Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 22 (2017) 245–254

Transportation Research Procedia

www.elsevier.com/locate/procedia

19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016, Istanbul, Turkey

Determination of relief supplies demands and allocation of temporary disaster response facilities

Asli Sebatli [a], Fatih Cavdur [a]*, Merve Kose-Kucuk [a]

[a]*Department of Industrial Engineering, Uludag University, Nilufer 16059, Bursa, Turkey*

Abstract

Distribution of relief supplies and allocation of the facilities to store these supplies are important pre- and post-Disaster Operations Management (DOM) activities. In this study, we propose a simulation-based approach to determine the demands of relief supplies until the governmental and/or central humanitarian organizations (i.e., the Turkish Red Crescent - TRC) reach to the affected area. We then develop a plan to allocate the so-called temporary-disaster-response (TDR) facilities and distribute the relief supplies stored in these facilities. An earthquake case study is constructed for the Yildirim district of Bursa-Turkey including 64 neighborhoods. Corresponding relief supplies demands are determined by analyzing the time it takes for the TRC to reach the affected area using the simulation model with two different system designs. The two-phase integer program is then used to develop a pre-positioning plan, i.e., allocation of TDR facilities and distribution of relief supplies.

Keywords: Disaster operations management; Relief supplies distribution; Facility allocation; Simulation; Integer programming

1. Introduction

Disaster Operations Management (DOM) is about the managerial activities performed before, during and after a disaster in order to reduce the unwanted effects of a disaster. According to a common classification in literature there are four phases in DOM as mitigation, preparedness, response and recovery (Altay and Green, 2006; Galindo and Batta, 2013). In this study, our solution approach to the problems of (i) determination of relief supplies demands and (ii) allocation of temporary-disaster-response (TDR) facilities and distribution of these relief supplies involves two of these phases; preparedness and response.

* Corresponding author. Tel.: +90-224-294-2077; fax: +90-224-294-1903.
E-mail address: fatihcavdur@uludag.edu.tr

10.1016/j.trpro.2017.03.031

In DOM, it is generally assumed that it is not possible to reach the affected area in the first 72 hours due to the destructive effects of the disaster, especially in areas with high infrastructure complexities. It is hence very important to provide relief supplies to disaster victims in this critical time period (Koehler, 1996). Therefore, humanitarian logistics and disaster supply chain studies gain more attention recently. Some related studies focus on providing relief supplies for disaster victims, representing an example of such humanitarian operations (Barbarosoglu and Arda, 2004; Wei and Ozdamar, 2007; Natarajarathinam et al., 2009; Rawls and Turnquist, 2010; Nagurney et al., 2011; Rawls and Turnquist, 2011; Ozdamar and Demir, 2012). Although simulation-based studies are commonly used for planning evacuation operations in DOM studies (Zou et al., 2005; Georgiadou et al., 2007; Chen and Zhan, 2008; Chiu and Mirchandani, 2008), it is also possible to use simulation for analyzing different type of DOM activities, such as resource allocation and mass decontamination (Albores and Shaw, 2008) and, as we also consider in this study, relief supplies distribution operations (Lee et al., 2009). Facility allocation is also another important DOM problem. Although it is mostly a pre-disaster decision, facility allocation requires the consideration of both pre- and post-disaster operations (Rawls and Turnquist, 2010; Gormez et al., 2011; Rawls and Turnquist, 2011; Murali et al., 2012; Salman and Gul, 2014; Kilci et al., 2015), since for an optimal allocation it is necessary to consider the post-disaster activities, such as the distribution of relief supplies.

In general, DOM activities are coordinated with some kind of governmental and/or central humanitarian organizations, such as the Federal Emergency Management Agency (FEMA) or the Red-Cross. In Turkey, we note that the corresponding organizations for such purposes are the Prime Ministry Disaster and Emergency Management Authority (AFAD) and the Turkish Red Crescent (TRC), respectively. In this study, we analyze the time it takes for these organizations (in particular the TRC since it is directly responsible for humanitarian relief supplies distribution operations) to reach the affected area via a simulation model using an earthquake case study developed by AFAD for the Yildirim district of Bursa-Turkey including 64 neighborhoods. There are three types of relief supplies considered in this study as water, meal ready-to-eat (MRE) and medical kit. After running the simulation model we determine the demands of these relief supplies for the corresponding time period representing the time it takes for the TRC to reach the affected area. Decisions involving the allocation of TDR facilities and distribution of relief supplies are then performed via a two-phase integer programming model.

2. Methodology

We estimate the amount of relief supplies required to satisfy the demands of disaster victims using the results of the simulation model. Pre-positioning of the corresponding TDR facilities are then performed via a two-phase integer programming model where the total cost (distance) of distributing relief supplies and the total number of facilities are minimized in the first and second phases, respectively. The overall solution approach is shown in Figure 1.

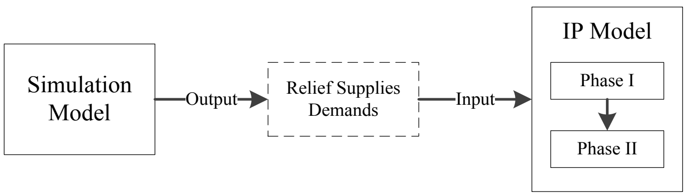

Fig. 1. Overall Solution Approach

2.1. Simulation model

Our model simulates the arrivals of all related resources (i.e., mobile kitchens etc.) of the TRC to the affected area to determine the corresponding relief supplies demands to be satisfied from the TDR facilities. We use ProModel to build the simulation model. There are totally 20 locations in our simulation model. One of them represents the affected area whereas the 19 disaster management centers of the TRC in Turkey are modeled as the other locations. We define the service units (i.e., mobile kitchens etc.) in these disaster management centers as the resources of our model. A dummy entity “Disaster” is used to request the resources in the locations representing the 19 disaster management centers. A path network is used to define the paths between the possible origin-destination pairs. We assume that there are three different types of activities involving stochastic parameters which affect the time required for these resources to be ready for service (ready-to-service time, in short) as their (i) arrangements in the supply nodes, (ii) travels from the supply nodes to the demand node and (iii) establishments in the demand node. We simply assume that the times required for the arrangements and establishments of the resources are exponentially distributed since these activities in the supply nodes and the demand node are highly sensitive to various disaster parameters. On the other hand, we assume that the travel times are less varied and simulated using uniform resource speeds in the model. To keep track of the ready-to-service times of the resources from different supply nodes, we define the corresponding variables and set them equal to the simulation time when the three activities for the resources from a particular supply node are completed. The simulation is ended when all resources get ready to serve after their arrangements, travels and establishments are completed. Our modelling approach is summarized in Figure 2.

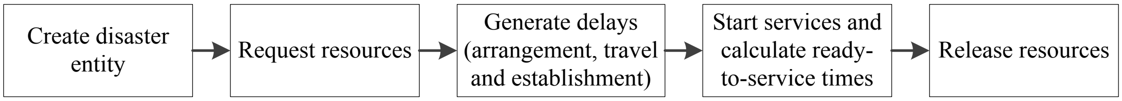

Fig. 2. Simulation Modelling Approach

After we estimate the time for the TRC to reach the affected area using the simulation model, the amounts of relief supplies to satisfy the basic needs of disaster victims for the corresponding time period are determined. These amounts are defined using the World Health Organization (WHO)'s daily requirement standard for water as 2.5 liters (WHO, 2011). We assume that 3 meals (3 MREs) are required per person-day. We further assume that each individual needs a single medical kit per person in the first 72 hours of the disaster. Using these standards and assumptions, relief supplies demands for the neighborhoods are determined considering their populations and the resource capacities of the supply nodes using the following formulation

$$d_{jk} = p_j r_k \left(\sum_s t_s q_s \right), \quad \forall j, k \tag{1}$$

where d_{jk} is the demand in neighborhood j for relief supply k, p_j is the affected population in neighborhood j, r_k is the requirement of relief supply k per person-unit time, t_s is the ready-to-service time for supply node s and q_s is the quantity representing the percentage of the demand satisfied by the resources in supply node s. Note that the demand computed in Equation 1 assumes that each arriving resource meets the demands of all neighborhoods homogenously. These relief supplies demands are then used as the input parameters of the integer programming model.

2.2. Integer programming model

We perform the allocation of TDR facilities to satisfy relief supplies demands and distribution of these relief supplies to disaster victims using the two-phase integer programming model. In the first phase of the model, total cost (distance) of distributing relief supplies is minimized whereas in the second phase, we minimize the total number of TDR facilities without compromising the objective of the first phase by adding its optimal objective function value as an additional constraint to the model.

2.2.1. Phase I: Minimization of the total cost of distributing relief supplies

In the first phase of the integer programming model, the total cost (distance) of distributing relief supplies is minimized by determining the optimal amount of these supplies each neighborhood sends and/or receives.

We model the problem using the following notation adapted from Cavdur et al. (2016):

Indices:

i, j : neighborhood
k : relief supply type

Parameters:

n_N : number of neighborhoods in the district
n_C : number of relief supply types
d_{jk} : demand for relief supply of type k in neighborhood j
c_{ij} : cost (distance) between neighborhood i and j
v_k : unit volume of relief supply of type k
w_k : unit weight of relief supply of type k
V : volume capacity of a single TDR facility
W : weight capacity of a single TDR facility
N_i : maximum number of TDR facilities for neighborhood i
α : maximum number of neighborhoods a neighborhood can serve
β : maximum number of neighborhoods a neighborhood can be served by
N_T : total number of TDR facilities available
$R_{k_p k_q}$: supply-ratio between relief supplies of type k_p and k_q for a balanced distribution
S_i : safety level of neighborhood i
T_S : threshold for safety level
M : a big number

Decision variables:

z_i : number of TDR facilities opened in neighborhood i
x_{ijk} : amount of relief supply of type k to be supplied by the facilities in neighborhood i for the disaster victims in neighborhood j

$$y_{ij} = \begin{cases} 1, & \text{if neighborhood } i \text{ serves neighborhood } j \\ 0, & \text{otherwise} \end{cases}$$

Objective function:

$$\min f_1 = \sum_{i=1}^{n_N} \sum_{j=1}^{n_N} \sum_{k=1}^{n_C} c_{ij} x_{ijk} \tag{2}$$

Subject to:

$$\sum_{i=1}^{n_N} x_{ijk} \geq d_{jk}, \quad \forall j, k \tag{3}$$

$$R_{k_p k_q} x_{ijk_p} = R_{k_q k_p} x_{ijk_q}, \quad \forall i, j; \forall k_p, k_q \in k \tag{4}$$

$$\sum_{j=1}^{n_N}\sum_{k=1}^{n_C} v_k x_{ijk} \le V z_i, \quad \forall i \tag{5}$$

$$\sum_{j=1}^{n_N}\sum_{k=1}^{n_C} w_k x_{ijk} \le W z_i, \quad \forall i \tag{6}$$

$$z_i \le N_i \left(\sum_{j=1}^{n_N}\sum_{k=1}^{n_C} x_{ijk} \right), \quad \forall i \tag{7}$$

$$\sum_{j=1}^{n_N} y_{ij} \le \alpha, \quad \forall i \tag{8}$$

$$\sum_{i=1}^{n_N} y_{ij} \le \beta, \quad \forall j \tag{9}$$

$$\sum_{k=1}^{n_C} x_{ijk} \le M y_{ij}, \quad \forall i, j \tag{10}$$

$$y_{ij} \le \sum_{k=1}^{n_C} x_{ijk}, \quad \forall i, j \tag{11}$$

$$z_i \le N_i, \quad \forall i \tag{12}$$

$$\sum_{i=1}^{n_N} z_i \le N_T \tag{13}$$

$$z_i = 0, \quad \exists i \in \{ i : S_i \le T_S \} \tag{14}$$

$$z_i \in \mathbb{Z}^+ \bigcup \{0\}, \quad \forall i \tag{15}$$

$$x_{ijk} \in \mathbb{Z}^+ \bigcup \{0\}, \quad \forall i, j, k \tag{16}$$

$$y_{ij} \in \{0,1\}, \quad \forall i, j \tag{17}$$

The objective function given in Equation 2 minimizes the total cost (distance) of distributing relief supplies. Equation 3 ensures that the relief supplies demands are satisfied. Equation 4 defines the supply-ratios between different relief supply types to satisfy all relief supplies from the same neighborhood with a balanced supply distribution based on the assumptions given in the previous sub-section. Equation 5 and Equation 6 performs capacity checks in terms of volume and weight, respectively. By combining these with Equation 7, we also relate the corresponding decision variables. Note that Equation 7 ensures that no TDR facility is opened in neighborhood *i* if neighborhood *i* does not provide any relief supplies to any neighborhood. Equation 8 and Equation 9 are some kind of "humanitarian" constraints representing the maximum number of neighborhoods a neighborhood can serve and be served by, respectively. Equation 10 and Equation 11 defines the logical relationships between the corresponding variables. Equation 12 (Equation 13) restricts the number of facilities per neighborhood (the total number of facilities) whereas Equation 14 prevents allocating facilities in the neighborhoods whose safety conditions are below the required safety level. Constraints about the safety conditions simply identifies the neighborhoods in which it is allowed/not allowed to allocate facilities since it is also important to ensure that the minimum safety conditions are satisfied in a neighborhood for preventing the occurrences of unwanted situations before, during and after a disaster. Equation 15, 16 and 17 are default constraints.

2.2.2. Phase II: Minimization of the total number of facilities

In the second phase of the integer programming model, we minimize the total number of TDR facilities (Equation 18) subject to the same constraints of the first phase (Equation 3-17) as well as its optimal objective function value; that is, we use an additional constraint (Equation 19) in the second phase as the optimal first phase objective value with a small amount of relaxation (i.e., the ε -constraint approach). The resulted model is solved to minimize the total number of facilities without -*significantly*- increasing the total cost (distance) of distributing relief supplies.

Objective function:

$$\min f_2 = \sum_{i=1}^{n_N} z_i \tag{18}$$

Subject to:

Equations (3)-(17)

$$\sum_{i=1}^{n_N}\sum_{j=1}^{n_N}\sum_{k=1}^{n_C} c_{ij}x_{ijk} \le f_1 + \varepsilon \tag{19}$$

3. Implementation and Results

In this study, we use an earthquake case study developed by AFAD (Figure 3) to illustrate our approach, according to which affected population in each neighborhood is estimated. We first determine the proportion of the total affected population in each neighborhood that is served by the resources in each supply node in our simulation model. Using the travel distances and times obtained from Google Maps (https://maps.google.com/), we estimate the average speed of each resource with some uniform variation (±10 km/h). Note that average speeds of the resources from different supply nodes also differ due to various conditions such as geographical properties of the region of the corresponding supply nodes. The times required for the arrangements and establishments of resources are assumed to be as 3 hours and 1 hour on average, respectively, both exponentially distributed.

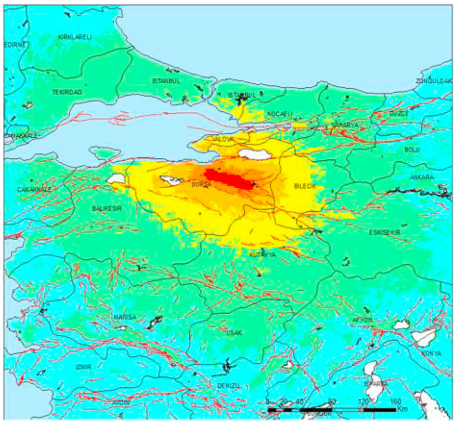

Fig. 3. Representation of the Earthquake Scenario Developed by AFAD

After we get the ready-to-service times for the resources in each supply node as a result of the simulation model, we calculate the corresponding relief supplies demands according to the formulation given in Equation 1. Two different system designs are considered where we simulate the current system and an alternative design in which we increase the number of resources in Istanbul and Yalova, two of the closest supply nodes to the affected area. It is noted that in this alternative, the resources in the supply nodes representing the most distant three nodes (i.e., Agri, Mus and Erzurum) are not included since with the additional resources in Istanbul and Yalova, these resources are not needed any more. Both alternatives are implemented in ProModel each with 50 replications. In our analysis, we consider the average and worst cases where the average and the longest run times of the 50 replications are considered, respectively. Figure 4 presents the run time simulation layout.

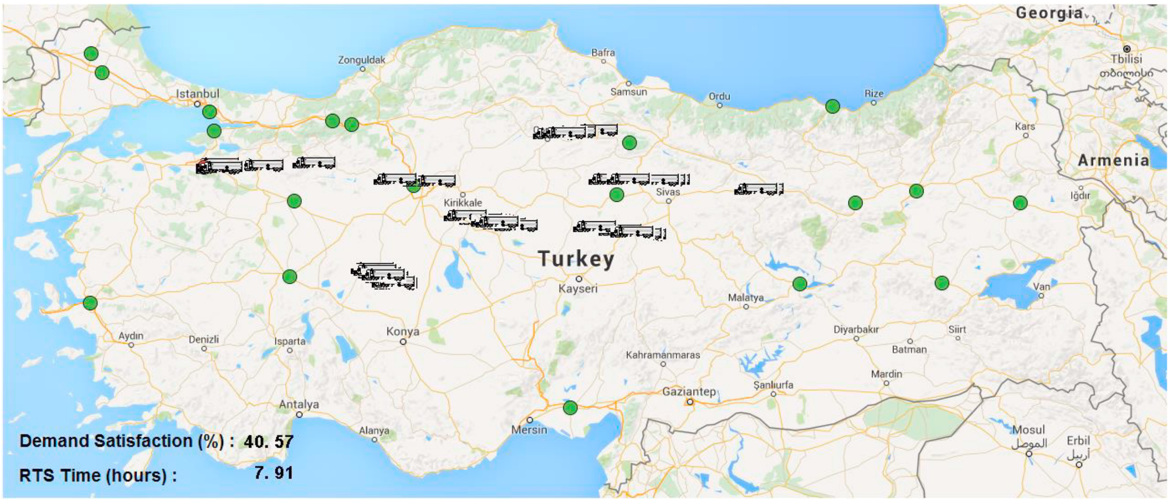

Fig. 4. Layout of the Simulation Model (Run Time)

On average, ready-to-service time of 763.88 (920.39) minutes are obtained for the average (worst) case of the current system whereas the corresponding ready-to-service times for the alternative design are 633.77 minutes and 712.85 minutes, respectively; implying respective decreases of 17% and 22%. Simulation results are then used to determine the relief supplies demands via Equation 1 for both alternatives as seen in Table 1. The quantities in Table 1 represent the total demand of each relief supply for each alternative and its case.

Table 1. Summary of Results (Simulation Model)

	Water (liters)	MRE (units)	Medical Kit (units)
CS – Average Case	366,447	439,730	48,887
CS – Worst Case	456,592	547,907	60,904
AD – Average Case	281,131	337,352	37,514
AD – Worst Case	346,533	415,827	46,233

CS: Current System, AD: Alternative Design

After we determine the relief supplies demands, the integer programming model is solved for again both alternatives and cases. We implement the integer programming model using the Mathematical Programming Language (MPL) with Gurobi. As in the simulation model, we obtain the distances between the neighborhoods using Google Maps. Turkish Statistical Institute (TUIK)'s population statistics are used to determine the relief supply demands (http://www.tuik.gov.tr/). The three types of relief supplies considered in this study as water, MRE and medical kit have unit volumes (weights) of 1 liter (1 kilogram), 0.5 liters (0.25 kilograms) and 0.5 liters (0.25 kilograms), respectively. We assume that 1,000 TDR facilities are available totally each of which has a volume capacity of 34,560 liters and weight capacity of 30,480 kilograms, and the maximum number of TDR facilities allowed per neighborhood is 100. We further assume that a neighborhood can serve and be served by 10 neighborhoods at most. Since the demands are directly related to the populations of the neighborhoods, the big number we use in the model (M) is set equal to 50,000 which approximately represents the amount of total relief supplies demand for the most populated neighborhood in the district. The integer programming model is solved for a safety level of 97.5%. To see the effects of different safety levels on the solution, the interested reader can refer to Cavdur et al. (2016).

The results are summarized in Table 2. As expected, increases in the total cost of distributing relief supplies (phase-I) and the total number of TDR facilities opened (phase-II) are observed in the worst case compared to the average case. In terms of the benefits of allocating more resources in Istanbul and Yalova in the alternative design, it is noted that the total costs of distributing relief supplies decrease 23% and 24% in the average and worst cases, respectively. The total number of TDR facilities in the average (worst) case for the current system is 30 (38) whereas it decreases to 24 (28) in the alternative design.

Table 2. Summary of Results (Integer Program)

	Phase I	Solution Time (sec.)	Phase II	Solution Time (sec.)
CS – Average Case	1,582,705.00	0.17	30	0.73
CS – Worst Case	1,971,830.70	0.19	38	2.06
AD – Average Case	1,214,517.00	0.17	24	0.85
AD – Worst Case	1,496,833.25	0.19	28	2.12

CS: Current System, AD: Alternative Design

An example distribution network is shown in Figure 5 where the nodes and arcs of the network represent the neighborhoods with their approximate coordinates (also obtained using Google Maps) in the Yildirim district and the flows of relief supplies between the neighborhoods, respectively. Note that the white nodes in the network show the neighborhoods in which it is allowed to open TDR facilities whereas the gray ones do not satisfy the corresponding safety level under the minimum required safety conditions.

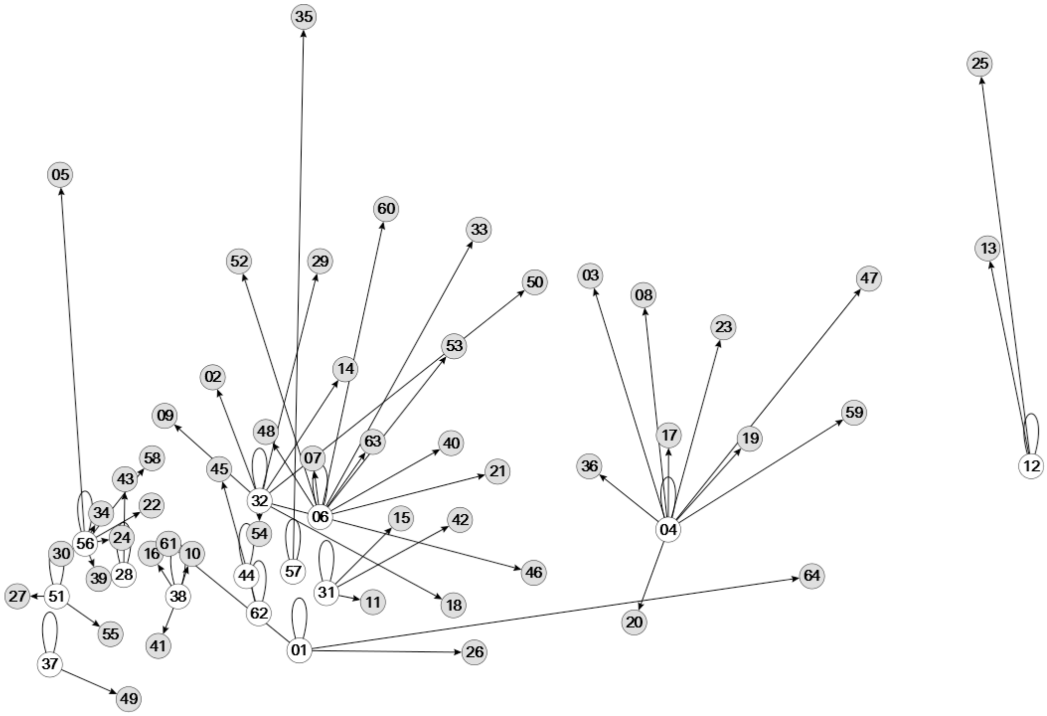

Fig. 5. An Example Network Representation for the TDR Facilities Allocation and Relief Supplies Distribution

4. Conclusions

In this study, we propose an approach for determination of relief supplies demands and the optimal allocation of TDR facilities using a combined methodology utilizing a simulation model and an integer program. We first determine the corresponding relief supplies demands by analyzing the time it takes for the TRC to reach the affected area using the simulation model. We then present a two-phase integer program in order to develop a pre-positioning plan, i.e., considering both the allocation of TDR facilities and the distribution of relief supplies. Our approach includes both preparedness and response activities in DOM, and although itis illustrated with an earthquake case study, we can easily generalize it for other types of disasters. Instead of allocating TDR facilities using a pre-defined relief supplies demand setting, we simulate possible disaster conditions to estimate the corresponding demands. In addition to the common problem specifications, we also adapt some additional constraints from Cavdur et al. (2016), such as safety conditions, satisfying all relief supplies from the same neighborhood with a balanced supply distribution and the maximum number of neighborhoods a neighborhood can serve and be served by. Some extensions can be considered in future studies. One of them is about an integrated evaluation of the parameters of the simulation model and the integer program together. Considering inventory replenishments might be another future study direction.

Acknowledgements

This research was supported by TUBITAK, the Scientific and Technological Research Council of Turkey (115M020). We would like to thank Burcu Balcik in Ozyegin University; Ibrahim Tari, Nurdan Ilhan and Esat Duman in AFAD-Bursa Provincial Directorate and Nevzat Ugurer, Ercan Onalan and Arife Ermis in Yildirim-Bursa Police Department for their valuable contributions.

References

Albores, P., Shaw, D., 2008. Government preparedness: Using simulation to prepare for a terrorist attack. Computers & Operations Research 35(6), 1924-1943.

Altay, N., Green, W. G., 2006. OR/MS research in disaster operations management. European journal of operational research 175(1), 475-493.

Barbarosoglu, G., Arda, Y., 2004. A two-stage stochastic programming framework for transportation planning in disaster response. Journal of the operational research society 55(1), 43-53.

Cavdur, F., Kose-Kucuk, M., Sebatli, A., 2016. Allocation of temporary disaster response facilities under demand uncertainty: An earthquake case study. Working Paper.

Chen, X., Zhan, F. B., 2008. Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies. Journal of the Operational Research Society 25-33.

Chiu, Y. C., Mirchandani, P. B., 2008. Online behavior-robust feedback information routing strategy for mass evacuation. Intelligent Transportation Systems, IEEE Transactions on, 9(2), 264-274.

Galindo, G., Batta, R., 2013. Review of recent developments in OR/MS research in disaster operations management. European Journal of Operational Research 230(2), 201-211.

Georgiadou, P. S., Papazoglou, I. A., Kiranoudis, C. T., Markatos, N. C., 2007. Modeling emergency evacuation for major hazard industrial sites. Reliability Engineering & System Safety 92(10), 1388-1402.

Gormez, N., Koksalan, M., Salman, F. S., 2011. Locating disaster response facilities in Istanbul. Journal of the Operational Research Society 62(7), 1239-1252.

Kilci, F., Kara, B. Y., Bozkaya, B., 2015. Locating temporary shelter areas after an earthquake: A case for Turkey. European Journal of Operational Research 243(1), 323-332.

Koehler, G. A., 1996. What disaster response management can learn from chaos theory, California State Library, California Research Bureau.

Lee, Y. M., Ghosh, S., Ettl, M., 2009. Simulating distribution of emergency relief supplies for disaster response operations, Winter Simulation Conference (pp. 2797-2808). Winter Simulation Conference.

Murali, P., Ordonez, F., Dessouky, M. M., 2012. Facility location under demand uncertainty: Response to a large-scale bio-terror attack. Socio-Economic Planning Sciences 46(1), 78-87.

Nagurney, A., Yu, M., Qiang, Q., 2011. Supply chain network design for critical needs with outsourcing. Papers in Regional Science 90(1), 123-142.

Natarajarathinam, M., Capar, I., Narayanan, A., 2009. Managing supply chains in times of crisis: a review of literature and insights. International Journal of Physical Distribution & Logistics Management 39(7), 535-573.

Ozdamar, L., Demir, O., 2012. A hierarchical clustering and routing procedure for large scale disaster relief logistics planning. Transportation Research Part E: Logistics and Transportation Review 48(3), 591-602.

Rawls, C. G., Turnquist, M. A., 2010. Pre-positioning of emergency supplies for disaster response. Transportation research part B: Methodological 44(4), 521-534.

Rawls, C. G., Turnquist, M. A., 2011. Pre-positioning planning for emergency response with service quality constraints. OR spectrum 33(3), 481-498.

Salman, F. S., Gul, S., 2014. Deployment of field hospitals in mass casualty incidents. Computers & Industrial Engineering 74, 37-51.

WHO technical notes on drinking-water, sanitation and hygiene in emergencies, Technical note 9: how much water is needed in emergencies, 2011. World Health Organization / Water Engineering Development Centre.

Yi, W., Ozdamar, L., 2007. A dynamic logistics coordination model for evacuation and support in disaster response activities. European Journal of Operational Research 179(3) 1177-1193.

Zou, N., Yeh, S. T., Chang, G. L., Marquess, A., Zezeski, M., 2005. Simulation-based emergency evacuation system for Ocean City, Maryland, during hurricanes. Transportation Research Record: Journal of the Transportation Research Board 1922, 138-148.