A Mathematical Model for the Planning of Production, Inventory and Logistics with Direct Shipment and Milk Run

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Abstract

We analyze a supply chain consisting of a manufacturer owning multiple production lines and a warehouse, and multiple retailers buying from the manufacturer.The manufacturer can choose to send the product to the retailers directly from loading area or send the product to be stored at the warehouse. If the retailer order is filledby the warehouse inventory, the company can choose the logistics strategy. The company can send the product from the warehouse to a retailer using a direct shipment mode (a truck only visits the retailer) or using milk-run mode (a truck visits multiple retailers in a single trip). We develop a mixed integer programming model to find the optimal decisions in every period for the planning of production quantities at each production line, the quantities of inventories at the loading area, the warehouse and the retailers, and the transportation strategies to deliver the products to retailers. We extensively conduct numerical experiments and then analyze the results using the multiple regression analysis. We found that a decrease in average fixed truck cost and an increase in holding cost will result in an increase in quantity of product transported using milk-run approach. A decrease in average travel cost from loading area to retailer, an increase in average travel cost from warehouse or distribution center (DC) to retailer and a decrease in order quantity or sale volume will result in an increase in quantity of product transported using direct shipment approach from loading area. Lastly, an increase in average fixed cost of truck, an increase in average travel cost from loading area to retailer and a decrease in average travel cost from warehouse or distribution center (DC) to retailer will result in an increase in quantity of product transported direct shipment approach from distribution center.

1. INTRODUCTION

Supply chain management aims to efficiently and effectively control the flow of materials from suppliers via many intermediate stages of supply chain such as a manufacturer and a warehouse to retailers or end-customers. As the competition of business increases, not only the two companies compete but also the supply chains of the two companies compete. The coordination of companies in a supply chain such collaborative joint planning becomes common. The integration and collaboration in supply chain cannot be ignored because it affects operations of supply chain to fit with supply chain strategy (Graham, 2005). Logistic management, as a part of supply chain management, makes use of the flow of information, resource or knowledge to move product, part or raw material within supply chain to meet the requirements of customers or corporations. Logistics integration plays an importance role to seamlessly transfer products from producer to end customer (Caputo &Mininno, 1996). Moreover, the information or knowledge is the key to link various stages of supply chain management. The idea of knowledge supply network (KSN) being used in the supply chain management to effectively and efficiently integrate suppliers, manufacturers, warehouses, and stores because a firm has to get the data, information and knowledge in order to distribute at the right quantities to the right locations and at the right time (Mak and Ramaprasad, 2003).

The distribution of products from a manufacturer to retailers is complicated task. However, to minimize the operational cost, a supply chain must synchronize all the planning of production, inventory and distribution strategies at the same time. Many distribution strategies exist to help company reduce the cost. A manufacturer can opt to transport products from the production line to a retailer directly without keeping the products in the warehouse. This method is called a direct shipment which is a direct transport of finished product from a manufacturer to a retailer without stopping at any intermediate facility. It can help reduce the logistics cost, material handling cost and inventory holding cost at warehouse. On the other hand, the product can be sent to be stored in a warehouse and then transported to a retailer when needed. To transport the products from the warehouse to the retailer, the manufacturer can use the direct shipment which is the transport of a full-truck load of product to a retailer, or a milk run distribution which is the distribution of finished products from a manufacturer to multiple retailers using the same truck. The milk run distribution will allow retailers to order products in a smaller lot size, thereby lowering inventory holding cost without increasing the transportation cost. In addition, because the supply chain can keep the inventory at the retailers or in a warehouse, the supply chain manager can decide replenishment frequency of the product. The frequency of replenishment affects the transportation cost directly. A temporal aggregation is the aggregation of shipment over time to make a single larger shipment, as opposed to multiple shipments, and gain the economy of scale. The temporal aggregation will make unit transportation cost smaller at the expense of lower responsiveness or larger inventory holding cost. As many distribution strategies can be adopted, it is not clear when a supply chain manager should use to lower the total supply chain cost. Our research aims to provide managerial insight and guidelines for practitioners or business managers to follow without resorting to the optimization software at all time. By using one of strategies or the combination of strategies selectively, a supply chain structure is flexible and can quickly react to the changes in the supply chain. Also, when distribution planning is integrated with production planning, more total cost can be saved as the operations work seamlessly together.

To provide the guideline of distribution strategies integrated with production plan, we develop a mathematical model called Mixed Integer Linear Programming Model, solve the model using optimization software called IBM ILOG CPLEX, and analyze the numerical results using regression analysis to conclude the findings and provide the managerial insights as guidelines for supply chain managers.

A milk run distribution is commonly used to support Just-In-Time (JIT) production because it allows small shipment sizes. It can reduce cost of transportation and inventory. The manufacturer can use a truck to visit each supplier along the provided route to collect finished goods, or parts. After the truck has collected all of the parts, it will go back to the factory (Nemoto, Hayashi, & Hashimoto, 2010). The milk run method is suitable when the density of part suppliers is high. The milk run method helps lower transportation cost due to the shipment consolidation, higher truck-load utilization, and lower number of trucks (Sadjadi, Jafari&Amini, 2008).

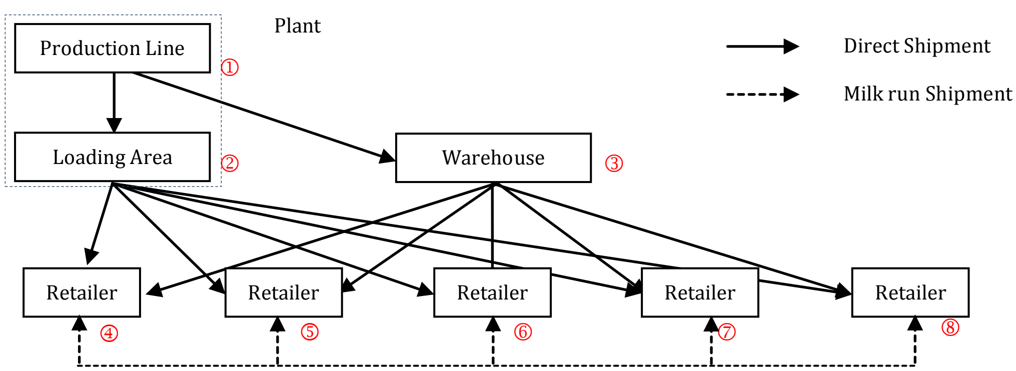
Another method of distribution is a direct shipment. The direct shipment uses a truck carrying shipment with nearly full capacity to deliver the products directly from supplier, or manufacturing location to a retail location (Puranik, 2010). This shipping does not pass the distribution center and the products do not be exchanged between vehicles. Typically, each product is made available at suppliers and delivered to retailer at constant production and consumption rates (Goldstein, 1997). Many industries such as high-tech, apparel, footwear as well as durables industries have adopted the direct shipment strategy. The main benefit of direct shipping method is the saving in transportation and storage costs. Also, it does not use a distribution center and, therefore, it does not waste time, money and distance (Bertazzi, 2008). With small truck size and fast transportation, the retailers can store fewer quantities of inventory. It provides efficiency as well as flexibility with no intermediate storage space, and the cost of insurance and maintenance (Cattani& Souza, 2002).

Our research is different from previous works in the literature. As many distribution strategies, i.e. direct shipment, milk run and temporal aggregation, can be mixed, the optimal strategies can be very flexible. Most researches will focus on one strategy. Also, by analyzing the complex numerical results using a regression analysis, we can provide guidelines for business managers without resorting to the optimization software. Most researches will focus on developing an efficient heuristic procedure. The remaining of paper is organized as follows. Section 2 discusses the key assumptions and the model proposed. Section 3 tests the model to provide the managerial insights from studying the optimal solutions using regression analysis. Section 5 concludes the research and provides directions for future research.

2. MODEL

In this research, we study a supply chain with a manufacturer and multiple retailers. The manufacturer produces multiple products by using multiple production lines. Then, the products are sent to a warehouse to be stored until needed. Alternatively, the products can be transported the retailers directly. The manufacturer incurs holding cost at the warehouse, the production changeover cost and all the transportation costs including the truck fixed cost and distance-dependent costs. A retailer faces deterministic demands for a finite number of periods. When a retailer needs replenishment, the order is placed to the manufacturer. The manufacturer satisfies the demand using the distribution strategies: direct shipment from a loading area to the retailer, direct shipment from the warehouse to the retailer, the milk run shipment from the warehouse to all retailers requesting for replenishment using one truck. The retailer incurs the holding cost at the retail store and fixed reorder cost. Figure 1 shows the possible routes of distribution strategies when the number of retailers is five as an example. The numbers in circle show the node number. For example, the retailer at node 4 is called Retailer 4. The manufacturer faces constraints from limited loading area space, the limited range of production quantity, limited total production time and limited truck capacity. The supply chain manager has to determine the optimal production planning, inventory replenishment planning, the optimal quantities of inventory kept at loading area, the warehouse and retail stores and the distribution strategies including the direct shipments from loading area or warehouse and the milk run shipment and truck routings.

Figure1: Flow of products at from production line to each retailer



Based the problem description above, we formulate the problem as a Mixed Integer Linear Programming Model for solving the problem with the objective to minimize the total cost function. The total cost consists of fixed reorder cost in period t, fixed cost of truck, inventory holding cost, production changeover cost, transportation cost from the warehouse to each retailer, transportation cost from the loading area to each retailer, transportation cost from the production lines to the warehouse. The summary of variables and parameters is shown in Table 1.

According to the problem that we have, we formulate the problem as a Mixed Integer Linear Programming for solving the problem with the objective to minimize the total cost function. The total cost that we want to minimize consists of fixed reorder cost in period *t*, fixed cost of each sized truck, inventory holding cost, setup cost, transportation cost travelling from warehouse to each retailer, transportation cost travelling from loading area to each retailer, transportation cost travelling from production line to warehouse. We also have the constraints that state the limitation in each equation. Table 1, 2, and 3 provides the descriptions of indexes, parameters and decision variables used in the mathematical model.

Table 1: The indexes used in mathematical model

Indexes	
i	Product index and $i \in Set\ I = \{1,..., I\}$
j	Product index and $i \in SetI = \{1,...,I\}$
t	Production line index and $j \in Set\ J = \{1,...,J\}$
n	Period index and $t \in Set\ T = \{1,...,T\}$
v	Node index and $n \in Set\ N = \{1,...,N\}$
o	Truck index and $v \in Set\ V = \{1,...,V\}$
d	Original node index and $o \in Set\ R = \{1,...,R\}$
r	Destination node index and $d \in SetR = \{1,...,R\}$
i	Retailer index and $r \in Set\ R = \{1,...,R\}$

Table 2: The parameters used in mathematical model

Parameters	
Rc_r	Fixed reorder cost of retailer *r* in period *t*
FC_v	Fixed cost of truck *v*
$h_{n,i}$	Inventory holding cost of product *i* per pallet per period at node *n*
$Sc_{i,j}$	Setup cost incurred from changeover from product *i* to *j*
$l_{o,d}$	Cost from node *o* to node *d*
$S_{r,i,t}$	Sale volume for product *i* at retailer *r* in period *t*
M	Maximum number of space that provided for loading area
M	Big number
P	Maximum production capacity for all production lines
$\underline{P}$	Minimum production capacity for all production lines
$\mathrm{Pr}_{i,j}$	Production rate of product *i* at production line *j*
$Ct_{i,j}$	Changeover time of product *i* at production line *j*
H	Number of available production time (hours) per period per one production line
$TruckCapacity_v$	The capacity of truck *v*
$TruckCapacity_D$	The capacity of a direct shipment truck
$PalletSize$	The space of a pallet

Table 3: The decision variables used in mathematical model

Decision Variables	
$Inv_{n,i,t}$	Inventory of product *i* at node *n* at the beginning of period *t*
$Sh_{i,o,d,t}$	Quantity of product *i* being shipped from *o* to *d* in period *t*

$L_{j,t,i}$	Quantity of product *i* produced by production line *j* and sent to loading area in period *t*
$A_{i,r,v,t}$	Quantity of product *i* shipped to retailer *r*
$P_{j,t,i}$	Production quantity of product *i* from production line *j* in period *t*
$ND_{r,t}$	Number of direct shipment trucks going to retailer *r* using in period *t* (Assume to be only medium size truck)
$Or_{r,t}$	1 if product is ordered by retailer *r* via loading area in period *t*, 0 otherwise
$Tr_{v,t}$	1 if truck *v* is used in period *t*, 0 otherwise
$x_{v,r,t}$	1 if truck *v* is visited retailer *r* in period *t*, 0 otherwise
$x_{v,o,d,t}$	1 if truck *v* travels from node *o* to node *d* in period *t*, 0 otherwise
$Tr_{r,v,t}$	1 if truck *v* is used or visited any nodes in period *t*, 0 otherwise
$f_{j,t,i}$	1 if product *i* is produced from production line *j* in period *t*, 0 otherwise
$u_{n,v,t}$	Arbitrary real numbers representing the sequence the nodes are being visited by truck *v* in period *t*. It is used to prevent subtours in the solutions using Miller-Tucker-Zimlin method.

MATHEMATICAL MODEL

The mixed Integer Linear Programming Model is developed to minimize the total cost function subject the constraints from production, inventory and logistics requirements. The short explanation of each equation is provided below the model.

$$Minimize\ Total\ Cost\ Function =$$

$$\sum_{t=1}^{T}\sum_{r\in N_r} Rc_r \times Or_{r,t} + \sum_{t=1}^{T}\sum_{v} FC_v \times Tr_{v,t} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{n=2}^{N} h_{n,i} \times Inv_{n,i,t}$$
$$+\sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{i=1}^{I}\left(f_{j,i,t}\right)\times Sc_{i,j} + \sum_{t=1}^{T}\sum_{d\in SetR+\{3\}}\sum_{o\in SetR+\{3\}}\sum_{v=1}^{V} x_{v,o,d,t}\times l_{o,d}$$
$$+\sum_{t=1}^{T}\sum_{r\in N_r} ND_{r,t}\left(l_{2,r}+FC_{direct}\right)+\sum_{t=1}^{T}\sum_{i=1}^{I} Sh_{i,1,3,t}\times l_{1,3} \qquad (1)$$

$$Subject\ To:$$

$$Inv_{2,i,t} = Inv_{2,i,t-1} + \sum_{j=1}^{J} L_{j,t,i} - \sum_{d\in N_r} Sh_{i,2,d,t}\ for\ all\ i \in\ Set\ i\ and\ t \in\ Set\ t \qquad (2)$$

$$Inv_{r,i,t} = Inv_{r,i,t-1} + Sh_{i,2,r,t} + \sum_{v=1}^{V} A_{i,r,v,t} - S_{r,i,t}\ for\ all\ i \in\ Set\ i,\ t\in\ Set\ t,\ and\ r \in\ Set\ r \qquad (3)$$

$$Inv_{3,i,t} = Inv_{3,i,t-1} + Sh_{i,1,3,t} - \sum_{v=1}^{V}\sum_{r\in N_r} A_{i,r,v,t}\ for\ all\ i \in\ Set\ i\ and\ t \in\ Set\ t \qquad (4)$$

$$Inv_{n,i,0} = 0\ for\ all\ i \in\ Set\ i \qquad (5)$$

$$L_{j,t,i} \le P_{j,t,i}\ for\ all\ i \in\ Set\ i,\ j \in\ Set\ j,\ and\ t \in\ Set\ t \qquad (6)$$

$$Sh_{i,1,3,t} = \sum_{j=1}^{J}\left(P_{j,t,i} - L_{j,t,i}\right)\ for\ all\ i \in\ Set\ i,\ and\ t \in\ Set\ t \qquad (7)$$

$$\sum_{i=1}^{I} Inv_{2,i,t} \times PalletSize \le \overline{M}\ for\ all\ t \in\ Set\ t \qquad (8)$$

$$P_{j,t,i} \le f_{j,t,i} \times \overline{P}\ for\ all\ i \in Set\ i,\ j\ \ Set\ j,\ and\ t \in\ Set\ t \qquad (9)$$

$$P_{j,t,i} \ge f_{j,t,i} \times \underline{P}\ for\ all\ i \in\ Set\ i,\ j \in\ Set\ j,\ and\ t \in\ Set\ t \qquad (10)$$

$$\sum_{i=1}^{I}\left(\frac{P_{j,t,i}}{\Pr_{i,j}}\right) + \sum_{i=1}^{I}\left(f_{j,t,i} \times Ct_{i,j}\right) \le \overline{H}\ for\ all\ i \in\ Set\ i,\ and\ j \in\ Set\ j \qquad (11)$$

$$\sum_{o=2}^{3}\sum_{i=1}^{I} Sh_{i,o,r,t} \le Or_{r,t} \times M \text{ for all } t \in \text{ Set } t \tag{12}$$

$$\sum_{r\in N_r}\sum_{i=1}^{I} A_{i,r,v,t} \le TruckCapacity_v \times Tr_{v,t} \text{ for all } t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{13}$$

$$\sum_{i=1}^{I} A_{i,r,v,t} \le TruckCapacity_v \times Tr_{r,v,t} \text{ for all } r \in \text{Set } N_r, t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{14}$$

$$\sum_{r\in N_r} Tr_{r,v,t} \le R \times Tr_{v,t} \text{ for all } t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{15}$$

$$\sum_{r\in N_r+\{3\}} x_{v,r,d,t} = Tr_{d,v,t} \text{ for all } d \in \text{ Set } N, t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{16}$$

$$\sum_{r= N_r+\{3\}} x_{v,d,r,t} = Tr_{d,v,t} \text{ for all } d \in \text{Set } N, t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{17}$$

$$\sum_{r= N_r+\{3\}} x_{v,r,3,t} = Tr_{v,t} \text{ for all } t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{18}$$

$$\sum_{r= N_r+\{3\}} x_{v,3,r,t} = Tr_{v,t} \text{ for all } t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{19}$$

$$\sum_{i=1}^{I} \frac{Sh_{i,2,r,t}}{TruckCapacity_D} \le ND_{r,t} \text{ for all } r \in N_r \text{ and } t \in \text{ Set } t \tag{20}$$

$$u_{3,v,t} = 1 \text{ for all } t \in \text{ Set } t, \text{ and } v \in \text{ Set } v \tag{21}$$

$$2 \le u_{o,v,t} \le n \text{ where } n = \left|N_r \cup \{3\}\right| \text{ for all } o \in \text{ Set } N_r, v \in \text{ Set } v, \text{ and } t \in \text{ Set } t \tag{22}$$

$$u_{o,v,t} - u_{d,v,t} + 1 \le n \times \left(1 - x_{v,o,d,t}\right) \text{ for all } o \in \text{ Set } N_r, \text{ all } d \in \text{Set } N_r, v \in \text{ Set } v, \text{ and } t \in \text{ Set } t \text{ where } n = \left|N_r \cup \{3\}\right| \tag{23}$$

The meaning of each equation can be summarized as follows. Equation (1) specifies the total costs. Equations (2)-(4) establish the relationship between the inventory in period t and t+1, the quantities of inbound shipments, and the quantities of outbound shipments (or sales quantities) at loading area, warehouse and retail stores, respectively. Equation (5) sets up initial inventory at all locations to be zero. Equation (6) limits the quantities sent to loading area to be fewer than the production quantities. Equation (7) calculates the quantities to be stored at the warehouse. Equation (8) limits the number of products to be kept at loading area. Equations (9) and (10) set up the lower bound and the upper bound for production quantities. Equation (11) limits the total production time and changeover times for each production line to be less than the total production time available in a period. Equation (12) links the shipment quantities to reorder decision. Equations (13) and (14) set up the relationship between the milk run shipments with truck usage variables and also set up the capacity of milk run shipment. Equations (16)-(19) conserve the truck inflow decision and truck outflow decision and also link them with the truck usage variables. Equation (20) calculates the number of trucks used for direct shipment from loading area. Equations (21)-(23) are the standard Miller-Tucker-Zemlinsubtour-elimination constraints.

3. NUMERICAL EXPERIMENT AND RESULTS

We have conducted the numerical experiments by using an example with 1 production line, 1 product, 5 retailers and 4 periods. The problem is solved to optimality using IBM ILOG CPLEX version 12. We assume there are three truck sizes: small, medium and large. The numbers of small, medium and large trucks available at the warehouse are 4, 3, and 3 trucks, respectively. The number of trucks at the plant is unlimited. The travel cost from the production line to the warehouse is 5 per pallet. The number of retailers of five allows us to examine in details the optimal distribution strategies adopted in each period and also allow some flexibility to use the mixed distribution strategies at the same time. Table 4 shows the values of parameters in the base case.

Table 4: The Parameters of Base Case Used In The Experiments

Travel cost between														
Node 2 and node 4	Node 2 and node 5	Node 2 and node 6	Node 2 and node 7	Node 2 and node 8	Node 3 and node 4	Node 3 and node 5	Node 3 and node 6	Node 3 and node 7	Node 3 and node 8	Node 4 and node 5	Node 4 and node 6	Node 4 and node 7	Node 4 and node 8	Node 5 and node 6
40	80	120	160	200	20	40	60	80	100	10	20	30	40	10

Travel cost between					Truck Capacity			Fixed Cost			Unit Holding cost	Production Changeover		Retailer Demand
Node 5 and node 7	Node 5 and node 8	Node 6 and node 7	Node 6 and node 8	Node 7 and node 8	Small Truck	Medium Truck	Large Truck	Small Truck	Medium Truck	Large Truck		Cost	Time	
20	30	10	20	10	40	70	100	1500	2000	4000	20	500	5	90

Based on the parameters of the base case in Table 4, a parameter is varied to different levels one parameter at a time to generate thedata set of 90 incidents. The data set and the results are omitted in this paper due to their large size. Based on the data set and results obtained, we develop multiple regression models to test the effect of parameters to the distribution strategy. The multiple regression model iscomputed using MS-Excel's Data Analysis. Table 6 shows the independent variables and dependent variables.

Table 5: The Independent Variables and Dependent Variables

Independent Variables	
x_1	Average fixed cost of truck
x_2	Holding cost
x_3	Average travel cost from loading area to retailer (i.e. fuel cost)
x_4	Average travel cost from warehouse or distribution center (DC) to retailer (i.e. fuel cost)
x_5	Average travel cost between retailers (i.e. fuel cost)
x_6	Order quantity or sale volume
x_7	Average truck capacity
Dependent Variables	
Y_1	Quantity of product transported using milk-run approach (all nodes)
Y_2	Quantity of product transported using direct shipment approach from loading area
Y_3	Quantity of product transported using direct shipment approach from distribution center

3.1 Quantity of Product Transported Using Milk-Run Approach

We use the seven independent variables to explain the variation of quantity of product transported using milk-run approach. Table 6 shows the result of multiple regression analysis. The multiple regression model is:

$$\hat{Y}_1 = -0.052x_1 + 2.04x_2 - 0.006x_4 + 0.034x_5 - 0.006x_6 - 0.026x_7 - 0.065x_8 + 107.4702.$$

From F-test, the model can significantly explain the variation in quantity of product transported using milk-run approach (p-value =8.67E-20) with adjusted R^2 of 68.9%. From the 95% confident interval (and the conclusion of one-sided hypothesis testing of coefficients), the coefficients of average fixed costof truck (x_1) and holding cost (x_2) can be concluded to be significantly less than zero and greater than zero respectively (at 0.05 significant level). That is, a decrease in average fixed truck cost and an increase in holding cost will result in an increase in quantity of product transported using milk-run approach.This means when the fixed truck cost (e.g. rent, lease, depreciation) is low or medium and the holding cost is high (due to for example the value of products, the cost of capital) it is appropriate for supply chain managers to adopt the milk-run strategy from warehouse. When the truck fixed cost is expensive, it is cheaper to send large quantity and milk-run strategy is not suitable. Also, when the holding cost is high, the milk-run strategy can avoid keeping the inventory at retailers by sending in small quantity to match any demand despite of its small size.

Table 6: MultipleRegression Analysis of Quantity of Product Transported Using Milk-Run

Regression Statistics						
R Square	0.713561	Standard Error	44.21373			
Adjusted R Square	0.689109	Observations	90			
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	7	399325.3	57046.47	29.18196	**8.67E-20***	
Residual	82	160298	1954.854			
Total	89	559623.3				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	107.4702	38.99	2.756354	**0.007201***	29.90671	185.0338
x_1	-0.05156	0.014325	-3.5996	**0.000544***	-0.08006	-0.02307
x_2	2.03956	0.148842	13.70282	**6.55E-23***	1.743465	2.335655
x_3	-0.00586	0.02675	-0.21914	0.827089	-0.05908	0.047352
x_4	0.034305	0.027299	1.256634	0.212454	-0.02	0.088613
x_5	-0.00565	0.019229	-0.29399	0.769509	-0.0439	0.032599
x_6	-0.02563	0.083874	-0.30563	0.760658	-0.19249	0.141218
x_7	-0.06529	0.116337	-0.56123	0.576171	-0.29672	0.166139

* *Significant at* 0.001 *level*

3.2 Quantity of Product Transported Using Direct Shipment Approach from Loading Area

Similarly, we use the seven independent variables to explain the variation of quantity of product transported using direct shipment approach from loading area. Table 7 shows the result of multiple regression analysis. The multiple regression model is:

$$\hat{Y}_2 = -0.141x_1 - 0.394x_2 - 0.900x_4 + 0.767x_5 - 0.091x_6 + 20.46x_7 + 0.922x_8 - 19.64448$$

From F-test, the model can significantly explain the variation in quantity of product transported using direct shipment approach from loading area (p-value =2.48E-48) with adjusted R^2 of 93.84%. From the 95% confident interval (and the conclusion of one-sided hypothesis testing of coefficients), the coefficients of average travel cost from loading area to retailer (x_3), average travel cost from warehouse or distribution center (DC) to retailer(x_4), and order quantity or sale volume (x_6)can be concluded to be significantly less than zero, greater than zero and greater than zero respectively (at 0.05 significant level). That is, a decrease in average travel cost from loading area to retailer,an increase in average travel cost from warehouse or distribution center (DC) to retailer and a decrease in order quantity or sale volumewill result in an increase in quantity of product transported using direct shipment approach from loading area.This means when thetravel cost from loading area to retailer is low and the travel cost from warehouse to retailer is high, it is better transport product using direct shipment from loading area because of its lower transportation cost. Also when the order quantity or sale volume is large, the quantity is already closer to full-truck load and therefore it is appropriate to send direct from the loading and achieve high utilization of truck capacity without sharing truck.

Table 7: MultipleRegression Analysis ofQuantity of Product Transported Using Direct Shipment Approach from Loading Area

* *Significant at* 0.001 *level*

Regression Statistics						
R Square	0.943287852	Standard Error	297.4955479			
Adjusted R Square	0.938446572	Observations	90			
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	7	1.21E+08	17244274	194.8426	**2.48E-48***	
Residual	82	7257295	88503.6			
Total	89	1.28E+08				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-19.6445	262.3473	-0.07488	0.940493	-541.537	502.2478
x_1	-0.14071	0.096384	-1.45991	0.148136	-0.33245	0.051026
x_2	-0.39363	1.001498	-0.39305	0.695306	-2.38593	1.598664
x_3	-0.90017	0.179988	-5.00128	**3.19E-06***	-1.25822	-0.54212
x_4	0.767223	0.183686	4.17681	**7.33E-05***	0.401812	1.132633
x_5	-0.09126	0.129381	-0.70536	0.482585	-0.34864	0.16612
x_6	20.45908	0.564356	36.25209	**3.02E-52***	19.3364	21.58176
x_7	0.921768	0.782782	1.177554	0.242381	-0.63543	2.47897

3.3 Quantity of Product Transported Using Direct Shipment Approach from Distribution Center

Similar to the previous cases, we use the seven independent variables to explain the variation of quantity of product transported using direct shipment approach from distribution center. Table 8 shows the result of multiple regression analysis. The multiple regression model is:

$$\hat{Y}_3 = 0.192x_1 - 1.646x_2 + 0.906x_4 - 0.802x_5 + 0.097x_6 - 0.433x_7 - 0.856x_8 - 87.8258$$

From F-test, despite the low adjusted R^2 of 27.55%, the model can significantly explain the variation in quantity of product transported using direct shipment approach from distribution center (p-value =1.64105E-05). From the 95% confident interval (and the conclusion of one-sided hypothesis testing of coefficients), the coefficients of average fixed cost of truck (x_1), average travel cost from loading area to retailer (i.e. fuel cost)(x_3), and average travel cost from warehouse or distribution center (DC) to retailer (x_4)can be concluded to be significantly greater than zero, greater than zero and less than zero respectively (at 0.05 significant level). That is, anincrease in average fixed cost of truck,an increase in average travel cost from loading area to retailer and a decrease in average travel cost from warehouse or distribution center (DC) to retailer will result in an increase in quantity of product transported direct shipment approach from distribution center.When the fixed cost of truck is expensive, the larger quantity should be sent using direct shipment to reduce the frequency of replenishment. The fixed truck cost significantly affects both milk-run (in Section 3.1) and direct shipment from distribution center. As the fixed truck cost is more expensive, the supply chain manager should divert the quantity sent using milk-run strategy to the direct shipment from warehouse. Also, when the travel cost from loading area to retailer is high and the travel cost from warehouse to retailer is low, it is better transport product using direct shipment from a warehouse because of its lower transportation cost. This is opposite to strategy observed from Section 3.2.

Table8: Multiple Regression Analysis of Quantity of Product Transported Using Direct Shipment Approach from Distribution Center

Regression Statistics						
R Square	0.33249248	Standard Error	294.3730815			
Adjusted R Square	0.275510131	Observations	90			
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	7	3539449.377	505635.6253	5.835008285	**1.64105E-05****	
Residual	82	7105751.912	86655.51112			
Total	89	10645201.29				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-87.82575409	259.5937115	-0.338320037	0.735986733	-604.2403416	428.5888334
x_1	0.192274137	0.095372133	2.016041066	**0.047069974***	0.002548583	0.381999691
x_2	-1.645925347	0.990986111	-1.660896485	0.100553421	-3.617312407	0.325461712
x_3	0.906031959	0.178098841	5.087242313	**2.26145E-06****	0.55173663	1.260327289
x_4	-0.801527884	0.18175828	-4.409856238	**3.11441E-05****	-1.163103003	-0.439952765
x_5	0.09691327	0.128023189	0.756997782	0.451220862	-0.157765636	0.351592177
x_6	-0.433445568	0.558432482	-0.776182586	0.439874247	-1.544345667	0.677454532
x_7	-0.856476211	0.774565739	-1.105750187	0.272068326	-2.397334208	0.684381787

**Significant at* 0.05 *level* , ***Significant at* 0.001 *level*

4. CONCLUSIONS

We study a supply chain system consisting of a manufacturer owning multiple production lines and a warehouse, and multiple retailers buying from the manufacturer. The manufacturer can choose whether to send the product to the retailers directly from loading area using direct shipment or send the product to be stored at the warehouse. If the demand is satisfied from the warehouse, the company can choose the logistics strategy. The company can send the product from the warehouse to a retailer using a direct shipment mode or using milk run mode. A mixed integer programming model is constructed to help analyze the optimal distribution strategies. We conduct numerical experiments and then analyze the results using multiple regression analysis. We found that a decrease in average fixed truck cost and an increase in holding cost will result in an increase in quantity of product transported using milk-run approach. A decrease in average travel cost from loading area to retailer,an increase in average travel cost from warehouse or distribution center (DC) to retailer and a decrease in order quantity or sale volumewill result in an increase in quantity of product transported using direct shipment approach from loading area. Lastly, an increase in average fixed cost of truck,an increase in average travel cost from loading area to retailer and a decrease in average travel cost from warehouse or distribution center (DC) to retailer will result in an increase in quantity of product transported direct shipment approach from distribution center.

REFERENCES

Bertazzi, L. (2008). Analysis of Direct Shipping Policies in an Inventory-Routing Problem with Discrete Shipping Times. Management Science, 54(4), 748-762.

Caputo, J., &Mininno, M. (1996).Internal, vertical and horizontal logistics integration. International Journal of Physical Distribution & Logistics Management, 26, 64-90.

Cattani, K., & Souza, G. C. (2002).Inventory rationing and shipment flexibility alternatives for direct market firms. Production and Operations Management, 11, 441-457.

Goldstein, S. (1997). M.S. Distributing trying direct-shipment approach. Billboard, 109(41), 12-100.

Graham, C. S. (2005). Integrating the Supply Chain. International Journal of Physical Distribution & Logistics Management, 19, 3-8.

Lai, C. L., & Lee, W. B., &Ip, W. H. (2003).A study of system dynamics in just-in-time logistics.Journal of materials Processing Technology, 138, 265-269.

Mak, K-T., &Ramaprasad, A. (2003).Knowledge Supply Network. The Journal of the Operational Research Society, 54(2), 175-183.

Nemoto, T., Hayashi, K., Hashimoto, M. (2010).Milk-Run logistics by Japanese automobile manufacturers in Thailand.Procedia Social and Behavioral Sciences, 2 , 5980-5989.

Puranik, A. S. (2010). Direct/Indirect Delivery Decisions in a Collaborative Supply Distribution Network. West Lafayette, Indiana: UMI Dissertation Publishing.

Sadjadi, S. J., &Jafari, M., &Amini, T. (2008). A new mathematical modeling and a genetic algorithm search for milk run problem (an *auto industry supply chain case study). Int J AdvManufTechnol, 44, 194-200.*