportation, respectively. Transportation costs can be used as an effectiveness metric (E) to capture the criterion delivery time, just as the transportation time weights. Percentage of fulfilled demand is an effectiveness metric used to capture the criterion relief item quantity. Efficiency of the configuration is measured by the objective function's value. It conveys the extent of demand coverage possible with a given budget. Hence the objective function's value is a productivity metric (P). See the following Table 4 for an overview on the decision criteria and metrics used in [15].

Table 4. Decision criteria and metrics used in Balcik and Beamon (2008).

Category	Criterion	Sub-criterion	Metrics (U: utilization, E: effectiveness, P: productivity)
Inputs	Resources	Procurement	Procurement costs (U)
		Warehousing	Warehouse setup costs (U)
		Transportation	Transportation costs between warehouses and demand points (U)
Outputs	Delivery service	Relief item quantity	Percentage of fulfilled demand (E)
		Delivery time	Transportation time weight (E)
			Transportation costs between warehouses and demand points (E)
Efficiency			Objective function value (P)

Particular challenges arise with the application of [15] when defining the values representing the importance of relief items for beneficiaries and the weights assigned to transportations times since both definitions leave room for interpretation and [15] do not present a procedure that can support the model-user in the definition process.

3.2. Stationary warehouse specification model of Bozorgi-Amiri et al. (2013)

In the program of [16] two objectives are pursued simultaneously using the Compromise Programming approach. Both objectives are weighted and linearly combined to an objective function which aims at minimizing the sum over the normalized differences between each objective's value and a user-defined target value. Both objectives consist of two terms and both second terms are weighted with a user-defined factor. The first term of the first objective computes the total costs of the configuration, consisting of procurement costs, warehouse setup costs, transportation costs between suppliers and warehouses, transportation costs between warehouses and demand locations, holding costs for unused stocks, and shortage costs for unfulfilled demands; the second term of the first objective computes the differences between scenario-dependent costs. Furthermore, the first term of the second objective computes the maximum relief item shortage in each scenario while the second term of the second objective computes the differences between the maximum relief item shortages across scenarios.

Procurement costs are used as an utilization metric to capture the criterion procurement, warehouse setup costs and relief item holding costs are used as utilization metrics to capture the criterion warehousing, and the transportation costs between suppliers, warehouses, and demand locations are utilization metrics to capture the criterion transportation. Transportation costs between warehouses and demand locations can also be used as an effectiveness metric to capture the criterion delivery time. Relief item shortage costs are used as an effectiveness metric to capture the criterion relief item quantity. Furthermore, the maximum relief item shortage in a scenario is a metric that captures the criterion relief item quantity. More precisely, it captures the impartiality of the configuration regarding the supply of demand locations with relief items in a specific scenario. The difference between the maximum relief item shortages across scenarios is also a metric that captures the criterion relief item quantity. In this case it captures the impartiality of the configuration regarding the supply of demand locations with relief items across all scenarios. Efficiency of the configuration is measured by the total costs. This term conveys the costs that come with a certain amount of unfulfilled demand and can be considered a productivity metric. Efficiency of the configuration is also measured by the difference between scenario-dependent costs. Obviously, the lower the difference between scenario-dependent costs the higher is the configuration's action flexibility (F). The objective function combines both objectives. Since the first objective contains utilization, effectiveness, and flexibility metrics and the second objective contains effectiveness and impartiality metrics, the objective function's value is a metric that captures the configuration's productivity and flexibility. See the following Table 5 for an overview on the decision criteria and metrics used in [16].

Table 5. Decision criteria and metrics used in Bozorgi-Amiri et al. (2013).

Category	Criterion	Sub-criterion	Metrics (U: utilization, E: effectiveness, I: impartiality, P: productivity, F: flexibility)
Inputs	Resources	Procurement	Procurement costs (U)
		Warehousing	Warehouse setup costs (U)
			Relief item holding costs (U)
		Transportation	Transportation costs between suppliers and warehouses (U)
			Transportation costs between warehouses and demand points (U)
Outputs	Delivery service	Relief item quantity	Relief item shortage costs (E)
			Maximum relief item shortage in a scenario (I)
			Difference between maximum relief item shortage across scenarios (I)
		Delivery time	Transportation costs between warehouses and demand points (E)
Efficiency			Total costs including shortage costs (P)
			Differences between scenario-dependent costs (F)
			Objective function value (P,F)

Particular challenges with the application of [16] are connected with a multitude of parameters whose definitions leave room for interpretation. These include the definitions for relief item shortage costs, weighting factors of the second terms in both objectives, weights of each objective in the objective function and target levels for each objective in the objective function. [16] do not present a procedure that can support the models-user in the definition process of these parameters.

4. Conclusions and Outlook

Humanitarian logistics networks realize relief item flows from stationary relief item warehouses via several hubs to the beneficiaries within disaster areas. Their setup and operations comprises several activities and the execution of these activities can be more efficient and effective if analytical models are applied. In this paper, a framework is proposed that should enable practitioners in the field of humanitarian logistics to compare available OR models. This framework will be a crucial part of a methodological toolkit for humanitarian logistics – a part necessary to guide its users to a model that fits to their particular problem. The development of such a toolkit is the overarching goal of this work-in-progress. Once a first version of the toolkit is completed, each included model should be accompanied with a corresponding program code in an appropriate language and with an example of its application. An appropriate language to code the mathematical programs of [15] and [16] could be OPL, a programming language frequently used to code mixed-integer linear programs. In the long run, the toolkit should be made available online in order to spread the use of analytical models in the field of humanitarian logistics. From then on, researchers should be able to add their model to the platform. It could also be of use to identify open research questions as well as sufficiently covered activities in the field of humanitarian logistics whereby the risk of redundant model building could be reduced.

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