The Capacitated Multi-items, Multi-facilities, Multi-periods Logistics Networks Optimisation Problem: A Warehouse Capacity Selection Problem

Muhammad Izman Herdiansyah[1]
Fakultas Ilmu Komputer Universitas Bina Darma, Jl. Jend. A. Yani No 3 Palembang
m.herdiansyah@binadarma.ac.id

Abstract

One important strategic issue related to the design and operation of a physical distribution network is the determination of the best sites for warehouses for intermediate stocking points as well as its capacity. Therefore, it is important to integrate the facility location models and decision with logistical functions and components in the logistics performance analysis. This paper focuses on optimizing the capacitated multi-items, multi-facilities, multi-periods logistics network problem. It differs from previous research in that the model includes the selection of warehouse location and capacity, and also considers backlogging. The problem is optimizing the production and distribution plan over a finite time horizon to satisfy demand requirements while determining the best selection of warehouses to be used from available warehouses and choosing its optimum capacity and the best strategy to distribute products to customers. A mixed integer linear programming (MILP) model is developed. To validate the model, several small data sets are used. The problem is solved using commercial linear programming package, CPLEX ver. 11. From the experiments there are several managerial insights. First, networks with higher warehouse capacity can expect better reduction in total network cost. Second, the number of warehouses activated and its capacity selected are related to the total demand that must be satisfied. Third, networks with high fixed setup cost tend to increase the production level to maximum capacity and store more inventories distributed in several periods And, networks with allowing backorder have a better performance when handling low demand and high demand.

Keywords: Logistics network, Facility selection, Mixed Integer Linear Programming

1. Introduction

It is quite common nowadays in business and industry for manufacturers and retailers to combine their efforts to efficiently handle the flow of products and to closely coordinate their production and logistics networks. One important strategic issue related to the design and operation of a physical distribution network is the determination of the best sites for warehouses for intermediate stocking points as well as its capacity. The use of warehouses provides a company with flexibility to respond to changes in the marketplace and can result in significant cost savings due to economies of scale in transportation or shipping costs. Therefore, it is important to integrate the facility location models and decision with logistical functions and components in the logistics performance analysis.

In order to improve the logistics network performance in an integrated way, we need to consider the integration of production planning, and the distribution problems. This includes the merging of the production, inventory, and transportation problems in a single formulation. This is very crucial in logistics system optimization. In a company operation, a production planner is concerns with optimizing the production and inventory level in each period so that the cost is minimized. On the other hand, the distribution planner is concerns with determining the distribution plan to satisfy customer demand so that the transportation cost is minimized. Without the integrated analysis, these two processes independently could increase the inventory holding cost and yield longer lead times. Therefore, a company needs to explore a better model in order to achieve its objective of minimizing the total costs.

The integration of production planning and distribution model systems needs to be developed in a strategic perspective, tactical as well as operational (Bramel & Simchi-Levi, 1997). Strategic decisions are generally long-term in scope. These decisions include the number, location and capacities of plants and warehouses, or the flow of material through the logistics network. Tactical decisions have a time horizon of several months up to one year. These decisions include purchasing and production decisions, inventory policies and transportation strategies. The operational decisions involve the day-to-day activities of a business operation such as scheduling, and vehicle routing. The operations of production and distribution can be decoupled if there is a sufficient amount of inventory between them (Chen, 2004).

The importance of the integrated analysis in logistics network problems have been considered by several authors, as mentioned in the previous section, and substantial evidence exists in the real business application (such as Haq et al. (1991), Arntzen et al. (1995), Robinowitz and Mehrez (2001)) to demonstrate that integrating decisions can lead to substantial increases in efficiency and effectiveness. Therefore, the crucial questions that arise in business application nowadays are: how can we develop an integrated model from which we are able to improve the logistics network performance of a company especially in the problem of the capacity selection of company facilities.

In this paper, we focus on optimizing the capacitated multi-items, multi-facilities, multi-periods logistics network problem. We differ from previous research in that our models include the selection of warehouse location and capacity, and we also consider backlogging. The problem is optimizing the production and distribution plan over a finite time horizon to satisfy demand requirements while determining the best selection of warehouses to be used from available warehouses and choosing its optimum capacity and the best strategy to distribute products to customers.

This paper is organized as follows. Section 2 presents the literature review. Section 3 presents model formulation in form of a mixed integer linear programming (MILP) for the single-product problem as well as the multi-product problem. Computational results are discussed in Section 4.

2. Literature Review

Over the past several decades, many authors have proposed models and methods for solving the facility location problem. Francis et al. (1983), Aiken (1985), Current et al. (1990), Sridharan (1995), Owen and Daskin (1998) provided reviews on various facility location problems. Francis et al. (1983) provided a review on formulation and solution of facility location problem. Aiken (1985) provided a review on facility location problem on physical distribution management. Current et al. (1990) provided a review on model of multi-objectives facility location problems. Sridharan (1995) provided an extensive review of capacitated plant location problems. Owen and Daskin (1998) reviewed facility location model in strategic planning decisions.

There are many classifications of location problem that have been widely studied. One is the uncapacitated facility location problem versus capacitated problem. The uncapacitated problem was studied, among others, by Khumawala and Whybark (1976), Roodman and Schwarz (1977), Van Roy and Erlenkotter (1982), Kelly and Maruckeck (1984), Koerkel (1989), Gao and Robinson (1994), Chardaire et al. (1996), and Wang et al. (2003). Recently, Resende and Werneck (2006) presented a multi-starts heuristic for the uncapacitated facility location problem.

The capacitated facility location problem was studied, among others, by Geoffrion and Graves (1974), Kaufman et al. (1977), Erlenkotter (1981), Lee and Luss (1987), Shulman (1991), Melachrinoudis et al. (1995), Hormozi and Khumawala (1996), Pirkul and Jayaraman (1998), Hinojosa et al. (2000), Antunes and Peeters (2001), Melkote and Daskin (2001). Recently, Klose and Drexl (2005) provided a review on continuous location models, network location models, mixed integer programming models, and their application. Wu et al. (2006) provided an extension of capacitated facility location problem in which the general setup cost functions and multiple facilities in one site are considered.

The integration of facility location and logistics aspects had also been studied by a number of authors, such as Jayaraman and Pirkul (2001), Syam (2002), Melo et al. (2005), and recently Thanh et al. (2008). Jayaraman and Pirkul (2001) provided a study on integrated logistics model for locating production and distribution facilities in a multi-echelons environment. They model both strategic and operational decisions to design and test a production and distribution system model and evaluate its performance. They presented a mixed integer programming formulation of the integrated, multi-products, production and distribution problem subject to constraints associated with locating and operating the firm's production and facilities. In their model, customers are supplied from a single warehouse and backorders are not permitted.

Syam (2002) stated that the critical logistics issue in current logistics problems is the determination of optimal locations for plants and warehouses, as well as the determination of optimal consolidation policies, given the set of open sites. He provided a location-consolidation model that simultaneously determines facility locations, flows, shipment compositions, and shipment cycle times in a multi-commodities, multiple plants and warehouse environment. He presented a mixed integer programming formulation for minimizing total cost comprises inventory holding cost, ordering costs, transportation costs, manufacturing costs, handling costs at warehouses and fixed costs both at plants and warehouses. Their model does not allow backlogging.

Melo et al. (2005) provides a mixed integer linear programming model for dynamic facility location that captures important features of strategic supply chain planning problems. The features include the relocation of existing facilities through capacity transfer to new location, integration of inventory, transportation, and supply decision, the availability budget for investment in facility location and relocation and supply decision, the generic structure of the supply chain network. They assumed that products can be transferred between warehouses or distribution centers (DCs), or transfer directly to customers. In their model however the backorders are not permitted.

Thanh et al. (2008) recently proposed a dynamic model for facility location and supply chain design. Their model is a mixed integer linear programming model for a multi-commodities multi-echelons production-distribution network with deterministic demand. The features are selection of suppliers, opening or closing facilities, planning capacity for existing facilities, production management and distribution management as well as inventory management. They assumed products can be transferred between plants or transfer directly to customers, but they do not consider transfers between warehouses. In their model, they consider a capacity extension options at plants and backorders are not permitted.

3. Model Formulation

In order to solve logistics network optimization problem, several optimization methods can be used, such as mathematical programming, genetic algorithms, simulated annealing, etc. This paper will use mathematical programming for the reason: it provides insight into problem, its characteristics and the linkages between the various interacting factors. Furthermore, there has been considerable progress in recent years with solving large-scale integer programming problems.

We consider the problem of designing a distribution network that involves determining simultaneously the best selection of warehouses used and the best strategy for distributing the product from the plants to the warehouses and from the warehouses to the customers. Our problem has the following features:

- *l* plants P1, P2, …, Pl where the product can be produced.
- *m* potential warehouses sites W1, W2, …, Wm where the product can be stored.
- *q* products identified as 1,2,…q, which can be produced in the plants over a period of time. In general, it is assumed that in each time period, the production facility is allowed to produce more than one product, coupled with limited production capacity.
- *r* capacity level available identified as 1,2,…, R of the potential warehouses sites
- *n* customer locations C1, C2, …, Cn where the product is required.
- Plant production capacities for each product and storage capacities of the potential warehouses are known.

- Customer requirements at each centre are deterministic and known for each period. Furthermore, they must be met, that is backorders are not permitted.
- All products are assumed delivered directly to warehouse.
- A planning horizon of T periods.
- A homogeneous fleet of vehicles to transport the product through the network.

Our model in this section assumes that there are a number of plants that capable to produce multi products with a specific capacity for each product over a period time. The setup cost is a fixed cost on a lot-for lot basis, not dependent on the realized volume. It is incurred at each plant whenever the production runs. All products are assumed to be directly delivered to warehouses or retail outlets. Customers typically demand multiple units of different products that are distributed from open warehouses. Meanwhile, warehouses could receive those products from several plants where are assumed directly delivered to warehouse or retail outlet location. Each warehouse could keep a limited amount of inventory for each product, with specific holding cost. Whenever a potential warehouse is used and operated, a fixed charged will be incurred.

Products are delivered using a homogeneous fleet vehicle with specific capacity for each product. The movement of vehicle incurs a variable transportation cost only. The transportation capacity constraints in our problem are both between Plants and Warehouses and between Warehouses and Customers. The transport capacity in this model is the limitation of the maximum quantity of product that can be carried out by the vehicle in period T. If represents the capacity of transportation line between plant i and warehouse j in period t, then constraint $\sum_q X_{ijq}^t \leq T_{ij}^t$ shows the upper bound of the total product that can be transported from plant i to warehouse j in period t, the total transportation line capacity.

On the warehouses side, represents the capacity of transportation line between warehouse j and customer k in period t. There is a following constraint$\sum_q Y_{jkq}^t \leq U_{jk}^t$ that forces the total product transported from warehouse j to customer k in period t to be below its upper bound, total transportation line capacity. By definition these parameters are nonnegative; so we have another constraint $T_{ij}^t, U_{jk}^t \geq 0$ in our extended model.

It is assumed that the demands are given. We consider a finite horizon divided into periods where in each period the demand of product q can be satisfied by production, by stock or inventory carried over from previous periods, or by backlog. In the case of demand being satisfied by backlogging, Johnson & Montgomery (1974) stated that to represent the possibility of satisfying demand in a period through production in a later period, we could use network flow model. We define the decision variables for the quantity of inventory of product q in period t that is carried over from the previous period at warehouse j is denoted by Ih_{jq}^t. The quantity of product q that is backordered in period t is denoted by Ib_{jq}^t. The net inventory level at warehouse j in period t is $I_{jq}^t = Ih_{jq}^t - Ib_{jq}^t$

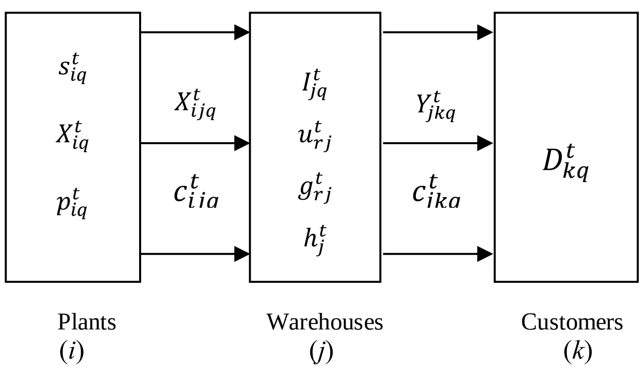

Figure 1. Network model representative for logistics problem with warehouse selection

The issues that will be answered in this section are: which plant will be used to produce which product; the quantity to be produced at each plant; and which warehouse facilities will be used or opened and its capacity.

We can represent the problem in the form of a network (Figure.1). We define the network for the flow of products from their production points to customers through the warehouse as storage. This model then refers to three components: the production sites, indexed by *i*, the candidate warehouses, indexed by *j*, and the customers, indexed by *k*.

A mixed integer linear programming (MILP) model is developed to solve the problem. We formulate the problem as a multi-products network flow problem with a fixed charge cost function. The problem is to determine a production and distribution plan over the planning horizon that meets the customer demands, satisfies the capacity restrictions and minimizes the total logistics costs. The costs include: production, transportation, and inventory holding. It is assumed those initial inventories are zero for all items.

3.1. Model Parameters

Logistics network problem studied in this paper will be formulated using the following notation:

T : number of periods in the planning horizon.
l : number of plants where product can be produced.
m : number of potential warehouses site where the product can be stored.
n : number of customer locations where the product is required.
q : number of type product which can be produced in plants.
R : number of capacity levels available to potential warehouses.

For each product q, we define the following notation for our cost data:

s_{iq}^{t} : setup cost for product *q* at plant *i* in period t, i = 1,2, …, *l* ; t = 1,2, …, *T*; q = 1,2, …, *q*.
p_{iq}^{t} : unit cost of production for product *q* at plant *i* in period t, i = 1,2, …, *l*; t = 1,2, …, *T*; q = 1,2, …, *q*.
c_{ijq}^{t} : unit cost of transportation to deliver product *q* from plant *i* to warehouse *j* in period t, i = 1,2, …, *l*; j = 1,2, …, *m*; t = 1,2, …, *T*; q = 1,2, …, *q*.
c_{jkq}^{t} : unit cost of transportation to deliver product *q* from warehouse *j* to customer *k* in period t, j = 1,2, …, *m*; k= 1,2, …, *n*; t = 1,2, …, *T*; q = 1,2, …, *q*.
h_{jq}^{t} : unit inventory holding cost at warehouse *j* for product *q* in period t, j = 1,2, …, *m*; t = 1,2, …, *T*; q = 1,2, …, *q*.
b_{jq}^{t} : unit backorder cost at warehouse *j* for product q in period t, j = 1,2, …, *m*; t = 1,2, …, *T*; q = 1,2, …, *q*.
g_{rj}^{t} : fixed cost of operating warehouse *j* with capacity level *r* in period t, j = 1,2, …, *m*; r = 1,2, …, *R;* t = 1,2, …, *T*.

The other notations that we use are:

P_{iq} : capacity of plant *i* to produce product *q* , i = 1,2, …, *l*; q = 1,2, …, *q*.
W_{rj} : potential warehouse *j* with capacity level *r*, j = 1,2, …, *m*; r = 1,2, …, *R*.
D_{kq}^{t} : demand for product *q* of customer *k* in period t, k = 1,2, …, *n*; t = 1,2, …,*T*; q = 1,2, …, *q*.
I_{jq}^{t} : inventory level of product *q* at warehouse *j* at the end of period t, j = 1,2, …, *m*; t = 1,2, …, *T*; q=1,2, …, *q*.
Ib_{jq}^{t} : backorder level of product q at warehouse j in period t.
Ih_{jq}^{t} : inventory level of product q in period t that is carried over from the previous period at warehouse j.

3.2. Decision Variables

The decision variables that we use are:

X_{iq}^{t} represents the amount of product q produced at plant i in period t.

X_{ijq}^{t} represents the amount of product q transported from plant i to warehouse j in period t.

Y_{jkq}^{t} represents the amount of product q transported from warehouse j to customer k in period t.

z_{iq}^{t} represents the binary setup variable at plant i in producing product q in period t.

u_{rj}^{t} represents the binary variable at warehouse j with capacity level r in period t.

3.3. Problem Formulation

Our problem is to minimize the total cost of production, transportation, and inventory over the T periods. The model assumes no starting inventory. The studied can be formulated as a MILP as follows:

Minimize

$$\sum_{t=1}^{T}\sum_{i=1}^{l}\sum_{q=1}^{q}\left(X_{iq}^{t}p_{iq}^{t}+s_{iq}^{t}z_{iq}^{t}\right)+\sum_{t=1}^{T}\sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{q=1}^{q}X_{ijq}^{t}c_{ijq}^{t}+\sum_{t=1}^{T}\sum_{j=1}^{m}\sum_{q=1}^{q}Ih_{jq}^{t}h_{jq}^{t}$$
$$+\sum_{t=1}^{T}\sum_{j=1}^{m}\sum_{q=1}^{q}Ib_{jq}^{t}b_{jq}^{t}+\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{j=1}^{m}g_{rj}^{t}u_{rj}^{t}+\sum_{t=1}^{T}\sum_{j=1}^{m}\sum_{k=1}^{n}\sum_{q=1}^{q}Y_{jkq}^{t}c_{jkq}^{t} \tag{1}$$

where, $z_{iq}^{t}=\begin{cases}1, & if\ X_{iq}^{t}>0\\ 0, & else\end{cases}$

$u_{rj}^{t}=\begin{cases}1, & if\ Y_{jkq}^{t}>0\\ 0, & else.\end{cases}$

Subject to following constraints:

$X_{iq}^{t}\leq Mz_{iq}^{t}$	,	$\forall\, i,t$	(2)
$\sum_{qi}X_{iq}^{t}\leq P_{i}$	,	$\forall\, i,t$	(3)
$\sum_{qj}X_{ijq}^{t}\leq X_{iq}^{t}$	,	$\forall\, i,t$	(4)
$\sum_{qi}X_{ijq}^{t}+\sum_{q}\left(Ih_{jq}^{t-1}-Ib_{jq}^{t-1}\right)-\sum_{qk}Y_{jkq}^{t}\leq\sum_{r}W_{rj}u_{rj}^{t}$	,	$\forall\, j,t$	(5)
$\sum_{qi}X_{ijq}^{t}+\sum_{q}\left(Ih_{jq}^{t-1}-Ib_{jq}^{t-1}\right)\geq\sum_{qk}Y_{jkq}^{t}$	,	$\forall\, j,t$	(6)
$\sum_{i}X_{ijq}^{t}+Ih_{jq}^{t-1}-Ib_{jq}^{t-1}=\sum_{k}Y_{jkq}^{t}+Ih_{jq}^{t}-Ib_{jq}^{t}$	,	$\forall\, j,q,t$	(7)
$\sum_{qk}Y_{jkq}^{t}\leq\sum_{r}W_{rj}u_{rj}^{t}$	,	$\forall\, j,t$	(8)
$D_{qk}^{t}=\sum_{qj}Y_{jkq}^{t}$	,	$\forall\, k,t$	(9)
$\sum_{q}X_{ijq}^{t}\leq T_{ij}^{t}$	,	$\forall\, i,j,t$	(10)
$\sum_{q}Y_{jkq}^{t}\leq U_{jk}^{t}$	,	$\forall\, j,k,t$	(11)
$\sum_{r}u_{rj}^{t}\leq 1$	,	$\forall\, j,t$	(12)
$u_{j}^{t}-\sum_{r}u_{rj}^{t}\geq 0$	,	$\forall\, j,t$	(13)
$\sum_{j}u_{j}^{t}\leq nW$	,	$\forall\, t$	(14)
$X_{iq}^{t},\ X_{ijq}^{t},\ Y_{jkq}^{t},I_{jq}^{t},\ Ih_{jq}^{t},\ Ib_{jq}^{t}\ \geq 0$			(15)
$P_{i}\ ,\ W_{rj},\ T_{ij}^{t},\ U_{jk}^{t}\ \ \geq 0$			(16)
z_{iq}^{t} = 0 or 1			(17)
u_{j}^{t} = 0 or 1			(18)
u_{rj}^{t} = 0 or 1.			(19)

The objective function (1) represents the total costs over the T periods. It consists of production costs with a fixed charge cost function, warehousing fixed costs, inventory holding costs, backorder costs, and transportation costs.

As the production cost function is a fixed charge cost function, thus constraint (2) assures that a setup cost will be incurred if there is product type q produced in plant i in period t. It will guarantee that takes value one whenever is positive. Note that a period t is called a production period if > 0. The amount of product q produced at plant i in period t, and transferred from plant i to warehouse j in period t is restricted by the capacity constraints (3) and (4).

Total Product flow from plant i to warehouse j with capacity r and from warehouse j to customer k must respect the throughput capacity of warehouse j, as indicated in (5). The product flow is including the backorder position in period t. It is the nature of multi-products problem. Without this constraint, our problem can be stated as separated single product problem. Constraint (6) related to product flow requirement in warehouse j. Total product delivered out from warehouse j cannot exceed total product delivered to warehouse j.

Constraint (7) requires that the amount of product coming to warehouse j together with inventory from previous periods and backorder to previous periods, should be equal to the ending inventory and backorder position in warehouse j plus amount of product shipped to the customers. It is a balance constraint of inventory level in warehouse j during period time t. Constraint (8) assures that a fixed cost at warehouse j will be incurred if there is a demand of product q that are supplied from warehouse j in period t. Constraint (9) requires that warehouses must satisfy all demand. Constraint (10) limits the maximum number of product can be transported from plant i to warehouse j in period t. Constraint (11) limits the maximum number of products can be transported from to warehouse j to customer k in period t.

Constraint (12) ensures that only one type of capacity of warehouse is used in period t. Constraint (13) is a logical relation that ensures demand will be satisfied by open warehouse j in period t. Constraint (14) is the maximum number of warehouse can be opened or used. Constraints (15) and (16) are non-negative value constraints. Constraint (17), (18) and (19) are the zero-one variables.

4. Computational Results and Discussions

4.1. Data

In this section, we describe the computational experience in solving our model. We generate several test data to demonstrate the applicability of the mathematical formulations above. The following data are used:

- There are 9 nodes which represent 2 Plants (Plant 1 and Plant 2), 5 Warehouses (Warehouse 1, Warehouse 2, Warehouse 3, Warehouse 4, and Warehouse 5), and 2 Customers (Customer 1 and Customer 2).
- T period observation is 12 period.
- Plants production capacities per-period are in the range low or high.
- Inventory storage capacities in warehouses per-period are in the range low or high.
- Demand are deterministic modeled.
- Setup cost and production cost in production facilities are deterministic modeled.
- Costs incurred in warehouses and warehouses fixed cost are deterministic modeled.
- Transportation cost between plants, warehouses, and customers deterministic modeled.

The results in this section seek to illustrate the impact of different factors on logistics network with capacitated facilities to its total costs when we open or activate the available warehouses and select its capacity. We observe the effect of capacity constraints changing in production and warehouse facilities in handling various demand models.

In order to test and illustrate the impact of different factor on basic model, 40 test problems are generated. It can be categorized in 10 cases:

- Case 1: Low Plant Capacity and 1 Warehouse (LP-1W). Plant capacities used in this case are 8000 units/period.
- Case 2: Low Plant Capacity and 2 Warehouses (LP-2W). Plant capacities used in this case are 8000 units/period.
- Case 3: Low Plant Capacity and 2 Warehouses (LP-3W). Plant capacities used in this case are 8000 units/period.
- Case 4: Low Plant Capacity and 4 Warehouses (LP-4W). Plant capacities used in this case are 8000 unit/period.
- Case 5: Low Plant Capacity and all Warehouses (LP-5W). Plant capacities used in this case are 8000 units/period.
- Case 6: High Plant Capacity and 1 Warehouse (HP-1W). Plant capacities used in this case are 15000 units/period.
- Case 7: High Plant Capacity and 2 Warehouses (HP-2W). Plant capacities used in this case are 15000 units/period.
- Case 8: High Plant Capacity and 3 Warehouses (HP-3W). Plant capacities used in this case are 15000 unit/period.
- Case 9: High Plant Capacity and 4Warehouses (HP-4W). Plant capacities used in this case are 15000 units/period.
- Case 10: High Plant Capacity and all Warehouses (HP-5W). Plant capacities used in this case are 15000 units/period.

For each case we generate 4 scenarios of various setup costs and demand variation model. There are two demand models which are low level demand and high level demand, and two types of setup cost (low and high setup cost). We classify our scenarios as follows:

A: for low setup cost, low demand,

B: for high setup cost, low demand,

C: for low setup cost, high demand,

D: for high setup cost, high demand,

The optimal production schedule and product movements as well as its total costs are computed for each configuration under all scenarios using CPLEX ver 11. The experiments were conducted on personal computer with Intel Core 2 Duo 2.66 GHz and 2 Gbyte memory.

4.2. Results and Discussions

The results of this section seek to illustrate the effect of increasing various model costs on the warehouses and its capacity selection. There are three warehouse capacities which should be selected, i.e. 3000 units/period, 6000 units/period or 9000 units/period. We observe using two plants capacity option: low capacity (8000 units/period) and high capacity (15000 units/period).

First, we examined the case if we use low plants capacity. We examined how the total network cost change as we select the available warehouses and its capacity in storing products. We change the setup cost, from low cost to high setup cost, and vary demand from low to high demand setting. We classify the result based on the various cases. We found that the total network cost increases as we increase the setup cost, except in case 1 where the result is infeasible. We observed that having a high setup cost when handling demand changing from low demand to high demand generally is more favorable in low plants capacity model as resulting lower average total cost increment, 19.31% compare to 19.71% if we use lower setup value.

We observed that the optimal number warehouses should be operated is 3 warehouses. When we use 3 warehouses we gain total cost reduction of: 4.14% in scenario A; 4.20% in scenario B; 3.71% in scenario C; and 3.74% in scenario D. While using 4 or 5 warehouses there are no further reduction obtained. We found that if we only use 1 warehouse to supply demand, the result is infeasible due to the insufficient capacity in our network. This finding brings us to the fact that our optimal solution will be achieved when we have sufficient capacity, in this case the warehouse capacity.

Table 8. Type of warehouse capacity operated for low plants capacity

	Scenario A	Scenario B	Scenario C	Scenario D
Case2	Type 1,2,3	Type 1,2,3	Type 1,2,3	Type 1,2,3
Case3	Type 1,2	Type 1,2	Type 1,2,3	Type 1,2,3
Case4	Type 1,2	Type 1,2	Type 1,2,3	Type 1,2,3
Case5	Type 1,2	Type 1,2	Type 1,2,3	Type 1,2,3

We observed the optimal warehouses schedule and found that when demand is low our model tend to operate warehouse type 1 and 2, except in case 2 where we limit to operate maximum only 2 warehouses (Table 8). In case 2, all types of warehouses are used. If demand is high, all types of warehouses will be used. From our results, we observed that the most warehouses used are warehouse 3 and 4.

From Table 9 we also observed that by allowing backorder in the model, we gain cost reductions as we compare to the result of no-backorder model. We conclude that by allowing backorder in our model, we can handle demands better than basic model.

Table 9. Comparison of total network cost reduction between backorder case and no-backorder case

Number of Warehouse open	Scenario A	Scenario B	Scenario C	Scenario D
2	-0.19%	-0.26%	-0.21%	-0.30%
3	-0.04%	-0.09%	-0.03%	-0.02%
4	-0.04%	-0.09%	-0.03%	-0.02%
5	-0.04%	-0.09%	-0.03%	-0.02%

Another observation from this case problem could be seen in Table 10. We summarize the running time of all scenarios and find that the problem difficulty to solve depends on the maximum number of warehouses operated and the values of the fixed costs. When we only allowed operating maximum 2 warehouses, our problems are more difficult to be solved as indicated in higher solution times. In other cases, the scenarios are solved faster. Table 5.32 is a result of the mixed integer linear programming relaxation done in CPLEX with emphasis on the optimality. We set a dynamic search as a searching method.

Table 10. CPLEX running time of case with low plants capacity

Case Scenario	Solution Time (Sec)	Case Scenario	Solution Time (Sec)
LP-2W-A	20.53	LP-4W-A	0.25
LP-2W-B	167.31	LP-4W-B	0.91
LP-2W-C	60.31	LP-4W-C	1.19
LP-2W-D	288.31	LP-4W-D	2.94
LP-3W-A	0.19	LP-5W-A	0.19
LP-3W-B	2.50	LP-5W-B	0.78
LP-3W-C	0.45	LP-5W-C	0.53
LP-3W-D	2.94	LP-5W-D	3.16

Finally, we examined the case if we use high plants capacity. We examined how the total network cost change as we select the available warehouses and its capacity in storing products. We change the setup cost, from low cost to high setup cost, and vary demand from low to high demand setting. We found that the total network cost increases as we increase the setup cost, except in case 6 where the result is infeasible. We observed that having a high setup cost when handling demand changing from low demand to high demand generally is more favorable in low plants capacity model as resulting lower average total cost increment, 17.69% compare to 17.92% if we use lower setup value.

We observed the effect of number warehouses operated to network total costs. We found that if we only use 1 warehouse to supply demand, the result is infeasible due to the insufficient capacity in our network. This finding brings us to the fact that our optimal solution will be achieved when we have sufficient capacity, in this case the warehouse capacity. It can be referred to constraint (5) in our model that indicates the property of our optimal solution.

We observed that the optimal number warehouses should be operated is 3 warehouses. When we use 3 warehouses we gain total cost reduction of: 4.55% in scenario A; 4.57% in scenario B; 4.00% in scenario C; and 4.05% in scenario D. While using 4 or 5 warehouses there are no further reduction obtained. We also observed that by allowing backorder in the model, when we supply high demand we gain cost reductions as we compare to the result of no-backorder model. However, no further cost reduction if we cover the low demand, except in scenario B (Table 11). We can conclude that by allowing backorder in our model, we can handle demands better than basic model.

We also observed the optimal warehouses schedule and found that in all cases and scenarios warehouse type 1, type 2 and type 3 will be used.

Table 11. Comparison of total network cost reduction between backorder case and no-backorder case

Number of Warehouse open	Scenario A	Scenario B	Scenario C	Scenario D
2	0.00%	-0.02%	0.00%	-0.01%
3	0.00%	0.00%	-0.02%	-0.05%
4	0.00%	0.00%	-0.02%	-0.05%
5	0.00%	0.00%	-0.02%	-0.05%

Another observation from this case problem could be seen in Table 12. We summarize the running time of all scenarios and find that the problem difficulty to solve depends on the maximum number of warehouses operated and the values of the fixed costs. When we only allowed operating maximum 2 warehouses, our problems are more difficult to be solved as indicated in higher solution times. In other cases, the scenarios are solved faster. Table 12 is a result of the mixed integer linear programming relaxation done in CPLEX with emphasis on the optimality. We set a dynamic search as a searching method.

Table 12. CPLEX running time of case with high plants capacity

Case Scenario	Solution Time (Sec)	Case Scenario	Solution Time (Sec)
HP-2W-A	0.31	HP-4W-A	0.06
HP-2W-B	0.38	HP-4W-B	0.08
HP-2W-C	0.14	HP-4W-C	0.08
HP-2W-D	0.31	HP-4W-D	0.09
HP-3W-A	0.06	HP-5W-A	0.05
HP-3W-B	0.08	HP-5W-B	0.05
HP-3W-C	0.06	HP-5W-C	0.06
HP-3W-D	0.08	HP-5W-D	0.06

5. Conclusion

In this paper we study a class of production-distribution problems arising in logistics supply chain networks. We discussed a facility selection problem in logistics network. In particular the selection of warehouses activation and its capacity selection. We studied the capacitated multi-items, multi-facilities, multi-periods logistics network problem. Our problem considers fixed-charge production cost with production capacities, fixed-charge warehousing cost with warehousing capacities, and linear transportation cost. We also considered the problems with transportation capacities and backorder capability. The models that we studied help managers to answer question that arise in managing the logistics network.

In order to study our problems, for each model we generated several test problems which are categorized into 10 cases and 4 scenarios. In each case, we carried out our experiments by varying the plant's capacity and the number of warehouses operated. To illustrate the impact of different factors, we generate our scenarios by varying the setup cost, and demand models. The problems are solved using CPLEX version 11. Our results indicate that the performance of our model depends on the value of setup costs, the value of demands, and the number of warehouses activated as well as the value of capacity of each facility.

From those results we obtain several managerial insights. First, networks with higher warehouse capacity can expect better reduction in total network cost. Second, the number of warehouses activated and its capacity selected are related to the total demand that must be satisfied. Third, networks with high fixed setup cost tend to increase the production level to maximum capacity and store more inventories distributed in several periods. Fourth, the network configuration will avoid storing inventories in warehouse with high holding cost. Fifth, the capacity of transportation line directly affects the total network cost. It is increased when its capacity tightens. Finally, networks with allowing backorder have a better performance when handling low demand and high demand.

Acknowledgements

I wish to thank Prof. Lou Caccetta for his supervisory in my research and his constructive comments. This support is gratefully acknowledged.

References

Aikens, C. (1985). Facility location models for distribution planning. European Journal of Operational Research , 22, 263-279.

Antunes, A., & Peeters, D. (2001). On solving complex multi-period location models using simulated annealing. European Journal of Operational Research , 130, 190-201.

Arntzen, B. C., Brown, G. G., Harrison, T. P., & Trafton, L. L. (1995). Global supply chain management at Digital Equipment Corporation. Interfaces , 25, 69-93.

Bramel, J., & Simchi-Levi, D. (1997). The Logic of Logistics: Theory, Algorithms, and Applications for Logistics Management. (P. Glynn, & S. Robinson, Eds.) New York: Springer-Verlag.

Chardaire, P., Sutter, A., & Costa, M. (1996). Solving the dynamic facility location problem. Networks , 28, 117-124.

Chen, Z. (2004). Integrated production and distribution operations: Taxonomy, models, and review. In Handbook of Quantitative Supply Chain Analysis: Modeling in the E-business Era. Kluwer Publisher.

Current, J., Min, H., & Schilling, D. (1990). Multiobjective Analysis of Facility Location Decisions. European Journal of Operational Research , 49 (3), 295-307.

Erlenkotter, D. (1981). A comparative study of approaches to dynamic location problems. European Journal of Operational Research , 6, 133-143.

Francis, R. L., McGinnis, L. F., & White, J. A. (1983). Locational Analysis. European Journal of Operational Research , 12, 220-252.

Gao, L.-L., & Robinson Jr, E. P. (1994). Uncapacitated facility location: General solution procedure and computational experience. European Journal of Operational Research , 76, 410-427.

Geoffrion, A., & Graves, G. (1974). Multicommodity distribution system design by benders decomposition. Management Science , 20, 822-844.

Haq, A., Vrat, P., & Kanda, A. (1991). An integrated production-inventory-distribution model for manufacture of urea: A case. International Journal of Production Economics , 25, 39-49.

Hinojosa, Y., Puerto, J., & Fernandez, F. (2000). A multiperiod two-echelon multicommodity capacitated plant location problem. European Journal of Operational Research , 123, 271-291.

Hormozi, A., & Khumawala, B. (1996). An improved algorithm for solving a multi-period facility location problem. IIE Transaction , 28, 105-112.

Jayaraman, V., & Pirkul, H. (2001). Planning and coordination of production and distribution facilities for multiple commodities. European Journal of Operational Research , 133, 394-408.

Johnson, L. A., & Montgomery, D. C. (1974). Operation research in production planning, scheduling, and inventory control. New York: John Wiley & Sons. Inc.

Kaufman, L., Eede, M., & Hansen, P. (1977). A plant and warehouse location problem. Operation Research Quarterly , 28, 547-554.

Kelly, D., & Maruckeck, A. (1984). Planning horizon result for the dynamic warehouse location problem. Journal f Operations Management , 4, 279-294.

Khumawala, B., & Whybark, D. (1976). Solving the dynamic warehouse location problem. International Journal of Production Research , 6, 238-251.

Klose, A., & Drexl, A. (2005). Facility location models for distribution system design. European Journal of Operational Research , 162, 4-29.

Koerkel, M. (1989). On the exact solution of large-scale simple plant location problems. European Journal of Operational Research , 39 (2), 157-173.

Lee, S., & Luss, H. (1987). Multifacility type capacity expansion planning: algorithms and complexities. Operations Research , 35, 249-253.

Melachrinoudis, E., Min, H., & Wu, X. (1995). A multipleobjective model for the dynamic location of landfills. Location Science , 3, 143-166.

Melkote, S., & Daskin, M. S. (2001). Capacitated facility location/network design problems. European Journal of Operational research , 129, 481-495.

Melo, M., Nickel, S., & Gama, F. S. (2005). Dynamic multi-commodity capacitated facility location: A mathematical modeling framework for strategic supply chain planning. Computers and

Owen, S. H., & Daskin, M. S. (1998). Strategic Facility Location: A Review. European Journal of Operational Research , 111, 423-447.

Pirkul, H., & Jayaraman, V. (1998). A multi-commodity, multi-plant, capacitated facility location problem: Formulation and eficient heuristic solution. Computers and Operations Research, 25, 869-878.

Resende, M., & Werneck, R. (2006). A hybrid multistart heuristic for the uncapacitated facility location problem. European Journal of Operational Research , 174 (1), 54-68.

Robinowitz, G., & Mehrez, A. (2001). A multi-echelon multi-commodities, logistics system design at the Dead Sea Works Ltd. Computers & Industrial Engineering , 39, 65-79.

Roodman, G., & Schwartz, L. (1975). Optimal and heuristic facility phase-out strategies. AIIE Transaction , 7, 177-184.

Roy, V. T., & Erlenkotter, D. (1982). Dual-based procedure for dynamic facility location. Management Science , 28, 1091-1105.

Shulman, A. (1991). An algorithm for solving dynamic capacitated plant location problems with discrete expansion sizes. Operations Research , 39, 423-436.

Sridharan, R. (1995). The capacitated plant location problem. European Journal of Operational Research , 87, 203-213.

Syam, S. S. (2002). A Model and Methodologies for The Location Problem with Logistical Components. Computers & Operations Research , 29, 1173-1193.

Thanh, P. N., Bostel, N., & Peton, O. (2008). A dynamic model for facility location in the design of complex supply chains. International Journal of Production Economics , 113, 678-693.

Wang, Q., Bhadury, J., & Rump, C. (2003). Budget constraint location problem with opening and closing of facilities. Computers and Operations Research , 30, 2047-2069.

Wu, L.-Y., Zhang, X.-S., & Zhang, J.-L. (2006). Capacitated facility location problem with general setup cost. Computers and Operations Research , 33, 1226-1241.

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