Methodological tool kit for humanitarian logistics

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ABSTRACT

Disasters trigger the need for relief items. The flows of relief items to the beneficiaries in the disaster area are determined by humanitarian logistics networks. The setup and operations of such networks can be supported by employing Operations Research models. Several models, based on different methodologies are available to support decision-making in the field of humanitarian logistics. This work-in-progress analysis suggests a structure of a methodological tool kit for humanitarian logistics. With its help, practitioners in the field of humanitarian logistics should be better equipped to find, compare, and apply available analytical models for their individual decision problem. To serve as an illustration, one OR model is presented in detail according to the proposed structure of the methodological tool kit.

Keywords

Humanitarian logistics, methodological tool kit, Operations Research

INTRODUCTION

Natural and man-made disasters are serious disruptions of the functioning of society and pose a significant, widespread threat to human life, health, property and the environment (Kovács and Spens, 2009). Between 1970 and 2010 natural disasters killed 3.3 million people, an annual average of 82,500 deaths worldwide in a typical year (World Bank, 2010). Besides fatalities, disasters can cause severe injuries, communicable diseases, damage to health facilities, damage to water supplies, damage to food supplies, and population displacement. Experience has shown that these effects 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 the displacement of population requires the provision of shelter, non-food items (e.g. clothes and bedding) and sanitation systems (Pan American Health Organization, 2001). Humanitarian logistics networks are used for the distribution of relief items in the aftermath of a disaster. These networks are setup and operated by various actors in the field of humanitarian logistics, including national disaster response agencies, the private sector, specialized military and non-military institutions, NGOs, and UN agencies (Pan American Health Organization, 2001).

In order to support the different decisions that are necessary to setup and run a humanitarian logistics network, several Operations Research (OR) models have been published in recent years in relevant academic journals. These models are based on different types of methodologies – mainly on mathematical programming. In this work-in-progress analysis a structure of a methodological tool kit for humanitarian logistics is proposed. The tool kit's main purpose is to reduce the effort of a practitioner in the field of humanitarian logistics to find and apply an OR model that fits best to support her or his particular decision problem.

HUMANITARIAN LOGISTICS

The designing and operations of humanitarian logistics networks require humanitarian organizations to make several types of decisions. These decisions can either be assigned to the disaster preparedness or the disaster response phase of the disaster management cycle (Tomasini and Van Wassenhove, 2009). In the disaster preparedness phase, the permanent part of the humanitarian logistics network is determined. This step comprises the specification of locations, capacities, suppliers, and stocks of the stationary warehouses where humanitarian organizations store ready-to-dispatch piles of relief items. This step also comprises the specification of types, numbers, locations, capacities, and suppliers of pre-positioned transportation vehicles as well as the specification of the number and location of the professional workforce. After a disaster strikes, the permanent part of the humanitarian logistics network is extended by a temporary part. How the temporary part of the network spreads into the disaster area depends on the results of the initial rapid assessments. One of the decisions in the disaster response phase is the specification of the routes and schedules of community level assessment teams. Others are the locating, capacitating, and stocking of temporary warehouses, the locating of distribution 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 (Pan American Health Organization, 2001). Table 1 outlines the decisions that comprise the field of humanitarian logistics.

Decisions in the disaster preparedness phase	**Decisions in the disaster response phase**
Specification of… • location, capacity, suppliers, and stocking of stationary relief item warehouses • type, number, location, capacity, and suppliers of pre-positioned transportation vehicles • location and number of professional workforce	Specification of… • routes and schedules of community level assessment teams • location, capacity, and stocking of temporary warehouses • location of distribution points in the disaster area • location of staging areas for non-priority donations • location and number of professional and volunteer workforce • suppliers and replenishment orders of relief items during the operations • type, number, loads, routes, and schedules of transportation vehicles

Table 1. Decisions in the field of humanitarian logistics

METHODOLOGICAL TOOL KIT FOR HUMANITARIAN LOGISTICS

Commonly used OR methodologies that provide a scientific approach in the process of decision-making are mathematical programming, simulation, decision analysis, and soft OR (Altay and Green, 2006; Galindo and Batta, 2013). Recently, Galindo and Batta (2013) gave an overview on methodologies used in the field of disaster operations management – a field that includes humanitarian logistics. They found out that decision support models for disaster operations management are mainly based on mathematical programming (23%) followed by decision analysis (9%) and simulation (9%). However, as it is pointed out by Altay and Green (2006), analytical 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 an organization's effort to adopt available analytical models, a methodological tool kit for humanitarian logistics is being developed and outlined in this paper.

With the help of such a tool kit, practitioners should be able to find, compare, and apply available OR models for their particular decision problem. Several challenges arise with the development of such a tool kit. Firstly, the available OR models should be assigned to the decision(s) they support using the framework shown in Table 1. Secondly, the available models should be sorted by their underlying methodologies; namely if they are based on mathematical programming, simulation, decision theory, or soft OR. Thirdly, models using the same methodology and supporting the same decisions should be made comparable by adjusting their mathematical notations. Fourthly, the tool kit should enable practitioners to get a quick inside in the mechanics of OR models without going through the mathematical formulation in detail; it is assumed that this could be achieved by a structured model profile that explicitly analyzes a model's decision criteria and performance metrics, the influence the model-user has on the model's outcome, the assumptions the model makes about the task environment, and the scope of interpretation associated with the definition of certain model parameters. Fifthly, the application of the OR models included in the tool kit needs to be eased. Therefore each model should come with a corresponding program code in an appropriate language and with an example of its application. Table 2 shows an extract of the proposed structure of the methodological tool kit.

Phase	Decision	OR Methodology	OR Model	Characterization
Disaster preparedness	Specifying location, capacity, suppliers and stocking of stationary relief item warehouses	Mathematical programming	Rawls & Turnquist (2011)	1. Mathematical formulation
				2. Model profile: a) Decision criteria & performance metrics b) Model-user's influence on outcome c) Assumptions & parameters
				3. Program code
				4. Example
			…	…
		Simulation	…	…
		Decision analysis	…	…
		Soft OR	…	…
…	…	…	…	…

Table 2. Proposed structure of the methodological tool kit for humanitarian logistics

To serve as an illustration, in the following section some characteristics of a specific OR model are presented as they will be in the tool kit. The model under consideration is the mathematical program of Rawls and Turnquist (2011) that can support decision-makers to specify the location, capacity, and stocks of stationary relief item warehouses. The model was identified using the reviews of Caunhye, Nie, and Pokharel (2012) and De La Torre, Dolinskaya, and Smilowitz (2012) and additionally searching appropriate databases. In total, four analytical models – all based on mathematical programming – were identified for the specification of stationary relief item warehouses; namely those developed by Balcik and Beamon (2008), Bozorgi-Amiri, Jabalameli, and Mirzapour (2013), Döyen, Aras, and Barbarosoğlu (2012), and Rawls and Turnquist (2011).

TOOL KIT INFORMATION ABOUT THE MATHEMATICAL PROGRAM OF RAWLS & TURNQUIST (2011)

In this section, the mathematical program of Rawls and Turnquist (2011) is characterized by its mathematical formulation (1.), its decision criteria and performance metrics (2.a), and the influence the model-user has on the model's outcome (2.b). Hence, this section comprises only the first parts of an OR model characterization according to the structure in Table 2. The other parts of the characterization (analysis of model assumptions & parameters, program code, and an example of the model's application) cannot be shown in this section due to the limited size of the paper.

Part 1. of the model characterization is the description of the model's mathematical formulation. This description is a recapitulation of the information given in the original publication of Rawls and Turnquist (2011). They developed a stochastic mixed-integer linear program which decides about the locations of stationary warehouses, their stocks, and the flows of relief items between these stationary warehouses and demand locations. Uncertainty about the location of a disaster and associated relief item demands is modelled through the use of scenarios, making the program a stochastic program. The model's objective function (1) minimizes the costs that come with the coverage respectively non-coverage of relief item demands. Costs can incur through the setup of warehouses, their stocking with relief items, with the transfer of relief items to demand locations, the non-use of relief items, and the failure to fulfill demands (shortage costs). Constraint set (2) ensures flow conservation, i.e. that the amount of relief item pre-positioned at a warehouse together with those arriving from warehouses at other nodes can either be consumed, left untouched, sent to another node, or not enough to cover the node's demand (resulting into relief item shortages). Constraint set (3) prohibits the exceeding of the opened warehouses' capacities. Constraint set (4) limits the maximum number of warehouses per node to one. Constraint set (5) ensures that the arc capacities are not exceeded. Constraint (6) defines the reliability set; a subset of the scenarios in which the relief item demands have to be fulfilled completely. Complete demand fulfillment in these scenarios is realized by constraint set (7). Constraint set (8) limits the average distance for transports occurring in the scenarios of the reliability set. Finally, constraint set (9) defines the non-negativity constraints on the continuous variables and constraint set (10) defines the binary variables.

$$(1)\ \text{Min} \sum_i \sum_n F_{in} y_{in} + \sum_i \sum_l c_l^a x_{il}^p + \sum_s p_s \left[\sum_i \sum_j \sum_l c_{ijls}^t x_{ijls}^t + \sum_i \sum_l \left(c_l^s x_{ils}^s + c_l^u x_{ils}^u \right) \right]$$

$$(2)\ \sum_{j \neq i} x_{jils}^t + Des_{ils} x_{il}^p - x_{ils}^u = \sum_{i \neq j} x_{ijls}^t + d_{ils} - x_{ils}^s, \forall s \in S, i \in I, l \in L$$

$$(3)\ \sum_l Vol_l x_{il}^p \leq \sum_n Cap_n y_{in}, \ \forall i \in I$$

$$(4)\ \sum_n y_{in} \leq 1, \forall i \in I$$

$$(5)\ \sum_l u_l x_{ijls}^t \leq U_{ijs}, \forall s \in S, i \in I, j \in I$$

$$(6)\ \sum_s p_s \gamma_s \geq \alpha$$

$$(7)\ x_{ils}^s \leq d_{ils} \left(1 - \gamma_s\right), \forall s \in S, i \in I, l \in L$$

$$(8)\ \sum_i \sum_j Dist_{ij} x_{ijls}^t \leq MxDist_l \sum_i d_{ils} + Big\left(1 - \gamma_s\right), \ \forall s \in S, l \in L$$

$$(9)\ x_{ijls}^t, x_{ils}^s, x_{ils}^u, x_{il}^p \geq 0, \ \forall s \in S, i \in I, j \in I, l \in L$$

$$(10)\ y_{in}, \gamma_s \in \{0,1\}, \forall i \in I$$

p_s Probability of occurrence of scenario s
d_{ils} Expected demand in scenario s for relief item type l at node i
Cap_n Capacity of warehouse size n
Vol_l Volume of relief item type l
Des_{ils} Percentage of destroyed stocks of relief item type l at node i in scenario s
F_{in} Fixed costs of setting up a warehouse of size n at location i
c_l^a Acquiring costs of relief item type l
c_{ijls}^t Transportation costs for transferring relief item type l from node i to node j in scenario s
c_l^s Shortage costs for relief item type l
c_l^u Costs for not using relief item type l
$Dist_{ij}$ Distance between node i and node j
$MxDist_l$ Distance limit for relief item type l
U_{ijs} Capacity of arc between nodes i and j in scenario s
u_l Necessary transportation capacity of relief item type l
α Confidence level; collective probability of occurrence in the reliability set
Big Big number
x_{ijls}^t Amount of relief item type l transferred between node i and node j in scenario s
x_{ils}^s Shortage of relief item type l at node i in scenario s
x_{ils}^u Amount of relief item type l unused at node i in scenario s
x_{il}^p Pre-positioned relief items of type l at node i
y_{in} 1 if warehouse at location i is located and has a size n, 0 otherwise
γ_s 1 if scenario s is included in reliability set, 0 otherwise

Part 2.a) of the model characterization in the tool kit is the explicit specification of the model's decision criteria and performance metrics. Table 3 highlights the decision criteria and performance metrics of the program developed by Rawls and Turnquist (2011). Explanations to the table are given in the next paragraph.

Category	**Criterion**	**Sub-criterion**	**Metrics (U: utilization, E: effectiveness, P: productivity)**
Inputs	Resources	Procurement	Procurement costs (U)
		Warehousing	Warehouse setup costs (U) Holding costs of unused relief items (U)
		Transportation	Transportation costs between warehouses and demand locations (U)
Outputs	Delivery service	Relief item quantity	Relief item shortages in scenarios not included in the reliability set (E)
		Delivery time	Average transportation distances in scenarios included in the reliability set (E) Transportation costs between warehouses and demand locations (E)
Efficiency			Objective function value (P)

Table 3. Decision criteria and performance metrics used in Rawls and Turnquist (2011)

The resources needed as the inputs of the logistics system depicted in the program of Rawls and Turnquist (2011) are those necessary to realize procurement, warehousing, and transportation processes. The output of the modelled system is the delivery service, broken down to delivered relief item quantity and the corresponding delivery times. Social and ecological effects of the logistics system are not considered. Consequently, the necessary procurement, warehousing, and transportation resources as well as the delivered relief item quantity and the delivery times can be interpreted as the decision criteria of the mathematical program. The criteria procurement, warehousing, and transportation are captured by utilization metrics (U); to be more precise by the spending metrics procurement costs, warehouse setup costs, holding costs of unused relief items, and transportation costs between warehouses and demand locations. The criterion delivery time is captured by the average distance of transports, which is an effectiveness metric (E). However, this metric is only calculated for those transports occurring in scenarios which are included in the reliability set. Transportation costs can also be interpreted as an effectiveness metric that captures the criterion delivery time – in this case in all scenarios. Relief item shortage is an effectiveness metric, which captures the criterion relief item quantity. This metric is only calculated for those demand locations which need to be served in scenarios not included in the reliability set since complete demand fulfillment is ensured for demand locations which are served in scenarios included in the reliability set. Efficiency of the configuration is measured by the objective function's value. It conveys the total costs resulting on the one hand from complete demand fulfillment and restricted average transportation distances in those scenarios included in the reliability set and on the other hand from demand fulfillment in those scenarios not included in the reliability set. The objective function can be interpreted as a productivity metric (P). Metrics that measure the configuration's impartiality and flexibility are not included in the program.

Part 2.b) of the model characterization according to the tool kit's structure is the description of the model-user's influence on the model's outcome. In the case of the program developed by Rawls and Turnquist (2011), relief item quantities can be influenced by changing the size of the reliability set or by changing the relief item shortage costs while delivery times can be influenced by changing maximum average transportation distances for relief items. By setting the collective probability of all scenarios in the reliability set to 1, the decision-maker can ensure the complete adherence to the quantitative needs of the beneficiaries.

CONCLUSION AND OUTLOOK

Humanitarian logistics networks realize relief item flows from suppliers or stationary relief item warehouses via several hubs to the beneficiaries within disaster areas. Their setup and operations comprise several activities and the execution of these activities can be supported by analytical models. In this paper, a structure of a methodological tool kit for humanitarian logistics has been proposed. Once a first version of this tool kit is completed, it should support practitioners to identify, compare, and apply suitable OR models. In the long run, the tool kit 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(s) to the platform. However, it should be ensured that added models are presented to the tool kit user in a well-defined way, possibly using the structure proposed in this paper. The platform 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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