CHAPTER II

LITERATURE

2.1 Inductive Study

The supplier selection and order allocation (SSOA) problem has been widely addressed by many researchers. The inductive study below is from similar research of previous study.

Park et al. (2018) presented the sustainable SSOA 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. The finding is the optimum order allocation under a multiple sourcing strategy for different product designs.

Lo et al. (2018) presented an integrated model for solving problems in green SSOA by proposed a novel that integrates the best-worst method. The method is using fuzzy TOPSIS and fuzzy multi-objective linear programming (FMOLP) to solve problems in green supplier selection and order allocation. The results indicate that this model can effectively evaluate the performance of green suppliers and can also optimize order allocation for qualified suppliers.

Ghadimi et al., (2017) presented a multi-agent sustems approach for sustainable SSOA in partnership supply chain. The method is using Fuzzy Inference System (FIS) for calculation the suppliers' sustainability performance score based on the defined evaluation criteria and influencing factors. Then, multi-objective programming model to deal with sustainable supplier selection problem with multiple products and multiple sourcing decision in a required decision period. This research shows that financial performance of manufacturing companies adopting environmental and social sustainability in their operations strategy enhanced their competitive advantage that can lead to long-term sourcing relationships for the buyer-supplier.

Chang & Chang (2017) presented a multi-stage and multi-supplier inventory model allowing different order quantities and proposed single-objective and multi-objective method. The finding is single-objective problem consistently obtains a better results.

Babbar & Amin (2017) presented an integrating environmental concerns for SSOA and porposed 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 and fuzzy is used to consider the vagueness in human thoughts. The finding is the best suppliers are selected and the optimum result of comparing 3 methods (weighted-sum, ε-constraint, distance method) are shown because no single method is good in all situation.

Ghorabaee et al., (2017) presented supplier evaluation and order allocation with environment consideration and proposed an integrated model for supplier evaluation and order allocation with respect to environmental criteria. The method is using fuzzy and multi-objective linear programming. The finding is the optimum order allocation is obtained.

Hamdan & Cheaitou (2017) presented SSOA with green criteria. The methodology includes fuzzy TOPSIS, AHP, and multi-objective optimization is used. Fuzzy TOPSIS is used to assign two preference weights to each potential supplier. AHP to assign a global importance weight to each of the two sets of criteria based on the strategy of the company and independently of the potential suppliers. MOP is used to select the best supplier and allocate orders. The finding is the optimum order allocation is obtained.

Kırılmaz & Erol (2017) presented order allocation considering supply risk. The method used integer linear programming and risk management. Risk management was used to mitigate supply risk. The finding is the optimum order allocation is obtained with considering the supply risk.

Çebi & Otay (2016) presented supplier evaluation and order allocation problem with quantity discount and lead time. The method applied fuzzy MULTIMOORA which originated from MOORA (Multi-Objective Optimization by Ratio Analysis) and fuzzy goal programming to determine the amount of order allocated to selected suppliers. The finding is optimum order allocation is obtained under multiple products.

PrasannaVenkatesan & Goh (2016) presented SSOA under disruption risk. The method employed multi-objective MILP model to determine the choice of suppliers and order quantity allocation under disruption risk. A two-phase solution approach is proposed where the suppliers are first ranked based on the preference value obtained using fuzzy AHP and fuzzy PROMETHEE. Then MOPSO is used to obtain a set of Pareto-optimal solutions with the choice of suppliers and order allocation among them. The finding resumed that supplier failures affects the expected total cost.

Azadnia et al. (2015) presented sustainable supplier selection and order lot-sizing. The method used fuzzy analytical hierarchy process and multi-objective 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. The finding is comparisons to proposed approach leads to a higher TVSP (total value of sustainable purchasing) rather than the single-objective cost-based model.

Pazhani et al, (2015) presented 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.

The finding is optimum order allocation is obtained and integrated approach resulted in saving of total cost and logistic cost.

Arabzad et al., (2014) presented 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. The result is the optimum allocated quantity to each supplier.

Singh (2014) presented supplier evlauation and demand allocation problem by integrating the supplier rating. The method is using TOPSIS and MILP. 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. The result is best suppliers are selected and optimum order allocation is obtained.

Kannan et al. (2013) presented SSOA in a green supply chain. Researchers 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. The result is the selected best supplier and order allocation is obtained.

From the inductive study that already done, the researcher finally found the state of the art that would be used in this research, which is supplier selection and order allocation considering the environmental, economic, and supply risk criteria with using the method of AHP analysis, multi-objective linear programming, and risk management. The summary of related research is shown in Table 2.1.

Table 2.1 Literature survey

Author	Supplier Selection Criteria					Method						
	Econ	Env	Soc	SR	Others	Fuzzy	TOPSIS	AHP	QFD	MOLP	MILP	RM
(Park et al., 2018)	●	●	●			√		√		√		
(Lo et al,, 2018)	●	●				√	√			√		
(Ghadimi et al., 2017)	●	●	●			√				√		
(Chang & Chang, 2017)	●									√		
(Babbar & Amin, 2017)	●	●			●	√			√	√		
(Ghorabaee et al., 2017)	●	●				√				√		
(Hamdan & Cheaitou, 2017)	●	●				√	√	√		√		
(Kırılmaz & Erol, 2017)	●			●							√	√
(Çebi & Otay, 2016)	●	●			●	√				√		
(PrasannaVenkatesan & Goh, 2016)	●			●	●	√		√		√		
(Azadnia et al., 2015)	●	●	●			√		√		√		
(Pazhani et al., 2015)	●				●						√	
(Arabzad et al., 2014)	●				●	√	√				√	
(Singh, 2014)	●	●			●	√	√				√	
(Kannan et al., 2013)	●	●				√	√	√		√		
(Amanita, 2018)	●	●		●				√		√		√

Econ : Economic
Env : Environmental
Soc : Social
SR : Supply Risk

2.2 Deductive Study

2.2.1 Supplier Selection and Order Allocation

Supplier selection is an activity recognized as the most important and prominent part of the purchasing function as it contributes to enhance competitive strategy and global market share by reducing operational costs (e.g., maintenance cost), offering high-quality products, enlarging total supply chain profit, and improving total supply chain performance (Sanayei et al., 2008). In another word, supplier selection problem is one of the complex multiple criteria problem which consider qualitative factors and quantitative factors. Supplier selection or evaluation is a common problem to find and to evaluate the most suitable suppliers for an organization based on assessing suppliers' capabilities. Also, the process of supplier evaluation and ranking is necessary. Supplier selection and order allocation is a problem of selecting the supplier out of available suppliers, and allocate the order quantity (Weber & Current, 1993). Supplier selection and order allocation decisions directly affect competitiveness. It is essential to select the right suppliers and determine the optimum order quantities among selected suppliers in order to maintain the competitive advantage.

According to Aissaoui et al. (2007), The steps of supplier selection and purchasing process are defined as follows.

1. Evaluating each possible supplier's capabilities to construct a candidate list of potential suppliers.
2. Selecting suppliers from this list for single or multi sourcing of raw materials and components.
3. Determining quantities of each raw material and component to order from each selected supplier.

2.2.2 Sustainability 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) mentioned 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 considering 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.

Grover et al. (2016) mentioned the criteria of environmental includes the pollution control, like air emissions, waste water, solid wastes, and use of harmful materials. Green product and eco-design, which are the use of environmentally friendly technology and materials, design capacbility for reduces consumption of material/energy, reuse, recycle of material, design of products to avoid or reduce use of harmful materials, green packaging. Environmental management system, related to environmental related certificates like ISO 14001, environmental policies, checking and control of environmental process.

Therefore, according to Song et al. (2017), the environmental criteria for sustainable supplier selection summarized as environmental management system (EMS), eco-design, and reduce, reuse, recycle (3R). The descriptions are defined as follows :

- EMS : A set of systematic processes and practices that enable a supplier to reduce its environmental impacts, which includes the organizational structure, planning & control of environmental activities and implementing policy. ISO 14001:2004 are the most widely used standards in an environmental management system.
- Eco-design : 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, and waste recycling & reuse.

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 other influencing factors in the supply chain (Carter & Rogers, 2008).

2.2.3 Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty (1980). It is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc., or from subjective opinion such as satisfaction feelings and preference. AHP allows some small inconsistencies in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value. The steps of AHP are illustrated as follows.

1. **Hierarchy**

The first step in an AHP analysis is to build a hierarchy for the decision. This is also called decision modeling and it simply consists of building a hierarchy to analyze the decision. The analytic hierarchy process (AHP) structures the problem as a hierarchy as shown in Figure 2.1.

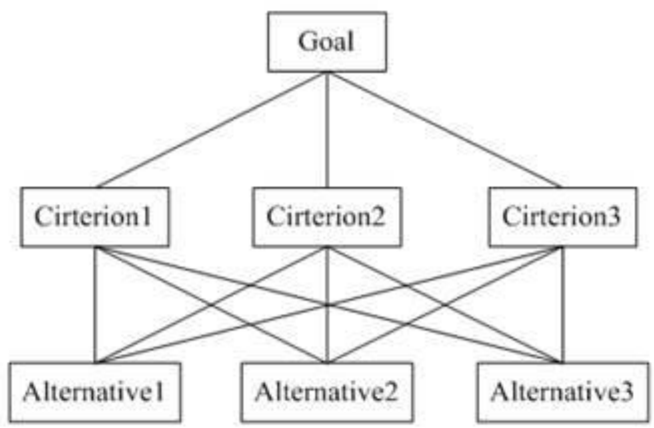

Figure 2.1 The hierarchy

The first level of the hierarchy is the goal. The second level in the hierarchy is constituted by the criteria. The third level consists of the available alternatives. The advantages of this hierarchical decomposition are clear. By structuring the problem in this way, it is possible to better understand the decision to be achieved, the criteria to be used and the alternatives to be evaluated. This step is crucial and in more complex problems, it is possible to request the participation of experts to ensure that all criteria and possible alternatives have been considered. Also that, in complex problems, it may be necessary to include additional levels in the hierarchy such as sub-criteria.

2. Pairwise comparison

The evaluation phase is based on pairwise comparison. The criteria on the same level of the hierarchy are compared to establish relative importance. This process obtains values of weight criteria and defines a ranking of the alternatives. The scheme proposed by Saaty, reported in Table 2.2, can be used to translate linguistic judgments into numbers.

Table 2.2 AHP judgement scores

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

The table of pairwise comparison matrices shown in Table 2.3 where, element A has B_1, B_2,…B_n as a sub from element A. Hence, matrices of A of n x n can be written as follows.
$A = (b_{ij})$, i,j=1,2,3,…n

Table 2.3 Pairwise comparison matrices

A	B_1	B_2	…	B_n
B_1	1	b_{12}	...	b_{1n}
B_2	$1/b_{12}$	1	...	...
…	...	...	...	...
B_n	$1/b_{1n}$	...	...	...

3. Deriving Priorities (Weights) for the Criteria

Calculate the relative weight of the elements to each level. This calculation is to determine the priority in hierarchy, the steps of determining the priority are defined as follows.

a. Adding the value of the columns to normalize the matrix.

b. In the normalized matrix, the lines are summed up to obtain the relative priority of the criteria.
c. Evaluating the consistency of the matrix, by calculating the eigen values to compare with the random consistency according as matrix size. If there is a consistency problem, the decision maker must review his/her comparisons again.
d. For each criterion, the anterior steps must be done
e. Calculating values of each alternative for each criterion are included in one matrix, with the application of calculated priority
f. Adding the values of each alternative to obtain the final value. The best alternative is the one with the highest value (priority).

4. Checking the consistency

Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. For this purpose, AHP calculates a consistency ratio (*CR*) comparing the consistency index (*CI*) of the matrix in question (the one with our judgments) versus the consistency index of a random-like matrix (*RI*). Saaty provides the calculated RI value for matrices of different sizes as shown in Table 2.3.

Table 2.4 Random Index

M	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Consistency Index (*CI*) is obtained by first computing the scalar *x*. The steps of calculating the scalar *x* is as follows.

a. Multiplying the matrix with the corresponding priority.
b. Summing up the results of multiplications per row.
c. The sum of each row divided by the corresponding priority and the results are summed.
d. Results is divided by the number of elements, and scalar x will be obtained.

Calculating the consistency index with the formulation as shown below.

$$CI = \frac{x-m}{m-1} \tag{2.1}$$

In AHP, the consistency ratio is defined as *CR* where *CR* = *CI/RI*. Saaty has shown that a consistency ratio (*CR*) of 0.10 or less is acceptable to continue the AHP analysis. If the consistency ratio is greater than 0.10, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it. A perfectly consistent decision maker should always obtain *CI*=0, but small values of inconsistency may be tolerated. In particular, if

$$\frac{CI}{RI} < 0.1 \tag{2.2}$$

The inconsistencies are tolerable, and a reliable result may be expected from the AHP.

2.2.4 Multi-Objective Linear Programming

Multi-objective linear programming is used in application for many real world problems including problems in the fields of engineering, mining and finance. A multi-objective linear programming problem simultaneously optimizes some objectives subject to the given constraints. In general, the problem has no optimal solution that could optimize all objectives simultaneously and concept of optimal solution gives rise to the concept of non-dominated solutions, for which no improvement in any objective function possible without sacrificing at least one of the other objective functions (Yap, 2010). The objectives are often conflicting, sometimes even opposing, in all cases the relative "weight" of each is difficult to assess a priori. Consider the mathematical formulation of a typical MOLP problem. This multi-objective linear programming problem is formulated as follows:

Objective function: maximize or minimize

$$Z_1(x) = c_{11}x_1 + c_{12}x_2 + \cdots + c_{1n}x_n = c_1x \tag{2.3}$$

$$Z_2(x) = c_{21}x_1 + c_{22}x_2 + \cdots + c_{2n}x_n = c_2x \tag{2.4}$$

$$Z_k(x) = c_{k1}x_1 + c_{k2}x_2 + \cdots + c_{kn}x_n = c_kx \tag{2.5}$$

Subject to:

$$Ax = b,\ x = (x_1, x_2, \ldots, x_n) \tag{2.6}$$

$$x_i \geq 0,\ i = 1,2,\ldots,n \tag{2.7}$$

2.2.5 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 weighted-sum method can be formulated as follows.

$$U = \sum_{i=1}^{K} w_i F_i(x) \tag{2.8}$$

Subject to:

$$\sum_a w_a = 1 \tag{2.9}$$

$$w_a \geq 0 \tag{2.10}$$

The weighting coefficient denotes the relative importance of the responses. Since a minimizing objective can be converted to a maximize objective by multiplying it by -1 (i.e. minimize $f_i(x)$ = maximize $-f_i(x)$). Also 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.

2.2.6 Risk Management

According to the introduction to ISO 31000:2009, the term risk management refers to the architecture that is used to manage risk. This architecture includes risk management principles, a risk management framework, and a risk management process. 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 follows.

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 obtained from literature or the expert by interviewing and brainstorming to select the suitable supply risk.

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 2.5. Table 2.6 shows the impact scale, while Table 2.7 shows the likelihood scale.

Table 2.5 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

Source : Kırılmaz & Erol (2017)

Table 2.6 Impact Scale

Risk Impact	Impact index	Definition
Catastrophic	5	Cease the production for 1 week or more
Major	4	Cease of production for 2-3 days

Risk Impact	Impact index	Definition
Moderate	3	Slows down of production for 3-5 days
Minor	2	Decrease in customer service level
Insignificant	1	Unaffected customer service level

Source : Kırılmaz & Erol (2017)

Table 2.7 Likelihood Scale

Risk likelihood	Likelihood index	Definition
Almost certain	5	At least once a week
Likely	4	1-2 times in a month
Moderate	3	1-2 times in 6 months
Unlikely	2	Once a year
Rare	1	Once every 2 years or more

Source : Kırılmaz & Erol (2017)

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 2.8. Risk rating is a measure that indicates the risk level of a supplier.

$$Rt = \sum_{j=1}^{J} R_j * Y_j \tag{2.11}$$

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 company

j = Identified risk from 1 to J

Table 2.8 Risk evaluation

Risk rating	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

Source : Kırılmaz & Erol (2017)

d. Risk Mitigation

A mitigation strategy is proposed to decrease the expected impact of risk. In this study, the order allocation is being identified using linear programming with minimizing the total cost.

The second stage the order allocation is modified, which considers the risk rating of suppliers. The order allocation from minimum total cost is proportioned to the risk rating of each supplier and the quantity is transferred to a more reliable supplier or less risky supplier.

The total risk rating of each supplier which has the least risky supplier (R_{t2}) is set to zero, then this risk rating is subtracted from the risk rating of other suppliers and the value are normalized, which shown in Table 2.9. This normalized value represent the risk status of supplier and used to find the quantity transferred to less risky supplier, which shown in Table 2.10.

Table 2.9 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

Source : Kırılmaz & Erol (2017)

Table 2.10 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

Source : Kırılmaz & Erol (2017)

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

$$\text{Max} = \sum_{i}^{I}\sum_{j}^{J} N_{ij} * X_{ij} \quad (2.12)$$

$$\sum_{j}^{J} X_{ij} \leq Q_{Ti} \quad (2.13)$$

$$\sum_{k}^{K} X_{ki} - \sum_{j}^{J} X_{ij} \leq C_{Ri} \quad (2.14)$$

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

K = Indicates all more risky supplier than supplier i

Q_{Ti} = Quantity to be transferred from supplier i

C_{Ri} = Remained capacity of supplier i

Equation 2.14 satisfies the condition that the difference between the quantity entering and leaving the node cannot be greater than the remained capacity of that supplier.

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.