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A study on three different dimensional facility location problems

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ABSTRACT

In supply chain strategy, designing a network is one of the most important part. This model deals with various dimensional facility location models. Initially, this paper begins with two echelon facility location model of dimension two. Then, it is extended to three dimensional model by adding commodity type and then, different types of transportation modes are added to make it four dimensional model. Delivery lead time and outside suppliers are assumed to meet the retailer's demand too. We construct some lemmas to compare the optimal solution for each of the problem. We also study the procedure of reducing the total cost of the supply chain network by applying a small change in constraint set. This is described by another lemma. Some numerical examples are allowed to illustrate the models.

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1. Introduction

The facility location problem plays a tremendous role in supply chain strategy. It has been studied for a long time ago. The first research work was done by Weber (1909) in his industrial location theory. It was extended by Hakimi (1964). The concept of supply chain management (SCM) was established by Oliver and Webber (1982). Since 1970, the global competition level among various companies throughout the world increased by many folds (for instance Erengüc et al., 1999). Now, we define the concept of SCM. It is a coordination between suppliers, manufacturers and retailers or distributers to meet the customer's demand. Actually, SCM was introduced independent of OR (Operations Research). Then, it was gradually appeared to be the combination of OR and SCM. In the same way, facility location problem also entered into SCM after its independent appearance. Facility location models are used to design various distribution networks along with facilities which have a great importance in strategic supply chain. Chopra et al. (2006) showed an excel based solution of facility location model. According to ReVelle et al. (2008), future studies led to different location models such as analytic model, continuous model, discrete location model and network model. Sana (2012) introduced an inventory model in supply chain environment. Teng et al. (2012) developed a supply chain model where the optimal economic order quantity for buyer–distributor–vendor was derived without derivative. Sarkar (2012a) considered a two echelon supply chain model with probabilistic deterioration.

This model deals with discrete location policy as it is more convenient for designing distribution networks. Melo et al. (2009) mentioned, in his review article that, six different groups of discrete facility location problem entitled as median problems, center problems, covering problems, uncapacitated facility location problems (UFLP), capacitated facility location problems (CFLP) and supply chain network design (SCND) problems. The first three problems were well discussed in Owen and Daskin (1998)'s paper. Further extension of the above first five groups involves multi products, multi echelon networks, stochastic or dynamic costs, demands etc. in a facility location model. The combination of these extensions of those five models formed the SCND group. The two-echelon, multi-commodity, capacitated facility location problem was introduced by Pirkul and Jayaraman (1998), aiming to locate different facilities in a supply chain so that the total network cost was minimized. This model was again extended by them by assuming raw material vendors for supplying goods to plants. It was a mixed integer programming problem and also a lagrangian relaxation based heuristic procedure was proposed to solve this model. A one echelon supply chain model was considered by Wu and Zhang (2006) with facility setup cost function. The aim of that model was to determine the location along with number of facilities. Two echelon supply chain network was introduced by Amiri (2006). That model was based on heuristic approach along with lagrangian relaxation. He assumed multi capacity level of each facility apart from the single capacity level used in the previous studies. A multi-stage multi-customer supply chain with optimizing inventory decision was introduced by Cárdenas-Barrón (2007). Hinojosa et al. (2008) studied a dynamic supply chain with inventory. A simple derivation for optimal manufacturing batch size with rework was developed by Cárdenas-Barrón (2008). An economic production quantity model with inflation in the imperfect production was found out by Sarkar and Moon (2011). Sarkar et al. (2011) considered an economic manufacturing quantity model for imperfect production and time varying demand with inflation and time value of money.

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Cárdenas-Barrón et al. (2011) studied the vendor–buyer integrated inventory system with arithmetic and geometric inequality. Chen et al. (2011) developed a joint inventory location problem. They considered the risk of probabilistic facility disruption. Teng et al. (2011) did a simple derivation for a economic lot size of the integrated vendor–buyer inventory system. Cárdenas-Barrón et al. (2012a, 2012b) developed a production inventory model in a three layer supply chain. There was an improved algorithm to show the optimal solution of the model. Roy et al. (2012) obtained optimal replenishment order in a three layer supply chain with uncertain demand. Pal et al. (2012b) assumed a multi item economic order quantity model where the demand rate decreases quadratically with increasing sales price and increases exponentially increasing level of price breaks. Some inventory models were developed which deal with variable demand, imperfect production, delay in payments and variable deterioration rate. The reliability in an imperfect production process was also included (for instances Sarkar 2012b, 2012c, 2012d). An alternative heuristic algorithm to solve a vendor managed inventory system was proposed by Cárdenas-Barrón et al. (2012a, 2012b). They used multi product and multi constraint in that model. Pal et al. (2012a) considered a multi-echelon supply chain for reworkable items in multiple markets with supply disruption. Farahani et al. (2012), in their review article, studied the covering problems in facility location model. Kucukdeniz et al. (2012) assumed the integrated use of fuzzy for convex programming in capacitated multi-facility location model. Sadjady and Davoudpour (2012) discussed two echelon multi-commodity supply chain network design with mode selection. Also, a lagrangian relaxation based heuristic solution procedure was implemented by them. The solving procedures are used to solve the facility location problem as branch and bound algorithm, plant growth simulation algorithm, combination of lagrangian-heuristic and ant colony algorithm (for instances Chen and Ting, 2008; Dupont, 2008; Tong and Zhong-tuo, 2008).

In this paper, we have studied the facility location problem of three different dimensions. We discuss about the meaning of this dimension. Two echelon supply chain model has been developed in this paper. In first step, commodities are transported between manufacturing plants and warehouses. In the second step, same for warehouses and retailers. But, no item or commodity type or type of transportation mode has been considered in problem P1. Thus, only commodities of single product type along with single type of transportation mode have been used. Hence, the costs of transportation and continuous decision variables can be represented by a two dimensional array which makes the continuous decision variables, transportation costs as well as the entire problem as dimension two. But, one thing is to be remembered that all variables, costs and demands, do not lie in this category because capacities of plants or warehouses, inventory costs are fixed. They do not depend on product type, type of transportation mode or locations of retailers. Therefore, they always posses dimension one. Same situation happens with the binary variables too, as they only confirm that a manufacturing plant or a warehouse is opened or not at a particular site. Demand of the retailers depends on retailer's locations and product types. But since, in two dimensional problem, no product types have been assumed, so the demand becomes dimension one. Therefore, dimension two means, the highest dimension that the problem preserves. In the similar way, we extend the two dimension to three dimension by adding type of products. Problem P2 represents three dimensional model. Problem P3 is of dimension four where the type of transportation mode is set to extend the dimension of the model. One important thing is to be noted that two types of dimension is used to extend the problem P1. The first one is product type which is dependent on demands of the retailer. The second one is transportation mode which no longer depends on the demand.

Now, we are about to discuss our aim which is to compare these three models to examine how they differ. Two lemmas have been described to compare them. Then, a small change has been applied on a particular constraint set and the difference between the previous and new values of the objective functions of the described models have been studied. Another lemma is described for this too.

2. Assumptions and notation

We consider some assumptions to develop our model.

2.1. Assumptions

1. The model deals with two echelon supply chain network.
2. All the plants and warehouses have with fixed capacities.
3. Delivery lead time is considered here.
4. The demand of each retailer is satisfied.
5. Outsider suppliers are considered to fulfill the demands of the retailers too.
6. An annual fixed cost is needed for each warehouse and plant to be opened.
7. Plant and warehouse at each site have a fixed inventory holding.

The following notation are considered to develop the model:

Notation

I	Set of retailer $i \in I$;
J	Set of potential warehouse sites $j \in J$;
K	Set of plant sites $k \in K$;
P	Set of different product types $p \in P$.
T	Set of available transportation modes $t \in T$;
WC_j	Capacity of warehouse j;
PC_k	Capacity of plant k;
D_i	Demand of retailer i;
D_{ip}	Demand of product p of retailer i;
TCW_j	Total cost of warehouse j open;
TCP_k	Total cost of plant k open;
PTC_{jk}	Production and transportation cost per unit of product from plant k to warehouse j;
PTC_{jkp}	Production and transportation cost per unit of product p from plant k to warehouse j;
PTC^t_{jkp}	Production and transportation cost per unit of product p from plant k to warehouse j via transportation mode t;
TC_{ij}	Transportation cost per unit of product from warehouse j to retailer i;
TC_{ijp}	Transportation cost per unit of product p from warehouse j to retailer i;
TC^t_{ijp}	Transportation cost per unit of product p from warehouse j to retailer i via transportation mode t;
IC_j	Unit inventory holding cost of a product at warehouse j;
IC_{jp}	Unit inventory holding cost of product p at warehouse j;
JC_k	Unit inventory holding cost of a product at plant k;
JC_{kp}	Unit inventory holding cost of product p at plant k;
OSC_i	Transportation cost per unit of product to retailer i from an outside supplier;
OSC_{ip}	Transportation cost per unit of product p to retailer i from an outside supplier;
OSC^t_{ip}	Transportation cost per unit of product p to retailer i from an outside supplier via transportation mode t;
M	Monetary value per unit of lead time;
M_p	Monetary value per unit of lead time for product p;
TWR_{ij}	Delivery lead time per unit of product from warehouse j to retailer i;
TWR_{ijp}	Delivery lead time per unit of product p from warehouse j to retailer i;
TWR^t_{ijp}	Delivery lead time per unit of product p from warehouse j to retailer i via transportation mode t;
TPR_{jk}	Delivery lead time per unit of product from plant k to warehouse j;

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