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Research Article

Order Allocation Model Considering Transportation Alternatives and Lateral Transhipment

Ashylla Maharani, Cucuk Nur Rosyidi, Pringgo Widyo Laksono

Department of Industrial Engineering, Universitas Sebelas Maret, Surakarta 57126, Central Java, Indonesia

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CORRESPONDENCE

Phone : +6281287824027
E-mail : ashyllam5@gmail.com

A B S T R A C T

Intense competition among companies encourages them to provide the best quality of products in competitive price. It is important for company to manage supply chain properly in order to achieve that. Selecting the best reliable supplier is the key to reduce purchasing cost, increase customer satisfaction and improve the competitive ability. In this study, we develop an order allocation model in multi echelon environment which includes supplier, manufacturer, and retailer. We consider transportation alternatives for the shipment from supplier to manufacturer and also the shipment from manufacturer to retailer. This model allows lateral transshipment between retailers. A Mixed Integer Linear Programming (MILP) is used to model the system. Sensitivity analysis is conducted at the end of the research. The result show that the retailer demand, lead time, material variable price are sensitive to the objective function while the transportation costs from supplier to manufacturer, from manufacturer to retailers, and between retailers are not sensitive to the objective function. Retailer demand parameter is also sensitive to all decision variables. The transportation cost from supplier to manufacturer, material prices, and lead time are sensitive to the order allocation from manufacturer to supplier, while transportation cost from manufacturer to retailers and transportation cost between retailers are sensitive to the allocation of product sent from the manufacturer to retailers and the allocation of product sent between retailers.

INTRODUCTION

Supply Chain Management (SCM) is an approach to manage various activities from raw materials to finished goods before sending the products to consumers through distribution system [1]. Intense competition in the business world encourages companies to provide the best quality products so as to increase customer satisfaction at competitive prices. One of the factors that support the company in achieving this goal is by maintaining the supply chain management efficiently. The supply chain extends from the source which is original supplier to the ultimate customer [2]. It is important for companies to select the best and reliable supplier and maintain a long relationship with them. Selecting the right supplier is a key to reduce purchasing cost, increase customer satisfaction, and improve competitive ability [3]. Therefore, supplier selection is one of the most significant processes in the purchasing and supply chain management which is a crucial management responsibility [4]. The availability of raw materials, competitive prices, and the fulfilment of the quality of raw materials can be achieved if the selection of supplier is carried out effectively. Manufacturing cost is dependent on raw material suppliers which takes about 60% of manufacturing cost [5]. The procurement department spends of about 80% of company revenue on purchasing activities [6]. Therefore, the procurement department has an important role in minimizing the total cost significantly. The department has an important role in determining the right supplier and the amount of order quantity as well as the transportation mode to increase company profits through cost reduction [7].

Supplier selection and order allocation is a problem that is generally solved in two different phases. The first phase is supplier selection and the second phase is order allocation. The purpose of supplier selection phase is to evaluate and select the best supplier using multi-criteria-decision-making (MCDM) method. Auoadni et al. [8] divide the supplier selection phase into two steps, which include pre-selection of potential supplier and final selection using MCDM methods. The purpose of pre-selection of potential supplier is to reduce the number of suppliers while the final selection aim to select the best supplier using MCDM methods. In multiple sourcing environment where no supplier can satisfy all the buyer's requirement, the buyer needs to select more than one supplier [9]. Therefore, an order allocation decision needs to be considered in addition to supplier selection problem [10]. In order allocation phase, the decision maker need to make decision regarding what product to order, in what quantity, from which supplier, and when to order. Order

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allocation problem can be solved by using optimization models. Auoadni et al. [8] classified two types of order allocation in multi-sourcing strategies, the first one regarding the number of different purchased items, and the second one regarding the scheduling horizon.

There are many studies discussed about supplier selection and order allocation. One of them is Songhori's research [11], which develops a supplier selection and order allocation model by considering transportation alternatives. The objective function is to maximize the efficiency of transportation alternatives and minimize the total cost consisting of ordering costs, transportation costs, and inventory costs in transit during the planning period. Another example of study about supplier selection and order allocation is Venkatesan and Goh study [12]. They developed a multi-objective MILP model for supplier selection and order allocation. They evaluate the suppliers using a hybrid fuzzy AHP-fuzzy PROMETHEE and use Multi-objective Particle Swarm Optimization to allocate orders. Shalke et al. [13] develop a sustainable supplier selection and order allocation model in a multi-period, multi-item, and multi-supplier. In addition, their research also considered quantity discount under two assumptions: all unit and incremental.

Logistic cost are the total costs incurred to make available a good or service to the market, mainly to end customer [14]. There are many activities in logistics, from transportation to warehouse management. Transportation cost has a large contribution on logistics activities. Based on the analysis of consulting agency in America, Armstrong & Associates inc., transportation costs accounted for about 58% of the total logistics costs [14]. A good transportation system will support logistics activities because transportation acts as a link between actors in the supply chain, both from suppliers to manufacturers and from manufacturers to retailers.

Many studies discuss about logistic cost. Ghodyspour and O'Brien [15] presented a mixed integer non-linear programming (MINLP) to solve multiple sourcing problem which consider total logistic cost, including net price, storage, transportation, and ordering cost. They also consider buyer limitation on budget, quality, service, etc. Nasiri et al. [16] developed a mixed integer linear programming model (MILP) which combine supplier selection and order allocation program into vehicle routing problem with cross-docking (VRPCD) in multi-cross-dock system. The objective function of this paper is minimizing total cost which include purchasing, transportation, cross-docking, inventory, and early/tardy delivery penalty cost. Basa et al. [7] developed an MINLP model to solve single item supplier selection, economic lot sizing, and order allocation problem which consider inventory holding cost, ordering cost, transportation cost, and quantity discount.

Generally, large-scale companies adopted multi-echelon supply chain network in distributing their products [17]. In this case, it is necessary to optimize the inventory system that involves the time and inventory level of each echelon in the supply chain. Commonly, inventory system designs only consider hierarchical or sequential delivery from one echelon to another, such as from suppliers to manufacturers or from distributors to retailers [18]. The inventory system design can be made more flexible with the application of lateral transhipment, such as delivery between retailers or delivery between distributors. Paterson [18] divided lateral transhipment into two types, namely reactive transhipment and proactive transhipment. Proactive transhipment deals with redistribution of inventory among all storage points in one echelon at a predetermined time. Meanwhile, reactive transhipment is used to respond the situations where one storage point runs out of its stock (or is at risk of stock out) while the other storage point has sufficient stock. Zhi et al. [19] considers the existence of lateral transhipment in their research on a three-echelon supply chain network consisting of suppliers, distributors, and retailers. Four types of shipments considered in the model, namely shipments from suppliers to distributors, shipments from suppliers to retailers, direct shipments from suppliers to retailers, and deliveries between distributors.

In this study, we develop an order allocation model by considering transportation alternatives in a three-echelon supply chain by allowing lateral transhipment. The type of lateral transhipment used is a proactive lateral transhipment between retailers. Three parties of supply chain are considered includes suppliers, manufacturers and retailers. Mixed Integer Linear Programming (MILP) is used to model the system with the objective function of minimizing total costs consisting of ordering costs, inventory costs in transit, and transportation costs of three types of shipments. The model involves three shipments: from supplier to manufacturer, manufacturer to retailer, and lateral transhipment from one retailer to another.

METHOD

In this section, model is described which include assumptions, model formulation, and numerical example. Notations are shown in Appendix A1.

The assumptions of this research are as follows:

- Transportation vehicle is assumed to be available at each period
- Alternative transportation for delivery between retailers is not considered
- Demand is deterministic
- Retailers can deliver to any retailer
- One material purchased from a supplier is used to produce one unit of product at the manufacturer level.
- The type of lateral transshipment used in this model is a proactive lateral transshipment
- Lead time for delivery between retailers is not considered

The notation used in the mathematical model can be seen in Nomenclature section.

The objective function of the model is to minimize total cost which includes ordering costs, inventory costs, transportation costs from suppliers to manufacturers, transportation costs from manufacturers to retailers and transportation costs from retailers to retailers. The decision variables of the model are the allocation of raw material orders to supplier (YY_{ijt}), the allocation of products sent from manufacturer to retailers (XX_{kt}), the allocation of products sent between retailers (VV_{mkt}), manufacturer's inventory (INV_t). The objective function of the model is formulated in Equation (1), while the detail formulation of the cost components is shown in Equations (2)-(6).

$$\text{Min } TC = PC + IC + TCIM + TCMR + TCRR \quad (1)$$

where the formulation of the cost components of the objective function is stated as follows:

$$PC = \sum_{i\in I}^{n}\sum_{t\in T}^{r} O_i \times Z_{it} \tag{2}$$

$$IC = \sum_{i\in I}^{n}\sum_{j\in J}^{p}\sum_{t\in T}^{r} L_{ij} \times (PP_{it} + H_t) \times YY_{ijt} + (INV_t \times H_t) \tag{3}$$

$$TCIM = \sum_{i\in I}^{n}\sum_{j\in J}^{p}\sum_{t\in T}^{r} \frac{CT_{ij} \times YY_{ijt}}{CPT_j} \tag{4}$$

$$TCMR = \sum_{k\in K}^{q}\sum_{t\in T}^{r} \frac{CC_{jk} \times XX_{jkt}}{CPT_j} \tag{5}$$

$$TCRR = \sum_{m\in K}^{q}\sum_{k\in K}^{q}\sum_{t\in T}^{r} TS_{mk} \times VV_{mkt} \tag{6}$$

subject to:

$$\sum_{j\in J}^{p} YY_{ijt} \le CPS_{it} \tag{7}$$

$$\sum_{i\in I}^{n}\sum_{j\in J}^{p} YY_{ijt} \le CPM_t \tag{8}$$

$$\sum_{k\in K}^{q} XX_{kt} \le CPM_t \tag{9}$$

$$XX_{kt} \le CP_{kt} \tag{10}$$

$$\sum_{m\in K}^{q} VV_{mkt} + \sum_{k\in K}^{q} XX_{kt} = CS_{kt} + \sum_{m\in K}^{q} VV_{kmt} \tag{11}$$

$$\sum_{k\in K}^{q} D_{kt} \le INV_{t-1} + \sum_{i\in I}^{n}\sum_{j\in J}^{p} YY_{ijt} \tag{12}$$

$$XX_{kt} + \sum_{m\in K}^{q} VV_{mkt} \ge D_{kt} \tag{13}$$

$$INV_t = INV_{t-1} + \sum_{i\in I}^{n}\sum_{j\in J}^{p} YY_{ijt} - \sum_{k\in K}^{q} D_{kt} \tag{14}$$

$$\frac{YY_{ijt}}{CPT_j} \le N_j \tag{15}$$

$$\sum_{j\in J}^{p} YY_{ijt} \le M \times Z_{it} \tag{16}$$

$$INV_t, YY_{ijt}, XX_{kt}, VV_{mkt} \text{ integer} \tag{17}$$

$$YY_{ijt}, XX_{kt}, VV_{mkt} \ge 0 \tag{18}$$

$$Z \in \{1,0\} \tag{19}$$

Equation (2) expresses the ordering costs incurred every time the manufacturer places an order to a certain supplier. Equation (3) is used to calculate the inventory cost which divides into two types, namely cost of inventory in transit and the cost of manufacturer's inventory. Equation (4) needs to calculate the transportation costs per truck from suppliers to manufacturers, while Equations (5) and (6) express the transportation cost per truck from manufacturers to retailer and between retailers respectively.

The set of constraints used in the model are shown in Equations (7)-(19). Equation (7) ensures the number of products ordered by manufacturers do not exceed the supplier's capacity. Equation (8) ensures the number of products ordered by manufacturers do not exceed the manufacturer's capacity. Equation (9) ensures the number of products sent from manufacturer to retailers to not exceed the manufacturer's capacity. Equation (10) restrict the number of products sent from manufacturer to retailers to not exceed the retailer's capacity. Equation (11) represents the flow of products from manufacturer to retailers and between retailers. Equation (12) limits the product ordered from supplier and the inventory prior to period t not to exceed the retailer demand. Equation (13) limits the products sent from manufacturer to retailers and products sent between retailers not to exceed the retailer demand. Equation (14) calculates the existing product at manufacturer's inventory on period t. Equation (15) limits the number of transportation available for supplier *i* using transportation alternatives j. Equation (16) represents ordering cost constraint to ensure there is an ordering cost for every order to a supplier. In Equation (16), Z denotes the binary variables and *M* is large value of number. The number of products ordered by manufacturer to supplier, product sent from manufacturer to retailer, product sent between retailers and manufacturer's inventory are integer variables defined by Equation (17). Equation (18) ensures that the number of products ordered by manufacturer to supplier, product sent from manufacturer to retailer and product sent between retailers are non-negative. Equation (19) defines binary variable to assign the ordering cost on selected supplier.

RESULT AND DISCUSSION

Numerical Example

In this section, a numerical example is given to show the applicability of the model. Appendix A1 shows the ordering cost, transportation cost, and lead time, and number of transportation alternatives of supplies and their respective transportation alternatives. Appendix 2 shows the transportation cost per truck from manufacturer to retailers. Appendix A3 shows the raw materials variable price for each supplier and product holding cost for each period. Appendix A4 shows retailers demand for each period. Appendix A5 shows the transportation cost between retailers. It is assumed that suppliers have the same capacity at each period at 1400, 2000, 1600, 1880, and 1920 units for Supplier 1 to 5 respectively. The retailer capacity was set at 900, 1000, 800, 800, 700, and 700 for Retailer 1 to 6 respectively. Number of available transportations are the same for all supplier at 8, 4, 6 for small truck, medium truck, and large truck respectively. Number of available transportations for manufacturer are 7, 5, 7 for small truck, medium truck, and large truck, respectively. The manufacturer capacity is assumed to be 4000 units.

The results are shown in Table 1, Table 2, and Table 3. Table 1 shows the allocation of products sent from manufacturer to retailers. Table 2 shows the order allocation by manufacturer to the suppliers. Table 3 shows the quantity of products sent between retailer.

According to Table 1, all shipment from manufacturer is sent using large truck for all retailer at each period. The quantity of product sent for retailer 2 and 5 are equal to the demand. The lowest quantities is the shipment for retailer 6 and the largest quantity is the shipment to retailer 1. Table 3 shows the order allocation by manufacturer to the supplier. According to the Table 2 manufacturer ordered raw materials from all suppliers. Medium truck is used for the shipment from supplier 1 on all period and supplier 5 on period 2 and 3. Small truck, medium truck, and large truck are used for the shipment from supplier 2 and 3 on all period. The orders made to supplier 4 are sent using small trucks on all period. According to Table 2, the lateral transshipment occurred between retailer 5 and retailer 3, and also occurred between retailer 6 and retailer 1.

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Sensitivity Analysis

Sensitivity analysis is necessary to study the effects of the uncertainty of some important parameters to the decision variables and objective function [20]. The analysis was performed by changing the value of parameters with a certain percentage and determine how the change of those values affect the decision variables and objective function. The results of the sensitivity analysis are shown in Table 4 and Table 5.

Based on Table 4 and Table 5, retailer demand, variable material price, and lead times are sensitive to the objective function. The scenario of 15% decrease in parameter value of retailer demand, variable material price, and lead time causes a 19%, 10%, and 11% decrease in the value of objective function value respectively and continue to decrease until the scenario of a 30% decrease in parameter value. Meanwhile, the scenario of 15% increase in parameter value of material price and lead time causes a 10% and 11% increase in objective function value respectively and continue to increase until the scenario of 30% increase in parameter value. The scenario of an increase in retailer demand parameter values by 15% and 30% causes the model to be infeasible. This is due to the increase in the number of retailers demands that are not parallel to the increase in capacity both owned by suppliers, manufacturers, and retailers and causes demand cannot be met so that the model is not feasible. Responding to this analysis, the decision maker needs to put greater effort to obtain a highly accurate data regarding the retailer demand or implement an ordering policy to reduce the impact of lead time and price uncertainty. Meanwhile, transportation costs from supplier to manufacturer, from manufacturer to retailers and between retailers are not sensitive to the objective function.

Retailer demand parameter is also sensitive to the decision variables. In the order allocation by manufacturer to supplier, at supplier 3, it decreases by 72% in the -30% scenario and by 41% in the -15% scenario. In the product sent from manufacturer to retailer decision variable, changes in the amount of allocation occur to retailer 6. The amount of change in retailer 6 is 80% in both -15% dan -30% scenario. In the product sent between retailer decision variable, there are changes in retailer 1. The amount of change in retailer 1 in the -15% scenario is 26% and remain unchanged in the -30% scenario.

For transportation cost from supplier to manufacturer parameter, there is a change in the order allocation from supplier decision variable. The value change of supplier 4 in -30% scenario is 33% and in +30% is decreased by 100%. For material prices and lead time parameter, in the order allocation by manufacturer to supplier decision variable, there is a change in the value of suppliers 3 and 4. The quantity of order allocation made to supplier 4 in the -30% scenario has decreased by 100% the +30% scenario it has increased by 33%. For transportation cost from

Table 1. Result of product sent from manufacturer to retailer

Period	Transportation Alternatives	Retailer					
		1	2	3	4	5	6
1	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	600	300	800	300	0
2	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	700	450	800	450	0
3	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	700	500	800	600	0
4	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	650	300	800	550	300
5	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	600	450	800	600	150
6	Small Truck	-	-	-	-	-	-
	Medium Truck	-	-	-	-	-	-
	Large Truck	900	600	300	800	400	0

Table 2. Results of product sent between retailer

Period	Retailer (m)	Retailer (k)						Period	Retailer (m)	Retailer (k)					
		1	2	3	4	5	6			1	2	3	4	5	6
1	1	0	0	200	0	0	200	4	1	0	0	0	0	0	150
	2	0	0	0	0	0	0		2	0	0	0	0	0	0
	3	0	0	0	0	0	0		3	0	0	0	0	0	0
	4	0	0	0	0	0	0		4	0	0	0	0	0	0
	5	0	0	0	0	0	0		5	0	0	0	0	0	0
	6	0	0	0	0	0	0		6	0	0	0	0	0	0
2	1	0	0	0	0	0	200	5	1	0	0	0	0	0	250
	2	0	0	0	0	0	0		2	0	0	0	0	0	0
	3	0	0	0	0	0	0		3	0	0	0	0	0	0
	4	0	0	0	0	0	0		4	0	0	0	0	0	0
	5	0	0	0	0	0	0		5	0	0	0	0	0	0
	6	0	0	0	0	0	0		6	0	0	0	0	0	0
3	1	0	0	150	0	0	150	6	1	0	0	0	0	0	250
	2	0	0	0	0	0	0		2	0	0	0	0	0	0
	3	0	0	0	0	0	0		3	0	0	0	0	0	0
	4	0	0	0	0	0	0		4	0	0	0	0	0	0
	5	0	0	0	0	0	0		5	0	0	0	0	0	0
	6	0	0	0	0	0	0		6	0	0	0	0	0	0

Table 3. Result of order allocation by manufacturer to supplier

Supplier	Transportation Alternatives								
	Period 1			Period 2			Period 3		
	Small Truck	Medium Truck	Large Truck	Small Truck	Medium Truck	Large Truck	Small Truck	Medium Truck	Large Truck
1	-	280	-	-	280	-	-	280	-
2	160	280	1200	160	280	1200	160	280	1200
3	160	280	380	160	280	500	160	280	500
4	160	-	-	160	-	-	160	-	-
5	-	-	-	-	280	-	-	280	-
Supplier	**Transportation Alternatives**								
	Period 4			**Period 5**			**Period 6**		
	Small Truck	**Medium Truck**	**Large Truck**	**Small Truck**	**Medium Truck**	**Large Truck**	**Small Truck**	**Medium Truck**	**Large Truck**
1	-	280	-	-	280	-	-	280	-
2	160	280	1200	160	280	1200	160	280	1200
3	160	280	700	160	280	1140	160	280	1140
4	160	-	-	160	-		160	-	-
5	-	-	-	-	-	-	-	-	-

manufacturer to retailer, in the product sent from manufacturer to retailer decision variable, there are changes in retailers 1,2,3,5 and 6. The magnitude of changes in supplier 1 in the -30% and -15% scenario is 29% and remain unchanged in the +15% and +30% scenario. In the product sent between retailers' decision variable, changes occur in retailers 1,2 and 4. The magnitude of changes in retailer 1 in the -30% and -15% scenarios is 100% and remain unchanged in the +15% or +30% scenarios. For

Table 4. Results of sensitivity analysis

Value Change	Retailer Demand				
	-30%	-15%	0	15%	30%
Objective Function	3,344,630	4,335,368	5,379,884	Infeasible	Infeasible
Order Allocation by manufacturer to supplier	1990	4235	7140	Infeasible	Infeasible
Product sent from manufacturer to retailer	450	450	2200	Infeasible	Infeasible
Product sent between supplier	1550	1150	1550	Infeasible	Infeasible
Value Change	**Transportation Cost of Supplier**				
	-30%	**-15%**	**0**	**15%**	**30%**
Objective Function	4,993,906	5,187,962	5,379,884	5,571,806	5,757,889
Order Allocation by manufacturer to supplier	6980	7140	7140	7140	7620
Product sent from manufacturer to retailer	2300	2300	2300	2300	2300
Product sent between supplier	1550	1550	1550	1550	1550
Value Change	**Variable Cost of Raw Material**				
	-30%	**-15%**	**0**	**15%**	**30%**
Objective Function	4,285,180	4,837,126	5,379,884	5,922,587	6,463,980
Order Allocation by manufacturer to supplier	7640	7640	7140	7140	6980
Product sent from manufacturer to retailer	2300	2300	2300	2300	2300
Product sent between supplier	1550	1550	1550	1550	1550
Value Change	**Lead Time**				
	-30%	**-15%**	**0**	**15%**	**30%**
Objective Function	4,191,496	4,790,293	5,379,884	5,968,844	6,555,918
Order Allocation by manufacturer to supplier	7620	7620	7140	7140	6980
Product sent from manufacturer to retailer	2300	2300	2300	2300	2300
Product sent between supplier	1550	1550	1550	1550	1550
Value Change	**Transportation Cost of Manufacturer**				
	-30%	**-15%**	**0**	**15%**	**30%**
Objective Function	5,336,300	5354124	5,379,884	5,385,130	5,399,259
Order Allocation by manufacturer to supplier	7140	7140	7140	7140	7140
Product sent from manufacturer to retailer	2900	2900	2300	2300	2300
Product sent between supplier	0	0	1550	1550	1550
Value Change	**Transportation Cost Between Retailer**				
	-30%	**-15%**	**0**	**15%**	**30%**
Objective Function	5,363,594	5,367,503	5,379,884	5,393,096	5,395,496
Order Allocation by manufacturer to supplier	7140	7140	7140	7140	7140
Product sent from manufacturer to retailer	900	2300	2300	2300	1350
Product sent between supplier	1850	0	0	0	0

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Table 5. Recap of the results of sensitivity analysis

Parameter	**Objective Function**	**Decision Variables**		
		Order allocation by manufacturer to supplier	**Product sent from manufacturer to retailer**	**Product sent between retailer**
Retailer Demand	Sensitive	Sensitive	Sensitive	Sensitive
Transportation Cost of Supplier	Not Sensitive	Sensitive	Not Sensitive	Not Sensitive
Variable Material Price	Sensitive	Sensitive	Not Sensitive	Not Sensitive
Lead Time	Sensitive	Sensitive	Not Sensitive	Not Sensitive
Transportation Cost of Manufacturer	Not Sensitive	Not Sensitive	Sensitive	Sensitive
Transportation Cost Between Retailer	Not Sensitive	Not Sensitive	Sensitive	Sensitive

transportation cost between retailers, in the product sent from manufacturer to retailer decision variable, there is a change in the value of retailer 1,2,3, and 6. The magnitude of changes in supplier 1 in the +30% and +15% scenario is 26%, in the -15% and -30% scenario the value is remain unchanged. In the product sent between retailers' decision variable, there is a change in retailer 1,2, and 4. The change in supplier 2 in the -30% scenario is 100% and there is no change in the -15%, +15%, nor +30% scenarios. In respond to this sensitivity analysis, the decision maker needs to implement a safe policy regarding transportation cost to reduce the impact of transportation cost uncertainty.

CONCLUSIONS

We developed an optimization model to determine optimal order allocation in a three-echelon supply chain by considering transportation alternatives and lateral transshipment among retailers with the objective function of minimizing total costs consisting of ordering costs, inventory costs, and transportation costs. Based on the result of sensitivity analysis, it is known that the retailer demand, lead time, and material variable price are sensitive to the objective function. Retailer demand parameter is also sensitive to the decision variables. The transportation cost from supplier to manufacturer, material prices, and lead time are sensitive to the order allocation from manufacturers to suppliers, while transportation cost from manufacturer to retailers and transportation cost between retailers are sensitive to the allocation of product sent from the manufacturer to retailers and of product sent between retailers. Responding to this analysis, the decision maker needs to put greater effort to obtain a highly accurate data regarding the retailer demand or implement an ordering policy to reduce the impact of lead time, price, and transportation cost uncertainty. For further research, more parameter can be added in order to adapt to the complexity of real environment such as safety stock, allowing backorders, and considering inventory level of retailers to allow reactive lateral transshipment.

REFERENCES

[1] J. Heizer, et al. Operations management: sustainability and supply chain management, 12/e. Pearson Education, 2017.

[2] D. Blanchard, Supply chain management best practices. John Wiley & Sons, 2021. https://doi.org/10.1002/9781119738275.

[3] Jain, et al. "Supplier selection using fuzzy AHP and TOPSIS: a case study in the Indian automotive industry." Neural computing and applications, vol. 29, no. 7, pp. 555-564, 2018. https://doi.org/10.1007/s00521-016-2533-z.

[4] A. Wetzstein, E. Hartmann, W.C. Benton Jr, and N.O. Hohenstein, "A systematic assessment of supplier selection literature–state-of-the-art and future scope." Int. J. Prod. Econ., vol. 182, pp. 304-323, 2016. https://doi.org/10.1016/j.ijpe.2016.06.022.

[5] A. Arabsheybani, M.M. Paydar, and A.S. Safaei, "An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk." J. Clean. Prod., vol. 190, pp. 577-591, 2018. https://doi.org/10.1016/j.jclepro.2018.04.167.

[6] A.N. Mishra, S. Devaraj, and G. Vaidyanathan, "Capability hierarchy in electronic procurement and procurement process performance: An empirical analysis." J. Oper. Manag., vol. 31, no.6, pp. 376-390, 2013. https://doi.org/10.1016/j.jom.2013.07.011.

[7] G. Basa, T. Becker, and A. Kedir, "Single Item Supplier Selection and Order Allocation Problem with a Quantity Discount and Transportation Costs." Momona Ethiop. J. Sci., vol. 12, no. 1, pp. 20-38, 2020. https://doi.org/10.4314/mejs.v12i1.2.

[8] S. Aouadni, I. Aouadni, and A. Rebaï, "A systematic review on supplier selection and order allocation problems." J. Ind. Eng. Int., vol. 15, no.1, pp. 267-289, 2019. https://doi.org/10.1007/s40092-019-00334-y.

[9] A. F. Guneri, A. Yucel, and G. Ayyildiz, "An integrated fuzzy-lp approach for a supplier selection problem in supply chain management," Expert Syst. Appl., vol. 36, no. 5, pp. 9223-9228, 2009. https://doi.org/10.1016/j.eswa.2008.12.021.

[10] A. Amindoust, S. Ahmed, and A. Saghafinia, "Supplier selection and order allocation scenarios in supply chain: A review." Eng. Manag. Rev. (EMR) vol. 2, no. 3, pp. 75-80, 2013.

[11] M. J. Songhori, M. Tavana, A. Azadeh, and M.H. Khakbaz, "A supplier selection and order allocation model with multiple transportation alternatives," Int. J. Adv. Manuf. Technol., vol. 52, no.1, pp. 365-376, 2011. https://doi.org/10.1007/s00170-010-2697-0.

[12] S. PrasannaVenkatesan and M. Goh, "Multi-objective supplier selection and order allocation under disruption risk." Transp. Res. E: Logist. Transp. Rev, vol. 95, pp. 124-142, 2016. https://doi.org/10.1016/j.tre.2016.09.005.

[13] P. N. Shalke, M.M. Paydar, and M. Hajiaghaei-Keshteli. "Sustainable supplier selection and order allocation through quantity discounts," Int. J. Manag. Sci. Eng. Manag., vol. 13, no. 1, pp. 20-32, 2018. https://doi.org/10.1080/17509653.2016.1269246.

[14] J. P Rodrigue, The Geography of Transport Systems. Routledge, 2020. https://doi.org/10.4324/9780429346323.

[15] S.H. Ghodsypour and C. O'brien. "The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint," Int. J. Prod. Econ., vol. 73, no.1, pp. 15-27, 2001. https://doi.org/10.1016/S0925-5273(01)00093-7.

[16] M. M. Nasiri, A. Rahbari, F. Werner, and R. Karimi, "Incorporating supplier selection and order allocation into the vehicle routing and multi-cross-dock scheduling problem." Int. J. Prod. Res., vol. 56, no. 19, pp. 6527-6552, 2018. https://doi.org/10.1080/00207543.2018.1471241.

[17] M. Firoozi, M.Z. Babai, W. Klibi, and Y. Ducq, "Distribution planning for multi-echelon networks considering multiple sourcing and lateral transshipments," Int. J. Prod. Res., vol. 58, no.7, pp. 1968-1986, 2020. https://doi.org/10.1080/00207543.2019.1639841.

[18] C. Paterson, G. Kiesmüller, R. Teunter, and K. Glazebrook, "Inventory models with lateral transshipments: A review." Eur. J. Oper. Res., vol. 210, no.2, pp. 125-136, 2011. https://doi.org/10.1016/j.ejor.2010.05.048.

[19] J. Zhi and B.B. Keskin, "A multi-product production/distribution system design problem with direct shipments and lateral transshipments," Netw. Spat. Econ., vol. 18, no. 4, pp. 937-972, 2018. https://doi.org/10.1007/s11067-018-9436-8.

[20] C. Pichery, C. "Sensitivity Analysis," Encyclopedia of Toxicology, pp. 236-237, 2014. https://doi.org/10.1016/B978-0-12-386454-3.00431-0.

NOMENCLATURE

Indice

i index for supplier, $i = 1, 2, \ldots, I$

j index for transportation alternatives, $j = 1, 2, \ldots, J$

k index for retailer, $k = 1, 2, \ldots, K$

t index for period, $t = 1, 2, \ldots, T$

Parameters

D_{kt} Demand of retailer k at period t (unit)

O_i Ordering cost to supplier I ($)

CT_{ij} Transportation cost for supplier i using transportation alternatives j ($/truck)

CPS_{it} Capacity of supplier i at period t (unit)

CPT_j Capacity of transportation alternative j (unit)

H_t Holding cost at manufacturer at period t ($/unit)

CPM_t Capacity of manufacturer at period t (unit)

PP_{it} Material variable cost of supplier i at period t (unit)

L_{ij} Lead time of supplier i with transportation alternatives j (days)

CC_k Transportation cost from manufacturer to retailer m (unit/truck)

TS_{mk} Transportation cost from retailer m to retailer k ($/unit)

CP_{kt} Capacity of retailer k at period t (unit)

N_j Number of transportation alternatives j available for all supplier (unit)

NM_j Number of transportation alternatives j available for all manufacturer (unit)

CSk_t Demand of retailer k at period t (unit)

M A large arbitrary number, Big M

Decision Variables

YY_{ijt} Order allocation of raw material to supplier I using transportation alternative j at period t (unit)

XX_{kt} Product allocation from manufacturer to retailer k at period t (unit)

VV_{mkt} Product allocation sent between retailer k and retailer m at period t (unit)

INV_t Amount of inventory of manufacturer at period t (unit)

Objective Function

PC Ordering cost of manufacturer to certain suppliers ($)

IC Holding cost of manufacturer (S)

$TCMR$ Transportation cost from manufacturer to retailers ($)

$TCIM$ Transportation cost from suppliers to manufacturer ($)

APPENDIX

A.1. Ordering cost, lead time, and transportation cost of supplier

Supplier	OC	Small truck		Medium truck		Large truck	
		CT	L	CT	L	CT	L
1	2200	3200	12,5	7083	8	10810	16,7
2	2040	2040	3	4333	5,3	8756	4,8
3	1720	2720	4	4966	7	9567	9
4	2040	3040	5	6200	9	10864	14
5	2680	3680	10	6800	7	11621	15

A.2. Transportation cost for manufacturer to retailer

Retailer	Transportation Alternatives		
	Small truck	Medium truck	Large truck
1	175	245	310
2	680	950	1115
3	1365	1911	2220
4	380	530	765
5	1257	1755	2040
6	1525	2135	2470

A.3. Raw material variable price for each supplier

Supplier	Period					
	1	2	3	4	5	6
1	20	22	20	25	18	18
2	30	30	30	30	30	30
3	32	32	32	30	33	30
4	32	32	32	42	42	42
5	38	28	28	48	48	48
H_t	2	2	2	3	3	3

A.4. Retailer demand for each period

Retailer	Period					
	1	2	3	4	5	6
1	500	700	600	750	650	650
2	600	700	700	650	600	600
3	600	500	650	300	450	400
4	700	600	650	750	700	600
5	300	450	600	550	600	400
6	200	350	300	500	500	350

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A.5. Transportation cost between retailers

Retailer (m)	**Retailer (k)**					
	1	**2**	**3**	**4**	**5**	**6**
1	0	7	7	4	8	10
2	7	0	7	8	7	8
3	7	7	0	6	4	4
4	4	8	6	0	8	9
5	8	7	4	8	0	5
6	10	8	4	9	5	0