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Reliable Facility Location Model Considering Disruption Risk in Logistic Model

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Abstract: In this study, researchers consider random disruption risks in designing a reliable distribution network model. Researchers consider two types' distribution centers, one that is unreliable and another that is reliable. Researchers develop the three echelon of logistic model considering manufacturing plant, distribution centers and customers. Researchers consider the distribution centers are subject to probability of disruption. If distribution centers fail, customer may assign to other reliable distribution centers and incur excessive transportation cost, handling cost and opening cost of facility. Researchers consider the case where facilities are subject to probability failure. If facilities fail, customer may assign to other facilities and incur excessive transportation cost and opening cost of the reliable facility. Researchers formulate this as a mixed integer programming model and determine optimal facility location, as well as customer assignment strategies, allowing the facilities to fail under disruption probabilities consideration. The goal is to minimize the sum of initial opening cost of distribution center, transportation cost from manufacturing plant, handling cost at distribution centers and expected customer transportation cost under primary and backup assignment.

Key words: Logistic network, facility location, mixed integer programming, customers, transportation cost

INTRODUCTION

The word is increasingly uncertain and vulnerable. Researchers have witnessed many types of unpredictable disasters, including terrorist attacks, wars, earthquake, tsunami, economic crisis, etc. A recent example of disruptions is Tohoku earthquake and followed by tsunami in Japan, 2011. This tragedy has had a dramatic impact on the supply chains and logistic distribution of many companies, including those in the automotive, electronics and chemical industries. The resulting slowdowns and cessation of operations some companies. One example is Hitachi factory which has produced electronic component for the Peugeot Citroen, Europe's second largest volume car maker disrupted by this disaster to the distribution process. The Peugeot Citroen was argued to slow the production in 7 plants in France and Spain due to shortage of material from Hitachi.

Researchers argue that decision makers should consider the possibility of consider disruption risk into account when planning the logistic network design. This is important strategic planning because these decisions cannot easily be modified. Supply chain disruptions come with failure consequence, even though with their low probability of occurrence. When disruption strikes, there is very little choice for strategic decision like facility location and network design.

The occurrence of any disruption is stochastic. Researchers can anticipate the disruption by considering preventive action to ensure the supply chain is not adversely affected. If the supply chain takes preventive action in anticipation of a disruption, then such actions are term as mitigation planning. Under mitigation plan, the supply chain tries to build a robust system that can minimize the impact of the disruption which is expected to happen in the future. One such mitigation mechanism would be to have backup facilities that may provide supplies in the event that primary facility is disrupted. Such cases are considered in Tomlin (2006) where a supply is considered from two suppliers one of which is reliable but expensive while the other is unreliable but cheap.

Snyder and Daskin (2005) introduced several models, based on traditional facility location problem in which facility may fail with given probability. The researcher assumed that all customers assign to several facilities. In normal circumstances, customer assign to primary facilities and other facilities will serve the customers if the primary facility fails. Snyder and Daskin (2005) presented deterministic formulation for Uncapacitated Facility Location Problem (UFLP) and p-median problem when the facilities are unreliable. The researchers assume that some facilities are reliable while others are subject to failure, as unreliable facility that might disrupt with some probabilities.

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Lim *et al*. (2010) developed Facility Reliability Problem (FRP) which is extended the Uncapacitated Facility Location Problem (UFLP). The researchers studied the Facility Reliability Problem (FRP), how to design a reliable supply chain network in the presence of random facility disruption. There are two kinds of facility consider in the network, unreliable facilities and reliable facility. The reliable facility assumes no disruption but more expensive than unreliable facility which is subject to disruption.

RESEARCH OVERVIEW

Supply chain disruptions have gained wide attention, especially in the last few years. Within the literature, there are two main perspectives in developing mitigation strategies for the supply chain disruptions. Chopra and Sodhi (2004) identify or categorize supply chain risk and recommended a wide range mitigation strategy. One of the varieties of risk that might affect the supply chain is disruption. In this research, researchers also define the disruption as cessation of product flows from one facility to another facility or customers in supply chain which is unpredictable and rare but often quite destructive.

In the classical facility location problems, implicitly assume that all facilities are perfectly reliable and derive the optimal facility locations under this ideal situation. The research of Daskin investigates the impact of considering unreliable facilities for the facility location problems. The network design model considered in this research consists of three echelons of plants, DCs and customers. The location decisions are made in the DC level. In DC level, researcher proposed two kinds of DC; the Reliable DC (RDC) and Unreliable DC (UDC).

Unreliable Distribution Centers (UDC) are the regular ones which are subject to failure. Reliable Distribution Centers (RDC) are the hardened ones which have additional capacity and or external alternative sourcing strategy. So it is more expensive to establish or operate such facilities.

The proposed model is different from the previous model in which the model only considers two echelons problems. In this study, researchers consider extending the model in three echelons considering plants exist in the network. In practice products are produced at plants and distributed to customers and each facility has potential being disrupted by external natural hazard.

In this research when designing a logistic network researchers consider two kinds of DC, such as unreliable and reliable. So, the unreliable DCs can fail due to the various reasons mentioned earliar. Failure of the DCs means that the DCs are no longer available to serve customers. When the DCs fail, the firm has to find alternate sources of supply to provide service to the customer. Kleindorfer and Saad (2005) introduced a conceptual framework for managing disruption risks and cost effective mitigation methodologies in supply chain. They proposed that in order to minimize total cost, organization must trade-off between investment in mitigation and the disruption loss weighted by the probability of disruption. When the supply chain is poorly configured, finding alternate supply sources can be very expensive.

PROBLEM FORMULATION

In this research, researchers design multistage logistic network and researchers set up some disruption probabilities on the facilities. Researchers consider a multistage supply chain network that consist of plant, Distribution Center (DC) and customer.

The set of potential DCs mentioned earliar divided into reliable and unreliable ones, as well as their assignment primary and backup assignment. Unreliable DCs are facility that vulnerable to disruption. When such DCs has failed, it is assume that it can no longer provide service to its customers. Reliable DCs is robust against the disruption and can serve the customers all the time. In other words, RDCs are supposed to be completely sound and safe against the disruption while UDCs are affected.

Let, I be the set of plants and J a set of potential DCs and K a set of customers. Each customer $k \in K$ has a demand d_k. The product will be distributed from plant I to DC J and DC J to customers, respectively. The model will determine the optimal location of DC, so as to minimize the total cost of the network. At each customer k, researchers may locate either RDC with opening cost F_j^R or UDC with opening cost F_j^U. Fixed cost for opening RDC is higher than UDC ($F_j^R > F_j^U$) due to undisrupted reason. The transportation cost per unit demand from plant I to DC J is given by $T1_{jk}^P$ and $T1_{jk}^B$ for primary assignment and backup assignment, respectively. Researchers also consider the relation $T1_{jk}^P < T1_{jk}^B$ due the consequence of using the backup resources. Similarly, the transportation cost per unit demand from DC to the customer is given by $T2_{jk}^P$ and $T2_{jk}^B$ for primary assignment and backup assignment, respectively. Researchers also assume the relation $T2_{jk}^P < T2_{jk}^B$ due to the consequence of using the backup resources.

Moreover, the handling cost at each distribution center is denoted as H_k^P and H_k^B for primary and backup condition, respectively. Researchers assume that the relation $H_k^P < H_k^B$. Researchers assume the disruption probability at DCs is q (0<q<1). In this model, researchers assume that each facility has the same disruption probability. After all, researchers formulate the problem as a mixed integer programming problem. The objective function is expected costs that consist of fixed cost for opening DC, production cost at plant, transportation cost between each facility and holding cost at DC.

The following notations are used to describe the mathematical model.

Index set:

I = Set of plants ($i\in I$)
J = Set of distribution centers ($j\in J$)
K = Set of customers ($k\in K$)

Parameters:

F_j^U = Fixed cost for opening UDC j
F_j^R = Fixed cost for opening RDC j
C_i = Production cost at plant i as primary assignment
H_j^P = Handling cost at DC j as primary assignment
H_j^B = Handling cost at DC j as backup assignment
$T1_{ij}^P$ = Transport cost from plant i to DC j as primary assignment
$T1_{ij}^B$ = Transport cost from plant i to DC j as backup assignment
$T2_{jk}^P$ = Transport cost from DC j to customer k as primary assignment
$T2_{jk}^B$ = Transport cost from RDC j to customer k as backup assignment
U_j = Capacity of DC j
PU_i = Maximum production ability of plant i
PL_i = Minimum production ability of plant i
d_k = Demand of customer k
q = Probability of disruption (0<q<1)

Decision variable:

a_{ij}^P = Shipped amount from plant i to DC k as primary assignment
a_{ij}^B = Shipped amount from plant i to DC j as backup assignment
b_{jk}^P = Shipped amount from DC j to customer k as primary assignment
b_{jk}^B = Shipped amount from DC j to customer k as backup assignment

$$x_j^U = \begin{cases} 1, & \text{If DC jis opened as unreliable one;} \\ 0, & \text{otherwise} \end{cases}$$

$$x_j^R = \begin{cases} 1, & \text{If DC jis opened as reliable one;} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{jk}^P = \begin{cases} 1, & \text{If DC j disributes customer k as primary assingment;} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{jk}^B = \begin{cases} 1, & \text{If DC j disributes customer k as backup assingment;} \\ 0, & \text{otherwise} \end{cases}$$

$$z_{ij}^P = \begin{cases} 1, & \text{If plant i distributes DC j as primary assignment;} \\ 0, & \text{otherwise} \end{cases}$$

$$z_{ij}^B = \begin{cases} 1, & \text{If pant i distributes DC j as backup assignment;} \\ 0, & \text{otherwise} \end{cases}$$

ALLOCATION MODEL

In this study, researchers consider Multi-Single Allocation Model (MSA). In MSA model, customer only receive product from specific DC, Fig. 1 shows for the difference between them.

In this model, researchers consider DC J will receive the product from multi plants and customer only received from single DC. The model for MMA model is described as follows:

Minimize:

$$\sum_{j\in J} F_j^U x_j^U + \sum_{j\in J} F_j^R x_j^R + (1-q)\left(\begin{array}{l}\sum_{i\in I}\sum_{j\in J}\left(C_i^P + T1_{ij}^P\right)a_{ij}^P + \\ \sum_{j\in J}\sum_{k\in K}\left(H_j^P + T2_{jk}^P\right)d_k y_{jk}^P\end{array}\right) + q\left(\begin{array}{l}\sum_{i\in I}\sum_{j\in J}\left(C_i^B + T1_{ij}^B\right)a_{ij}^B + \\ \sum_{j\in J}\sum_{k\in K}\left(H_j^B + T2_{jk}^B\right)d_k y_{jk}^B\end{array}\right) \quad (1)$$

Subject to:

$$\sum_{j\in J} y_{jk}^P = 1,\ \forall k \in K \quad (2)$$

$$\sum_{j\in J} y_{jk}^B = 1,\ \forall k \in K \quad (3)$$

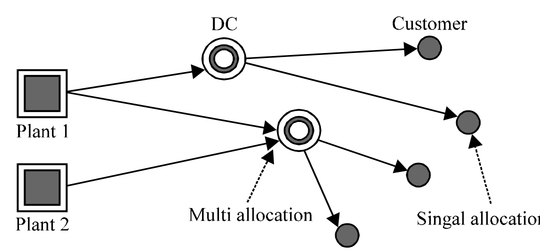

Fig. 1: Multi-single allocation model

$$y_{jk}^{P} \le x_j^U + x_j^R,\ \forall j \in J,\ k \in K \tag{4}$$

$$y_{jk}^{B} \le x_j^R,\ \forall j \in J,\ k \in K \tag{5}$$

$$x_j^U + x_j^R \le 1,\ \forall j \in J \tag{6}$$

$$\sum_{j\in J} x_j^R \ge 1 \tag{7}$$

$$\sum_{i\in I} a_{ij}^P \le U_j\left(x_j^U + x_j^R\right),\ \forall j \in J \tag{8}$$

$$\sum_{i\in I} a_{ij}^B U_j x_j^R,\ \forall j \in J \tag{9}$$

$$\sum_{j\in J} a_{ij}^P \le PU_i^P,\ \forall i \in I \tag{10}$$

$$\sum_{j\in J} a_{ij}^B \le PU_i^B,\ \forall i \in I \tag{11}$$

$$\sum_{j\in J} a_{ij}^P \ge PL_i,\ \forall i \in I \tag{12}$$

$$\sum_{j\in J} a_{ij}^B \ge PL_i,\ \forall i \in I \tag{13}$$

$$\sum_{i\in I} a_{ij}^P - \sum_{k\in K} b_{jk}^P = 0,\ \forall j \in J \tag{14}$$

$$\sum_{i\in I} a_{ij}^B - \sum_{k\in K} b_{jk}^B = 0,\ \forall j \in J \tag{15}$$

$$x_j^R, x_j^U, \in \{0,1\},\ \forall j \in J \tag{16}$$

$$y_{jk}^P, y_{jk}^B, \in \{0,1\},\ \forall j \in J, k \in K \tag{17}$$

$$a_{ij}^P, a_{ij}^B \ge 0,\ \forall i \in I, j \in J \tag{18}$$

The objective function (1) minimizes the total cost for reliable and unreliable DC, as well as the transportation cost for primary and backup assignment. Primary assignments occur with probability 1-q for each demand node and backup assignment occurs with probability q. If a customer's primary facility is reliable, then its backup assignment will be the same facility. Constraints 2 and 3 required that each customer must be assigned to primary and backup assignment, respectively. Constraints 4 state that the primary assignment is possible to open either RDC or UDC while constraints 5 state that backup assignment must be to RDC. Constraint 6 states that either of RDC or UDC can be open both not both. Constraint 7 requires the model to locate at least one RDC. Constraint 8 and 9 are capacity constraint for DC, constraint 10 and 11 are upper bound for available production as primary and backup assignment, respectively. Constraint 12 and 13 are lower bound for available production as primary and backup assignment, respectively.

NUMERICAL EXPERIMENT

In this study, a data set is used to compare the performance of the proposed model and solved using commercial software CPLEX 12.2. This instance consists of 2 plants, 5 candidate DCs and 50 customers. Researchers show the problem as $(|I|\times|J|\times|K|)$: 2×5×50 and these facilities are located randomly on the plane. The problem size for MMA model in terms of system parameters are real variable number is 531, binary variable is 510 and constrain number is 634. There are 5 candidates DC locations from which researchers want to choose a set of DC location to open by considering disruption risk probability.

The model proposed, as a mixed integer programming problem and solved using commercial software IBM ILOG CPLEX. The model performed on a computer with 2.66 GHz core 2 duo processor and 2 GB of RAM.

The disruption probability q assumes 0.01 for the safe condition and 0.1-0.5 for risky situation. The fixed cost for opening RDC F_j^R determines by 2 times of UDC F_j^U. The distances between nodes calculated basis of Euclidian norm. Researchers multiplied the distance by TRCOST1 = 1.5 and TRCOST2 = 1.0 to get the transportation cost per unit distance between plant to DC and DC to customer, respectively. Backup transportation cost set to 1.5 from normal values.

The computation result with disruption probability 0.01 or safe condition is obtained in 0.64 sec after 3834 iteration for MSA model. Figure 2a,b shows the location of DCs and assignment of customer demand to the DC for probability 0.01 and 0.1. The solution located one reliable DC (DC No. 4) and two reliable DCs (DC No. 2 and 5). The demand of customers which primary DC is reliable (RDC) showed with only single assignment while demand customer served primary by the UDC depicted with two assignments.

As multistage logistic problem, products are produced in the plant and distributed to DCs and from this point distributed to the customers depend on quantity of demand. As it is seen in Fig. 2, plant 1 responsible to cover distribution of product to DC No. 2, 4 and 5. Plant 2 only covers the demand of products from DC No. 2.

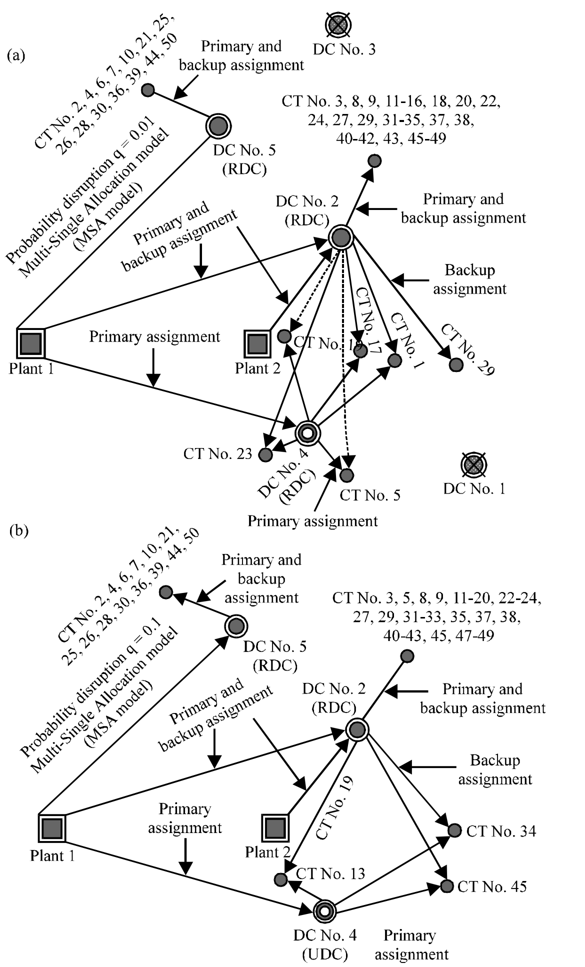

Fig. 2: The solution for MSA model with probability: a) q = 0.01; b) q = 0.1

Figure 2 shows the MSA model, product delivered to customers from single DC as primary assignment and backup assignment if customers assigned to reliable DC then if customer assigned to unreliable DC then the backup assignment will provide by other reliable DCs. Figure 2a shows with disruption probability 0.1, the optimal solution finds three DC open in the logistic network. There are two RDC and one UDC. Customers CT No. 13, 34 and 45 are assigned to unreliable DC No. 4 as primary assignments. Their backup assignments will provide by DC No. 2.

Table 1 shows the result associated with applying model as I = 2, J = 5 and K = 50 data set for assignment MSA model with different disruption probability. From Table 1, researchers notice that for these instances with probabilities q = 0.01, 0.1, 0.2, 0.3, the selected location for DCs is the same. There are two RDC and one UDC is selected with these probabilities. When researchers set

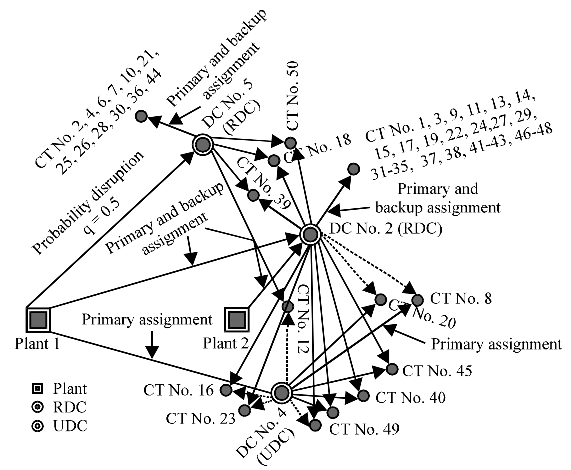

Fig. 3: The solution for MSA model with probability q = 0.5

Table 1: The comparison result of MMA and MSA

Probability	Facilities opened	Type of facility RDC (DC No.)	UDC	Objective function	Solution time (sec)
0.01	3	2 (2 and 5)	1(DC No. 4)	4630423	0.64
0.1	3	2 (2 and 5)	1	4816931	0.33
0.2	3	2 (2 and 5)	1	5024161	0.17
0.3	3	2 (2 and 5)	1	5231724	0.28
0.4	2	2 (2 and 5)	0	5438172	0.08
0.5	3	3 (2, 4 and 5)	0	5642365	0.30

the disruption probability q = 0.4 to the data set, researchers find the optimal solution only by opening two reliable DC (DC No. 2 and 5). When researchers set the probability q = 0.5 the optimal solution find 3 RDC will open satisfy the customers demand.

Researchers also confirmed by changing the disruption probabilities. Figure 3 corresponds to the circumstances where the probability q is large (q = 0.5). Here, researchers set the probability q = 0.5 and the other parameter were unchanged. In each case, researchers can observe that the number of open DC remain the same but DC No. 4 changed in to RDC when disruption probability q = 0.5.

CONCLUSION

In this study, researchers present multistage logistic network consider disruption risk that minimize the total cost. Researchers proposed Multi-Single Assignment (MSA) model. Researchers formulate the models as a mixed integer programming and use commercial optimization software to solve the model and the computation result show that when probability of disruption increased than DC will become reliable. If researchers assume in risky condition with probability q = 0.5 every DC will turn to reliable.

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