Sustainable supplier selection and order allocation using multi-objective linear programming

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Abstract
The importance of supplier selection and order allocation has given the advantage to manufacturer to improve the flow of supply chain. Although, recent several studies have been accomplished to incorporate environment sustainability, but there is still much less attention to consider the supply risk. In this study, those aspects will be taken into consideration. For supplier selection, AHP analysis is used to determine the weight of supplier based on suplier evaluation of environment criteria. For order allocation, multi-objective linear programming (MOLP) is proposed to determine the initial order allocation considering the aspect of economic and environmental sustainability, which the objective function consists of minimizing total purchasing cost and maximizing supplier evaluation. Then, risk management is used to mitigate supply risk by trasnferring the product from risky supplier to a least risky supplier. The problem of supplier selection and order allocation is applied to an automotive component manufacturer. Result shows the selected suppliers and the optimum order allocation obtained.

Keywords— Environmental sustainability; Supply risk; AHP; MOLP; Risk Management

1. Introduction

The rapid growth of industry in today's competitive environment has increased the competition between companies. In order to gain business competitiveness, companies are trying to focus on customer expectations of higher quality, lower price, shorter lead time, and less environmental impact (Azadnia et al., 2015). Due to this competition, companies are trying to improve the performance of their entire supply chain. Supplier selection and order allocation are essential decision steps in supply chain design to reduce purchasing costs, supply risks, and environmental impacts as well as to improve corporate price competitiveness (Azadnia et al., 2015; Kannan et al., 2013).

The conventional of supplier selection process was focused only on economic criteria such as cost, delivery, and quality during decision process. However, within rapidly changing environment, economic criteria are not enough to evaluate the suppliers. Therefore, different perspectives should be considered also. One of these is the sustainability. Chaharsooghi & Ashrafi (2014) reviewed the literature and summarized the sustainability supplier selection criteria consists of economy, environment, social, and also inclide risk management system, transparency, and culture & strategy that could be a consideration for sustanability.

The interest of sustainability has been increased among practitioners in the field of sustainable supply chain management (Amindoust et al., 2012). Giannakis & Papadopoulos (2016) stated that sustainability can be defined as the ability of an organization in making decisions, so that these decisions will have no bad impact on the future situation. As a result, the traditional supplier selection and order allocation problem has been changed into a sustainable supplier selection and order allocation problem where environmental and other influencing factors are incorporated in the selection and sourcing processes (Azadnia et al., 2015).

The supplier selection process starts with a performance evaluation where the suppliers are evaluated based on predefined criteria to determine the weight of each alternative. Handfield et al., (2002) evaluated the suppliers using AHP based on environmental criteria such as waste management, packaging/ reverse logistic, environmental certificates and environmental friendly product design. This is mostly due to the fact that AHP incorporates both qualitative and quantitative evaluation of the decision maker by the use of tangible and intangible factors designed in a hierarchical manner. The extensive application of the analytic hierarchy process (AHP) method is due to its simplicity, ease of use, and flexibility (Borade et al., 2013).

The used of multi-objective linear programming is widely used for supplier selection or selection and order allocation for multiple objective. Azadnia et al. (2015) proposed multi-objective function model to determine the quantity of orders allocated to each supplier, in order to minimize the cost (inventory, purchasing, ordering and transportation cost), maximize the total score of all suppliers in terms of social and environmental issues and maximize the overall score of suppliers in terms of economical qualitative criteria.

It is not difficult to see the impact of suppliers on a firm's total cost. In most industries the cost of raw materials and component parts represents the main cost of a product. For instance, in high technology firms, purchased materials and services represent up to 80% of the total product cost (Weber et al, 1991). Therefore, optimizing the order allocation is crucial in maintaining the total cost of a product.

In dealing with the supply chain, companies often face risks that occurred caused by within and outside of the supply chain. In a survey conducted by Deloitte, 71 percent of the respondents view supply chain risk as a crucial factor in their firm's strategic decision-making (Marchese & Paramasivam, 2013). Supply chain risk categorizes as either operational or disruption risk (Jianlin, 2011). Uncertain customer demand, supply, and cost are the operational risk and disruption risk refers to the major disruptions caused by natural and man-made disasters.

The impact of disruption risk can lead to a loss in productivity, quality, market share, and reputation for the suppliers and the supply chain (Chopra & Sodhi, 2014). This also leads to an increase in the purchasing and logistics cost as the manufacturers are often forced to find and select suppliers quickly from elsewhere and to do the shipping right in time to maintain service levels.

The role of risk management is not just in responding to anticipated events but also to implement the culture and organization that can respond to unanticipated risk events (Coleman, 2011). Most companies recognize the importance of risk assessment programs and use different methods, ranging from formal quantitative models to informal qualitative plans, to assess supply chain risks. However, most companies still less invest in risk management for mitigating SC risks (Jianlin, 2011).

Based on literature, there are still very limited research activities have been done of supplier selection and order allocation considering environmental sustainability and supply risk of multi-product. Therefore, supplier selection and order allocation considering environmental sustainability and supply risk using multi-objective linear programming is developed. In addition, this problem is applied to an automotive component manufacturer.

The rest of his paper is organised as follow: in Section 2, a literature review which includes suppplier selection and order allocation and related supplier selection criteria is given. Section 3, a detailed explanation of the proposed framework, proposed model of multi-objective linear programming, and model of mitigating supply risk are presented, then followed by Section 4 in which industry application is presented. Finally, in section 5 present the conclusion.

2. Literature Review

In this section, a brief review of the recent literature is presented in two sub-section including supplier selection & order allocation and supplier selection criteria.

2.1 Supplier selection and order allocation

The supplier selection and order allocation problem have been widely addressed by many researchers. Various decision problems and criteria category have been considered as supplier selection. Park et al. (2018) presented the sustainable supplier selection and order allocation considering the economic, social, and environmental factors. Multi-objective integer linear programming model is formulated to find the optimal suppliers and determine their order quantities.

Chang & Chang (2017) presented multi-objective method and focuses on cost minimization, as well as quality and capacity maximization. The proposed model not only considers the allocation of different order quantities among the selected suppliers, but also incorporates the multi-stage inventory problem.

Babbar & Amin (2017) present suppluier selection and order allocation, and proposed a two-stage QFD model to determine the weights of suppliers and then rank them, multi-objective mixed integer linear programming developed to find order quantity with considering five objectives (cost, defect rate, carbon emission, weight of suppliers, on-time delivery), and fuzzy is used to consider the vagueness in human thoughts.

Hamdan & Cheaitou (2017) developed a model to find the supplier in multi period problem considering green criteria. This methodology includes three steps in which fuzzy TOPSIS, AHP, and multi-objective optimization are used. In this approach, weights are assigned to both green and traditional criteria.

Kırılmaz & Erol (2017) present the integer linear programming for order allocation. They focus on the aspect of economic and risk management. The minimization of procurement cost for the order allocation procurement plan, then risk managament is taken into consideration to mitigate supply side risks.

Azadnia et al. (2015) propose an integrated approach of rule-based weighted fuzzy method, fuzzy analytical hierarchy process and multi-objective mathematical programming for sustainable supplier selection and order allocation combined with multi-period multi-product lot-sizing problem. The mathematical programming model consists of four objective functions which are minimizing total cost, maximizing total social score, maximizing total environmental score and maximizing total economic qualitative score.

Pazhani et al, (2015) present the supplier selection and order quantity allocation in a multi-stage serial supply chain system with multiple suppliers considering inventory replenishment, holding, and transportation costs simultaneously. They proposed a mixed integer nonlinear programming model to determine the optimal inventory policy for the stages in the supply chain and allocation of orders among the suppliers at the initial stage.

Arabzad et al., (2014) present supplier selection and order allocation problem. FTOPSIS is used to do the supplier evaluation. The result from supplier evaluation and determined constraints were considered as inputs for MILP and the output was the allocated quantity to each supplier.

Singh (2014) presented supplier evlauation and demand allocation problem by integrating the supplier rating with mixed linear integer programming method. The customer demand is allocated by using a hybrid algorithm based on the technique for order preference by similarity to ideal solution (TOPSIS) and the mixed linear integer programming (MILP) approaches.

Kannan et al. (2013) proposed FAHP for determining the relative weights of supplier selection criteria, and fuzzy TOPSIS for ranking the best green suppliers according to economic and environmental criteria and then allocating the optimum order quantities among them using multi-objective programming.

2.2 Supplier selection criteria

The concept of sustainability has become a key factor in supply chain management. Companies are trying to incorporate sustainability elements on their supplier, in order to meet their customers' sustainability expectations. Chaharsooghi & Ashrafi (2014) mention that there are various criteria to evaluate supplier selection, which include economic, environmental, and risk management system criteria.

a. Economic Criteria

Economic criteria have been considered for evaluating the suppliers in conventional supplier selection approach, such as price, quality and delivery (Govindan et al., 2013). Economic criteria can be considered as the most important factor. Economic criteria concern on the main purpose of the organization, which is to gain higher profits. It can be attained by reducing costs in different areas. It includes criteria like product cost, ordering and logistic cost, inventory cost, custom and insurance cost (Grover et al., 2016).

b. Environmental Criteria

In recent years, environmental criteria have been used by many researchers in the process of evaluation of suppliers. Green supplier and sustainable supplier are the most common terms which have been used in the studies of this field. The environment has the impact and directly affects the quality of life on earth by the manufacturing and industrial activities. This caused by consuming raw materials and energy, emitting toxic gases and materials which causes air pollution, and making sound pollution (Molamohamadi et al., 2013).

c. Risk Management system Criteria

The concept of risk and its management was identified as a reoccurring theme in the sustainability theory. Such supply chain risks can result from natural disasters such as hurricanes, legal liabilities, poor demand forecasting, failure to fulfill demand requirements across the supply chain, fluctuating prices for key raw materials including energy, poor supplier quality, shipment quantity inaccuracies, and poor environmental and social performance by a firm and its suppliers which can result in costly legal actions. Within the context of sustainability, supply chain risk management is defined as the ability of a firm to understand and manage its economic, environmental, and social risks in the supply chain (Carter & Rogers, 2008).

3. Proposed framework

In this section, the proposed framework of this study is presented by explaining each step. The proposed framework of this research is shown in Figure 1. The approach shows how the supplier selection and order allocation consider three criteria of economy, environment, and risk management The steps of the proposed framework are shown in Figure 1.

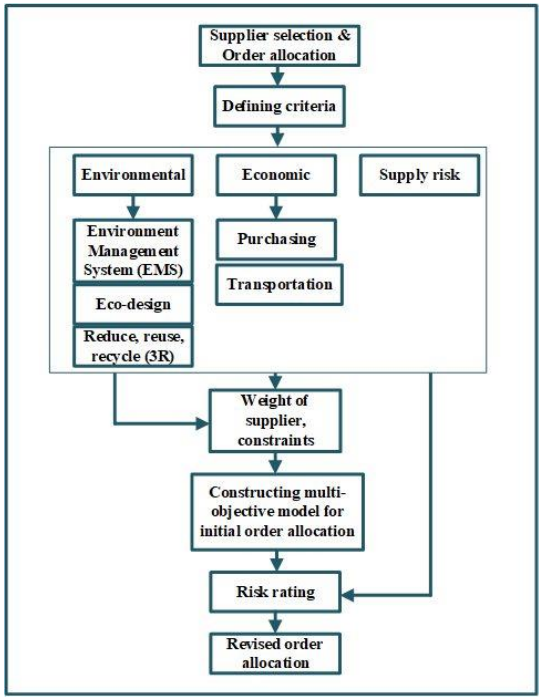

Figure 1. Proposed framework

(1) Selecting available suppliers.
(2) Determine the criteria, sub criteria, and influencing factors to evaluate the suppliers.
(3) Assessing the suppliers based on environment criteria using AHP analysis.
(4) Determine the initial order allocation based on environment and economy criteria by constructing multi-objective model.
(5) Determine the revised order allocation corresponding to risk rating of each supplier.

A detailed description of each step is as follows.
Step 1 : Select all available supplier
Step 2 : Determine the criteria, sub criteria, and other influencing factors for supplier evaluation. The criteria and sub criteria are obtained from previous study as reference. In this step, environment criteria are considered for supplier evaluation and selection. The environment criteria is divided into three sub criteria including EMS, eco-design, and 3R as shown in Figure 1.
Step 3 : . The environment criteria are assessed using AHP analysis, which resulted in weight of supplier. This result as the input for determine the order allocation.
Step 4 : Determine the initial order allocation regarding to environment and economy criteria. Economy criteria is including cost (purchase and transportation). The weight of supplier and other constraints, which are demand, capacity, are as input to determine the initial order allocation. The weight of supplier is intended to give rank for supplier evaluation. The highest weight of supplier means the best supplier which the most reliable supplier. Determining the initial order allocation by constructing the multi-objective linear programming. The proposed model of multi-objective is shown in Equation (1) and (2). Sum-weighted is used to determine the importance of each objective by giving weight to each objective. This method is formulated as shown in Equation (6).

3.1 Multi-objective linear programming of initial order allocation

Decision variable

Q_{si} : Quantity of product s^{th} allocated from supplier i^{th} to manufacturer
Y_i : 1 if an order allocated from supplier i^{th},
0 otherwise

Notation

s : Product indices (s=1,2,..,5)
i : Supplier indices (i=1,2,..,4)

Parameter
V_{si} : Capacity of i[th] supplier for s product
D_s : Demand of product s[th]
PS_i : Purchasing price per unit of product s delivered by supplier i[th]
TC_i : Transportation cost of supplier i[th] per delivery
W_i : Weight of supplier i[th]

Objective functions and constraints of the proposed model are presented as follows:

a. Minimizing total purchasing cost
The objective function is determining the order allocation based on total purchasing cost, which consist of purchasing price and transportation cost.
$$\text{Min} = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*P_{si} + \sum_{i=1}^{4} TC_i*Y_i \quad (1)$$

b. Objective function of Z2 maximizing supplier evaluation
This objective function is determining the order allocation based on supplier evaluation with weight of supplier.
$$\text{Min} = \sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si}*W_i \quad (2)$$

Constraint
Capacity constraint
The capacity constraint means that the quantity allocated for each product from each supplier should be less than or equal to supplier's capacity.
$$\sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si} \geq V_{si} \quad (3)$$

Demand Constraint
The demand constraint requires the quantity for each product allocated should be more than or equal to demand.
$$\sum_{s=1}^{5}\sum_{i=1}^{4} Q_{si} \geq D_s \quad (4)$$

Non-negative constraint
$$Q_{si} \geq 0 \quad (5)$$

3.2 Weighted-sum method
The weighted sum model (or WSM) is probably the most commonly used approach, especially in single dimensional problems (Triantaphyllou et al., 1998). Weighted-sums method is the most straightforward technique for solving multi-objective problems. Using the weighted sum method to solve a problem entails selecting scalar weights w_i and optimizing the following composite objective function. The values of different functions or the coefficients of the terms in the functions may have different order of magnitude, it is necessary to normalize the objectives, in order to convert all objectives into the same dimensions or dimensionless before combining them into one.

The objective function of Z3 is defined which is minimized. w_1 and w_2 are the weights of objective functions. a is defined as the index of the objectives. This method is formulated as follows.
$$\text{Min } Z3 = w_1z_1 - w_2z_2 \quad (6)$$
Subject to:
$$\sum_a w_a = 1 \quad (7)$$
$$w_a \geq 0 \quad (8)$$
Equations (3)-(5)

Step 5 : Determine the revised order allocation corresponding to risk rating of each supplier. Risk rating is considered to determine the revised order allocation, which to transfer the product from risky supplier to a less risky supplier. The model developed by Kırılmaz & Erol (2017). The model is shown in section 3.3.

3.3 Risk Management
Kırılmaz & Erol (2017) presented the risk management to mitigate the supply risk and they also developed the model to transfer the product item supplied from risky supplier to a least risky supplier. Zsidisin (2003) mentioned supply

risk is the transpiration of significant and/or disappointing failures with inbound goods and service. The steps of risk management process are as follow.

a. Risk Identification

Risk identification is the first stage of the risk management. The supply chain risk is identified and divided into elements such as suppliers and manufacturer which known as inbound logistic risk. The SC risk identification is obtained from literature and the expert (manager of logistic) by brainstorming with the expert to evaluate the suitable risk from literature.

b. Risk Measurement

Risk measurement is measuring the risk by two criteria, probability and impact of the risk. Probability can be analysed by historical data of past risk events, how often the risk is likely to occur. The impact of the risk is usually expressed in cost, performance loss and time loss. The probability-impact matrix is presented in Table 1.

Table 1. Probability-impact matrix

			Impact Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	Rare	1	1	2	3	4	5
	Unlikely	2	2	4	6	8	10
	Moderate	3	3	6	9	12	15
	Likely	4	4	8	12	16	20
	Almost certain	5	5	10	15	20	25

c. Risk Evaluation

Risk evaluation is the process of comparing the results of risk analysis with risk criteria to determine whether the risk is acceptable or tolerable. Risk evaluation is shown in Table 2. Risk profile is a measure that indicates the risk level of a supplier.

$$Rt = \sum_{j=1}^{J} R_j * Y_j \quad (9)$$

Rt = Risk total value

Y_j = 0, risk index of j identified risk is less than the risk criteria of the company

1, risk index of j identified risk is greater than or equal to the risk criteria of a company

j = Identified risk from 1 to J

Table 2. Risk evaluation

Risk index	Definition
1-2	Acceptable, no action required
3-4-5	Acceptable, should be monitored
6-8-9-10-12-15	Undesirable and measure should be taken
16-20-25	Unacceptable

d. Risk Mitigation

A mitigation strategy is proposed to decrease the expected impact of risk. In this study, the first stage of order allocation is being identified using linear programming with minimizing the total cost. The second stage of order allocation is modified, which considering the risk profiles of suppliers. The order allocation from minimum total cost is proportioned to the risk profile of each supplier and the quantity is transferred to a more reliable supplier or less risky supplier. The total risk profiles of each supplier which has the least risky supplier is set to zero, then this risk profile is subtracted from the risk profiles of other suppliers and the value are normalized, which shown in Table 3. This normalized value represent the risk status of supplier and used to find the quantity transferred to less risky supplier, which shown in Table 4.

Table 3. Normalized risk value

Suppliers	Total risk rating	Subtraction risk rating	Normalized value
1	R_{t1}	$R_{t1}-R_{t2}$	$R_{N1}= (R_{t1}-R_{t2})/ R_{gt}$
2	R_{t2}	0	$R_{N2}=0$
3	R_{t3}	$R_{t3}-R_{t2}$	$R_{N3}= (R_{t3}-R_{t2})/ R_{gt}$
4	R_{tn}	$R_{t4}-R_{t2}$	$R_{Nn}= (R_{t4}-R_{t2})/ R_{gt}$
	Total	R_{gt}	1

Table 4. Parameters used in model

Suppliers	Initial order allocation	Normalized risk values	Quantity transferred	Remaining quantity in supplier	Remaining capacity of supplier
1	Q_{c1}	R_{N1}	$Q_{c1*}*R_{N1}$	$Q_{c1}-(Q_{c1*}*R_{N1})$	RC_1
2	Q_{c2}	R_{N2}	$Q_{c2*}*R_{N2}$	$Q_{c2}-(Q_{c2*}*R_{N2})$	RC_2
3	Q_{c3}	R_{N3}	$Q_{c3*}*R_{N3}$	$Q_{c3}-(Q_{c3*}*R_{N3})$	RC_3
4	Q_{cn}	R_{Nn}	$Q_{cn*}*R_{Nn}$	$Q_{cn}-(Q_{cn*}*R_{Nn})$	RC_n

The objective is to maximize the product transferred from high risk supplier to less risky supplier.

$$\text{Max} = \sum_i^I \sum_j^J N_{ij} * X_{ij} \quad (10)$$

$$\sum_j^J X_{ij} \leq Q_{Ti} \quad (11)$$

$$\sum_k^K X_{ki} - \sum_j^J X_{ij} \leq C_{Ri} \quad (12)$$

Where N_{ij} is the positive difference between the normalized risk value of the node (supplier) i and node j,

j = Indicates all less risky supplier than supplier i
i = Indicates all more risky supplier than supplier i
Q_{Ti} = Quantity to be transferred from supplier i
C_{Ri} = Remained capacity of supplier i

e. Risk Monitoring and Control

The risk management process is a cycle and the risk monitoring and control phase enables this process to be dynamic. Since risk is related to the future, events should be observed and the data about events should be updated and assessed all the time.

4. Industry application

The data is obtained from an automotive component manufacturer. Its raw material which is plate material supplied by 4 suppliers, which the supply network shown in Figure 2. There are 5 type of plate material. The demand from manufacturer is in Table 5, which shows demand for 3 months. The capacity presented in Table 6, the unit purchasing price is in Table 7, and the transportation cost per delivery from suppliers to manufacturer shown in Table 8.

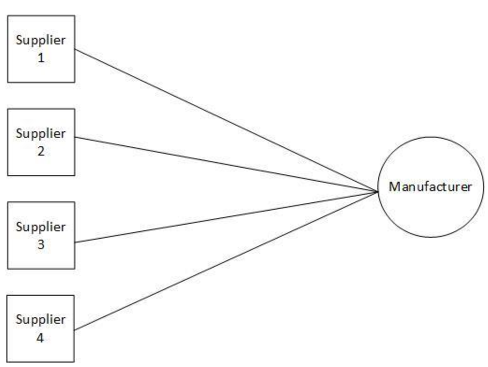

Figure 2. Supply network

Table 5. Demand

Products	Months		
	May	June	July
A1	450	450	450
A2	1150	1150	1150
A3	250	250	250
A4	3250	3250	3250
A5	2300	2300	2300

Table 6. Capacity

Items	Suppliers			
	1	2	3	4
A1	150	150	100	150
A2	450	350	300	400
A3	100	100	100	100
A4	1050	1000	1000	1000
A5	1000	600	600	600

Table 7. Price per unit

Items	Suppliers			
	1	2	3	4
A1	12,500	12,400	12,600	12,475
A2	12,500	12,400	12,600	12,475
A3	12,500	12,400	12,600	12,475
A4	12,000	12,100	12,200	12,050
A5	12,000	12,100	12,200	12,050

Table 8. Transportation cost

Suppliers	1	2	3	4
Cost	1,152,000	3,744,000	1,632,000	4,500,000

4.1 Supplier selection

The step of supplier selection is evaluating the supplier with determining the weight of each supplier and the method is using AHP. The aspect of environment sustainability is considered in this research. The environment criteria is obtained from literature review. To do the supplier evaluation accurately, it is necessary to calculate criteria weights to know the rank of alternatives. Therefore, the result is the weight of criteria and the rank of each supplier. The criteria of environment is adopted from Song et al. (2017). The environment criteria are EMS (environment management system) (C1), eco-design (C2), and 3R (reduce, reuse, recycle) (C3) as shown in Figure 3, which the hierarchy of supplier evaluation. The company's expert was asked to make pairwise comparison. The scheme proposed by Saaty, shown in Table 9, can be used to translate linguistic judgments into numbers. The result for final weight or global priority of environment criteria is shown in Table 10. After the global priority obtained, the weight of each alternative is calculated with sum all weight of global priority of each supplier and the ranks of each supplier are obtained. The weight supplier evaluation and rank for suppliers are presented in Table 11.

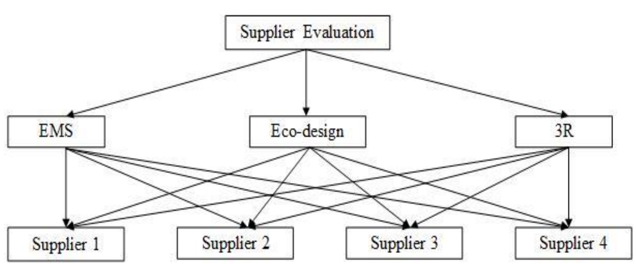

Figure 3. Hierarchy of supplier evaluation

EMS is a set of systematic processes and practices that enable a supplier to reduce its environmental impacts, which includes the organizational structure, planning and implementing policy (e.g., ISO 14001 and TQEM) for environmental protection.. Eco-design is designing product with consideration of environmental impacts during the whole product lifecycle including the stages of procurement, manufacture, use, and disposal. 3R relates to pollution (e.g., air pollution and water pollution) reduction, greening packaging and waste recycling & reuse.

Table 9. AHP judgement score

Judgement	Score
Equal	1
Barely better	2
Weakly better	3
Moderately better	4
Definitely better	5
Strongly better	6
Very strongly better	7
Critically better	8
Absolutely better	9

Table 10. Global priority of environment criteria

Goal	Criteria	Weight	Alternatives	Alt. Weight Evaluation
Supplier Evaluation	Environment management system	0.137	S1	0.013
			S2	0.022
			S3	0.034
			S4	0.069
	Eco-design	0.239	S1	0.025
			S2	0.064
			S3	0.052
			S4	0.098
	3R	0.623	S1	0.060
			S2	0.129
			S3	0.146
			S4	0.289

Table 11. Overall weight alternative

Alternatives	Eigen Value	Rank
S1	0.096	4
S2	0.215	3
S3	0.232	2
S4	0.456	1

4.2 Multi-objective of initial order allocation

The linear programming software LINGO 17.0 was used to perform the initial order allocation. The final results of optimization for the problem of environment and economy criteria are shown in Table 12. The result shows the initial order allocation of each product from each supplier. The result of objective function Z1 is the minimization of total purchasing, and the objective function Z2 is the maximization of supplier evalation. The result of objective Z2 doesn't represent any quantity but the maximazation satisfies the condition of supplying the product from selected supplier of environment criteria by supplier evaluation weight.

Table 12. Optimal soultion of order allocation

Weight (w_1, w_2)	Product	Month	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Objective Function Z1	Objective Function Z2
(0.8, 0.2)	A1	May	150	150	0	150	12,001,800	8.750396
		June	150	150	0	150	12,001,800	8.750396
		July	150	150	0	150	12,001,800	8.750396
	A2	May	450	0	300	400	17,343,200	22.36212
		June	450	0	300	400	17,343,200	22.36212
		July	450	0	300	400	17,343,200	22.36212
	A3	May	100	100	50	0	7,718,400	4.861331
		June	100	100	50	0	7,718,400	4.861331
		July	100	100	50	0	7,718,400	4.861331
	A4	May	1,050	1,000	200	1,000	40,174,400	63.19731
		June	1,050	1,000	200	1,000	40,174,400	63.19731
		July	1,050	1,000	200	1,000	40,174,400	63.19731
	A5	May	1,000	600	100	600	30,990,400	44.72425
		June	1,000	600	100	600	30,990,400	44.72425
		July	1,000	600	100	600	30,990,400	44.72425

4.3 Revised order allocation considering supply risk

The risk management is applied to the calculation of determining the revised order allocation based on risk rating, in order to mitigate the supply risk. The risk management consists of risk identification, risk measurement, risk evaluation, and risk mitigation. The risk mitigation is the result of revised order allocation plan. The risk events are adopted from Kırılmaz & Erol (2017) and Zsidisin (2003). The result of risk rating is presented in Table 13.

Table 13. Risk rating of each supplier

Risk	Risk Rating S1	S2	S3	S4
Delivery failures	4	2	2	2
Quality problems	9	6	9	3
Price/cost increases	3	3	3	2
Inability to meet quantity demand	3	3	3	3
Discontinuity of supply	4	4	4	4
Bankruptcy of supplier	3	3	3	3
Supplier capacity	6	6	6	6
Machine breakdowns	9	3	6	3
Malfunction of IT system	2	1	2	1
Accident risk	1	1	1	1
Extreme weather condition	1	1	1	1
Total risk rating	45	33	40	29

After the total risk rating is obtained, the risks should be mitigated by reallocated the order allocation or shifting the order from risky supplier to the less risky or reliable supplier. Table 14 shows the normalized value of risk rating. The result of reallocation order quantity is shown in Table 15, and this result also used as parameter for determining the revised order allocation. Table 16 shows the difference between normalized risk values, and it is also the other parameter that will be used for the calculation.

Table 14. Normalized value of risk of risk rating

Supplier	Total risk rating	Subtraction risk rating	Normalized value
1	45	16	0.516
2	33	4	0.129
3	40	11	0.355
4	29	0	0
Total		31	1

Table 15. Result of reallocation order quantity

Product	Supplier	Initial order allocation	Normalized risk values	Quantity transferred	Remaining quantity in supplier	Remaining capacity of supplier
A1	1	150	0.516	77	73	0
	2	150	0.129	19	131	0
	3	0	0.355	0	0	100
	4	150	0	0	150	0
A2	1	450	0.516	232	218	0
	2	0	0.129	0	0	350
	3	300	0.355	106	194	0
	4	400	0	0	400	0
A3	1	100	0.516	52	48	0
	2	100	0.129	13	87	0
	3	50	0.355	18	32	50
	4	0	0	0	0	100
A4	1	1050	0.516	542	508	0
	2	1000	0.129	129	871	0
	3	200	0.355	71	129	800
	4	1000	0	0	1000	0
A5	1	1000	0.516	516	484	0
	2	600	0.129	77	523	0
	3	100	0.355	35	65	500
	4	600	0	0	600	0

Table 16. Difference between normalized risk values

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	0.516	0.355	0.129	0.161	0.387	0.226

After determining parameters, those values will be used to determine the order allocation of product transfer from risky supplier to less risky supplier. The order allocation of every product is calculated with considering the constraint of each product. The objective function is to maximize the product transfer from risky supplier to less risky supplier. The value of objective function doesn't represent any quantity, but the maximization satisfies the condition of transferring product from risky supplier to a less risky supplier. The model is solved with Lingo 17.0 software. The mathematical model of each product is as follows.

1. Product A1

Objective function

Max: $0.516*X_{14} + 0.355*X_{34} + 0.129*X_{24} + 0.161*X_{13} + 0.387*X_{12} + 0.226*X_{32}$ (13)

Constraints

Equation (14), (15), (16) are the capacity constraint, while Equation (17),(18),(19) are the constraint for product transfer, and Equation (20) is the non-negative constraint.

$X_{13} - X_{32} - X_{34} \leq 100$ (14)

$X_{12} + X_{32} - X_{24} \leq 0$ (15)

$X_{14} + X_{34} + X_{24} \leq 0$ (16)

$X_{14} + X_{12} + X_{13} \leq 77$ (17)

$X_{24} \leq 19$ (18)

$X_{34} \leq 0$ (19)

$X_{ij} \geq 0$ (20)

The optimal solution of product A1 is shown in Table 17. In the Table 17 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 17. Optimal solution A1

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	0	0	0	77	0	0

In Table 17 above, it shows that the product transferred from supplier 1 to supplier 3 is 77 items. In table 18 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained product transferred from supplier 1, which is 77 items, and the revised order allocation of supplier 1 is obtained from quantity remaining in supplier and the other are obtained from the initial order allocation since there is no product transfer from these suppliers.

Table 4.18 Initial and revised order quantity A1

Suppliers	Initial order allocation	Risk rating	Revised order allocation
1	150	45	73
2	150	33	150
3	0	40	77
4	150	29	150
Total	450		450

2. Product A2

Objective function

Max: $0.516*X_{14} + 0.355*X_{34} + 0.129*X_{24} + 0.161*X_{13} + 0.387*X_{12} + 0.226*X_{32}$ (21)

Constraints

Equation (22), (23), (24) are the capacity constraint, while Equation (25) and (26) are the constraint for product transfer, and Equation (27) is the non-negative constraint.

$X_{12} + X_{32} - X_{24} \leq 350$ (22)

$X_{13} - X_{32} - X_{34} \leq 0$ (23)

$X_{14} + X_{34} + X_{24} \leq 0$ (24)

$X_{14} + X_{13} + X_{12} \leq 232$ (25)

$X_{32} + X_{34} \leq 106$ (26)

$X_{ij} \geq 0$ (27)

The optimal solution of product A2 is shown in Table 19. In the table 19 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 19. Optimal solution A2

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	0	0	0	0	232	106

In Table 19 above, it shows that the product transferred from supplier 1 to supplier 2 is 232 items, and from supplier 3 to supplier 2 is 106 items. In table 20 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 2 is obtained from product transferred from supplier 1 and supplier 3, which resulted in 338 items, and the revised order allocation of supplier 1 and supplier 3 are obtained from remaining quantity in the supplier and another order allocation is from initial order allocation since there is no product transfer from this supplier.

Table 20. Initial and revised order quantity A2

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	450	45	218
2	0	33	338
3	300	40	194
4	400	29	400
	1150		1150

3. Product A3

Objective function

Max: $0.516{*}X_{14} + 0.355{*}X_{34} + 0.129{*}X_{24} + 0.161{*}X_{13} + 0.387{*}X_{12} + 0.226{*}X_{32}$ (28)

Constraints

Equation (29), (30), (31) are the capacity constraint, while Equation (33), (34), (35) are the constraint for product transfer, and Equation (35) is the non-negative constraint.

$X_{13} - X_{32} - X_{34} \leq 50$ (29)

$X_{14} + X_{34} + X_{24} \leq 100$ (30)

$X_{12} + X_{32} - X_{24} \leq 0$ (31)

$X_{13} + X_{12} + X_{14} \leq 52$ (32)

$X_{24} \leq 13$ (33)

$X_{34} + X_{32} \leq 18$ (34)

$X_{ij} \geq 0$ (35)

The optimal solution of product A3 is shown in Table 21. In the table 21 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 21. Optimal solution A3

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	52	18	13	0	0	0

In Table 21 above, it shows that the product transferred from supplier 1 to supplier 4 is 52 items, from supplier 3 to supplier 4 is 18 items, and from supplier 2 to supplier 4 is 13 items. In table 22 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 4 is obtained from product transferred from supplier 1 , supplier 3, and supplier 2, which resulted in 83 items, and the other revised order allocation of other supplier are obtained from remaining quantity in the supplier.

Table 22. Initial and revised order quantity A3

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	100	45	48
2	100	33	87
3	50	40	32
4	0	29	83
Total	250		250

4. Product A4

Objective function

Max: $0.516{*}X_{14} + 0.355{*}X_{34} + 0.129{*}X_{24} + 0.161{*}X_{13} + 0.387{*}X_{12} + 0.226{*}X_{32}$ (36)

Constraints

Equation (37), (38), (39) are the capacity constraint, while Equation (40), (41), (42) are the constraint for product transfer, and Equation (43) is the non-negative constraint.

$X_{13} - X_{32} - X_{34} \leq 800$ (37)

$X_{12} + X_{32} - X_{24} \leq 0$ (38)

$X_{14} + X_{34} + X_{24} \leq 0$ (39)

$X_{14} + X_{13} + X_{12} \leq 542$ (40)

$X_{24} \leq 129$ (41)

$X_{32} + X_{34} \leq 71$ (42)

$X_{ij} \geq 0$ (43)

The optimal solution of product A3 is shown in Table 23. In the table 23 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 23. Optimal solution A4

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	0	0	0	542	0	0

In Table 23. above, it shows that the product transferred from supplier 1 to supplier 3 is 542 items. In table 24 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained from product transferred from supplier 1 and the initial order allocation, which resulted in 742 items, the revised order allocation of supplier 1 is only 508 left, and the other are obtained from initial order allocation.

Table 24. Initial and revised order quantity A4

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	1050	45	508
2	1000	33	1000
3	200	40	742
4	1000	29	1000
Total	3250		3250

5. Product A5

Objective function

Max: $0.516*X_{14} + 0.355*X_{34} + 0.129*X_{24} + 0.161*X_{13} + 0.387*X_{12} + 0.226*X_{32}$ (44)

Constraints

Equation (45), (46), (47) are the capacity constraint, while Equation (48), (49), (50) are the constraint for product transfer, and Equation (51) is the non-negative constraint.

$X_{13} - X_{32} - X_{34} \leq 500$ (45)

$X_{12} + X_{32} - X_{24} \leq 0$ (46)

$X_{14} + X_{34} + X_{24} \leq 0$ (47)

$X_{14} + X_{12} + X_{13} \leq 516$ (48)

$X_{24} \leq 77$ (49)

$X_{34} + X_{32} \leq 35$ (50)

$X_{ij} \geq 0$ (51)

The optimal solution of product A5 is shown in Table 25 with total solver iterations of 4 iteration. In the table 25 below is mentioned quantity that should be transfer from risky supplier to a less risky supplier.

Table 25. Optimal solution A5

R_{ij}	R14	R34	R24	R13	R12	R32
N_{ij}	0	0	0	500	0	0

In Table 25 above, it shows that the product transferred from supplier 1 to supplier 3 is 500 items. In table 26 also shows the difference between initial and revised quantity corresponding to the risk rating. The revised order allocation of supplier 3 is obtained from product transferred from supplier 1, which resulted in 600 items, revised order from supplier 1 is only 500 left, and the other revised order allocation of other supplier are obtained from initial order allocation.

Table 26. Initial and revised order quantity A5

Suppliers	Initial order allocation	Risk profile	Revised order allocation
1	1000	45	500
2	600	33	600
3	100	40	600
4	600	29	600
Total	2300		2300

5. Conclusion

This research is about supplier selection and order allocation with developing proposed framework of considering the aspect of environement and supply risk. The comparisons in this research are considering the aspect of environment sustainability and supply risk. The proposed framework is applied to an automotive component manufacturer. First of all, the criteria, sub criteria, and other influencing factors are determined. The criteria are economy, environement, and risk management. Then, AHP is used to determine the weight of supplier based on the supplier evaluation of environment criteria. Second, the weight of supplier as the input for determining the initial order allocation using multi-objective linear programming. MOLP is proposed with the objective function of minimizing the total purchasing cost and maximizing the supplier evaluation. Third, risk managament is performed, which determine the order allocation coressponding to risk rating, in order to mitigate the supply risk. Mitigating the supply risk is transferring the product from risky supplier to a less risky supplier, and resulted in revised order allocation. The result shows the optimum order allocation considering the maximization of supplier evaluation of environement sustainability, minimization of total purchasing cost, and maximization the flow of transferring product from risky supplier to less risky supplier to mitigate supply risk. For future research there might be other aspect to be considered, such as the inventory replenishment which can extend the model of considering multiple objective.

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