MATHEMAICAL MODEL FOR COMBINED OUTBOUND AND INBOUNDED LOGISTICS USING MILKRUN DELIVERIES

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Abstract

We study a firm managing the inbound and outbound logistics using milk-run deliveries. We develop a mixed integer linear programming model to plan the routing of multiple trucks to pick up shipments from suppliers and deliver shipment to customers. Unlike other researches, our model allows planning combined inbound and outbound milk-run deliveries. The routing allows the trucks to visit suppliers and customers without any restrictions on the sequence. As the number of locations to visit is larger because of the combined location, the trucks can shorten their routes without coming back to the distribution center. We conduct a numerical experiment. The combined outbound and inbound milk-run delivery can generate total cost saving of 38.6% and 87.1% for high demand and low demand case respectively. The total distance and average travel time are also improved at the minimum of 42.5% and 26.4% respectively. Lastly, the truck capacity utilization is improved 79.9% and 107.1% for high demand and low demand cases respectively. The observed saving and improvement is significant showing it as viable logistic cost reduction method. The saving and improvement tend to be higher for the case with low demand.

1. INTRODUCTION

Many firms are forced to perform the transportation analysis to find and implement the best optimum solution of minimizing the cost of transportation and time. A reduction of transportation cost and time results in an increase of the whole organization profitability. Logistics plays a vital role in economic systems. The cost of logistics operations accounts a large proportion of the value of general commodities in complex supply chains and globalization. However, innovation and technological development allows new cost cutting opportunities. (Dianwei, 2006).

Many researchers and institutions have been focused and analyzed the statistics of international logistics cost. The Council of Supply Chain Management Professionals (CSCMP) presented that there was an increased in USA logistics costs from 7.8% of GDP (USD 1,100 billion) in 2009 to 8.3% of GDP (USD 1,211 billion) in 2010. The Office of the National Economic and Social development Board (NESDB) reported that logistics cost of Thailand in 2008 was equivalent to 18.6% of GDP (1.7 trillion baht).

The milk-run logistics method can offer viable solution to the problem. Milk run delivery allows a truck to deliver products from a single originating location to multiple receiving locations or pick up products from multiple originating locations to a single receiving location. Scheduling milk run deliveries is a much more complex task than scheduling direct deliveries. Decisions must be made about deliveries quantities of different products, about the frequency of deliveries, and most importantly about the routing and sequencing of pickups and deliveries (Hugos, 2006). Due to consolidation of small shipments, milk-run system results in reduction in cost of transportation, travelling path and fuel consumption. In addition, milk run method is used to improve loading rates at possible levels and reduce the number of trucks and travel distances. As a result, it is an effective cost reduction technique.

Empty backhaul is one of the major factors that raise the logistics cost in most companies. According to a study of Council of Engineers in year 2006, Thailand freight movement had 690,000 trucks with more than 71.74 million trips and total distance for truck run was around 12,415 million kilometers per year. 46% of the figure was empty truck runs, or 33 million trips that included 5,586 million kilometers per year (Peetijade and Bangviwat, 2012). This problem can also be reduced by combined inbound and outbound milk run logistics, resulting in lower vacant space in the return trip. In order to eliminate empty backhaul, we develop a mathematical model to provide the optimal routes of delivery and pickup route for multiple trucks. The route consists of both delivery and pickup sequences combined in one truck. Different from other researches, our model allows the mixture of pickup and delivery sequences to lower the transportation cost.

Many researchers study cost-reductions using milk-run logistics. Raju, Ajitkumar, and Dhake (2007) stated that implementation of the milk run system had substantially reduced excess inventories in the stores, transportation cost and inventory carrying cost. Also, turning attention to inbound logistics will not only reduce costs, but also generate more collaborative relationship with internal organizations, suppliers and logistic providers, which will ultimately result in a more effective business process from which all parties will benefit. Yildiz et al. (2010) developed a network flow model combined with vehicle routing from the cross dock and the plant to minimize the system-wise logistics costs. They identified the opportunity for significant cost savings by using a mixed-integer programming model that matches opposite flows from and to the customers and suppliers. Sadjadi et al. (2008) suggested the advantage of running milk run logistics system that the performance of the supply chain and the logistic is improved due to effectively using of the transporting vehicles' spaces, controlling the transport charges, as well as reducing the level of parts inventory and their maintenance costs.

In this paper, we develop a mathematical model allowing a firm to plan routes of multiple trucks picking up and delivering the suppliers and customers at the same time. Due to complexity of keeping records of inventory on the truck during the delivery and pickup, most researchers limit the delivery to be completed first before pickup can start. Unlike other researches, our model allows a truck to deliver a shipment at a customer, pick up a shipment from suppliers and then deliver a shipment at another customer, without the restriction on sequences, to lower logistics cost. As a number of locations to visit larger due to combined pickup and delivery locations, the company can plan the routes more effectively to lower transportation cost and reduce empty backhaul. The model is tested in numerical experiments to show the benefits and cost-saving from using the method. The heuristics algorithm will be developed in the future research.

2. MODEL

In our model, a firm manages the inbound and outbound logistics. The firm owns multiple trucks and needs to pick up shipments from multiple suppliers and deliver shipments to multiple customers. Each truck could have different capacity to carry load. Each truck starts its route at a distribution center and end at the distribution center. A set of retailers and a set of suppliers request deliveries and pick-up, respectively. A truck can visit customers and suppliers to deliver shipments or pick up shipments. There is no restriction on sequence of a truck routing pattern. A truck has limited capacity which could be different for each truck. The amount of load on truck must not exceed the capacity. Multiple trucks can help deliver or pick up shipments at a node to fully satisfy the delivery or pick-up demands at the node. A truck has time limit to return to the distribution center. The shipments to be delivered to customers are loaded onto a truck when it leaves the distribution center. The company incurs the fixed cost of using each truck and variable costs to travel between any two nodes. The objective of the firm is to minimize the total cost consisting on the fixed cost and variable costs. We formulate a mixed integer linear programming model to solve the problems. The following are the details of the model.

Parameters

$Let\ node\ 1\ is\ a\ distribution\ center\ where\ all\ the\ trucks\ are\ located\ initially.$

$c_{kij} = Cost\ to\ transport\ one\ unit\ of\ shipment\ from\ i\ to\ j\ using\ truck\ k$

$T_{kij} = Travel\ time\ from\ i\ to\ j\ using\ truck\ k$

$D_j = Delivery\ required\ at\ Node\ j$

$P_j = Pick-up\ required\ at\ Node\ j$

$N = Maximum\ number\ of\ nodes$

$M = Total\ number\ of\ trucks$

$C_k = Capacity\ of\ truck\ k$

$ct_k = Fixed\ cost\ of\ using\ truck\ k$

$PT = Maximum\ transportation\ time\ allowed$

$\overline{L} = Maximum\ number\ of\ loops\ a\ truck\ is\ allowed$

Sets

$DN = Set\ of\ demand\ nodes = \{2, ..., N\}$

$T = \{0, 1, 2, ..., N\}$

$T_1 = \{0, 1, 2, ..., N-1\}$

$T_2 = \{1, 2, ..., N\}$

$K = \{1, 2, ..., M\}$

$I \in \{1, 2, ..., N\}$

Decision variables

$x_{kijt} = 1\ if\ truck\ k\ travels\ from\ node\ i\ to\ j\ and\ arrive\ node\ j\ in\ period\ t; otherwise\ 0$

$y_k = 1\ if\ truck\ k\ is\ used; otherwise\ 0$

$d_{kjt} = delivered\ quantity\ in\ period\ t\ at\ node\ j\ by\ truck\ k$

$p_{kjt} = pick-up\ quantity\ in\ period\ t\ at\ node\ j\ by\ truck\ k$

$l_{k,t} = Inventory\ level\ of\ load\ on\ truck\ k\ at\ the\ end\ of\ period\ t$

$$Minimize\ Total\ Cost = \sum_{k\in K}\sum_{t\in T}\sum_{i\in I}\sum_{j\in I} c_{kij}x_{kijt} + \sum_{k\in K} y_k \times ct_k \tag{1}$$

Subject to

$$\sum_{i\in I}\sum_{j\in I} x_{kijt} \le 1, \forall\ k \in K, t \in T \tag{2}$$

$$\sum_{i\in I} x_{kilt} = \sum_{j\in I} x_{klj(t+1)}, \forall\ k \in K, t \in T_1,\ l \in I \tag{3}$$

$$\sum_{t\in T_2}\sum_{j\in I} x_{k1jt} \le y_k \times \overline{L}, \forall\ k \in K \tag{4}$$

$$\sum_{t\in T}\sum_{j\in DN} x_{k1jt} = \sum_{t\in T}\sum_{i\in DN} x_{ki1t}, \forall\ k \in K \tag{5}$$

$$\sum_{t\in T_2}\sum_{k\in K} d_{kjt} = D_j, \forall j \in I \tag{6}$$

$$\sum_{t\in T_2}\sum_{k\in K} p_{kjt} = P_j, \forall j \in I \tag{7}$$

$$l_{k,t} = l_{k,t-1} + \sum_{j\in I}\left(p_{kjt} - d_{kjt}\right), \forall k \in K, t \in T_1 \tag{8}$$

$$l_{k,0} = \sum_{t\in T_2}\sum_{j\in I} d_{kjt}, \forall k \in K \tag{9}$$

$$l_{k,t} \le C_k\ , \forall k \in K, t \in T_2 \tag{10}$$

$$d_{kjt} \le \sum_{i\in I} x_{kijt} \times C_k, \forall k \in K, j \in I, t \in T_2 \tag{11}$$

$$p_{kjt} \le \sum_{i} x_{kijt} \times C_k, \forall k \in K, j \in I, t \in T_2 \tag{12}$$

$$\sum_{t\in T}\sum_{i\in I}\sum_{j\in I} x_{kijt} \times T_{ijk} \le PT, \forall k \in K \tag{13}$$

$$x_{k110} = 1, \forall k \in K \tag{14}$$

Equation (1) represents the total cost which is the objective function of the model. The total cost comprises the total variable cost and total fixed truck cost. Equation (2) states that a truck can be used once at time t. Equation (3) equates the number of in-flow truck and out-flow truck at any node. Equation (4) sets the relationship between the truck usage variables and the truck routing variables. If a truck leaves a distribution center, the truck usage variable is set to 1. Equation (5) states that if truck k leaves the distribution center, it must return to the distribution center. Equation (6) sets the number of deliveries by any trucks at any time to be equal the required delivery at the node. Equation (7) sets the number of pick-up quantities by any trucks at any time to be equal the required pick-up quantity at the node. Equation (8) sets up the relationship of inventory of shipment on a truck at any time. Equation (9) determines the initial load on the truck when it leaves the distribution center. Equation (10) limits the inventory on the truck to be fewer than the truck capacity. Equations (11) and (12) state that if a truck deliver or pick up shipment at a node j and period t, it must visit the node j at period t. Equation (13) limits the travel time of a truck to be less than the maximum time allowed. Equation (14) starts all trucks at the distribution center at period 0 initially.

3. NUMERICAL EXPERIMENT

In this section, the model is tested using a numerical example to illustrate the benefit of using combined inbound and outbound milk-run deliveries. In this experiment, there are 3 trucks (small, medium and large sizes) to deliver to 4 retailers and pick up from 3 suppliers. The truck must return to a distribution center within 30 hours. The parameters of each truck are shown in Table 1. The cost of fuel is approximated at 30 baht per liter. Table 2 shows the distances between all 8 nodes. Table 3 shows the delivery and pick-up requirements for two scenarios. The first scenario is high demand for both delivery and pick-up and the second scenario is low demand for both.

Table 1: Information that use for implementation

Types of Truck	Small	Medium	Large
Truck Capacity	3.5 tons	6 tons	10 tons
Fuel Consumption	10 km. per liter	6 km. per liter	3.5 km. per liter
Truck Fixed Cost	1500 baht	2000 baht	2250 baht

Table 2: Distance matrix between nodes (kilometers)

Node	1	2	3	4	5	6	7	8
1	0	192	149	97	92	169	137	167
2	192	0	27	107	156	191	86	28
3	149	27	0	166	118	42	150	182
4	97	107	166	0	126	48	36	188
5	92	156	118	126	0	134	109	107
6	169	191	42	48	134	0	57	54
7	137	86	150	36	109	57	0	64
8	167	28	182	188	107	54	64	0

Table 3: Delivery and pick up quantities for two cases: High Demand and Low Demand

	High Demand		Low Demand	
Node	Delivery	Pickup	Delivery	Pickup
1	0	0	0	0
2	4	0	0.2	0
3	0	4	0	0.2
4	4	0	0.2	0
5	0	4	0	0.2
6	4	0	0.2	0
7	0	4	0	0.2
8	4	0	0.2	0

We solve the mathematical model using IBM ILOG CPLEX version 12.4 using the data in table 1-3. Figure 1 shows the routings of truck for low demand case when inbound and outbound milk-run deliveries are planned independently. Figure 2 shows the routings of truck for low demand case when combined inbound and outbound milk-run deliveries are planned.

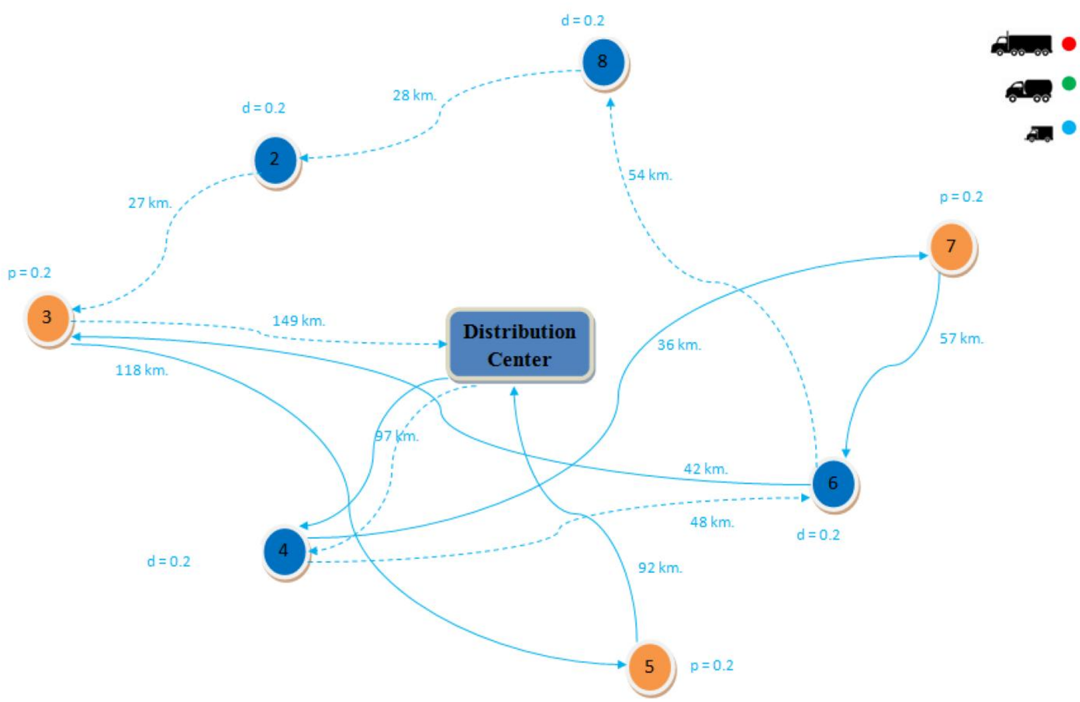

Figure 1: The routings of a truck for pick-up and delivery milk-run deliveries when planned independently for the low demand case

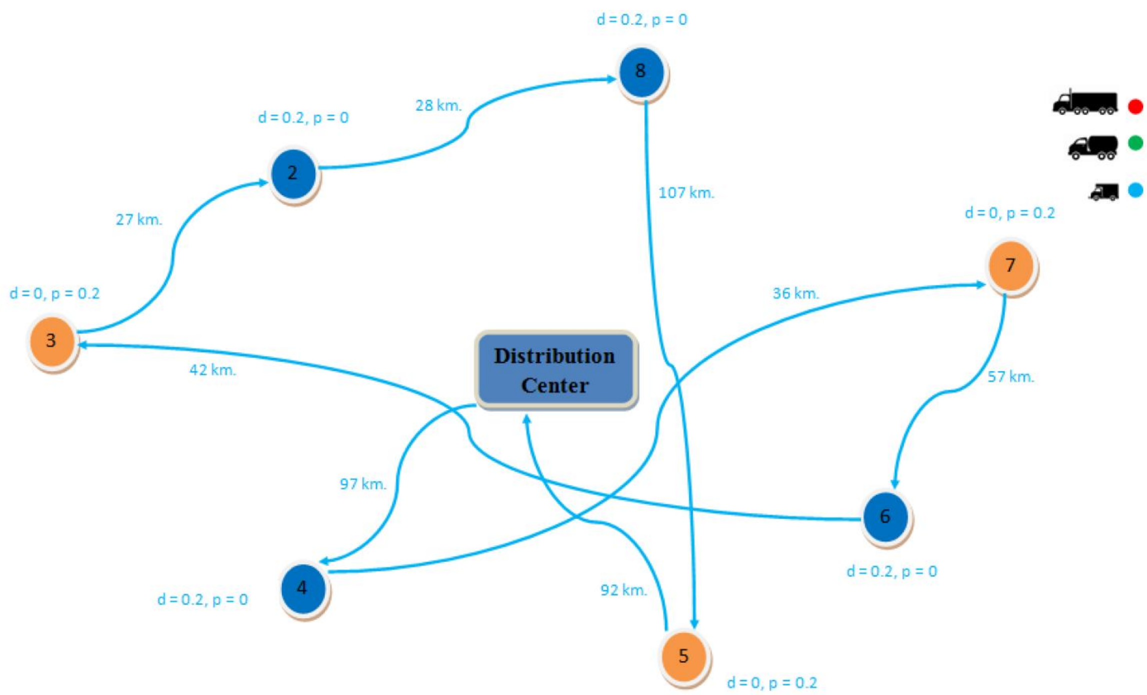

Figure 2: The routings of a truck for combined pick-up and delivery milk-run deliveries for the low demand case

Table 4 and 5 show the results of experiments. We would like to highlight the benefit of using the combined outbound and inbound milk-run delivery proposed by the model. We conduct an experiment for the case when the outbound and inbound milk-run delivery is scheduled optimally but independently. That means a truck must either deliver or pick up shipment but not both at the same time. Then, we repeat the experiment for the case but using combined outbound and inbound milk-run delivery which allows a truck to be able to pick up and deliver in its routing. Table 4 shows the comparison of costs, travel distances, travel time and truck capacity utilization, defined as the average amount of load on the truck calculated as average percentage of full truck capacity. Table 5 shows the percent improvement if the combined outbound and inbound milk-run delivery is used. The combined outbound and inbound milk-run delivery can generate total cost saving of 38.6% and 87.1% for high demand and low demand case respectively. The total distance and average travel time are also improved at the minimum of 42.5% and 26.4% respectively. Lastly, the truck capacity utilization is improved 79.9% and 107.1% for high demand and low demand cases respectively. The observed saving and improvement is significant showing it as viable logistic cost reduction method. The saving and improvement tend to be higher for the case with low demand.

Table 4: Results between independent inbound and outbound delivery and combined inbound and outbound milk-run delivery

Case		Total cost (baht)	Total distance (km)	Time (hrs)				Utilization (%)			
				Truck1	Truck2	Truck3	Average	Truck1	Truck2	Truck3	Average
High Demand for pickp and delivery	Outbound	10,962.00	850.94	3.23	4.83	6.18	4.75	11.11	42.59	44.44	32.71
	Inbound	8,090.57	621.63	3.07	0	7.37	3.48	76.19	0	64.2	46.80
	Total	19,052.57	1,472.57	6.3	4.83	13.55	8.23	43.65	21.3	54.32	39.76
	Combined Outbound and Inbound Milkrun	11,692.42	483.22	5.87	6.72	5.58	6.06	79.37	72.22	62.96	71.52
Low Demand for pickp and delivery	Outbound	2,709.00	398.97	6.72	-	-	6.72	11.43	-	-	11.43
	Inbound	2,825.99	437.58	7.37	-	-	7.37	6.35	-	-	6.35
	Total	5,534.99	836.55	14.08	-	-	14.08	8.89	-	-	8.89
	Combined Outbound and Inbound Milkrun	2,958.00	481.14	8.1	-	-	8.10	18.41	-	-	18.41

Table 5: Improvement after using combined inbound and outbound milk-run delivery

Case		Total cost (baht)	Total distance (km)	Time (hrs)				Utilization (%)			
				Truck1	Truck2	Truck3	Average	Truck1	Truck2	Truck3	Average
High Demand for pickp and delivery	Percent Improvement	38.6%	67.2%	6.8%	-39.1%	58.8%	26.4%	81.8%	239.1%	15.9%	79.9%
Low Demand for pickp and delivery	Percent Improvement	87.1%	42.5%	42.5%	-	-	42.5%	107.1%	-	-	107.1%

4. CONCLUSION

In most research, the milk-run delivery cannot be planned for both inbound and outbound logistics due to the complexity of keeping inventory record on truck. When allowed, the truck must complete all deliveries first before pick-up can be started. This limits the opportunities to save transportation cost and increase truck capacity utilization. We develop a mathematical model to allow planning of multiple trucks with combined inbound and outbound milk-run deliveries. There is no restriction of delivery or pick-up sequence imposed, thereby allowing a truck to travel freely to minimize the total cost. The model is tested in a small numerical example with eight nodes. From the numerical result, the solution from the model shows the savings of 38.6% and 87.1% for the high demand and low demand cases respectively. The total distance and average travel time also improve at least 42.5% and 26.4% respectively. The average truck capacity utilization is also improved at least 79.9%. As the improvement is quite significant, the proposed method shows a viable solution to save the logistics cost. In the future research, more numerical results will be tested to show the gained benefits. Also, to be able to keep tracks of inventory on truck, the time dimension is added to the variables. This increases the complexity of solving the large size problems. The efficient heuristic method will be developed in the future research.

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