IJE TRANSACTIONS A: Basics Vol. 31, No. 7, (July 2018) 1057-1065

International Journal of Engineering

Journal Homepage: www.ije.ir

A Procurement-distribution Coordination Model in Humanitarian Supply Chain Using the Information-sharing Mechanism

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PAPER INFO

Paper history:
Received 15 December 2017
Received in revised form 13 January 2018
Accepted 15 February 2018

Keywords:
Coordination
Humanitarian Relief Chain
Information-Sharing Mechanism
Possibilistic Chance-constrained
Possibilistic Chance-constrained
Programming

ABSTRACT

The coordination problem of relief items' distribution operations is essential in humanitarian relief chains. If the coordination is proper, it will improve the response phase to the crisis. In order to improve the coordination in humanitarian relief chains, distribution and warehousing operations of relief items were outsourced to the third-party logistics. In this paper, the procurement-distribution coordination problem in a humanitarian relief chain was studied by the information-sharing mechanism. For this purpose, three decision-making modes, including decentralized, centralized, and coordinated, were formulated to minimize the total cost of the relief chain in the form of mathematical modeling under uncertainty. In a decentralized model, humanitarian relief chains are independent of one another and pursue their own goals. In a centralized model, a central agent manages all activities, and in a coordinated model, independent members are communicated using the information-sharing mechanism. To illustrate the validity of the proposed model, the problem was implemented in the form of a numerical example. The results showed that the chain cost is high in the decentralized mode, total chain costs were reduced in the coordinated mode, and relief items were sent to affected areas without any shortage.

***doi**: 10.5829/ije.2018.31.07a.08*

1. INTRODUCTION

As an integral part of human life, crisis has always been life-threatening. A crisis is an incident which occurs naturally or is caused by humans and happens suddenly or increasingly and imposes difficulty on the society. Crisis can be natural (such as earthquake, famine, tsunami, cyclone, hurricane, and flood), anthropogenic hazard (such as terrorism, war, and civil disorder), diseases (e.g. AIDS and malaria), or extreme poverty. To overcome these, great actions are required [1].

In recent years, natural disasters have dramatically increased. From 1900 to 2015, natural disasters killed 26,181,954 people and caused $1,300,233,157 of financial loss in Asian countries [2]. Tehran is a large, rapidly growing, and important city, located at the foothills of the Alborz Mountains and bounded by several active faults [3].

In critical situations, various organizations provide relief items such as food, water, shelter, medicine, and other facilities to help injured people survived. For example, over 40 governments and more than 700 non-governmental organizations (NGOs) provided humanitarian assistance following the Indian Ocean Tsunami in late 2004/early 2005 [4]. In such a situation, meeting the needs of injured people or rebuilding the infrastructures is almost impossible for a single organization, and coordination among organizations is one of the basic requirements. The coordination problem in humanitarian relief logistics is a major challenge [5]. Coordination should help organizations to manage complex relationships to respond effectively and efficiently to disasters [6]. In order to improve coordination in humanitarian relief chains, specific functions such as warehousing and relief items' distribution are outsourced to third-party logistics (3PLs) [7]. 3PLs are independent companies which perform all or part of relief items' distribution due to supply chain (SC) complexity and the increasing

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Please cite this article as: F. Nikkhoo, A. Bozorgi-Amiri, A Procurement-distribution Coordination Model in Humanitarian Supply Chain Using the Information-sharing Mechanism, International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics Vol. 31, No. 7, (July 2018) 1057-1065

importance of transporting items between the supplier and the affected areas [8]. These companies procure relief items from suppliers, store them in distribution centers, and then deliver them through various routes to affected areas. In such a situation, it is necessary to establish a proper coordination between the 3PL company and the suppliers. Various coordination mechanisms, including contract, information technology, information sharing, and joint decision-making have been proposed in SCs [9]. In this paper, the information-sharing mechanism was used to establish coordination between the suppliers and the 3PL provider, and the procurement-distribution problem for relief items under uncertainty was formulated in three decision-making structures: decentralized, centralized, and coordinated. This study aimed to minimize the total costs and shortages in suppliers and distribution centers.

Some researchers have investigated different aspects of the coordination problem in humanitarian relief chains. In a comprehensive study, Balcik et al. [7] divided relief chain coordination challenges into three groups: procurement operations coordination, warehousing coordination, and transportation coordination. The coordination of procurement operations in the form of auction and contract types addresses the relationship between buyer and seller [10, 11]. According to the literature review, most published papers addressed the coordination problem in inventory categories, location of distribution centers, and transportation of relief items. Meanwhile, Yi and Ozadmar [12] provided an integrated location-routing model for coordinating evacuation and aid logistics in the response phase to crisis. Balcik et al. [13] suggest that lack of coordination in the last phase of the relief chain results from limited transportation resources, emergency demands, damaged transportation structures, and lack of coordination among relief chain actors. They studied the last-mile distribution problem in order to reduce transportation costs [13]. Moreover, Charles and Lauras [14] pointed to three key factors of balancing, synchronizing, and training for humanitarian relief chain coordination. They presented a conceptual model to illustrate how chain actors work and investigated a mixed-integer linear mathematical model focusing on minimizing the response phase costs to the crisis [14]. Duran et al. [15] reviewed the strategy for relief items' pre-location in order to improve coordination in the crisis response phase. The purpose of the mixed-integer programming model is to reduce the transfer time of items from selected warehouses to demand areas [15]. In addition, Huang et al. [16] presented a conceptual model based on the super-network theory to coordinate the humanitarian relief chain. In their proposed model, coordination mechanisms were divided into three main categories: procurement, warehousing, and transportation [16]. Sheu and Pan [17] introduced the suppliers' clustering mechanism in the humanitarian relief chain to reduce the lack of coordination resulting from supply and demand imbalances. In this mechanism, the suppliers (humanitarian organizations) based on cooperative indicators such as incentive alignment, resource, and information-sharing were divided into different groups [17].

The literature review showed that the coordination problem in the humanitarian relief chain has received little attention in the form of quantitative models. Although different organizations pursue the same goals (helping injured people survive), there is no proper coordination due to intra-organization policies or geographic issues. On the other hand, communication challenges and information-sharing among organizations are obstacles that have not been considered in previous studies. Furthermore, there has been no research on relief chains which considers the procurement-distribution coordination framework under the 3PL relationship. Therefore, due to research gaps, the information-sharing mechanism in the form of mathematical modeling was employed for the first time in this paper to solve the coordination problem of transportation operations and distribution between the 3PL and relief items' suppliers.

The main contributions of this paper can be summarized as follows:

- Presenting a coordinated model between the two independent members, supplier (relief organization) and distributor (3PL), in the humanitarian relief chain for the first time, utilizing the coordinated information-sharing mechanism
- Outsourcing the relief items' transportation to the 3PL as a coordinating transportation mechanism in a humanitarian relief chain
- Solving supplier and distributor models in decentralized, centralized, and coordinated decision-making processes
- Presenting the possibilistic chance-constrained programming (PCCP) models for supplier and distributor models

This paper is organized as follows: In section 2, the problem statement is presented. Mathematical models related to the 3PL and suppliers as well as the coordination algorithm are presented in section 3. In section 4, the concept of chance-constrained possibilistic programming to cope with the uncertainty of the mathematical models is proposed. In sections 5 and 6, a numerical example and sensitivity analysis are presented to validate the proposed model. Finally, the concluding remarks and possible future research directions are discussed in section 7.

2. PROBLEM DESCRIPTION

The coordination problem in relief chains can be investigated before and after the crisis. Before crisis, activities related to the procurement of relief items and their pre-positioning are carried out in local warehouses. After crisis, transportation coordination and relief items' distribution to the affected areas take place. In this paper, the procurement and distribution coordination problem of relief items in the aftermath of a crisis were examined. In post-disaster situations, suppliers and distributors do not have sufficient coordination due to having different information structures and logistics capacities and expertise. In most cases, the supplier's inventory is not as large as the volume of the distributor's request and there is a shortage. Lack of coordination in the transportation network results in late delivery and increases the relief items' lead time to affected areas and thus causes significant financial losses and deaths. Coordination is often accomplished through outsourcing transportation to a 3PL [7].

One of the coordination mechanisms in SCs is the information-sharing mechanism among the members. In this paper, we tried to create a framework for coordination among humanitarian supply chain (HSC) members using the above-mentioned mechanism in mathematical models (suppliers and the 3PLs). 3PLs provide the supplier with a number of requested items to accelerate the relief items' delivery to demand areas. The supplier also adjusts its procuring plan according to the amount requested by the 3PL.

The problem was explored in decentralized, centralized, and coordinated structures. In centralized systems, all activities are carried out under the supervision of a central agent. This central agent controls logistics resources and then makes a decision regarding all organizations and their activities after data collection. In decentralized systems, no single organization commands other sectors involved in the chain and each organization makes its own decisions. If there is information-sharing among these independent organizations, the coordinating state will be established. The purpose of this paper was that after the crisis, relief items suppliers and distributors utilizing information sharing and by collaborating with each other will make operations related to items distribution at a low cost and without any shortage to respond to affected areas demand.

3. MODEL FORMULATION

In this section, the mathematical models for each member of the HSC are presented with an objective function and related constraints.

3. 1. Model 1: 3PL In this problem, the transportation operations and relief items' warehousing were outsourced to the 3PL. The decisions, objective function, and 3PL model constraints are explained below:

Sets/indices:

I	Set of suppliers indexed by $i \in I$
J	Set of distribution centers indexed by $j \in J$
R	Set of affected area indexed by $r \in R$
K	Set of relief items indexed by $k \in K$
V	Set of vehicles indexed by $v \in V$
T	Set of time horizons indexed by $t \in T$

Parameters:

$\tilde{c}_{ijkvt}$	Transportation cost for a unit of relief item k from supplier i to distribution center j via vehicle v in period t
$\tilde{c}_{jrktv}$	Transportation cost for a unit of relief item k from distribution center j to affected area r via vehicle v in period t
h_{kjt}	Inventory holding cost for a unit of relief item k in distribution center j in period t
N_v	Maximum number of vehicles type v available for humanitarian operations
cap_v	Volume capacity of vehicle type v
a_v	Fixed cost for hiring vehicle type v.
v_k	Required unit space for relief item k
O_{jt}	Total capacity of distribution center j in period t (volume)
$\tilde{D}_{krt}$	Amount of demand for relief item k in affected area r in period t
$\tilde{\pi}_{krt}$	Penalty cost of unsatisfied demand of relief item k in affected area r in period t
S'_{kit}	Possible supply quantity of relief item k in supplier i in period t (received from the supplier)

Decision variables:

w_{ijkvt}	Amount of relief item k transferred from supplier i to distribution center j via vehicle v in period t (decision-maker: 3PL)
y_{kjrvt}	Amount of relief item k transferred from distribution center j to affected area r via vehicle v in period t
I_{kjt}	Inventory level of relief item k in distribution center j in period t
z_{krt}	Unsatisfied demand of relief item k in affected area r in period t
T_{ijvt}	Number of vehicles type v from supplier i to distribution center j in period t
T'_{jrvt}	Number of vehicles type v from distribution center j to affected area r via vehicle v in period t

Mathematical formulation:

$$\begin{aligned}\min\ Z_1 &= \sum_i \sum_j \sum_k \sum_v \sum_t \tilde{c}_{ijkvt} w_{ijkvt} \\ &+ \sum_j \sum_r \sum_k \sum_t \sum_v \tilde{c}_{kjrvt} y_{kjrvt} + \sum_k \sum_j \sum_t h_{kjt} I_{kjt} \\ &+ \sum_k \sum_r \sum_t \tilde{\pi}_{krt} z_{krt} + \sum_i \sum_j \sum_r \sum_v \sum_t a_v \left(T_{ijvt} + T'_{jrvt}\right)\end{aligned} \tag{1}$$

$st:$

$$\sum_j \sum_v w_{ijkvt} \le S'_{kit} \qquad \forall k,i,t \tag{2}$$

$$I_{kjt} = \sum_i \sum_v w_{ijkvt} + I_{kj(t-1)} - \sum_r \sum_v y_{kjrvt} \qquad \forall k,j,t \tag{3}$$

$$\sum_j \sum_v y_{kjrvt} = \tilde{D}_{krt} - z_{krt} \qquad \forall k,r,t \tag{4}$$

$$\sum_k I_{kjt} v_k \le O_{jt} \qquad \forall j,t \tag{5}$$

$$\sum_k w_{ijkvt} \le T_{ijvt} Cap_v \qquad \forall i,j,v,t \tag{6}$$

$$\sum_k y_{kjrvt} \le T'_{jrvt} Cap_v \qquad \forall j,r,v,t \tag{7}$$

$$T_{ijvt} \le N_v \tag{8}$$

$$T'_{jrvt} \le N_v \qquad \forall j,r,v,t \tag{9}$$

$$T_{ijvt}, T'_{jrvt} \in \mathbb{Z} \qquad \forall i,j,r,v,t \tag{10}$$

$$w_{ijkvt}, y_{kjrvt}, I_{kjt}, z_{krt} \ge 0 \qquad \forall i,j,k,r,v,t \tag{11}$$

Objective Function (1) minimizes the total costs, including transportation costs from suppliers to distribution centers; transportation costs from distribution centers to affected areas; inventory costs; costs related to unsatisfied demands; and vehicle allocation costs among suppliers, distribution centers, and affected areas. Constraint (2) shows that the delivery volume for each item from suppliers to distribution centers is less than the number of available items in suppliers. Constraint (3) indicates the inventory balance in each distribution center. Constraint (4) shows the relationship between item delivery volumes, demand, and shortage amount in affected areas. Constraints (5) to (9) are related to the inventory capacity of distribution centers as well as the capacity and number of vehicles. Finally, constraints (10) and (11) indicate that the numbers of vehicles are integers and other decision variables are non-negative.

3. 2. Model 2: Supplier In the proposed procurement-distribution coordination, the supplier has a major role and provides affected areas with relief items. The mathematical model for this member of HSC is presented below:

Parameters:

p_{kit}	Procuring cost of a unit of relief item *k* in supplier *i* in period *t*
h'_{kit}	Inventory-holding cost for a unit of relief item *k* in supplier *i* in period *t*
$\tilde{\pi}'_{kit}$	Shortage penalty cost for a unit of relief item *k* in supplier *i* in period *t*
v_k	Required unit space for relief item *k*
c'_{kit}	Inventory capacity for relief item *k* in supplier *i* in period *t*
S_{kit}	Requested supply quantity of relief item *k* in supplier *i* in period *t* (received from the 3PL)
$\tilde{b}$	Available budget

Decision variables:

x_{kit}	Amount of relief item *k* procured in supplier *i* in period *t*
f_{kijvt}	Transportation volume of relief item *k* from supplier *i* to distribution center *j* via vehicle *v* in period *t* (decision maker: supplier)
z'_{kit}	Shortage of relief item *k* in supplier *i* in period *t*

Mathematical formulation:

$$\begin{aligned}\min\ Z_2 &= \sum_k \sum_i \sum_t p_{kit} x_{kit} + \\ &\sum_k \sum_i \sum_t h'_{kit} I'_{kit} + \sum_k \sum_i \sum_t \tilde{\pi}'_{kit} z'_{kit}\end{aligned} \tag{12}$$

$st:$

$$I'_{kit} = I'_{ki(t-1)} + x_{kit} - \sum_j \sum_v f_{kijvt} \qquad \forall k,i,t \tag{13}$$

$$\sum_j \sum_v f_{kijvt} = S_{kit} - z'_{kit} \qquad \forall k,i,t \tag{14}$$

$$v_k I'_{kit} \le c'_{kit} \qquad \forall k,i,t \tag{15}$$

$$\sum_k \sum_i \sum_t p_{kit} x_{kit} \le \tilde{b} \tag{16}$$

$$x_{kit}, I'_{kit}, z'_{kit}, f_{kijvt} \ge 0 \qquad \forall k,i,j,v,t \tag{17}$$

Objective Function (12) minimizes total purchasing cost, inventory-holding costs, and costs of shortage of items in suppliers. Constraint (13) represents the inventory balance equation for each item in each supplier. Constraint (14) states the relationship between the items' shortage in the suppliers and the requested supply quantity of the 3PL. Constraint (15) ensures that the item storage in each supplier be less than its warehousing capacity. Constraint (16) does not allow the total purchase costs in suppliers to be more than the available budget. Finally, Constraint (17) refers to non-negative decision variables.

3. 3. Coordination Algorithm In models (1) and (2), each HSC member attempts to reduce its local costs and its main focus is on optimizing its main activities. In model (2), the main decision-makers are the suppliers of relief items which operate independently of the 3PL and are responsible for purchasing and relief items' procurement depending on the level of budget and other existing restrictions. On the other hand, the 3PL is planning for relief items' holding and transportation without any information exchange with the suppliers. Therefore, it is necessary to develop a procurement-distribution coordination model based on the information-sharing between the two independent parts of the crisis, i.e. the supplier and the 3PL, in order to plan the coordination and increase the efficiency of post-disaster logistic operations.

The logic of relationship between suppliers and the 3PL is as follows:

Step 1: First, the information on the amount of demands in affected areas is provided for the 3PL model.

Step 2: Model (1) is solved with respect to objective function (1) and constraints (2) to (11), and the distribution plan for relief items is obtained. The 3PL uses variable w_{ijkvt} to indicate the quantity of relief items which are delivered from suppliers to distribution centers. The requested supply quantity is equal to $\sum_j \sum_v w_{ijkvt}$ and is entered as a S_{kit} parameter into model (2).

Step 3: In model (2), the supplier presents its own procurement plan based on the requested supply quantity, objective function (12), and constraints (13) to (17). At this stage, if the supplier faces a shortage, it gives the possible supply quantity (S'_{kit}) to model (1) using Equation (18) in order to coordinate with the 3PL provider.

$$\min\left\{\left(S_{kit}-z'_{kit}\right)^{p-1},\left(S_{kit}-z'_{kit}\right)^{p}\right\} \qquad \forall k,i,t \qquad (18)$$

$$\text{if } z'^{p}_{kit} \geq 0$$

In Equation (18), p is the current coordinating iteration. If the z'_{kit} quantity is equal to zero in iteration, the coordination procedure will be terminated. The proposed coordination procedure is shown in more detail in Figure 1.

4. POSSIBILISTIC CHANCE-CONSTRAINED PROGRAMMING

After crisis, the demand of affected areas has a high uncertainty and can be of diverse proportions, depending on the severity of the incident and the number of injured people. Therefore, the demand parameter in the 3PL model is uncertain and has ambiguities. On the other hand, in the supplier model, the procurement budget level as an input parameter faces the assumption of uncertainty. Furthermore, transportation costs from the supplier to distribution centers and from distribution centers to affected areas and items shortage costs in the supplier and the 3PL model are considered as an uncertainty parameter.

In order to deal with uncertainty in optimization problems, various fuzzy mathematical programming approaches have been proposed. Basically, the fuzzy mathematical programming can be divided into two groups: possibilistic programming and flexible programming. In this paper, to address uncertainty, the possibilistic programming approach and the PCCP model were utilized in each supplier and 3PL models. In this model, uncertain parameters with trapezoidal possibilistic distribution $\tilde{c}=\left(c_1,c_2,c_3,c_4\right)$ were considered. In PCCP model, important fuzzy measurements such as possibility (Pos) measure and necessity (Nec) measure are used in order to deal with constraints with uncertain parameters. Pos and Nec measures indicate the optimistic and pessimistic attitude of decision-makers, respectively. In crisis management problems, since decision-makers act more conservatively, it is logical that their attitude to possibilistic constraints' satisfaction would be pessimistic [18]. Therefore, in this model, we use Nec measure to ensure the satisfaction of possibilistic chance constraints. Readers may refer to literature [18] for more details. The PCCP model of the supplier and 3PL model is presented below.

4. 1. The Equivalent Crisp Model of Supplier

$$\min\ Z_2=\sum_{k,i,t} p_{kit}x_{kit}+\sum_{k,i,t} h'_{kit}I'_{kit} + \sum_{k,i,t}\left(\frac{\pi'_{kit(1)}+\pi'_{kit(2)}+\pi'_{kit(3)}+\pi'_{kit(4)}}{4}\right)z'_{kit} \qquad (19)$$

$st:$

$$\sum_k\sum_i\sum_t p_{kit}x_{kit} \leq \left(1-\alpha_2\right)b_{(2)}+\alpha_2 b_{(1)} \qquad (20)$$

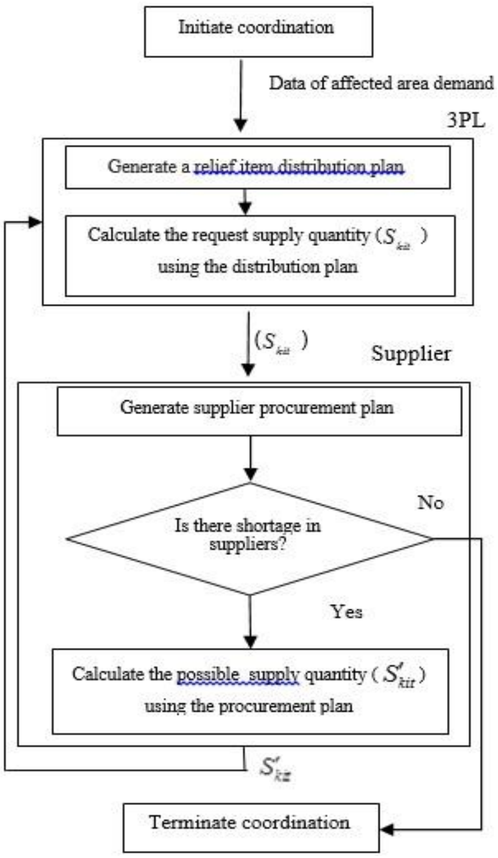

Figure 1. The procedure of the coordination algorithm

4. 2. The Equivalent Crisp Model of 3PL

$$\min\ Z_1 = \sum_{i,j,k,v,t} \left(\frac{c_{ijkvt(1)} + c_{ijkvt(2)} + c_{ijkvt(3)} + c_{ijkvt(4)}}{4} \right) w_{ijkvt} + \sum_{j,r,k,t,v} \left(\frac{c_{kjrvt(1)} + c_{kjrvt(2)} + c_{kjrvt(3)} + c_{kjrvt(4)}}{4} \right) y_{kjrvt} + \sum_{k,j,t} h_{kjt} I_{kjt} \tag{20}$$

$$+ \sum_{k,r,t} \left(\frac{\pi_{krt(1)} + \pi_{krt(2)} + \pi_{krt(3)} + \pi_{krt(4)}}{4} \right) z_{krt} + \sum_{i,j,r,v,t} a_v \left(T_{ijvt} + T'_{jrvt} \right) \tag{21}$$

$st:$

$$\sum_j \sum_v y_{kjrvt} \le \left(\frac{\alpha_1}{2} \right) D_{krt(3)} + \left(1 - \frac{\alpha_1}{2} \right) D_{krt(4)} - z_{krt} \tag{22}$$

$$\sum_j \sum_v y_{kjrvt} \ge \left(\frac{\alpha_1}{2} \right) D_{krt(2)} + \left(1 - \frac{\alpha_1}{2} \right) D_{krt(1)} - z_{krt} \tag{23}$$

5. RESULTS

This section describes the validation of the proposed model by presenting a numerical example. To evaluate the effectiveness of the proposed coordination model, the results of mathematical models are compared in centralized, decentralized, and coordinated decision-making structures. In the presented example, there is a three-level HSC consisting of suppliers, distribution centers, and affected areas. In this problem, two types of relief items are considered: The volume of the first item is 463 and that of the second item equals 401. Also, the number of vehicles Type 1 and Type 2 is 30 and 20, respectively, and the fixed allocated costs are \$266 and \$298, respectively.

The problem was solved using GAMS 23.4 on a Core i5, 4G RAM computer. In decentralized decision-making, the two SC members are completely independent. In this case, models 1 and 2 are solved separately and the outputs for each HSC member are extracted. In centralized decision-making, a central agent is responsible for commanding in which the objective functions of the supplier and 3PL models are merged and the problem is solved in the form of a single mathematical model. In coordinated decision-making, two independent members share information in the HSC using the proposed algorithm. Table 1 shows the results of the implementation of PCCP model in decentralized, centralized, and coordinated structures with the confidence levels of 0.7, 0.8, and 0.9, respectively.

As shown in Table 1, the total SC cost is greater in decentralized decision-making than the other two. For example, for α=0.7, the shortage cost in decentralized decision-making is equal to \$95763.231, but this value is zero in coordinated and centralized structures. The 3PL model cost in the centralized structure is higher than the decentralized one, while the 3PL model has the same behavior and cost in decentralized and coordinated structures. The decentralized supplier model has the highest cost, but this value is less in coordinated and

TABLE 1. PCCP implementation results

Confidence level of PCCP	Costs	Decentralized decision-making	Centralized decision-making	Coordination decision-making
0.7	3PL cost	3018593.2	3027055.5	3018593.2
	Supplier cost	812610.4	724511.6	795427.2
	Shortage cost	95763.2	0	0
	Total cost of HSC	3831203.6	3751567.1	3814020.4
0.8	3PL cost	3018974.6	3027426.3	318974.6
	Supplier cost	812619.2	724601.6	795527.3
	Shortage cost	95783.2	0	0
	Total cost of HSC	3831593.8	3752027.9	3814501.9
0.9	3PL cost	3019355.9	3027797.5	3019355.9
	Supplier cost	812633.1	724691.5	795627.5
	Shortage cost	95795.4	0	0
	Total cost of HSC	3831989.06	3752488.6	3814983.4

centralized structures. For example, at α=0.7, by transforming the decentralized decision-making into a centralized one, the supplier's profit is $880.88/76, the 3PL suffers from a $8,427.237 loss, and the whole HSC makes a benefit of $523.793636. However, in the coordinated structure, the whole HSC and the supplier model will make a profit in addition to the zero shortage, and the 3PL model does not suffer any loss due to the use of the information-sharing mechanism.

6. DISCUSSION

In this section, the sensitivity analysis of the models to the α parameter in the chance-constraint model is performed. As shown in Figure 2(a), as α increases, the total relief chain cost increases in centralized, decentralized, and coordinated decision-making structures.

The decentralized decision-making cost is greater than that of centralized and coordinated structures, and the coordinated decision-making cost is more than that of the centralized structure. As can be seen, for α=0.7, decentralized costs are 12.2% higher than that of the centralized structure, and the coordinated cost exceeds that of the centralized structure by 1.66%. In addition to investigating the total relief chain cost, each member's costs were compared before and after coordination with that of the centralized structure (Figures 2(b) and 2(c)). In Figure 2(b), the cost of a 3PL member is compared among centralized, decentralized, and coordinated decision-making structures, where the corresponding cost in decentralized and coordinated structures are the same, indicating that the 3PL does not suffer any loss after converting the structure from decentralized to coordinated. It should be noted that the cost of the centralized structure is more than that of decentralized and coordinated structures. Figure 2(c) depicts the supplier cost in three decision-making structures. As the confidence level increases, the costs also increase in non-coordinated (decentralized), centralized, and coordinated structures. These costs are higher in non-coordinated decision-making than coordinated decision-making and are higher than that of the centralized structure.

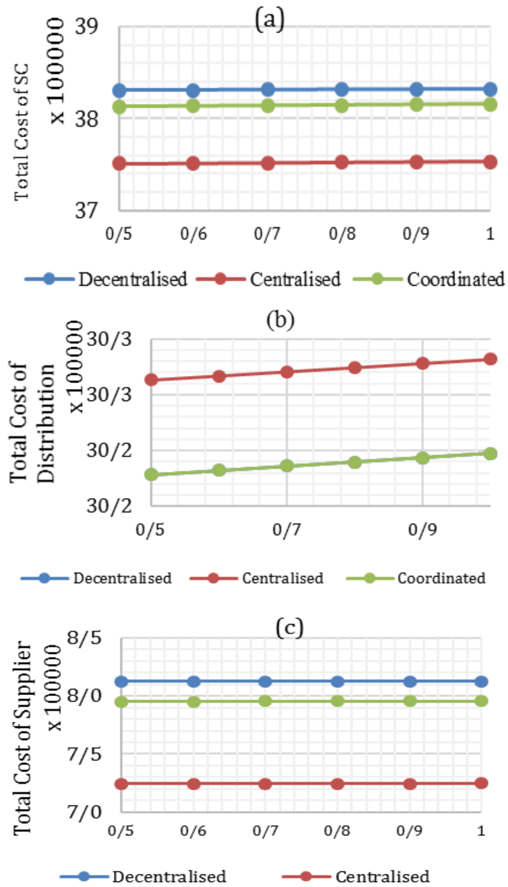

Figure 2. (a) The effect of changes in confidence level on total humanitarian relief chain costs; (b) the effect of changes in confidence level on the supplier member costs; and (c) the effect of changes in confidence level on the 3PL member costs

Therefore, the two HSC members tend to participate in the coordinated structure because none of the members suffers any loss.

7. CONCLUSION

This paper presented a new procurement-distribution coordination model based on mathematical models and the information-sharing mechanism under uncertainty for the first time. In the present model, suppliers had the role of relief items' providers and the 3PL as distributors were responsible for warehousing and transportation. The corresponding activities of each HSC member were formulated using mathematical models under uncertainty, and the problem was examined in decentralized, centralized, and coordinated decision-making structures. In decentralized decision-making, since each member of the HSC is independent of others, the total relief chain cost increases and the supplier always faces the shortage of many items to transport to affected areas due to lack of knowledge of one another's information. In the centralized structure, total HSC cost decreased compared to the decentralized structure. However, 3PL costs increased by converting the decision-making from a decentralized to a centralized structure. In the coordinated model, the use of the information-sharing mechanism between the 3PL and the supplier reduced the total HSC costs, and the supplier had less cost than the previous two ones. Also, the 3PL did not suffer any loss and remained at the decentralized structure. In general, according to the results obtained from the coordination model, we observed the good performance of the establishment of a mechanism for information-sharing in the humanitarian relief chain under uncertainty demand conditions, relief organization budget, and other cost parameters.

Future research may use case studies to implement the proposed approach in the humanitarian relief chain. For a realistic size, it is suggested that heuristic and metaheuristic methods be employed. Also, the consideration of disruption in the transportation network is recommended for model development.

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A Procurement-distribution Coordination Model in Humanitarian Supply Chain Using the Information-sharing Mechanism

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PAPER INFO

Paper history:
Received 15 December 2017
Received in revised form 13 January 2018
Accepted 15 February 2018

Keywocrds:
Coordination
Humanitarian Relief Chain
Information-Sharing Mechanism
Possibilistic Chance-constrained
Possibilistic Chance-constrained Programming

چکیده

مسأله هماهنگی عملیات توزیع کالاهای امدادی در زنجیره امداد بشردوستانه بسیار ضروری بوده و در صورت هماهنگی مناسب، سبب بهبود فاز پاسخ به بحران می‌شود. در زنجیره امداد بشردوستانه، به‌منظور بهبود هماهنگی، عملیات توزیع و انبارداری اقلام امدادی به لجستیک بخش سوم برون‌سپاری می‌شود و در چنین شرایطی لازم است میان بخش تأمین‌کننده و 3PL ارتباط برقرار شود. در این مقاله، مسأله هماهنگی تأمین – توزیع در زنجیره امداد بشردوستانه به‌وسیله مکانیسم اشتراک اطلاعات مورد مطالعه قرار گرفته است. بدین‌منظور، سه حالت تصمیم‌گیری؛ غیرمتمرکز، متمرکز و هماهنگ با هدف کمینه کردن هزینه‌های کلی زنجیره امداد در قالب مدل‌سازی ریاضی تحت عدم‌قطعیت فرموله شده است. در مدل غیرمتمرکز، زنجیره امداد بشردوستانه شامل واحد های مستقل از یکدیگر است که هر یک به‌دنبال اهداف خود هستند. در مدل متمرکز، یک واحد مرکزی تمامی فعالیت‌ها را مدیریت می‌کند و در حالت هماهنگ نیز، میان اعضای مستقل، با استفاده از مکانیسم اشتراک اطلاعات ارتباط برقرار شده است. برای نشان دادن کارایی مدل پیشنهادی، مسأله در قالب یک مثال عددی اجرا شده است. نتایج نشان می‌دهد که در حالت غیرمتمرکز هزینه‌های زنجیره بالا بوده و در حالت هماهنگ نیز هزینه‌های کل زنجیره کاهش یافته و اقلام امدادی بدون هیچ‌گونه کمبودی به نقاط آسیب‌دیده ارسال شده است.

***doi**: 10.5829/ije.2018.31.07a.08*