Decision support for the location planning in disaster areas using multi-criteria methods

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ABSTRACT

In this paper, a multi-criteria facility location model is represented. The model is meant to support relief organisations to determine the best warehouse location to stock emergency relief supplies in the pre-disaster phase of a natural disaster. As a result of the prepositioning of the goods the relief organisations are able to respond immediately to an occurring disaster. In consideration of a multiplicity of quantitative and qualitative objectives a criteria hierarchy is developed which can be adapted to any specific disaster area by omitting irrelevant goals. Afterwards the multi-criteria methods PROMETHEE I+II as well as different sensitivity analysis are described and the model is applied on a local level in a flood-prone area in Bangladesh. Small organisations with restrictive financial and personnel resources can especially benefit from the clear structure of the model and the user friendliness and high transparency of the PROMETHE I+II methods.

Keywords

Facility location, Emergency relief logistics, Pre-positioning, Multi-criteria methods.

INTRODUCTION

Over the last years, the occurrence of natural disasters worldwide has increased. As a result, emergency relief organisations with different mandates and size attempt to react in an effective and efficient way to help the affected people (Kovács and Spens, 2009). The location planning of warehouses to preposition relief supplies is an especially important strategic issue in the catastrophe management process (Balcik and Beamon, 2008). Even though there are already different models trying to face the complexity of a disaster situation (e.g. Balcik and Beamon, 2008; Campbell and Jones, 2011), only few models comprise more than one objective. Numerous authors describe the necessity of quantitative operations research models in the field of disaster logistics, which can be adapted to different disaster situations and help relief organisations to avoid making ad-hoc location planning decisions (e.g. Altay and Green, 2006).

Thus, multi-criteria decision making model (MCDM) as a quantitative approach can consider a multiplicity of relevant qualitative and quantitative objectives of a warehouse location decision (e.g. economy, time, infrastructure, climate etc.) and can be adapted to different disaster areas. The benefits of the application of MCDM are that it helps to point out the structure of the decision problem and therefore results in a high transparency. As a consequence the model helps relief organisations to make a well planned warehouse location decision instead of an often ineffective and inefficient ad-hoc decision.

The contribution starts with the development of a multi-criteria decision making model. The structuring process of the location problem is described, followed by the solving procedure with the PROMETHEE-methods. Furthermore the fruitful support of sensitivity analysis for relief organisations is pointed out. Finally, the application of the model to a flood prone area in Bangladesh is demonstrated as well as the adaptability of the decision support to different requirements is described.

MULTI CRITERIA FACILITY LOCATION MODEL FOR THE PREPOSITIONING OF RELIEF SUPPLIES

In this section a general warehouse location model is presented. First, the existing types of facility location models are summarized. Second, the discrete feasible alternatives of the facility location have to be identified. Third, the multiplicity of relevant objectives is illustrated in a decision tree. Afterwards the multi-attribute decision making method PROMETHEE can be used to rank the different alternatives and identify the best one. Subsequent sensitivity analyses help to show the robustness of the facility location decision.

Facility location problems in the field of disaster logistics have been addressed in several studies and different type optimization models have been developed, for example continuous location models (e.g. Kandel, Abidi and Klumpp (2011)) p-centre, p-median and maximum coverage location models (e.g. Jia, Ordóñez and Dessouky (2007)) as well as models with two or more objective functions (e.g. Tzeng, Cheng and Huang (2007)). In contrast to the existing models in the field of disaster logistics, MCDM models are not optimization models. They consider a multiplicity of objectives with the result of a rank order of the alternatives and the identification of the best one. The application of MCDM for the location planning in a commercial supply chain is described in the literature (Athawale and Chakraborty, 2010), hence can be adjusted to the context of disaster logistics.

Facility location alternatives and the criteria hierarchy

To determine feasible warehouse location alternatives, different criteria for exclusion can be used. First, there has to be a basis infrastructure (road, electricity and telecommunication access), because it is necessary to reach the aid recipients in the crisis situation and to run the warehouse (Kovács and Spens, 2009). Second, the warehouse capacity is a restrictive factor, because the storage space has to be adequate to stock the supplies, which are needed by the aid recipients in case of the breakout of the disaster (Tatham and Hughes, 2011), e.g. if an earthquake occurs the recipients need other goods than in case of a flood. Third, the topography of the region is a criterion for exclusion (Wiesner, 2005).

The decision tree includes the relevant objectives for a rational warehouse location decision in disaster areas. A global goal is divided into different main goals, which are themselves divided into other sub-goals with the result of a hierarchy of the objectives. The criteria on the lowest level of the hierarchy have to be measured by an appropriate key figure. The development process of a decision tree can be from the lowest to the highest level (Bottom-up-method) or the other way around from the highest to the lowest level (Top-down-method). To structure a decision problem it is recommended to use a combination of both methods (Eisenfuhr and Weber, 2003). For the facility location decision in a disaster area the bottom-up-method was used first. The determination of the objectives is based on the already existing location models, other disaster logistics literature and case studies. Beside these sources the facility location factors described in the commercial international management literature are considered. These location planning decisions often take place in development countries and therefore the planning process is similar to the facility location decision made by relief organisations (Correa, Ramirez and Sanahuja, 2011). To validate the hierarchy, the top-down-method was used additionally to check if the main goals are sufficiently operationalized by the goals on the lower hierarchy level.

As a result of the structuring process, seven main objectives are figured out, which are divided into further sub-goals. The main objectives are several cost aspects (Balcik and Beamon, 2008; Campbell and Jones, 2011), the delivery time needed to reach the aid recipients from the warehouse (Tzeng et al., 2007), the spatial distance to the potential disaster hot spot, other relief organisation and suppliers (Campbell and Jones, 2011), different infrastructure goals (Kovács and Spens, 2009), climate, several economic aspects (Kovács and Spens, 2007) as well as different personnel-related goals (Wiesner, 2005). The whole decision tree with the identified relevant objectives is shown in Figure 1. Relief organisations can adapt it to the requirements of a specific disaster region by eliminating irrelevant goals or by adding important objectives.

Multi Attribute Decision Making with the PROMETHEE method

As it is described above, the facility location problem contains a finite set of alternatives, for which Multi Attribute Decision Making (MADM) methods are adequate. One well known method is PROMETHEE, which is often applied on various decision problems and also for exemplary facility location problems in the commercial logistics sector (Brans and Mareschal, 1992). The advantages of the method are its user friendliness as well as transparency and well-documented sensitivity analysis to test the robustness of the final decision (Oberschmidt, Geldermann, Ludwig and Schmehl, 2010). Hence, PROMETHEE seems to be a suitable method for the warehouse location planning in the context of disaster logistics. The fundamental idea of PROMETHEE is to consider the preferences of the decision maker. The decision maker needs to determine one of six generalised preference functions and the corresponding threshold values for each criterion on the lowest level of the hierarchy (intra-criteria preferential information). The second type of preferences, are inter-criteria preferential information, which reflect the relative importance of one objective compared to the other goals by a weighting factor. To assess the objective weights different methods can be used (Brans and Mareschal, 2005). The PROMETHEE I+II approaches lead to two different kinds of rankings. A partial ranking is the result of PROMETHEE I and the PROMETHEE II method leads to a complete order (Brans and Mareschal, 1992).

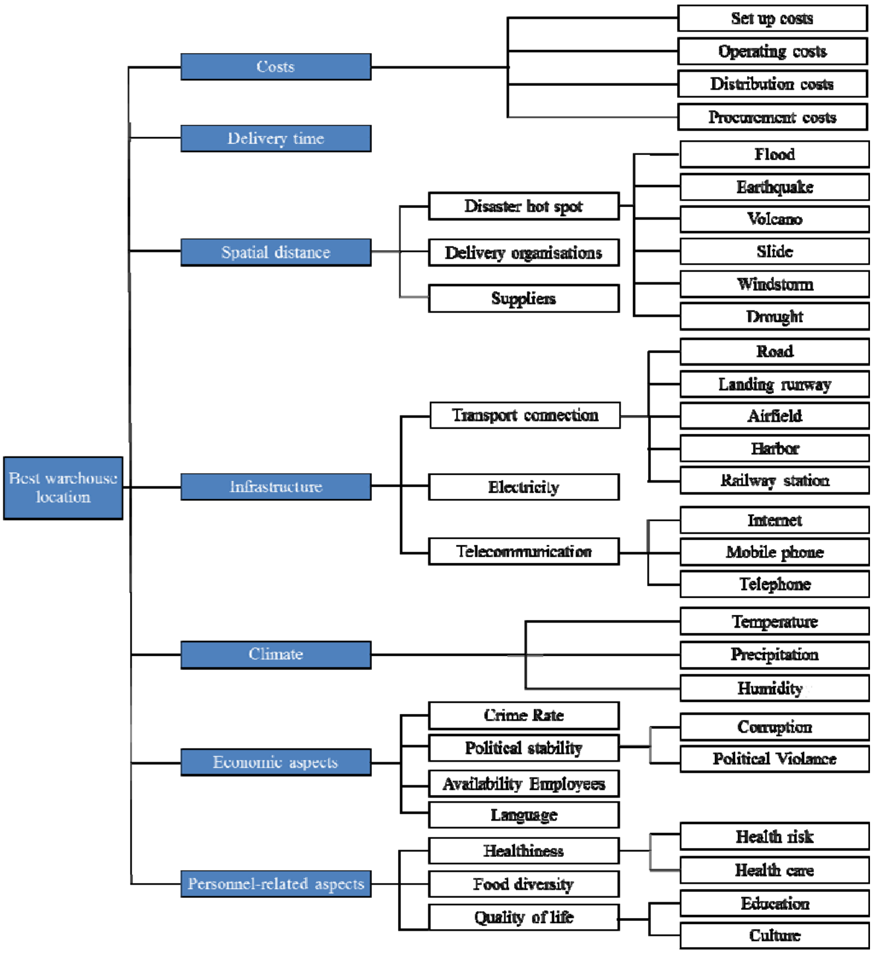

Figure 1. Decision tree of the location planning problem

Following the results from PROMETHEE I+II the robustness of the made decision can be tested by sensitivity analysis. The decision maker can change the input parameters to examine their influence on the decision and therefore the structure of the decision problem appears. In the special case of PROMETHEE the decision maker can change the weights of the objectives or the preference functions and the corresponding thresholds (Bertsch, Geldermann, Rentz and Raskob, 2007). One frequently applied sensitivity analysis is the calculation of stability intervals. The weighting of every criterion is changed to determine the magnitude of variation of the decision maker's preferences that is necessary to change the original rank order of the alternatives.

RESULTS OF THE CASE STUDY

The presented multi-criteria facility location model was applied for a flood prone area in the northeast of Bangladesh. This area contains eight districts and 22.6 million inhabitants. It is regularly affected by seasonal monsoon rain and the inundation of the Meghna River (Hofer and Messerli, 2006). The three criteria for exclusion were used to identify five feasible alternatives. Furthermore every main goal and the values of 19 criteria of the lowest hierarchy level were considered. The other criteria were omitted, because they are not important for the region or the data needed were not available. The weights of the objectives are based on an interview with an expert who had worked three years for a NGO in Bangladesh and were ascertained with a modified SWING-method (Bertsch et al., 2006). The preference functions and thresholds were based on the literature (e.g. Anand and Kodali, 2008). Table 1 shows the values of the considered attributes as well as the used preference functions and the corresponding thresholds. The alternatives are declared as A_1: Kishoreganj;

A_2: Brahmanbaria, A_3: Maulvi Bazar, A_4: Sylhet und A_5: Mymensingh, as the possible warehouse locations to stock emergency relief supplies in the pre-disaster phase of a natural disaster.

Attribute	**Unit**	**Min/ Max**	**Preference function**	A_1	A_2	A_3	A_4	A_5
Set up costs	€	Min	Type 5 (p = 1000, q = 500)	1747.6	1310.7	6990.2	1572.8	1048.5
Operating costs	€/a	Min	Type 3 (p = 400)	3840	3564	2916	3516	2800
Distribution costs	Low (1) – High (3)	Min	Type 4 (p = 1.9, q = 0.9)	2	2	1	3	1
Delivery time	Quick (1) – Slow (3)	Min	Type 4 (p = 1.9, q = 0.9)	2	2	3	1	3
Delivery organisations	Quantity	Min	Type 3 (p = 0.3)	7	11	13	4	15
Earthquake	Risk r_i	Min	Type 3 (p = 0.3)	0.12	0.59	0.04	0.1	0
Windstorm	Risk r_i	Max	Type 6 (σ = 5.5)	0.59	0.59	0.12	0.59	0.34
Road	Quantity	Max	Type 1	2	2	4	3	3
Landing runway	Quantity	Max	Type 1	0	0	0	1	0
Harbor	Quantity	Max	Type 1	1	1	0	0	0
Precipitation	mm	Min	Type 6 (σ = 580)	2174	2551	3334	3334	2174
Humidity	%	Min	Type 6 (σ = 4.92)	74.36	80.2	79.26	79.26	84.19
Availability Employees	Quantity	Max	Type 6 (σ = 9762)	35479	31797	22069	41593	26083
Language	%	Max	Type 3 (p = 5)	16.97	15.79	10.84	21.94	15.62
Food diversity	Quantity	Max	Type 6 (σ = 8)	22	24	18	8	24
Health risk	Quantity	Min	Type 1	2	2	2	2	3
Health care	Quantity	Max	Type 6 (σ = 1454.5)	6900	8002	5093	5093	6900
Culture	Quantity	Max	Type 6 (σ = 149.5)	364	269	205	206	504
Education	Quantity	Max	Type 6 (σ = 1043.5)	2800	1788	713	1822	1290

Table 1. Decision table of the Case Study

On the basis of the decision table and the weightings, the partial ranking as a result of the PROMETHEE I method is presented in Figure 2. It shows the incomparability of the two dominant alternatives A_4 and A_1, which are dominating the other alternatives.

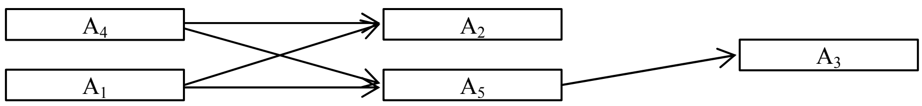

Figure 2. PROMETHEE I: Partial Ranking

In contrast the net flows resulting from the PROMETHEE II method shows a clearly dominant alternative (A_4), figured out in Figure 3.

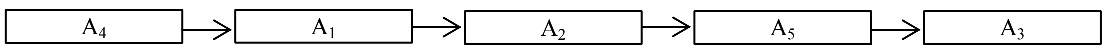

Figure 3. PROMETHEE II: Complete Ranking

Summing up the results, the relief organisation would prefer to build the warehouse at the location of alternative 4 as an outcome of the PROMETHEE II method. To respond to the incomparability of the PROMETHEE I ranking a sensitivity analysis can help to show the relief organisation the influence of their preferences on the final decision and enhance transparency. Therefore, the relief organisation is supported to choose the best location for the warehouse. The most sensitive criteria are the distribution costs, the delivery time, the road and harbor access, the precipitation as well as three personnel-related goals. An interesting result is that alternative 1 displaces the fourth alternative in every sensitive criterion. Therefore the relief organisation is now able to figure out the sensitive influence factors, re-evaluate them and make an informed facility location decision.

CONCLUSION

In this contribution a multi criteria warehouse location model is presented which supports relief organisations to preposition relief supplies in the pre-disaster phase of a natural disaster. In consideration of a multiplicity of relevant objectives for a well-founded decision the model can be adapted case specifically by eliminating irrelevant criteria for a disaster region. Even though the appliance of the model was tested on a local level in Bangladesh, the model can also be adapted to a global context. Small organisations often face the problem of restrictive financial and personnel resources. Hence they cannot develop case specific models by themselves or engage experts. Because of the user friendliness and the high transparency of the PROMETHE I+II methods these organisations can especially profit from the developed model. Furthermore relief organisations can use the hierarchy of objectives as a check list for the location planning of a warehouse without using PROMETHEE.

REFERENCES

1. Altay, N.; Green, W. G. (2006) OR/MS research in disaster operations management, *European Journal of Operational Research*, 175, 1, 475–493.
2. Anand, G.; Kodali,R. (2008) Selection of lean manufacturing systems using the PROMETHEE, *Journal of Modelling in Management,* 3, 1, 40-70.
3. Athawale, V. M.; Chakraborty S. (2010) Facility Location Selection using PROMETHEE II Method, *International Conference on Industrial Engineering and Operations Management*, Dhaka.
4. Balcik, B.; Beamon, B. M.(2008) Facility location in humanitarian relief, *International Journal of Logistics Research and Applications,* 11, 2, 101–121.
5. Bertsch, V.; Geldermann, J.; Rentz, O.; Raskob, W. (2006) Multi-criteria decision support and stakeholder involvement in emergency management, *International Journal of Emergency Management*, 3, 2, 114–130.
6. Brans, J.P; Mareschal, B. (1992) Promethee-V: MCDM Problems with Segmentation Constraints, *Information System & Operational Research*, 30, 2, 85–96.
7. Brans, J.P; Mareschal, B.(2005) PROMETHEE Methods, Ehrgott, M., Figueira, J. und Greco, S., (Eds.): Multiple Criteria Decision Analysis : State of the Art Surveys, Springer Science + Business Media Verlag New York, 163–192.
8. Campbell, A. M.; Jones, P. C.(2011): Prepositioning supplies in preparation for disasters, *European Journal of Operational Research*, 209, 2, 156–165.
9. Chang, M.; Tseng, Y.; Chen, J.(2007) A scenario planning approach for the flood emergency logistics preparation problem under uncertainty, *Transportation Research Part E: Logistics and Transportation Review*, 43, 6, 737–754.
10. Correa, E.; Ramirez, F.; Sanahuja, H. (2011) Populations at Risk of Disaster: A Resettlement Guide, World Bank, Washington D.C.
11. Eisenfuhr, F.; Weber, M. (2003) Rationales Entscheiden, Springer Verlag, Berlin.
12. Geldermann, J. (2006) Mehrzielentscheidungen in der industriellen Produktion, Universitäts-Verlag, Karlsruhe.
13. Geldermann, J.; Treitz, M.; Schollenberger, H.; Ludwig, J.; Rentz, O. (2007) Integrated process design for the inter-company plant layout planning of dynamic mass flow networks, Universitäts-Verlag, Karlsruhe.
14. Hofer, T.; Messerli, B. (2006) Floods in Bangladesh: History, dynamics, and rethinking the role of the himalayas, United Nations University Press, Tokio.
15. Jia, H.; Ordóñez, F.; Dessouky, M. M. (2007) Solution approaches for facility location of medical supplies for large-scale emergencies, *International Journal of Clinical Chemistry*, 52, 2, 257–276.
16. Kandel, C.; Abidi, H.; Klumpp, M. (2011) Humanitarian Logistics Depot Location Model, Navais, P., Machado, J., Analide, C. und Abelha, A., (Eds.): *ESM 2011: The 2011 European Simulation and Modelling Conference*, Guimaraes, 288–293.
17. Kovács, G.; Spens, K. M. (2007) Humanitarian logistics in disaster relief operations, *International Journal of Physical Distribution & Logistics Management*, 37, 2, 99–114.
18. Kovács, G.; Spens, K. M. (2009) Identifying challenges in humanitarian logistics, *International Journal of Physical Distribution & Logistics Management*, 39, 6, 506–528.
19. Oberschmidt, J.; Geldermann, J.; Ludwig, J.; Schmehl, M. (2010) Modified PROMETHEE approach for assessing energy technologies, *International Journal of Energy Sector Management*, 4, 2, 183–212.
20. Tatham, P. H.; Hughes, K. (2011) Humanitarian logistics metrics: where we are and how we might improve, Christopher, M. und Tatham, P., (Eds.): Humanitarian logistics: Meeting the challenge of preparing for and responding to disasters, Kogan Page Verlag; Philadelphia, 65–84.

21. Tzeng, G.; Cheng, H.; Huang, T. (2007) Multi-objective optimal planning for designing relief delivery systems, in: Transportation Research Part E: Logistics and Transportation Review, 43, 6, 673–686.

22. Wiesner, K. (2005) Internationales Management, Oldenbourg Verlag, München.