Modeling Prepositioning of Resources for Humanitarian Logistics

Shaligram Pokharel
Department of Mechanical and Industrial Engineering
Qatar University
P.O. Box 2713, Doha, Qatar
shaligram@qu.edu.qa

Jose Holguin-Veras
Department of Civil and Environmental Engineering, Rensselaer Polytechnic Institute, JEC 4030, 110 8th Street, Troy, NY 12180, USA jhv@rpi.edu

Rojee Pradhananga
Department of Mechanical and Industrial Engineering
Qatar University
P.O. Box 2713, Doha, Qatar

Abstract

Prepositioning of resources for humanitarian assistance to the victims of natural disaster is an important consideration to mitigate the problem that occurs due to the shortage in the supply of resources. Prepositioned resources should be distributed in the affected areas. Although prepositioning of the resources in natural cases like an earthquake is difficult, it can be done more systematically in the hurricane-prone, flood-prone zones. The distribution mechanism, network, supply of resources and quantities, feasible supply routes and transfer of the materials from one or several supply centers become some of the issues that can be studied systematically through the modeling process and is the focus of this paper. A model is developed and a small case has been used to test the model. The results and repercussions have also been discussed.

Keywords
Prepositioning, humanitarian logistics, resources demand, distribution mechanism.

1. Introduction

Pre-positioning is a key element in emergency preparedness planning which involves strategic positioning of resources at facilities near locations with disaster risks so as to ease the relief distribution process in case a disaster happens in the area (Rawls and Turnquist, 2011). Past disaster experiences have shown its effectiveness to reduce disaster impact firstly by reducing the reaction time and secondly by providing the first wave of critical and life-sustaining supplies. Advance placement of resources allows not only faster response but also better procurement planning and an improvement on distribution costs (Ergun et al., 2010). The scale of effectiveness however largely depends upon the decisions on pre-positioning locations and the allocated resources quantities. Therefore, the pre-positioning problem must be supplemented by a strong analytical tool that represents the actual situation in the field.

The pre-positioning problem presented in this paper focuses on the optimal locations of the pre-positioning facilities (distribution centers) with the optimal quantities of resources to be allocated considering the uncertainties of demand. The mathematical model considers multiple suppliers and multiple distribution centers. The model considers that in the pre-positioning structure, a set of suppliers would commit resources to a set of distribution centers in order to supply a set of commodities to the outlets spread around the disaster event in the future. The model considers capacity planning at supplier's location for pre-positioning of resources. The expected cost of distribution of resources following the disaster event is obtained considering the fact that the unmet demands are fulfilled either from the distribution centers with sufficient supplies or through direct post-disaster shipment of resources from the suppliers. Various possibilities of pre-disaster purchasing and post-disaster distribution from suppliers are discussed.

The model is formulated as a two-stage stochastic mixed integer programming model. The uncertainties following the disaster event are dealt with considering a set of discrete scenarios. When two-stage formulation is made, the decisions in the first stage are made under uncertainty about the conditions to be faced in the second stage (Birge and Louveaux, 1997). This assumption is going to be followed in this proposed research as well. Optimal suppliers and distribution centers locations along with optimal resource quantities to be allocated at the distribution centers by the suppliers are obtained as first-stage decisions. Decisions in the second-stage model are the recourse decisions that are dependent upon the first stage decisions. The second-stage model deals with detailed distribution of the resource to the demand points in response to specific scenarios.

2. Review of similar research

Related research has been mentioned over here. Some of the research related to the proposed prepositioning are given in (Rawls and Turnquist, 2010), Khayal et al (2015) and Pradhananga et al (2016). The distribution of resources in the humanitarian situation is subjected to several uncertainties related to demand, location, and the capacity of the distribution network. Researchers have used either dynamic approach to allocate resources such as that by Özdamar et al. (2004), Rottkemper et al. (2012), and Rawls and Turnquist (2012) or stochastic approach, such as that by (Barbarosoglu and Arda, 2004; Chang et al., 2007; Balcik and Beamon., 2008; Rawls and Turnquist, 2010; Mete and Zabinsky, 2010; Salmerón and Apte, 2010; Rawls and Turnquist, 2011; Campbell and Jones, 2011; Wei-Hua et al., 2011; Lodree et al,, 2012). A few pre-positioning studies above (Barbarosoglu and Arda, 2004; Wei-hua et al., 2011; Lodree et al, 2012) focus only on resource allocation considering the fixed locations of distribution centers. While most of the stochastic resource pre-positioning studies (Chang et al., 2007; Balcik and Beamon, 2008; Rawls and Turnquist, 2010; Mete and Zabinsky, 2010; Salmerón and Apte, 2010; Rawls and Turnquist, 2011; Campbell and Jones, 2011) consider combined facility location and resource allocation for determining optimal location of distribution centers and allocation of optimal resource quantities at these centers. Except for a few studies (Wei-hua et al., 2011; Balcik and Beamon., 2008; Campbell and Jones, 2011), all the above list of stochastic resource pre-positioning studies use two-stage stochastic programming approach which reflects its dominance in this area. The objectives in emergency logistics are related to either service-efficiency or cost-efficiency (Caunhye et al., 2012). All two-stage stochastic programming models have cost-based objective functions. The first stage corresponds to the supplier's cost of production, transportation, and inventory while the second stage is related supply shortage cost and the holding cost of the excess resource which are also considered as a part of the deprivation costs produced by the delivery strategy (Holguin-Veras et al., 2012) following the event.

Barbarosoglu and Arda (2004) give one of the earliest works in emergency logistics resource pre-positioning. A multi-commodity multi-modal network flow problem is formulated as a two-stage stochastic programming model. Lodree et al. (2012) proposed a two-stage stochastic model with similar objectives to that of Barbarosoglu and Arda (2004) in order to achieve optimal allocation of resources. Wei-hua et al. (2010) presented a resource allocation model with service efficiency as the main objective. Uncertainty in demand is dealt with by considering scenarios with probabilistic distributions. Chang et al. (2007), Rawls and Turnquist (2010), Mete and Zabinsky (2010), Salmerón and Apte (2010) and Rawls and Turnquist (2011) studied combined facility location and resource allocation problem. These authors have used two-stage stochastic programming model. Similar to models presented by Barbarosoglu and Arda (2004) and Lodree et al. (2012), the models presented in these studies have cost-based objective function and the later stage is related with the detailed distribution of the material from distribution center to the demand points.

The uniqueness of model presented by Rawls and Turnquist (2010) in comparison to two-stage models presented in other studies is that the study also considers the possibility of damages of the distribution centers and the transportation network during the disaster. For this purpose, a variable that indicates the proportion of stocked resources that remains usable in a particular scenario is assigned to each distribution center. Also, links in the transportation network are assigned based on the scenarios. Rawls and Turnquist (2011) have proposed an extension of the model and the solution approach proposed by Rawls and Turnquist (2010). The extension includes additional service quality constraints to ensure availability of sufficient supply at the distribution center and for timely response to the demand points.

The review of some of the literature shows that an important aspect in emergency logistics, pre-positioning of resources combined with facility location with multiple suppliers has not yet been studied and is the focus of this research paper. The two-stage stochastic programming model presented in this paper has some similarities with resource allocation model presented by Lodree et al. (2012) and Khayal et al (2015) in considering the possible direct transfer of resources from the supplier to the supply shortage locations in the second stage in addition to the possibilities of movement of excess resources pre-positioned at the first stage. Most importantly, the combined facility location and allocation model here considers capacity utilization of the multiple suppliers considering various possibilities of pre-disaster purchasing and post-disaster supplier distribution situations which has not been studied in the literature.

3. Emergency logistics distribution network modeling

3.1 Modeling framework

We consider a distribution network modeling framework for a supply item to be distributed during the disaster relief operations as shown in Figure 1. The item is supplied by a set of potential suppliers. The locations, named as facilities, that are going to be affected by the disaster is known before the disaster. However, their demand depends on the disaster scenario.

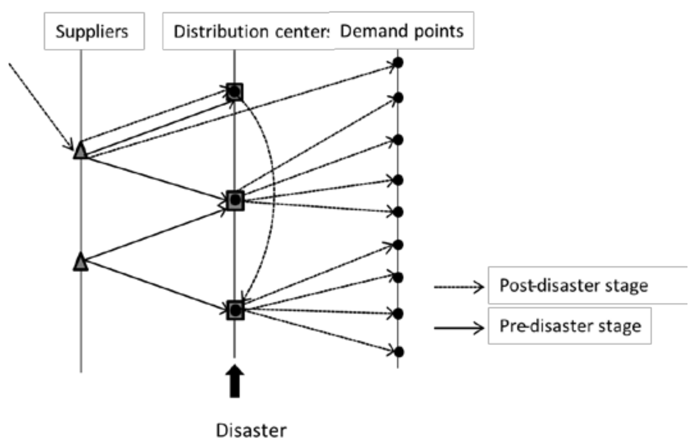

Figure 1 Emergency logistics distribution framework

We have two planning stages: the pre-disaster stage, where suppliers, supply volumes, some distribution centers are selected; the post-disaster stage, the volume of deliveries between various sources, and, if needed, the extra amounts to be purchased are decided. Decisions in the pre-disaster stage are made before the realization of the uncertain parameters. Therefore, the variables in this stage are fixed and are free of uncertainties. Variables in the post-disaster stage are referred to as resourse variables as their optimal values depend on both the realization of uncertain parameters and the optimal values of the pre-disaster stage variables. Uncertainties in the stage are dealt with considering a set of scenarios.

3.2 Formulation

The notations used for the formulation are given in Table 2.

Table 2 Notations used in model development

Symbol	Description
M	Set of suppliers
N	Set of facilities
S	Set of scenarios
P_s	Probability of occurrence of scenario $s \in S$
d_{is}	Demand at facility $i \in N$ in scenario $s \in S$
δ_{is}:	Proportion of the resources pre-positioned at facility $i \in N$ that remains usable in scenario $s \in S$ $(0 \le \delta_{is} \le 1)$
V_i	Capacity of facility $i \in N$
V_j	Capacity of supplier $j \in M$
U_j	Outsourcing capacity at supplier $j \in M$
f_i	Fixed cost of operation of a distribution center located at $i \in N$
f'_j	Fixed cost of operation of a supplier $j \in M$
c_{ji}	Unit cost of transportation and handling from supplier $j \in M$ to facility $i \in N$
c'_{jis}	Unit cost of transportation and handling from supplier $j \in M$ to facility $i \in N$ in scenario $s \in S$
c'_{iks}	Unit cost of transportation and handling from facility $i \in N$ to facility $k \in N$ in scenario $s \in S$
p_{is}	Unit cost of delayed shipment to facility $i \in N$ in scenario $s \in S$
v_j	Unit cost of production at supplier $j \in M$
g_{js}	Unit cost of outsourcing or producing of supplier $j \in M$ in scenario $s \in S$
h	Unit cost of holding of the unused items at facility
w	Unit cost of shortage at facility
y_i	= 1, if a distribution center is located at facility $i \in N$ = 0, otherwise
y'_j	= 1, if a supplier $j \in M$ is functional = 0, otherwise
x_{ji}	Pre-positioned amount from supplier $j \in M$ to facility $i \in N$
t_j	Total amount pre-positioned/purchased from supplier $j \in M$ ($t_j = \sum_{i \in N} x_{ji}$)
z_i	Total pre-positioned amount at facility $i \in N$ ($z_i = \sum_{j \in M} x_{ji}$)
q_{iks}	Quantity shipped from facility $i \in N$ to facility $k \in N$ in scenario $s \in S$
r_{jis}	Quantity shipped from supplier $j \in M$ to facility $i \in N$ in scenario $s \in S$
o_{js}	Outsourced or production amount at supplier $j \in M$ in scenario $s \in S$
n_{is}	Total amount delivered from facility $i \in N$ to other facilities in scenario $s \in S$ ($n_{is} = \sum_{k \in N} q_{iks}$)
m^f_{is}	Total amount delivered to facility $i \in N$ from other facilities in scenario $s \in S$ ($m^f_{is} = \sum_{k \in N} q_{kis}$)
m^s_{is}	Total amount delivered to facility $i \in N$ from suppliers in scenario $s \in S$ ($m^s_{is} = \sum_{j \in M} r_{jis}$)
m_{is}	Total amount delivered to facility $i \in N$ in scenario $s \in S$ ($m_{is} = m^f_{is} + m^s_{is}$)
t'_{js}	Total amount distributed from supplier $j \in M$ in scenario $s \in S$ ($t'_{js} = \sum_{i \in N} r_{jis}$)
l_{is}	Unused amount at facility $i \in N$ in scenario $s \in S$
u_{is}	Underage or shortage amount at facility $i \in N$ in scenario $s \in S$
$\mathbb{C}$	Big number

3.2.1 Pre-Disaster Stage Costs

Equations (1) to (3) are the expressions for the cost terms. C1 is the total fixed cost associated with the operations of the suppliers and the DCs. C2, on the other hand, is the total cost of the pre-positioned resources. C3 is the total cost of transportation and handling of resources from suppliers to the DCs in the pre-disaster stage.

$$C1 = \sum_{i \in N} f_i \, y_i + \sum_{j \in M} f'_j \, y'_j \quad (1)$$

$$C2 = \sum_{j \in M} v_j t_j \quad (2)$$

$$C3 = \sum_{j \in M} \sum_{i \in N} c_{ji} x_{ji} \quad (3)$$

3.2.2 Post-Disaster Stage Costs

Post-disaster stage corresponds to the distribution of resources following the disaster event when the actual demand quantities are already realized. The uncertainties associated with the demand quantities are solved considering a set of disaster scenarios S where each scenario s has a probability of occurrence P_s. Equations (4) to (8) respectively are the expressions for the costs. C4 is the expected total outsourcing cost which is the additional cost that the suppliers have to pay for acquiring o_{js} resources over all the scenarios in S. C5 is the expected total transportation and handling cost of resources q_{iks} and r_{jis}. C6 is the total expected delay cost associated with the post disaster shipment of resources r_{jis} from the suppliers. Scenario dependent unit costs of transportation and handling (c'_{jis} and c'_{kis}) in this study reflects possible effect of the disaster on the transportation network. While the unit cost of delayed shipment (p_{is}) is representative of the additional delay cost (excluding the increased transportation cost) associated with the supplier's post disaster shipment. It is a measure of the level of urgency of the resource at facility i in scenario s, and can vary from 0 to the unit shortage cost depending upon the resource under consideration. C7 is the expected total costs of holding the excess supply and C8 is the expected total supply shortage cost.

$$C4 = \sum_{s \in S} P_s \sum_{j \in M} g_{js} \, o_{js} \quad (4)$$

$$C5 = \sum_{s \in S} P_s \left[\sum_{i \in N} \sum_{k \in N} c'_{iks} \, q_{iks} + \sum_{j \in M} \sum_{i \in N} c'_{jis} \, r_{jis} \right] \quad (5)$$

$$C6 = \sum_{s \in S} P_s \sum_{i \in N} p_{is} \, r_{jis} \quad (6)$$

$$C7 = \sum_{s \in S} P_s \sum_{i \in N} h \, l_{is} \quad (7)$$

$$C6 = \sum_{s \in S} P_s \sum_{i \in N} w \, u_{is} \quad (8)$$

3.2.3 Mathematical Model

Combining the costs of prepositioning in pre-disaster stage [Equations (1) to (3)] and the expected costs of distribution in post-disaster stage [Equations (4) to (8)], a two-stage stochastic programming model for emergency logistics resource distribution can be formulated as follows:

Minimize

$$\sum_{i\in N} f_i\, y_i + \sum_{j\in M} f'_j\, y'_j + \sum_{j\in M} v_j t_j + \sum_{j\in M}\sum_{i\in N} c_{ji}\, x_{ji} + \sum_{s\in S} P_s \Bigg[\sum_{j\in M} g_{js}\, o_{js} + \sum_{i\in N}\sum_{k\in N} c'_{iks}\, q_{iks} + \sum_{j\in M}\sum_{i\in N} c'_{jis}\, r_{jis} + \sum_{j\in M}\sum_{i\in N} p_{is}\, r_{jis} + \sum_{i\in N} h\, l_{is} + \sum_{i\in N} w\, u_{is} \Bigg] \quad (9)$$

subject to

$$t_j \leq V_j\, y'_j \qquad \forall\, j \in M \qquad (10)$$

$$z_i \leq V_i\, y_i \qquad \forall\, i \in N \qquad (11)$$

$$y'_j \in (0,1) \qquad \forall\, j \in M \qquad (12)$$

$$y_i \in (0,1) \qquad \forall\, i \in N \qquad (13)$$

$$x_{ji} \geq 0 \qquad \forall\, j \in M, \text{and } i \in N \qquad (14)$$

$$\mathbb{C}\, y'_j \geq r_{jis} \qquad \forall\, j \in M, i \in N, \text{and } s \in S \qquad (15)$$

$$\delta_{is}\, z_i - n_{is} + m_{is} - l_{is} + u_{is} = d_{is} \qquad \forall\, i \in N, \text{and } s \in S \qquad (16)$$

$$t'_{js} = o_{js} \qquad \forall\, j \in M \text{ and } s \in S \qquad (17)$$

$$o_{js} \leq U_j \qquad \forall j \in M \text{ and } s \in S \qquad (18)$$

$$l_{is} \geq 0, u_{is} \geq 0, q_{iks} \geq 0, r_{jis} \geq 0, o_{js} \geq 0 \qquad \forall i, k \in N, j \in M, \text{and } s \in S \qquad (19)$$

Constraints (10) to (14) are related to the pre-disaster stage while constraints (15) to (19) are related to post-disaster stage. Constraints (10) and (11) are the capacity constraints in the pre-disaster stage. The first constraint corresponds to the capacity restriction at the supplier location. y'_j in the constraint ensures pre-positioning at pre-disaster stage be carried out from only those suppliers that are functional. The second constraint is related with the capacity restriction at the distribution center while it also constraints that the pre-positioning is carried out only at the located facilities (DCs). Constraints (12) to (14) are the non-negativity constraints in pre-the disaster stage. Constraint (15) similar to Constraint (10) assures distribution of resources in post-disaster stage from only the functional suppliers. Constraint (16) is the flow conservation constraint at facility i which depending upon the resource pre-positioned in pre-disaster stage defines the additional resource required to be shipped to the facility from the suppliers and the final supply overage and demand shortage at the facility in each scenario. Constraint (17) confirms that all post-disaster deliveries from suppliers are met through outsourcing during the same stage. The total outsourcing of each supplier however has an upper bound as represented in constraint (18).

4. Numerical Study

The proposed emergency logistics resource distribution model is tested on a realistic instance, derived from the case study presented by Rawls and Turnquist (2010). The case study has been developed considering hurricane threats in the Southeastern US region and is represented by a network of 30 nodes and 55 links. The case study data in Rawls and Turnquist (2010) are modified in order to fit it to the model presented in Section 3. Out of the 30 nodes, 3 nodes (Nodes 4, 16 and 20) are selected as the potential supplier locations. Rest of all the 27 nodes in the network represents facilities in the network which are the potential DC locations. Figure 2 shows the locations of the potential suppliers and facilities and their connectivity in the network.

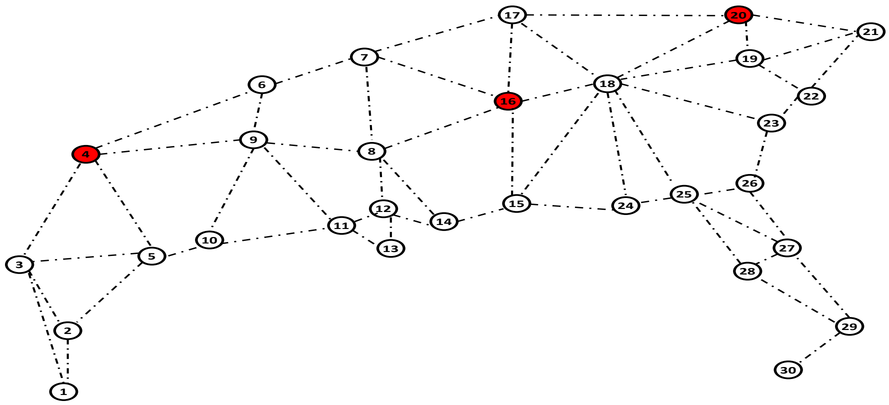

Figure 2 Facilities and potential suppliers in the test instance

The present study considers the distribution of a single commodity (say, water). Table 3 shows the capacities, fixed costs, and outsourcing limits at the potential suppliers. Each unit of the commodity is equivalent to 1000 gallons. The location of potential suppliers and the values in Table 3 and Table 4 are hypothetical.

Demand scenarios and the network reliability data in this study are derived from Rawls and Turnquist (2010). The holding and shortage costs which are 161.93$/unit and 6477$/unit are also the same used in their study. The delay penalty cost for the instance is assumed to be half of the shortage cost.

Table 3 Capacities, production cost, outsourcing cost, outsourcing limit and fixed cost at potential suppliers

Potential Supplier	Capacity (1000gals)	Production cost ($/unit)	Outsourcing cost ($/unit)	Outsourcing limit (1000 gals)	Fixed cost($)
4	7000	647.7	971.55	2500	350000
16	7000	647.7	971.55	2500	450000
20	7000	647.7	971.55	2500	425000

Table 4 Capacities and fixed costs of facilities

Nodes	Capacities(1000 gals)	Fixed cost($)
1, 11, 12, 13, 14, 27, 28	250	19600
2, 3, 5, 8, 9, 10, 15, 21, 22, 23, 24, 25, 26, 29, 30	2500	188400
6, 7, 17, 18, 19	5000	300000

Table 5 Demand and network reliability of the sample hurricanes

Hurricane	Category	Landfall node	Links unusable	Demand (1000 gals)
1	3	5	(4,5)	350
2	5	14	(12, 14) (14, 15) (15, 24)	560
3	2	22	-	861
4	2	22	(17,20)	9000
5	4	11, 29	-	7500
6	3	15	-	1000
7	2	21	(21, 22)	600
8	1	11	(8, 12)	1500
9	5	13, 29	(12, 13)	1040
10	2	2	-	2250
11	3	21	(21, 22)	5000
12	3	27	(15, 24)	18000
13	3	8	-	2818
14	4	14, 30	-	2239

15	4	22	-	4400

Table 6. Some of the scenarios for numerical study

Single hurricane threats			Combined hurricane threats			
Scenario	Hurricane	Probability	Scenario	Hurricanes		Probability
1	1	0.023	27	12	2	0.004
2	5	0.050	28	12	4	0.006
3	10	0.161	29	12	14	0.005
4	3	0.053	30	13	2	0.005
5	2	0.009	31	13	8	0.008
6	12	0.030	32	4	2	0.005
7	13	0.133	33	11	5	0.005
8	4	0.053				
9	11	0.022	49	6	3	0.006
10	14	0.022	50	6	7	0.006
11	15	0.022	51	No hurricane		0.017

5. Results and Discussions

Table 7 is the optimal resource distribution for the test instance. The optimal solution consists of the location of two suppliers at location 4 and 20 and distribution centers at locations 9 and 21. Resource allocation from the suppliers to the DCs in the pre-disaster stage and the expected values from suppliers to facilities including DCs in the post-disaster stage are also given in the table. The optimal solution associates a total cost of $12.64 million out of which $6.47 million is the pre-disaster cost while $6.17 million is the expected post-disaster cost. The shortage cost which accounts 23.1% of the total cost corresponds to expected unmet demand of 10.4%.

Table 7 Optimal solution of the test instance

Supplier	Facilities	Resource allocation (1000 gals)	
		Pre-disaster	Post-disaster (Exp.)
4	9 (DC)	2500	130
	5, 8, 11, 14, 18, 22, 25	-	73
20	19 (DC)	5000	27
	21, 22, 29	-	261

A special case of the present model with only one supplier having large capacity and a unit delay penalty cost *p* equal to or greater than the unit shortage cost *w* results in Rawls and Turnquist (2010) equivalent model for a single commodity. Considering the problem instance has a single supplier at node 4 with a capacity of 30000 units, the optimal solution as given in Table 8 is obtained. It consists of the location of 3 DCs at nodes 6, 9 and 12. The total pre-positioning amount is 7750 units of water and its distribution in post-disaster stage corresponds to an expected unmet demand of 20.8%.

The significance of direct post-disaster shipment of resources from suppliers to the facilities considered in this study can be observed noticeably while we consider the decreasing value of the delay penalty cost for the post-disaster shipments. The actual value as mentioned previously is dependent on the commodity under consideration. Table 9 lists out the optimal results obtained for the same problem with single supplier having large capacity but for different values of the delay penalty cost. As the table shows for lower values of delay penalty the optimal solution favors demand satisfaction with the more post-disaster shipment. It also corresponds to decreased expected unmet demand provided that the pre-positioning amount remains same. The slight increase of expected unmet demand % in Table 9 for very low values of the delay penalty is due to a reduction in the pre-positioning quantity itself that has a tendency to bring a higher reduction in the total cost.

Table 8 Optimal solution with single supplier having a large capacity

DC	Pre-positioning amount (1000 gals)
6	5000
9	2500
12	250

Table 9 Variation of delay penalty cost in a problem with a single supplier having a large capacity

p_{is}	Opt. DCs	Exp. unmet demand %	Exp. demand met by post-disaster allocation %
W	3	20.82	0
0.8w	3	20.58	0.24
0.6w	2	14.65	7.12
0.4w	2	14.65	7.12
0.2w	2	16.48	10.36
0	2	16.48	10.36

6. Conclusions

The paper presents a resource distribution model for emergency preparedness. It considers a distribution network of suppliers, DCs, and the demand points. A stochastic two-stage model is presented to determine the optimal locations of the suppliers (from a pre-specified set of potential suppliers) and the DCs (among the pre-specified facilities at demand points) and for optimal resource allocation from the suppliers. Various possibilities of pre-disaster purchasing and post-disaster deliveries of resources from suppliers are explored. The model considers pre-disaster purchasing from suppliers equivalent to the amount of pre-positioning and possibility of direct post-disaster delivery from the suppliers to all the facilities is presented. All the post-disaster delivery from the suppliers in the model are assumed to be carried out through post-disaster outsourcing/purchasing, the unit cost of which is pre-defined in the pre-disaster stage. The optimal suppliers and DCs location and resource allocation depending on the total cost of the allocation which includes the pre-disaster cost of pre-positioning and the expected post-disaster cost of resource distribution.

Acknowledgements

This research is made possible by a NPRP award NPRP 5-200-5–027 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

References

Balcik, B., Beamon, B. M. (2008). Facility location in humanitarian relief. *International Journal of Logistics: Research and Applications*, 11(2), 101-121.
Barbarosoğlu, G., Arda, Y. (2004). A two-stage stochastic programming framework for transportation planning in disaster response. *Journal of the Operational Research Society*, 55, 43-53.
Birge, J. R., Louveaux, F. (1997). *Introduction to Stochastic Programming*. Springer: New York.
Campbell, A. M., Jones, P. C. (2011). Prepositioning supplies in preparation for disasters. *European Journal of Operational Research*, 209, 156-166.
Caunhye, A. M., Nie, X., Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*, 46, 4-13.

Chang, M.-S., Tseng, Y. -L., Chen, J. -W. (2007). A scenario planning approach for the flood emergency logistics preparation problem under uncertainty. *Transportation Research Part E*, 43, 737-754.

Ergun, O., Karakus, G., Keskinocak, P., Swann, J., Villarreal, M. (2010). Operations research to improve disaster supply chain management. In *Wiley Encyclopedia of Operations Research and Management Science*. DOI: 10.1002/9780470400531.eorms0604.

Holguín-Veras, J., Jaller, M., Van Wassenhove, L. N., Pérez, N., Wachtendorf , T. (2012). On the unique features of post-disaster humanitarian logistics. *Journal of Operations Management*, 30, 494-506.

Khayal, D., Pradhananga, R., Pokharel, S., & Mutlu, F. (2015). A model for planning locations of temporary distribution facilities for emergency response. *Socio-Economic Planning Sciences*, 52, 22-30.

Loderee, E. J., Ballard, K. N., Song, C. H. (2012). Pre-positioning hurricane supplies in a commercial supply chain. *Socio-Economic Planning Sciences*, 46, 291-305.

Mete, H. O., Zabinsky, Z. B. (2010). Stochastic optimization of medical supply location and distribution in disaster management. *International Journal of Production Economics*, 126, 76-84.

Pradhananga, R., Mutlu, F., Pokharel, S., Holguín-Veras, J., & Seth, D. (2016). An integrated resource allocation and distribution model for pre-disaster planning. *Computers & Industrial Engineering*, 91, 229-238.

Özdamar, L., Ekinci, E., Küçükyazici, B. (2004). Emergency Logistics Planning in Natural Disasters. *Annals of Operations Research*, 129, 217-245.

Rawls, C., Turnquist, M. A. (2010). Pre-positioning of emergency supplies for disaster response. *Transportation Research Part B*, 44, 521-534.

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

Rawls, C., Turnquist, M. A. (2012). Pre-positioning and dynamic delivery planning for short-term response following a natural disaster. *Socio-Economic Planning Sciences*, 46, 46-54.

Rottkemper, B., Fischer, K., Blecken, A. (2012). A transshipment model for distribution and inventory relocation under uncertainty in humanitarian operations. *Socio-Economic Planning Sciences*, 46, 98-109.

Salmero´n, J., Apte, A. (2010). Stochastic optimization for natural disaster asset prepositioning. *Production and Operations Management*, 19(5), 561-574.

Wei-hua, L., Xue-cai, X., Zheng-xu, R., Yan, P. (2011). An emergency order allocation model based on multi-provider in two-echelon logistics service supply chain. *Supply Chain Management: An International Journal*, 16(6), 391-400.

Biographies

Shaligram Pokharel is a Professor and Program Coordinator of Industrial and Systems Engineering program at the Department of Mechanical and Industrial Engineering, in Qatar University. Shaligram earned B.E (Hons) in Mechanical Engineering from the Regional Engineering College, Kashmir, India and Masters and PhD in Systems Design Engineering from the University of Waterloo, Canada. Shaligram has published several papers in journals and conferences mainly related to energy and supply chains.

José Holguín-Veras is the William H. Hart Professor and Director of the Center for Infrastructure, Transportation, and the Environment at the Rensselaer Polytechnic Institute, USA. Jose earned B.Sc. in Civil Engineering, Magna Cum Laude, from the Universidad Autónoma de Santo Domingo, Dominican Republic, M.Sc. from the Universidad Central de Venezuela, and Ph.D. from The University of Texas at Austin. Jose has published several papers in the area of humanitarian logistics, freight transportation and decision support systems. He has received several research awards and sits in advisory committees of several important agencies.

Dr. Rojee Pradhananga worked as a Post Doctoral Fellow at Qatar University 2013-2016. She obtained PhD from Kyoto University in the area of Urban Management System. She also worked as a researcher in Kyoto University before joining Qatar University.