A Mixed Integer Linear Programming Model of Order Allocation Involving Mass Customization Logistic Service (MCLS)

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ABSTRACT

In an intensed business competition, a company has to improve its competitiveness by focus more on supply chain management. One of the crucial problems in supply chain deals with the allocation of orders. More and more companies are starting to adopt Mass Customization Logistics Service (MCLS) mode to determine the optimal allocations of order both from suppliers and to customized logistics services at the possible lowest cost. For this purpose, Logistics Service Integrator (LSI) is needed to integrate the logistics tasks which operationally done by Functional Logistics Service Provider (FLSP). This research aims at developing an optimization model to determine optimal decisions concerning order allocations of the needed items from the manufacturer to the respective suppliers and logistics tasks from LSI to FLSPs. The problems were formulated using Mixed Integer Linear Programming (MILP). The results of the analysis show that the demand becomes the only sensitive parameter towards both decision variables and objective function, while the purchasing cost only impact significantly to the objective function.

Keywords: mixed integer linear programming; order allocation; mass customization logistics services.

INTRODUCTION

In an intensed business competition, many companies made their best effort to improve their competitiveness through highly product adjustments, increase product quality, and reduce product costs with timely distribution. Hence, supply chain management has become more important in increasing the company competitiveness [1]. The company has to manage its supply chain efficiently to cope with increasing customer variety and demand, the advances of communication technology and information systems, and high competition in the era of globalization, and environmental awareness [2]. The short-term goal of supply chain management is to increase productivity while in the same time reduce total inventory costs and total cycle time. In the long-term, the goal of supply chain management is to increase customer satisfaction, market share, and profits for all parties involved in the supply chain, namely suppliers, manufacturers, distribution centers, and customers [3]. To achieve this goal, it is necessary to have good coordination of each element in the supply chain.

Several important decisions should be made by the decision makers in the supply

chain such as supplier selection, order allocation, and third-party logistics selection. Supplier selection activities are important for the company and involving multi criteria decision making techniques due to its problem nature [4-6]. Order allocation problem is usually solved using constrained mathematical programming approach which formulated in single or multi-objective formulation. The common objective of the model is to minimize cost or maximizing profit and maximizing total value purchasing [7]. With optimal order allocation the company can run the entire supply chain with its best performance [8].

Supplier selection and order allocation have attracted many researchers. For example, the model in [9] proposed multi attribute utility theory determine the optimal order allocation with two stages. In the first stage, supplier selection was performed using and in the second stage the optimal order allocation was found using multi-objective integer linear programming involving social and environmental objectives. Other recent model in supplier selection and order allocation were developed by [10]. In the research, the sustainable criteria were used to determine the weight of criteria using Best-Worst Method (BWM). Afterwards, the results of the weight were used to determine the suppliers rating and rating were found by the Measurement Alternatives and Ranking According to Compromise Solution (MARCOS) method. Research [11] only developed an optimization model to determine the optimal order allocation. Research [12] considered the transportation alternatives and lateral transhipment in order allocation problem. The model was used to determine the optimal order allocation and transportation alternative for three echelon supply chain consisting of supplier, manufacturer, and retailer.

Supply chain transportation has to be managed efficiently. Hence, according to [13-15], more and more companies adopted Mass Customization Logistic Service (MCLS) mode to make the oprations more efficient. In MCLS, customized logistics services are provided where the order allocation of logistics tasks are conducted by Logistic Service Integrator (LSI). The LSI allocates the logistics tasks to Functional Logistics Service Providers (FLSP). The research to solve MCLS problems has been conducted by many researchers. For example, the scheduling problems of the MCLS have been solved by [13] for deterministic and by [16] for uncertain FLSP's time. The optimization models have been developed to solve the order allocation problems of MCLS such as in [17, 18]. Both researches only considered the order allocation of logistics tasks from LSI to FLSPs. In fact, the manufacturer that uses the LSI services need to determine the optimal allocation of the needed items from the suppliers. Hence, an optimization model needs to develop in order to integrating the decision making of order allocations of needed items and logistics tasks. The problem is formulated using Mixed Integer Linear Programming (MILP) method to determine the allocation of orders to suppliers and the allocation of logistics tasks to FLSP to minimize the total supply chain costs.

METHODS

The model is formulated using MILP method. The objective function of the model is to minimize manufacturer's costs which comprise of supplier cost, outsourcing services cost, and transportation cost. There are two decision variables in the model, namely the allocation of order from each supplier and the assignment of logistics tasks to the respective FLSP. Several assumptions that involved in the modeling process are: (1) each supplier can supply more than one product, (2) the quantity of orders to each supplier is assumed to be constant for each period, (3) the budget for purchasing of orders is assumed to be constant for each period, and (4) each has different outsourcing price and

service capacity.

Model Notations

Index
i : supplier index (i=1…I)
f : FLSP index (f=1…F)
j : procedure index (j=1…J)
k : product index (k=1…K)

Decision variables
XC_{ki} : the order quantity of product k from supplier i
Q_{fjk} : The number of logistics tasks assigned by the LSI to the FLSP f
              for procedure j for product k
X_{fjk} $\begin{cases} 1, & \text{if FLSP } f \text{ of procedure } j \text{ is selected for product } k \\ & 0, \text{otherwise} \end{cases}$

Parameters
C_{ki} : unit cost of product k from supplier i ($)
TC : unit transportation cost per Kg ($)
WC_{fjk} : the mass of product k in procedure j processed by FLSP f (Kg)
OC_{ki} : unit order cost of product k from supplier i ($)
B : total budget for procurement ($)
DC_k : demand for product k (unit)
$CAPC_{ki}$: product k capacity from supplier i (unit)
P_{fjk} : unit service price of product k processed by FLSP f for procedure j ($)
A_{fjk} : maximum service capacity of FLSP f for procedure j and for product k
Var_{fjk} : variable for linearization
M   : big positive number (assumption of M value = 1000000)

Model Formulation

The formulation of the cost components is shown in Equations (1)-(3). Equation (1) expresses the supplier cost which determines by multiplying the order allocation with the summation of unit product cost and order cost. Equation (2) calculates the total cost of outsourcing services incurred by the company for FLSP and LSI services. The total cost was calculated by multiplying the order quantity with service price and the number of logistics tasks performed by FLSP. Equation (3) calculate total transportation cost which expressed as the function of the mass of product.

$$\text{TBP} = \left(\sum_i^{N_i} \sum_k^{N_k} C_{ik} + OC_{ik} \right) x \ XC_{ik} \tag{1}$$

$$\text{TBLO} = \sum_f^{N_i} \sum_j^{N_j} \sum_k^{N_k} X_{fjk} \ x \ P_{fjk} x \ Q_{fjk} \tag{2}$$

$$\text{TBT} = \sum_f^{N_i} \sum_j^{N_j} \sum_k^{N_j} TC \ . WC_{fjk} \tag{3}$$

The constraints of the model are expressed in Equations (4)-(12). Equation (4) ensures the expenditure to cover all the costs is not over budget. Equations (5) and (6) ensure the order quantity covers all the demand and does not exceed the supplier capacity. Equation (7) ensures at least one FLSP is selected to prevent the service delays. Equation (8) is needed to ensure all the demand are processed by FLSP. Equation (9) is

needed to ensure the number of logistics tasks assigned to the FLSP for each procedure does not exceed the capacity of each FLSP for each procedure. Equations (10) and (11) express the non-negative and integer values of the decision variables. Equation (12) defines the binary decision variable.

$$(\sum_{i}^{N_i} \sum_{k}^{N_k} C_{ik} + OC_{ik}) \cdot XC_{ik} + (\sum_{f}^{N_i} \sum_{j}^{N_j} \sum_{k}^{N_k} X_{fjk} \cdot C_{1_{fjk}} \cdot Q_{fjk} \cdot TC \cdot WC_{fjk}) \leq B \qquad (4)$$

$$\sum_{i}^{N_i} XC_{ik} \geq DC_k \qquad (5)$$

$$XC_{ik} \leq CAPC_{ik} \qquad (6)$$

$$\sum_{f}^{N_i} X_{fjk} \geq 1 \qquad (7)$$

$$\sum_{f}^{N_i} Q_{fjk} = DC_k \qquad (8)$$

$$Q_{fjk} \leq A_{fjk} \qquad (9)$$

$$XC_{ik} \geq 0 \text{ and integer} \qquad (10)$$

$$Q_{fjk} \geq 0 \qquad (11)$$

$$X_{fjk} \in \{0,1\} \qquad (12)$$

In Equation (4), there is a non-linear function as the result of multiplication of two decision variables. Hence, we have to conduct linearization by adding a surrogate variable. Equation (13) and (14) show the lower bound and upper bounds of the surrogate variable. In this case, the surrogate variable should not be greater than the integer decision variable to ensure the consistency of the model.

$$Var_{fjk} \geq Q_{fjk} - (1 - X_{fjk}) \times M \qquad (13)$$

$$Var_{fjk} \leq M \times X_{fjk} \qquad (14)$$

$$Var_{fjk} \leq Q_{fjk} \qquad (15)$$

RESULTS AND DISCUSSION

Optimization Results

In this section, we give a numerical example and sensitivity analysis to show the implementation of the model and how sensitive the model to the change of some input parameters. In the numerical example, a single manufacturer has to order three kinds of raw materials form three suppliers. All raw materials can be supplied by all suppliers except for Raw Material A which only supplied by Supplier 1 and 2. After determines the order allocation for each supplier, the delivery of the orders is done by single LSI which then order the logistics services to three FLSP with eight procedures. Unit product cost and unit order cost are shown in Table 1. The demand for each product is set at 9,500 units; the maximum budget for procurement expenditure is $5,000 and transportation cost per kg is $0.00023. The other parameters which deal with the FLSP activities are shown in Table 2.

Table 1. Unit product and order cost

Raw Material	Supplier	Unit Product Cost ($)	Unit Order Cost ($)	Supplier Capacity (Unit)
A	1	7.75	0.210	10,000
	2	6.15	0.210	5,000
	3	-	-	-
B	1	320	0.013	15,000
	2	290	0.014	1,000
	3	278.6	0.007	8,000
C	1	151.33	0.021	8,000
	2	34	0.004	10,000
	3	39.65	0.005	1,000

Table 2. Service Cost and FLS Capacity.

FLSP	Procedure	Raw Material Service Cost ($)			FLSP Capacity (Unit)		
		A	B	C	A	B	C
1	1	2.2	2.2	2.2	3350	3369	2576
	2	2.8	2.8	2.8	4557	3148	5560
	3	4.3	4.3	4.3	5847	5288	1170
	4	4.3	4.3	4.3	3573	3150	4734
	5	4.4	4.4	4.4	2311	3395	2048
	6	5.5	5.5	5.5	4500	4561	6751
	7	5.1	5.1	5.1	3457	2390	4286
	8	6.5	6.5	6.5	7890	6732	7865
2	1	2.3	2.3	2.3	2576	1096	3711
	2	3.2	3.2	3.2	2278	5589	3402
	3	4.5	4.5	4.5	3553	2911	2999
	4	5.2	5.2	5.2	4428	2152	3350
	5	4.8	4.8	4.8	4113	4866	5821
	6	4.6	4.6	4.6	3235	2387	4598
	7	4.8	4.8	4.8	2389	8798	6851
	8	5.6	5.6	5.6	6541	4531	3452
3	1	3.4	3.4	3.4	3711	5241	3350
	2	3.5	3.5	3.5	3947	4335	4756
	3	3.5	3.5	3.5	1320	3350	5899
	4	4.8	4.8	4.8	2987	4850	1887
	5	5.1	5.1	5.1	3541	1741	2435
	6	5.0	5.0	5.0	3576	5768	1578
	7	5.2	5.2	5.2	8976	2566	1897
	8	5.8	5.8	5.8	5456	3459	1765

Lingo 18.0 was used to solve the model using the embedded branch and bound method. The global optimum was found in the sixth iteration resulted a minimum cost at $1676.58. The optimal order for each supplier and the order for each FLSP is shown in

Table 3 and Table 4 respectively. From Table 3, the manufacturer should order Raw Material A from Supplier 1 and 2, Raw Material B from Supplier 1 and 3, and Raw Material C only from Supplier 2. As shown in Table 4, all FLSP are assigned to process the procedure for all materials.

Table 3. Optimal raw material order allocation

Raw material	Supplier	Order Allocation (Unit)
A	1	4500
	2	5000
	3	0
B	1	1500
	2	0
	3	8000
C	1	0
	2	9500
	3	0

Table 4. Order allocation for each FLSP

FLSP	Procedure	Order Allocation (Unit)		
		A	B	C
1	1	3350	3369	2576
	2	4557	3148	5560
	3	5847	5288	1170
	4	3573	3150	4734
	5	2311	3395	2048
	6	4500	4561	6751
	7	3457	2390	4286
	8	7890	6732	7865
2	1	2439	890	3574
	2	996	2017	1
	3	2333	862	2431
	4	2940	1500	2879
	5	3648	4364	5017
	6	1424	1	1171
	7	1	4544	3317
	8	1	1	1
3	1	3711	5241	3350
	2	3947	4335	3939
	3	1320	3350	5899
	4	2987	4850	1887
	5	3541	1741	2435
	6	3576	4938	1578
	7	6042	2566	1897
	8	1609	2767	1634

Sensitivity Analysis

The scenario for sensitivity analysis is shown in Table 5. Six parameters are studied to determine how sensitive the model towards the change of those parameters. For each parameter, we set four values each with the decrease and increase of 15% and 30% from the base line. Resume of the results of sensitivity analysis are shown in Table 6. From the table we can see that the change of all parameters value has the same effect on the decision variables, both the order allocation and outsourcing decisions. All the parameters value change are insensitive to both decision variables except for the demand. The increase of

demand by 15% made the model infeasible. This result indicates that when the demand increases by 15% the manufacturer should find other suppliers to fulfill the demand or otherwise requires some suppliers to increase their capacities. Two parameters are sensitive towards the objective function, namely the purchasing cost and demand. This becomes an indication for the manufacturer to have high awareness to those parameters especially when their value of those parameters increases.

Table 5. Sensitivity analysis scenarios

Parameter	Value Changes (%)				
C	-30	-15	0	15	30
TC	-30	-15	0	15	30
OC	-30	-15	0	15	30
B	-30	-15	0	15	30
DC	-30	-15	0	15	30
P	-30	-15	0	15	30

Table 6. Resume of the results of sensitivity analysis

Parameter	Order Allocation		Objective Function
	Suppliers	**FLSP**	
Purchasing cost	Insensitive	Insensitive	Sensitive
Unit Transportation Cost	Insensitive	Insensitive	Insensitive
Order Cost	Insensitive	Insensitive	Insensitive
Maximum Expenditure Cost	Insensitive	Insensitive	Insensitive
Demand	Sensitive	Sensitive	Sensitive
Unit Outsourcing Cost	Insensitive	Insensitive	Insensitive

CONCLUSIONS

In this research, we developed a MILP model to solve order allocation problem in a supply chain consists of multi supplier, single manufacturer considering MCLS to minimize total supply chain costs. MCLS was represented by single LSI which responsible to process the delivery of the raw material through a serial procedure done by several FLSPs. The costs of the supply chain comprise of purchasing cost, transportation cost, order cost, and outsourcing service cost. Based on the results of sensitivity analysis, among six parameters there are only one parameter has significant effect on the decision variables, namely the demand. On the other side, two variables have significant effect on the objective function, namely the unit purchasing cost and the demand. The model can be further developed by incorporating some decision variables such carrier selection, inventory, and lateral transhipment.

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