Multi-vendor-Single-buyer Transportation Model with Heterogeneous Vehicles for Perishable Product

David Try Liputra
Department of Industrial Engineering
Maranatha Christian University, Bandung, Indonesia
Tel: (+62) 878-8288-8808, Email: davidtlp@yahoo.com

Ika Deefi Anna
Department of Industrial Engineering
Trunojoyo University, Madura, Indonesia
Tel: (+62) 812-316-9208, Email: deefi_fian@yahoo.com

Winanda Kartika
APP Polytechnic, Jakarta, Indonesia
Tel: (+62) 813-2042-9923, Email: winanda-kartika@kemenperin.go.id

Abstract. Perishable products are all items that liable to perish, decay, or deteriorate within a fixed period of time. This research considers a supply chain transportation problem consisting of multi-vendor and single-buyer, where the vendor produces a perishable product and delivers it to a distribution center before it will be forwarded to the buyer facing a deterministic demand. The product is transported by first-in-first-out rule in daily planning period using heterogeneous vehicles with the principle of full-truck-load. A model is formulated to minimize the total transportation costs of the system, which is the combination of delivery cost, vehicle leasing cost, and deteriorating cost. Two algorithms are developed sequentially in order to obtain the optimal solution of shipment quantity, number of vehicles, and number of shipments from the vendor to the distribution center and from the distribution center to the buyer, respectively. A numerical example is also included in this paper to present the implementation results of the proposed model in a big milk-packaging-drink company in Indonesia.

Keywords: Perishable product, multi-vendor, single-buyer, supply chain, transportation model

1. INTRODUCTION

According to the Council of Supply Chain Management Professionals (CSCMP), supply chain management (SCM) encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. It also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. Moreover, CSCMP defines logistics management as the part of SCM that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet the customers' requirements.

A logistics system is made up of a set of facilities linked by transportation services (Ghiani et al., 2004). Facilities are sites where materials are processed (e.g. manufactured, stored, sorted, sold, or consumed), including manufacturing and assembly centers, distribution centers (DCs), warehouses, transhipment points, transportation terminals, retail outlets, mail sorting centers, garbage incinerators, dump sites, etc. Transportation services move materials between facilities using vehicles and equipment such as trucks, tractors, trailers, crews, pallets, containers, cars, and trains (Ghiani et al., 2004).

It can be seen that transportation planning is one of the main aspects that determines the success of SCM. Therefore, a transportation system should be designed effectively and efficiently. This transportation problem will be more complicated when it deals with perishable products (e.g. foods, beverages, medicines, etc.) since they have an expiry time. The products can be perished, decayed, or deteriorated if they have passed the expiry time. The complexity of transportation problem is also affected by the number of channel partners that involved and the characteristic of vehicles that used in the logistics or supply chain system. The more number of channel partners and the more heterogeneous of vehicles imply that the more complicated the transportation problem is.

The first comprehensive review on perishable products is performed by Nahmias (1982). Later on, Goyal and Giri (2001) propose a good review of classification of perishable products and the policies that can be used for managing them. In this research, we will focus on perishable products with a fixed life span. Many studies and reviews related to transportation problem have been developed (see for instance Mehrez et al., 1995; Shih, 1997; Sherali et al., 1999; Bilgen and Ozkarahan, 2004; Zanoni and Zavanella, 2007).

The starting point of our work is the mixed integer linear programming (MILP) transport-inventory model proposed by Zanoni and Zavanella (2007). In particular, we modify their model by only focusing on the transportation issue with a limited number of vehicles that can be assigned to distribute a single perishable product in a finite planning period. We also consider the deteriorating cost and vehicle leasing cost in the model.

2. METHODOLOGY

This model is developed for a supply chain system consisting of multi-vendor and single-buyer to find the optimal shipment quantity, number of vehicles, and number of shipments from the vendor to the distribution center and from the distribution center to the buyer, respectively. The aim of our model is to minimize the total transportation costs of the system, which is the combination of delivery cost, vehicle leasing cost, and deteriorating cost.

The Notations

In this research, the following notations will be used to develop the mathematical model:

i	Index of vendor $(i \in I)$
j	Index of shipment frequency $(j \in J)$
k	Index of vehicle $(k \in K)$
m	Index of shipment point $(m \in M)$
d	Transportation or delivery cost per trip performed
e	Perishable or expiry time of product
h	Deteriorating cost of product
s	Vehicle leasing cost
l	Transportation or delivery lead time
Q	Quantity of products that are available to be shipped in the distribution center
C	Storage capacity of the distribution center
q_i	Quantity of products that are available in vendor i
c_k	Capacity of each vehicle k
Y_k	Number of vehicles k
q_{ijk}	Quantity of products shipped by vendor i for the j-th frequency using vehicle k
f_j	j-th shipment frequency
q_k	Quantity of products shipped to the buyer using vehicle k
y_{ijkm}	Number of vehicles k used to distribute product from vendor i for the j-th frequency and m-th shipment point.
y_k	Number of vehicles k used to distribute product from the distribution center to the buyer
x_i	Number of vehicles that have been used to distribute product from vendor i to the distribution center
TC	Total transportation costs of the system

The Assumptions

The mathematical model of this research is developed on the basis of the following assumptions:

a. The product is perishable (it has to be produced, transported, and sold by an expiry time).
b. There are limited number of heterogeneous vehicles that can be assigned to distribute the product.
c. Transportation or delivery cost is a fixed cost for each vehicle and shipment (independent from the quantity transported).
d. Set-up cost of the vendor and ordering cost of the buyer are not considered.
e. The product is processed by first-in-first-out rule and shipped with the principle of full-truck-load in daily planning period.

3. RESULT

3.1 Model Formulation

In this section, a transportation model for a single perishable product in multi-vendor-single buyer supply chain system is developed to minimize the total transportation costs of the system, which is the combination of transportation cost (or delivery cost) from the vendor to the distribution center and from the distribution center to the buyer, vehicle leasing cost, and deteriorating cost of the product. In the following, we give some results which will be used to formulate the model:

- The transportation cost from the vendor to the distribution center and from the distribution center to the buyer are defined as:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} d \cdot y_{ijkm} + \sum_{k=1}^{K} d \cdot y_k \tag{1}$$

- The vehicle leasing cost is formulated as follows:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} s\left(\frac{q_i}{f_j \cdot c_k} - x_i\right) \tag{2}$$

- The deteriorating cost of the product is defined as:

$$h\left(Q - \sum_{k=1}^{K} q_k\right) \tag{3}$$

Since the objective of the model is to minimize the total transportation costs of the system, then it can be completely formulated as follows:

Minimize:

$$TC = d\left(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} y_{ijkm} + \sum_{k=1}^{K} y_k\right) +$$

$$s\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\left(\frac{q_i}{f_j \cdot c_k} - x_i\right) + h\left(Q - \sum_{k=1}^{K} q_k\right) \tag{4}$$

Subject to:

$$\sum_{i=1}^{I} q_i \le C \tag{5}$$

$$\sum_{i=1}^{I} q_{ijk} \le q_i \qquad \forall j \in J; k \in K \tag{6}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} q_{ijk} \le c_k \cdot y_k \qquad \forall k \in K \tag{7}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} y_{ijkm} \le Y_k \qquad \forall j \in J; m \in M \tag{8}$$

$$\sum_{j=1}^{J} f_j \cdot l \le e \tag{9}$$

$$\sum_{k=1}^{K} c_k \cdot y_k \le q_k \tag{10}$$

$$\sum_{k=1}^{K} q_k \le Q \tag{11}$$

$$y_k \le Y_k \qquad \forall k \in K \tag{12}$$

$$q_i, q_k, f_j \ge 0 \qquad \forall i \in I; j \in J; k \in K \tag{13}$$

$$y_k, y_{ijkm} \ge 0, \text{integer} \qquad \forall i \in I; j \in J; k \in K; m \in M \tag{14}$$

The constraint in equation (5) is the storage capacity constraint of the distribution center. The constraints in equation (6) state that the quantity of products shipped by vendor i for the j-th frequency using vehicle k has to be equal or lower than the quantity of products that are available to be shipped in vendor i. The constraints in equation (7) are the capacity constraints of the vehicles used to distribute the product from the vendor to the distribution center. The constraints in equation (8) ensure that the number of vehicles used to distribute the product the vendor to the distribution center do not exceed the total number of available vehicles.

The constraint in equation (9) is the product perishability constraint. The constraints in equation (10) and equation (11) are the capacity constraints of the vehicles used to distribute the product from the distribution center to the buyer. The constraints in equation (12) ensure that the number of vehicles used to distribute the product from the distribution center to the buyer are fewer than the total number of available vehicles. The set of constraints from equation (13) to equation (14) are the set of non-negativity value constraints for q_i, q_k, f_j, y_k, and y_{ijkm}. Moreover, the constraints in equation (14) also state that the values of y_k and y_{ijkm} have to be integer.

3.2 Solution Algorithm

Two solution algorithms are developed sequentially in this research, in order to get the optimal shipment quantity, number of vehicles, and number of shipments from the vendor to the distribution center and from the distribution center to the buyer, respectively as follows:

The First Algorithm

Step 1: Determine the allocation of the number of vehicles in each vendor, using the formula: $x_i = \dfrac{q_i}{\sum_{i=I} q_i} Y_k$.

Step 2: Determine the maximum number of shipment frequency to transport the product from the vendor to the distribution center, $f_j \le e/l$.

Step 3: By using the maximum shipment frequency, if the allocation of available vehicles are enough to be used to transport the product in the vendor, using the formula: $f_j \cdot c_k \cdot x_i \le q_i$, then go to Step 4. Otherwise, calculate the increasing number of vehicles using the formula:

$$x_i' = \left(\frac{q_i}{f_j \cdot c_k} - x_i\right) + x_i,$$ then set the maximum shipment frequency and go to Step 7 directly.

Step 4: Starting with the smallest shipment frequency for each vendor, compute the number of vehicles needed to transport the product in a single shipment, using the formula: $N = \frac{q_i}{f_j \cdot c_k}$. If $N \le x_i$, set $y_{ijkm} = x_i$ and $q_{ijk} = q_i$ then calculate the transportation cost from the vendor to the distribution center. Repeat the procedure for the next shipment frequency until all shipments are considered, then go to Step 5.

Step 5: Specify the quantity of products transported to the distribution center for the first shipment point, using the formula: $q_{ijk} = x_i \cdot c_k$ and $y_{ijkm} = x_i$, then go to Step 6.

Step 6: If $q_i - q_{ijk} \ge x_i \cdot c_k$, then set $q_{ijk+1} = x_i \cdot c_k$ and $y_{ijkm+1} = x_i$. If not, then set $q_{ijk+1} = q_i - q_{ijk}$ and $y_{ijkm+1} = \frac{q_i - q_{ijk}}{c_k}$. Repeat Step 5 for the next shipment point until all q_i are shipped, then calculate the transportation cost from the vendor to the distribution center.

Step 7: Set $q_{ijk} = x_i' \cdot c_k$ and $y_{ijkm} = x_i'$ for the first shipment point and go to Step 8.

Step 8: If $q_i - q_{ijk} \ge x_i' \cdot c_k$, then set $q_{ijk+1} = x_i' \cdot c_k$ and $y_{ijkm+1} = x_i'$. If not, then set $q_{ijk+1} = q_i - q_{ijk}$ and $y_{ijkm+1} = \frac{q_i - q_{ijk}}{c_k}$. Repeat Step 7 for the next shipment point until all q_i are shipped, then compute the transportation cost from the vendor to the distribution center plus the vehicle leasing cost, using the formula in equation (2).

Step 9: Decide the best shipment frequency based on the minimum transportation cost in Step 6 or Step 8.

The Second Algorithm

Step 1: Allocate the product in accordance with the capacity of largest vehicles until all largest vehicles are assigned, then the rest are adjusted with the second largest capacity vehicles and so on.

Step 2: If the combination of the vehicles assignment cannot transported the whole product, then the rest will be sold in retail, using the formula: $Q' = Q - \sum_{k \in K} q_k$.

Step 3: Compute the transportation cost from the distribution center to the buyer for all formed combinations, then select the minimum one.

Step 4: Calculate the total transportation costs of the system, using the formula in equation (4).

3.3 Numerical Example

In this section, we perform a numerical example to present the implementation results of the proposed model in a big milk-packaging-drink company in Indonesia. In the real system, there are three vendors, a distribution center, and a buyer. The initial data and the results are shown in Table 1 and Table 2, respectively as follows:

Table 1: The initial data of numerical example

Parameter	Value	Parameter	Value
Y_k	30	e	3
Q	70,000	f_j max	3
q_1	20,000	h	1,000
q_2	25,000	$x_i \cdot c_k$	8,000
q_3	25,000	d	100,000
l	1	C	70,000

Table 2: The shipment frequency of numerical example

Parameter	Vendor 1	Vendor 2	Vendor 3
q_i	20,000	25,000	25,000
x_i	8	10	10
$q_i(f_j \text{ max})$	24,000	30,000	30,000
f_1	20	25	25
f_2	10	12	12
f_3	6	8	8
q_{ijk}	8,000	10,000	10,000
y_k	8	10	10
$q_i - q_{ijk}$	12,000	15,000	15,000

Table 3: The results of numerical example

Vendor 1	q_{ijk}	y_k	Parameter	c_k	q_k
m_1	8,000	8	Q	70,000	
m_2	8,000	8	k_1	12,000	12,000
m_3	4,000	4	k_2	10,000	10,000
Vendor 2	q_{ijk}	y_k		10,000	10,000
m_1	10,000	10		10,000	10,000
m_2	10,000	10		10,000	10,000
m_3	5,000	5		10,000	10,000
Vendor 3	q_{ijk}	y_k	k_3	8,000	8,000
m_1	10,000	10		8,000	0
m_2	10,000	10		8,000	0
m_3	5,000	5		8,000	0

4. DISCUSSION

From Table 2, it can be known that the optimal number of shipments (or shipment frequency) is three times for each vendor since the number of vehicles used to transport the product to the distribution center is feasible (does not exceed the total number of available vehicles). Afterward, by using the two algorithms that have been developed in the previous section, we can obtain the optimal shipment quantity for each shipment point for vendor 1 are 8,000 liter by 8 units of vehicle, 8,000 liter by 8 units of vehicle, and 4,000 liter by 4 units of vehicle (see Table 3) and so on for vendor 2 and vendor 3.

Moreover, the optimal number of vehicles used to transport the product from the distribution center to the buyer is 7 units, i.e. 1 unit of vehicle with 12,000 liter capacity, 5 units of vehicle with 10,000 liter capacity, and 1 unit of vehicle with 8,000 liter capacity. Since the total number of available vehicles are enough, then the vehicle leasing cost is not considered in the calculation of the total transportation costs of the system. Transportation costs from the vendor to the distribution center and from the distribution center to the buyer are Rp7,000,000 and Rp3,500,000, respectively. Therefore, the minimum total transportation costs of the system is Rp10,500.000.

5. CONCLUSION

In this paper, we develop a multi-vendor-single-buyer transportation model with heterogeneous vehicles for perishable product. The aim of our model is to find the optimal shipment quantity, number of vehicles, and number of shipments from the vendor to the distribution center and from the distribution center to the buyer, respectively, that minimize the total transportation costs of the system, which is the combination of delivery cost, vehicle leasing cost, and deteriorating cost. In this research, we also develop two algorithms in order to obtain the optimal solution.

This model is only focusing on the transportation issue of the supply chain system under study. Therefore, for the future research, it will be good to also consider the inventory problem in our proposed model. Furthermore, this model can be improved by developing an algorithm that can simultaneously find the optimal solution.

REFERENCES

Bilgen, B. and Ozkarahan, I. (2004). Strategic, tactical, and operational production-distribution models: A review, *International Journal of Technology Management*, **28**, 151-171.

Ghiani, G., Laporte, G., and Musmanno, R. (2004) *Introduction to Logistics Systems Planning and Control*, John Wiley & Sons, Southern Gate, Chichester.

Goyal, S.K. and Giri, B.C. (2001) Recent trends in modeling of deteriorating inventory, *European Journal of Operational Research*, **134**, 1-16.

Mehrez, A., Hung, M.S., and Ahn, B.H. (1995) An industrial ocean-cargo shipping problem, *Decision Sciences*, **26**, 395-423.

Nahmias, S. (1982) Perishable inventory theory: A review, *Operations Research*, **30**, 680-708.

Sherali, H.D., Al-Yakoob, S.M., and Hassan, M.M. (1999) Fleet management models and algorithms for an oil tanker routing and scheduling problem, *IIE Transactions*, **31**, 395-406.

Shih, L.H. (1997) Planning of fuel coal imports using a mixed integer programming method, *International Journal of Production Economics*, **51**, 243-249.

Zanoni, S. and Zavanella, L. (2007) Single-vendor single-buyer with integrated transport-inventory system: Models and heuristics in the case of perishable goods, *Computers & Industrial Engineering*, **52**, 107-123.