

A LOCATION-ALLOCATION MODEL FOR RELIEF DISTRIBUTION AND VICTIM EVACUATION

Eko Setiawan¹, Jiyin Liu², Alan P. French³

Business School, Loughborough University, United Kingdom
Industrial Engineering Department, Muhammadiyah University Surakarta, Indonesia
E.Setiawan@lboro.ac.uk

Business School, Loughborough University, United Kingdom
J.Y.Liu@lboro.ac.uk

Business School, Loughborough University, United Kingdom
A.P.French@lboro.ac.uk

ABSTRACT

One stage of disaster relief operations (DRO) is dealing with disaster response, an aspect of which is logistics. This paper firstly presents previous work on logistics in this area, particularly that which relates to natural disasters, into certain classifications. It is found that the distribution practice of disaster relief, the evacuation process of the injured victims, and the determination of temporary medical facilities after natural disaster occurrences can be treated in stages, in which stage I is on the location-allocation aspect whereas stage II is on the routing aspect. A location-allocation model which addresses the first stage of the aforesaid problem is subsequently proposed. The model is mainly characterized by the possibility to carry out both the distribution process of commodities and the evacuation process of victims between a disaster area and a temporary site. In cases where no existing medical facility is allocated to a disaster area, injured victims as well as injury-free sufferers in the area need to be transferred to the same temporary site.

Keywords: relief distribution; victim evacuation; location-allocation model; temporary site

1. INTRODUCTION

Natural disasters are highly likely to lead to severe problems, including extensive human misery and physical losses or damage. Victims of a natural disaster could appear in the forms of heavily wounded victims, light-moderate ones, and injury-free sufferers. In certain circumstances, natural disaster occurrences cause death as well. The arrival of a natural disaster may cause damage to telecommunications, housing, schools, and government buildings, resulting in homeless victims. These homeless people are frequently forced to evacuate to more convenient and safer places.

In order to primarily reduce loss of human life, it is vital to respond quickly to natural disasters – especially for sudden-onset natural disasters. This usually incorporates the provision of disaster logistics and fatality management, to name but two.

Disaster logistics itself consists of various activities. They include the provision of emergency rescue and medical care service, the delivery of food, medicine, tents,

sanitation equipment, tools and other necessities to disaster sufferers, the activation of emergency operations centre, and the establishment of shelters and the provision of mass care service.

Different research papers address different aspects of disaster logistics. These include inventory aspects (e.g., Beamon and Kotleba (2006); Whybark (2007); Lodree Jr. and Taskin (2009)), relief distribution (e.g., Haghani and Oh (1996); Özdamar et al. (2004); Barbarasoğlu and Arda (2004); Sheu (2007); Balcik et al. (2008); Hsueh et al. (2008); Friedrich et al. (2000)), evacuation process routing (see, for instance, Yuan and Wang (2008); Chiou and Lai (2008); Lu et al. (2005)); location (for example, Drezner et al. (2006) on casualty collection points (CCPs); Doerner et al. (2009) on shelter/ temporary housing location and/ or allocation; Balcik and Beamon (2008) and Jia et al. (2007) on location of distribution centres; and Berman et al. (2007, 2008) on transfer point location)), location-allocation (see, for instance, Sherali et al. (1991)), relief distribution and evacuation process routing

(e.g., Yi and Kumar (2007); Özdamar and Yi (2008); Yi and Özdamar (2009)), and location-routing (see, for instance, Yi and Özdamar (2007); Mete and Zabinsky (2009); Ukkusuri and Yushimito (2008)).

To the best knowledge of the authors, only Yi and Özdamar (2007) deal with the optimisation of the distribution practice of disaster relief, the evacuation process of the injured victims, and the determination of temporary emergency centres simultaneously after natural disaster occurrences. Yet there is an opportunity to enhance the work of Yi and Özdamar (2007) by incorporating injury-free sufferers into the evacuation process. The sufferers (either light-injured, heavily wounded, or injury-free victims) who prefer to do the evacuation process by themselves - which are not uncommon in real-time disaster situations - give another opportunity of enhancement. It is also generally accepted that location-related decisions (in this case, the number and locations of temporary facilities) are strategic issues, whereas commodity dispatch and vehicle routing (in this case, relief distribution and victim evacuation process routing) are operational issues. Therefore, instead of treating facility location, commodity dispatch, and evacuation process routing simultaneously (Yi and Özdamar, 2007), it is more practical to treat them in stages: determining the facility location first and then making the detailed vehicle routing decisions for commodity distribution and victim evacuation with the fixed facility locations.

This paper is preliminary work on the first stage, i.e. facility location. The paper also takes account of injury-free sufferers into the evacuation process, as this additional type of victim is often present in real-life disaster situations.

In the rest of this paper, details of the problem under concern and related assumptions are firstly presented. Then a mathematical model is provided. The final part summarises the paper and indicates the future research work to be undertaken.

2. RESEARCH PROBLEM SETTING AND ITS RELATED ASSUMPTIONS

The occurrence of a sudden-onset natural disaster is generally surrounded by the

existence of certain assumptions. This paper recognises these conditions. These assumptions are as follows.

First, the potential sites for temporary facilities (which include temporary shelters, intermediate distribution points, and temporary medical centres/ facilities) are known. They are clustered together and presented as temporary sites. The pooling is supported by its presence in many practical disaster/ emergency management (see, for instance, Davis and Lambert, 2002).

Secondly, areas of disaster under study are known. Furthermore, estimates on aggregate demands of victims/ sufferers at each disaster area during typical time period are given. These demands are in the sense of total number of victims/ sufferers that need to be evacuated (due to either loss of residence or being injured) and total amount of commodities needed by the disaster area.

Thirdly, shortest travel times between locations/ areas are assumed to be known. Damage, congestion, etc. - which affect travel times - are assumed to be included into these travel times.

Fourthly, the locations of existing hospitals/ medical facilities are known. They are assumed to be able to receive any quantities of disaster victims/ sufferers.

Vehicles for transferring the victims from disaster areas to related temporary sites or existing medical facilities are assumed to come from temporary sites or existing medical facilities. Similarly, vehicles for transporting the commodities from temporary sites to related disaster areas are presumed to depart from temporary sites.

As noted by Jia et al. (2007), facility deployment strategies in response to disaster occurrences could be categorised into proactive facility deployment and reactive facility deployment. Regarding the fact that certain natural disasters are difficult to predict a long time before their arrival (an earthquake or a tsunami, for instance), this paper concentrates on the second position.

Injured victims - either light-injured or heavily injured - are treated individually. On the other hand, injury-free victims/ sufferers are treated as family units.

In regular emergency situations, different places are usually affected by a disaster at different times. In that case, giving response to those places nearly equally is usually

achieved by using a p -centre model (for example, in deciding where to locate a fire station serving many different areas). Different from day-to-day emergency management, the occurrence of a tremendous sudden-onset natural disaster needs a quick response to a large number of different areas at the same time. Along with limited supplies and/ or limited vehicle capacity, it is not unusual that response to a disaster area needs to be given more than once. Instead of balancing service to those disaster areas, minimising the total travel time is consequently the central issue. The application of a p -median model – which seeks to minimise the total travel time – is therefore more appropriate.

By considering the abovementioned description, this paper is hence dealing with the problem of selecting a certain number of temporary location sites from available alternatives and allocating disaster areas to each selected temporary site and/ or particular existing medical facilities in such a way that overall travel time is minimised.

3. MATHEMATICAL MODEL

This part of the paper presents a mathematical model for the problem described in the previous section.

Sets:

- I : Set of disaster areas;
- J : Set of existing medical facilities;
- K : Set of temporary site candidates;
- M : Set of commodities;

Parameters:

- H_i : Estimate on total number of injured victims who need to be evacuated from disaster area $i \in I$;
- F_i : Estimate on total number of injury-free family units at disaster area $i \in I$ who agree to be evacuated;
- C_m : Estimate on total amount of commodity type m needed by disaster area $i \in I$;
- V_c, V_H : vehicle capacity in terms of commodities as well as victims;
- t_{ij}, t_{ik} : Estimate on travel time from disaster area $i \in I$ to existing medical facility $j \in J$ / temporary site $k \in K$;

- P : Total number of available temporary medical facilities;
- N : Average number of persons in one injury-free family unit.

Decision variables:

- T_{ij}, T_{ik} : Total travel time needed for commodity distribution and victim evacuation between disaster area $i \in I$ and existing medical facility $j \in J$ / temporary site $k \in K$;
- U_k : Zero-one variable (its value is 1 if temporary site $k \in K$ is open, 0 otherwise);
- Z_{ij} : Zero-one variable (its value is 1 if injured victims at disaster area $i \in I$ is transported to medical facility $j \in J$, 0 otherwise);
- Z_{ik} : Zero-one variable (its value is 1 if disaster area $i \in I$ is connected to temporary site $k \in K$, 0 otherwise);

Objective function:

$$\text{Min } \sum_{i \in I} \sum_{j \in J} T_{ij} + \sum_{i \in I} \sum_{k \in K} T_{ik} \quad (0)$$

Equation (0) represents the objective function which has to be achieved in the model. It tries to minimize the total travel time needed to distribute commodities and evacuate victims from any disaster areas to their associated temporary sites and/ or existing medical facilities.

Constraints:

$$2 * t_{ik} * \left(\sum_{m \in M} C_{im} \right) * Z_{ik} / V_c \leq T_{ik} \quad (1)$$

$$(\forall i \in I, k \in K)$$

$$2 * t_{ik} * \left[N * F_i * Z_{ik} + H_i * (Z_{ik} - \sum_{j \in J} Z_{ij}) \right] / V_H \leq T_{ik} \quad (\forall i \in I, k \in K) \quad (2)$$

$$2 * t_{ij} * H_i * Z_{ij} / V_H \leq T_{ij} \quad (\forall i \in I, j \in J) \quad (3)$$

Constraints (1) stand for the total travel time required to send commodities for a disaster area from its associated temporary site. Constraints (2), on the other hand, represent the total travel time needed to pick up injured

victims as well as injury-free sufferers from a disaster area and subsequently transporting them to its associated temporary site (for injury-free sufferers) and either to a temporary site or to an existing medical facility (for injured victims). For the reason that any total travel time is always greater than or equal to zero, constraints (2) apply for all situation. Included here is the situation that injured victims are transported to an existing medical facility rather than to a temporary site. Restrictions on the total travel time needed to pick up injured victims at a disaster area and subsequently transporting them to an existing medical facility are represented by constraints (3).

$$\sum_{k \in K} Z_{ik} = 1 (\forall i \in I) \quad (4)$$

$$\sum_{j \in J} Z_{ij} \leq 1 (\forall i \in I) \quad (5)$$

$$\sum_{k \in K} U_k \leq P \quad (6)$$

Constraints (4) guarantee that a disaster area is always allocated to exactly one temporary site whereas constraints (5) allocate injured victims at a disaster area to at most one existing medical facility. The requirement that the total number of temporary sites to be opened could not exceed the total number of available temporary medical facilities is represented by constraint (6).

$$U_k - Z_{ik} \geq 0 (\forall i \in I, k \in K) \quad (7)$$

$$U_k = 0 \text{ or } 1 (\forall k \in K) \quad (8)$$

$$Z_{ij} = 0 \text{ or } 1 (\forall i \in I, j \in J) \quad (9)$$

$$Z_{ik} = 0 \text{ or } 1 (\forall i \in I, k \in K) \quad (10)$$

$$T_{ij} \geq 0 (\forall i \in I, j \in J) \quad (11)$$

$$T_{ik} \geq 0 (\forall i \in I, k \in K) \quad (12)$$

Constraints (7) ensure that either injury-free sufferers or injured victims can only be served by or allocated to a temporary site that is already open. Finally, (8)–(10) require that several decision variables need to be binary variables whereas the restrictions on variables which define total travel time are represented by constraints (11)–(12).

4. CONCLUSION AND FUTURE RESEARCH WORK

This paper deals with the location-allocation aspect of relief distribution, victim evacuation, and temporary site location problem. For that purpose, a mathematical model is subsequently constructed. It is characterized by two essential features: (1) The possibility to carry out both the distribution process of commodities and the evacuation process of victims between a disaster area and a temporary site, and (2) In case injured victims at a disaster area are not allocated to an existing medical facility, there is a necessity for those injured victims as well as injury-free sufferers located at the disaster area to be transferred to the same temporary location site.

Since this is a preliminary research, there are obviously great opportunities to extend the work, and the authors are in the process of working on most of them. Some of these future research works are as follows.

To check its feasibility, the model in this paper needs to be tested. Real data on past natural disasters will be collected for this purpose.

Some of key parameters in the model will clearly be subject to uncertainty, e.g., number of victims and travel time. Future work will consider the impacts of this uncertainty.

This paper deals with a one-layer location-allocation problem of relief distribution and victim evacuation. Incorporating more layers (for instance, the inclusion of main supply centres which are located in an upper layer) will also be investigated.

The model implies the use of one type of vehicle. In order to be more realistic, future work could also consider different vehicle types.

Future work will address issues related to the second stage, i.e. operational aspects of this problem, especially those which relate to the detailed vehicle routing decisions for commodity distribution and victim evacuation.

5. REFERENCES

Balcik, B. and Beamon, B.M. (2008). "Facility location in humanitarian relief"

- International Journal of Logistics: Research and Applications*, 11(2), 101-121.
- Balcik, B., Beamon, B.M., and Smilowitz, K. (2008). "Last mile distribution in humanitarian relief," *Journal of Intelligent Transportation Systems*, 12(2), 51-63.
- Barbarosoğlu, Gülay and Arda, Y. (2004). "A two-stage stochastic programming framework for transportation planning in disaster response," *The Journal of the Operational Research Society*, 55(1), 43-53.
- Beamon, B.M. and Kotleba, S.A. (2006). "Inventory modeling for complex emergencies in humanitarian relief operations," *International Journal of Logistics: Research and Applications*, 9(1), 1-18.
- Berman, O., Drezner, Z., and Wesolowsky, G.O. (2007). "The transfer point location problem," *European Journal of Operational Research*, 179, 978-989.
- Berman, O., Drezner, Z., and Wesolowsky, G.O. (2008). "The multiple location of transfer points," *Journal of the Operational Research Society*, 59, 805-811.
- Chiou, Y.C. and Lai, Y.H. (2008). "An integrated multi-objective model to determine the optimal rescue path and traffic controlled arcs for disaster relief operations under uncertainty environments," *Journal of Advanced Transportation*, 42(4), 493-519.
- Davis, J. and Lambert, R. (2002). *Engineering in emergencies: A practical guide for relief workers*, 2nd ed., London: ITDG Publishing.
- Doerner, K.F., Gutjahr, W.J., and Nolz, P.C. (2009). "Multi-criteria location planning for public facilities in tsunami-prone coastal areas," *OR Spectrum*, 31, 651-678.
- Drezner, T., Drezner, Z., and Salhi, S. (2006). "A multi-objective heuristic approach for the casualty collection points location problem," *Journal of the Operational Research Society*, 57, 727-734.
- Friedrich, F., Gehbauer, F., and Rickers, U. (2000). "Optimized resource allocation for emergency response after earthquake disasters," *Safety Science*, 35, 41-57.
- Haghani, A. and Oh, S.C. (1996). "Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations," *Transpn. Res-A*, 30(3), 231-250.
- Hsueh, C.F., Chen, H.K., and Chou, H.W., "Dynamic vehicle routing for relief logistics in natural disasters," in *Vehicle Routing Problem*, T. Caric and H. Gold, Eds., Croatia: In-Tech, 2007.
- Jia, H., Ordonez, F., and Dessouky, M. (2007). "A modeling framework for facility location of medical services for large-scale emergencies," *IIE Transactions*, 39, 41-55.
- Lodree Jr., E.J. and Taskin, S. (2009). "Supply chain planning for hurricane response with wind speed information updates," *Computers & Operations Research*, 36, 2-15.
- Lu, Q., George, B., and Shekhar, S., "Capacity constrained routing algorithms for evacuation planning: a summary of results," in C.B. Medeiros et al, Eds., *Lecture Notes in Computer Science Vol. 3633: Advances in Spatial and Temporal Databases*, Berlin Heidelberg: Springer-Verlag, 2005.
- Mete, H.O. and Zabinsky, Z.B. (2009). "Preparing for disasters: Medical supply location and distribution," to appear in *Interfaces*.
- Özdamar, L., Ekinci, E., and Küçükyazici, B. (2004). "Emergency logistics planning in natural disasters," *Annals of Operations Research*, 129, 217-245.
- Özdamar, L. and Yi, W. (2008). "Greedy neighborhood search for disaster relief and evacuation logistics," *IEEE Intelligent Systems*, 14-23.
- Sherali, H.D., Carter, T.B., and Hobeika, A.G. (1991). "A location-allocation model and algorithm for evacuation planning under hurricane/ flood conditions," *Transpn. Res.-B*, 25B(6), 439-452.
- Sheu, J.B. (2007), "An emergency logistics distribution approach for quick response to urgent relief demand in disasters," *Transportation Research Part E*, 43, 687-709.

- Ukkusuri, S.V. and Yushimito, W.F. (2008). "Location routing approach for the humanitarian prepositioning problem," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2089, 18-25.
- Whybark, D.C. (2007). "Issues in managing disaster relief inventories," *International Journal of Production Economics*, 108(1-2), 228-235.
- Yi, W. and Özdamar, L. (2007). "A dynamic logistics coordination model for evacuation and support in disaster response activities," *European Journal of Operational Research*, 179, 1177-1193.
- Yi, W. and Özdamar, L. (2009), "Fuzzy modeling for coordinating logistics in emergencies," accessed from <http://www.fss.uu.nl/ms/cvd/isj/fuzzy.pdf> at 28 June 2009.
- Yi, W. and Kumar, A. (2007). "Ant colony optimization for disaster relief operations," *Transportation Research Part E*, 43, 660-672.
- Yuan, Y. and Wang, D. (2008). "Path selection model and algorithm for emergency logistics management," *Computers & Industrial Engineering*, doi:10.1016/j.cie.2008.09.033.