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SUPPLY CHAIN RISK ANALYSIS AND ASSESSMENT USING ANALYTICAL HIERARCHY PROCESS (AHP): A REVIEW

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In these days, increasing consumer demand uncertainties, e.g. due to war in Europe, severe drought in west Europe or Covid pandemic, increase challenge in supply chain operation. Uncertainty and unreliable events interfere supply chain's operations and strategies. As a result, increasing risks in supply chain becomes vulnerable and leads to undesired circumstance. A systematic approach is therefeore required to manage the risks. Of many methods, supply chain risk management (SCRM), as a part of supply chain management (SCM), is offered in this paper to address this challenge. The SCRM increases supply chain resilience agains many uncertainties. An important key of SCRM is risk assessment as risk-impact ordering method which can deliver solution with the lowest risks. Of many methods applied for risk assessment, analytic hierarchy process (AHP) provides several advantages, e.g. it can be used as multi-criteria decision making, it can be used with high flexibility and it can be used as subjective assessment. This paper discusses the AHP method in supply chain risk assessment as well as offers a new AHP structure applied for risk analysis.

Keywords: *Supply Chain Risk Management, Analytic Hierarchy Process, Risk Assessment*

1. INTRODUCTION

Supply-demand activities in the global market have changed fast and significantly recently. Nowadays, consumer and producer price changes abruptly by several key factors, e.g. disrupted supply due to war in Europe, severe drought in west Europe and due to factory shutdown during the Covid pandemic. For example, severe drought across Europe in 2022 decreased 20% hydroelectricity generation, decreased the water supply required in industry and disrupted shipping of industrial goods, raw materials, fuel and coal through the Rhine river. However, customer demand for various goods still appears daily and this circumstance needs to be fulfilled with appropriate supplies to achieve supply and demand balance. This is to prevent skyrocketing prices due to inadequate supply. The dynamic circumstance of supply-demand requires good supply chain planning. The supply chain consists of parties who create demand, i.e. customers and parties who try to fulfill these demands. Customer's demand is not only fulfilled by manufacturer producing goods but also involves other corresponding parties e.g. parties supplying raw materials and services to manufacturer, parties delivering the goods from manufacturer to the customer, e.g. transporters, warehouses, and retailers [1]. A robust and reliable supply chain management (SCM) is therefore required to manage this supply chain. The SCM manages the supply chain of products from the production schedule until the product delivery to the end customer [3]. Thus, the SCM should guarantee every customer's satisfaction, i.e. customer receives the demanded good in requested quality, a correct schedule and reasonable price. Fulfillment of customer demand opens growth opportunities for the manufacturing company itself and other parties participating in the supply chain. The growth of various new demands not only opens supply chain's new opportunities but, unfortunately, also increases the supply chain's risk [4].

To maintain the company's sustainability and growth, the company should therefore search for better strategies to manage the increasing risks to fulfill the increasing customer demand and supply chain competition. Thus, companies and parties involved in the supply chain should address any unfavorable condition, both foreseen and unforeseen, and experience increasing vulnerability [5] since the supply chain's risk is disrupted by unreliable and uncertain circumstances [6]. The company's strategies to deal with the supply chain's risk must focus on its vulnerability and resilience under any uncertain circumstances, e.g. by putting attention to the other supply chain parties outside the company as well. This can be worked out by

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implementing supply chain risk management (SCRM) [5]. The SCRM implementation in many companies can improve company's resistance when dealing with uncertain economic risks [5]. The SCRM applies a systematic approach to assess, mitigate, and monitor every possible supply chain disruption so that the company can better address the estimated risks possibly disrupting company operation [7]. Correct risk response and mitigation ability are then competitive keys for the company to maintain its long-term sustainability.

Any interruptions in company's supply chain operation, strategy, and tactic are mainly due to uncertain and unpredicted events [8]. The identified risk in the supply chain could be mitigated based on the level of occurrence probability and severity impact. The most relevant risk could be identified by using a risk assessment [9]. Then, the risk can be managed based on the priority order. Risk assessment assists the company to assess and sort risk based on the impact on the supply chain. The allocation of resources and events in the company can then be optimized [10]. Of many methods, the analytic hierarchy process (AHP) method has been widely applied to assess the risk in the supply chain. The AHP assesses supply chain risk (SCR) and its interdependencies so that the best alternative to address the rick can be determined [10].

The AHP method is one of the most popular multi-criteria decisions making (MCDM) methods. The AHP can be useful for company executives to create decisions since it can create risk's priority rank when it compares various risk criteria [11]. The AHP can be therefore used to assess the supply chain's risk by identifying risk indicator, comparing the impact, and creating causal correlations occurring in the supply chain. This paper is a literature review concerning the application of the AHP method in assessing and managing risk in the supply chain. A new hierarchy of the AHP as well as future challenge in the supply chain are also outlined. Nevertheless, this paper is limited only to discussing the application of AHP in assessing SCR using the SCRM.

2. SUPPLY CHAIN RISK

The upstream side of the supply chain is dealing with any product requested by the customers. When involved parties in the supply chain are trying to fulfill the customer's demand, any uncertain event may possibly arise and then affect supply chain operation. The SCR is defined as uncertain and unreliable events in the supply chain system causing disruption [6] and increasing the opportunity of negative consequences in the supply chain [12]. The SCR includes every event that may occur, even a small event, and every event which results in any negative influence on the supply chain system [6]. Faizal and Palaniappan [12] reported that risk's sources can be from the upstream side (supply risk), downstream side (demand risk), and from manufacturing process, i.e. process risk. Risk always exists in the supply chain since uncertain circumstance affects the supply chain performance [7]. The supply chain can be vulnerable to risk when it faces uncertain events, and they will be in a rough position [13]. The supply chain should therefore quickly respond the uncertain events, both internally and externally, to preserve efficient and dynamic business to maintain its profitability [7].

Exemplary uncertainties which may occur are uncertain product development and technology, uncertain customer demand, and uncertain operational and product manufacturing [3]. The occurrence probability of these uncertain events has increased in recent years, e.g. due to war in Europe, severe drought in west Europe and the Covid pandemic as well as due to increasing changes in the industry, e.g. outsourcing, globalization, application of information technology, and application of artificial intelligence (AI) [12]. Uncertain events occurring in the supply chain may interfere with the operation of supply chain itself. This circumstance may disrupt the fulfillment of customer's demand either as delivery, quantity or quality issues. Any disruption in the supply chain affects the company in the supply network since the company becomes more vulnerable and less resistant to the risk and this circumstance is harmful since it can cause economic loss to the company.

2.1 Supply Chain Risk Management

The SCR affects the efficient movement of information, material, and product in the supply chain. In consequence, supply chain evaluation in its strategic and operational aspects will be interrupted [14]. When the supply chain is negatively affected, the fulfillment of customer's demand is then affected. Further, it can harm a company's reputation and decrease customer loyalty, disrupt the financial cycle, and in several cases also affect customers' health [14]. The SCRM handles the risk by identifying, evaluating, mitigating, and monitoring any negative events that could probably interfere with the supply chain operation [7]. The SCRM adaptation in the supply chain's strategy is therefore important to maintain the company's competitiveness in the supply network [5]. Any disruption leading to any negative effect on the supply chain system can be decreased with the implementation of the SCRM [7]. The main purpose of SCRM is to minimize the probability of risk occurrence, therefore key risks must be known and handled first using the risk assessment

[5]. The SCRM is implemented so that the company can better address various risks and their impacts [7]. The SCRM of each case consists of risk identification, risk assessment, risk mitigation, and risk monitoring [8].

The SCRM is a part of supply chain management [5] that aims to improve the performance of the supply chain [14]. Thus, the SCRM implementation in the supply chain management is mainly to reduce the occurrence probability of uncertain and unexpected events and their impacts [5,7]. To improve overall supply chain performance, the SCRM is important to eliminate any possible negative events that interrupt supply chain operation [5]. In the SCRM, potential risks are identified, assessed and treated to achieve the supply chain goals and objectives [15]. Aqlan and Lam [6] researched supply chain optimization under risk and uncertainty using simulation. Even the slightest possible risk in the supply chain must be addressed to optimally increase supply chain performance. Early SCR mitigation in the low-level risk increases the company's total profit and decreases the lead time [6,7]. Singh and Wahid [5] suggested that a company should implement the supply chain strategy, which considers risk management, in the supply chain management to identify, mitigate and decrease risk impact in the supply chain. Since the main purpose of SCRM is to find key risk in the SCR so that the risk probability and impact could be minimalized, risk assessment in the risk analysis is therefore required to identify key risk.

According to Faizal and Palaniappan [12], risk handling process in the SCRM falls into two main categories, i.e. risk analysis and risk control. The main task of the risk analysis is to identify and evaluate any possible risks in the supply chain. On the other hand, the risk control aims to control and monitor those possible risks. Ho *et al*. [8] constructed a framework to support the implementation of the SCRM by defining SCR types and factors (Figure 1). This framework consists of SCR types, SCR factor, and SCR method or process (Figure 1). In the first risk handling category, i.e. the risk analysis, the risk is handled through the risk identification step which is then continued by the risk evaluation and assessment step. In the risk control step, the risk is handled through risk monitoring and mitigation. The risk assessment step is important to rank risk importance and weight the risk so that the high-priority risk, according to the likelihood and the impact, could be earlier mitigated. The risk assessment aims to sort the identified risk to identify more easily the correlation between risks and the strategy to handle them [16] and it starts with risk categorization based on occurrence possibility and its impact on the supply chain [5]. Ganguly and Chatterjee [13] suggested the importance of risk weight so that the most effective operational plan could be implemented. This risk categorization was done by analysing risk's sources and the condition that poses a risk, which was already worked out in the previous process, i.e. the risk identification [12]. Risk categorization aims to see the correlation between the identified risk and its impact in the supply chain [16]. The risk assessment enables the management team, particularly the decision-maker, to allocate the company's resources for a successful SCRM implementation [15]. Many tools, e.g. failure mode effect analysis (FMEA), event tree analysis (ETA), and analytical hierarchy process (AHP), can be implemented in the step of ordering risk's importance [12].

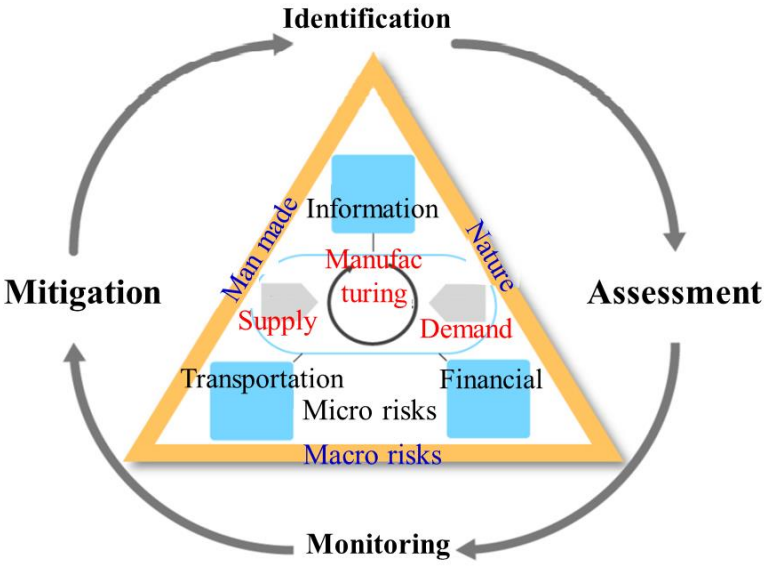


Figure 1. Supply chain risk framework [8]

2.2 Framework for Supply Chain Risk Assessment

Many frameworks were offered to support the SCRM implementation. Yassinne and Brahim [17] proposed a SCR database framework (Figure 2). In this framework, a predefined risk assists general risk identification and assessment. In general, the framework developed by Yassinne and Brahim resembles the risk analysis framework proposed by Faizal and Palaniappan (Figure 3) [12]. These two frameworks have the same function, i.e. their capability to identify risks that could disrupt the supply chain operation. Moreover, both frameworks also implement the step of risk identification in the supply chain operation. A slight difference between these two frameworks is the merging of mitigation and controlling steps in the Faizal and Palaniappan's framework which serves as a decision criterion to address any SCR.

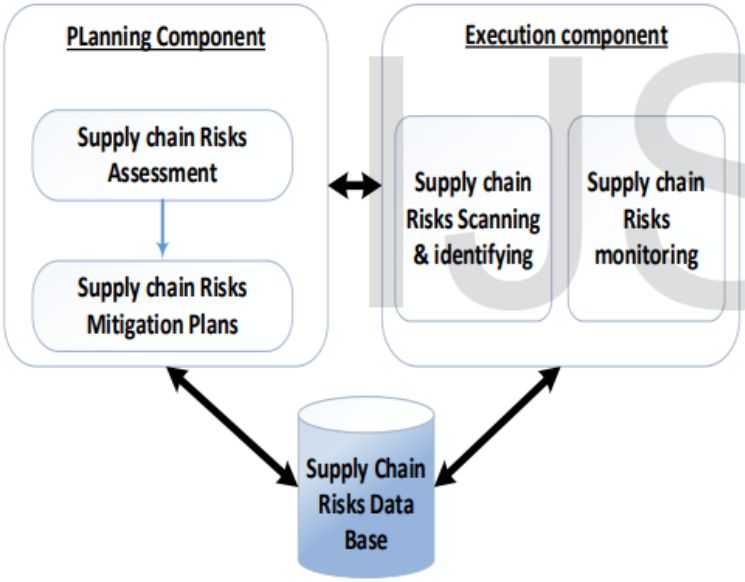


Figure 2. Supply chain risk management (SCRM) framework proposed by Yassinne and Brahim [17]

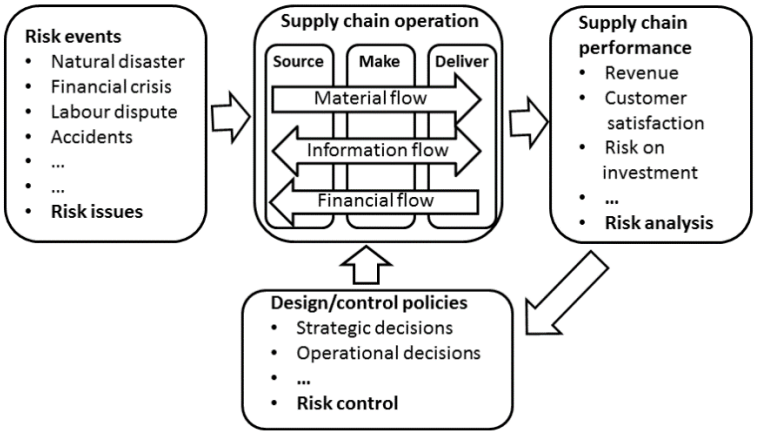


Figure 3. Supply chain risk management (SCRM) framework proposed by Faizal and Palaniappan [12]

The ability to respond and mitigate any risk that exists in the supply chain is an important expertise for a company to compete with other companies [7]. A company can correctly address the supply chain competition in several ways, e.g. better quality and quantity of requested raw materials, shorter delivery time, better payment deal, etc. Therefore, risks existing in the supply chain are analysed to realize a sustainable supply chain [5]. To address this issue, Ganguly and Chattterjee [13] constructed a basic research framework (Figure 4). This framework's main purpose is to maintain supply chain sustainability using the appropriate mitigation strategy. This framework suggested that the identification, classification and prioritization stages have to be worked out early in risk evaluation. Risk identification and risk prioritization provide support to decision-makers for understanding risks interdependency and their relative importance [13]. In the Ganuly and Chattterjee's framework, the risk assessment is important to define which risks are more important than

others [13]. In this framework, the identified, classified, and prioritized risks are evaluated to develop a strategy required for the risk mitigation. Therefore, this framework can be used as a base framework for other SCRM.

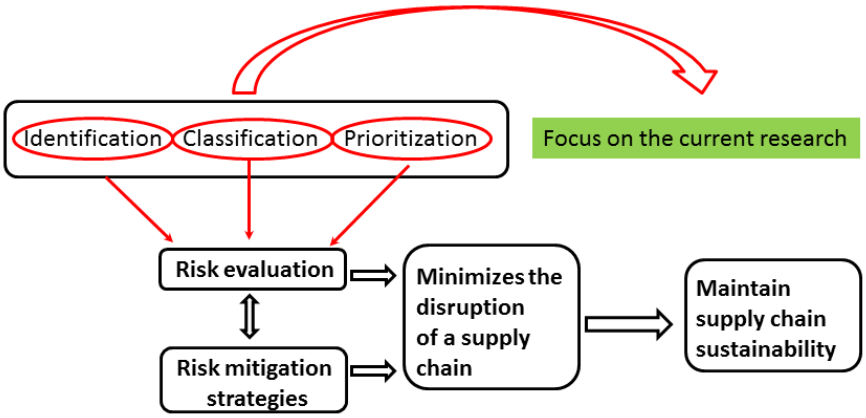


Figure 4. Framework of risk basic research offered by Ganguly& Chatterjee [13]

3. Analytical Hierarchy Process

This paper emphasizes implementation of analytical hierarchical process (AHP) for SCR assessment. The AHP implementation is popular in the risk assessment due to its capability to subjectively assess multi-criteria problems [18]. In the supply chain, the AHP is widely used to plan or choose the best alternative for resource allocation, or to find conflict's alternative decision [19]. The AHP's ability to compare quantitative and qualitative criteria shapes its competitive edge to flexibly assess SCR. In addition, the AHP is also useful for determining an attribute's relative importance in problem that influence a project [13], i.e. SCR in this case. By using the AHP to assist risk, the most suitable and effective operational alternative plan, which is based on the order of importance and criteria weighted, could be implemented to mitigate SCR [13].

The AHP assesses a problem by giving a weighted score in intangible and subjective criteria. This underlies the AHP popularity and superiority of the AHP over other multi-criteria decision making (MCDM) methods [14]. Thus, formal criteria measurement is no longer required as long as the same criteria have the same unit and comparable [18]. Badea *et al.* [14] suggested implementing the AHP method in SCR assessment when more than five factors are being assessed and prioritized. The AHP analyses a problem by constructing a problem's hierarchy structure into several levels by setting the main objective at the top level, attribute or criteria at the next level, and the problem's alternative at the last level [13]. Pairwise comparisons are then carried out at each level so that multi-criteria problems can be better solved [20]. After that, a square matrix is used to find the criteria's total weight [10]. Pairwise comparison is also used in the last level of the AHP method, i.e. the alternative level, to compare every alternative. The criterion is weighted again. The aggregate weighted from each level is then calculated to find the best alternative [13].

The implementation of the AHP structure depends on the specific existing risk problem and the main goal of a particular supply chain team. Its construction can therefore vary for each management team and it is not only a single solution. In assessing SCR by using the AHP, the estimated risk can therefore be constructed into a hierarchy comprising the main goal of the supply chain system, main dimension, sub-criterion and alternative to address the risk [20]. Many works were dedicated to constructing the AHP structure, e.g. Saxena and Seth [10], Hernadewita and Saleh [21], Suhaeni and Andayani [22], and Susanawati *et al*. [23].

3.1 Structure of The Analytical Hierarchy Process

As earlier discussed, many frameworks can be used for the AHP implementation. For example, Ganguly and Chatterjee[13] offered three levels in AHP hierarchical standard structure. The highest level consists of overall objectives of the management team. This hierarchical structure commences with locating the decision's main goal on the top level (upper level) and the criteria affected the goals at the next level. The next level is the mid-level consisting of objectives or criteria affecting the achievement of main goals [19]. This mid-level can also be elaborated, if required, into several sub-levels consisting of sub-criteria that affect the main criterion. After that, the last level will be the alternative solution to achieve the main goal [13]. Meanwhile, Badea *et al.* [14] mentioned four steps process of the AHP implementation as a risk assessment.

The process starts with constructing a hierarchal structure which is then followed by determining the importance, evaluating the performance and controlling consistency of the subjective evaluation. Hernadewita and Saleh [21] proposed two general steps in formulating the AHP structure (Figure 5). The first step is to define the goal and solutions that want to be achieved. After the first step is correctly defined, the second step is to construct a hierarchical structure based on those goals.

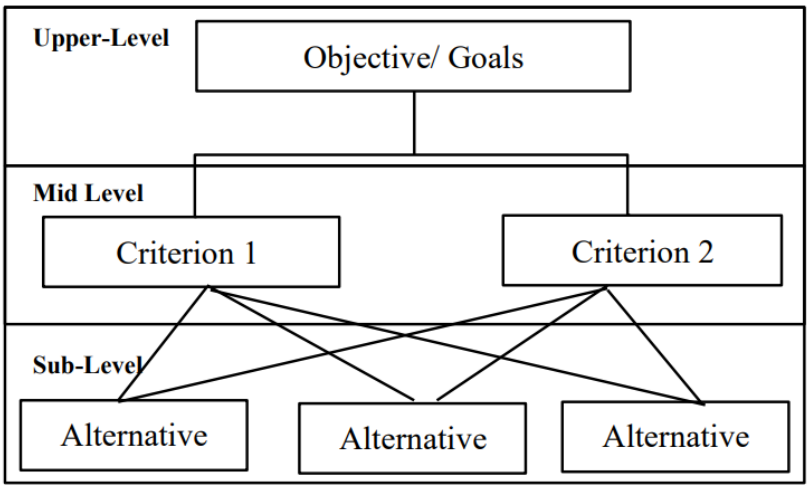


Figure 5. An exemplary AHP hierarchical structure proposed by Hernadewita and Saleh [21]

Based on the AHP structure proposed by Badea *et al.* [14] as well as Hernadewita and Saleh [21], this paper also proposes the AHP framework structure in assessing SCR to define the best mitigation strategy to maintain supply chain performance (Figure 6). This proposed framework consists of two stages, i.e. the constructing stage and the assessing stage. The constructing stage is developed based on the work of Hernadewita and Saleh [21]. Meanwhile, the assessment stage is developed based on the assessment of the relative importance of SCR by Badea *et al* [14]. This framework can be implemented as a SCR assessment framework can prioritize SCR to acquire the best alternative solution in mitigating the corresponding SCR.

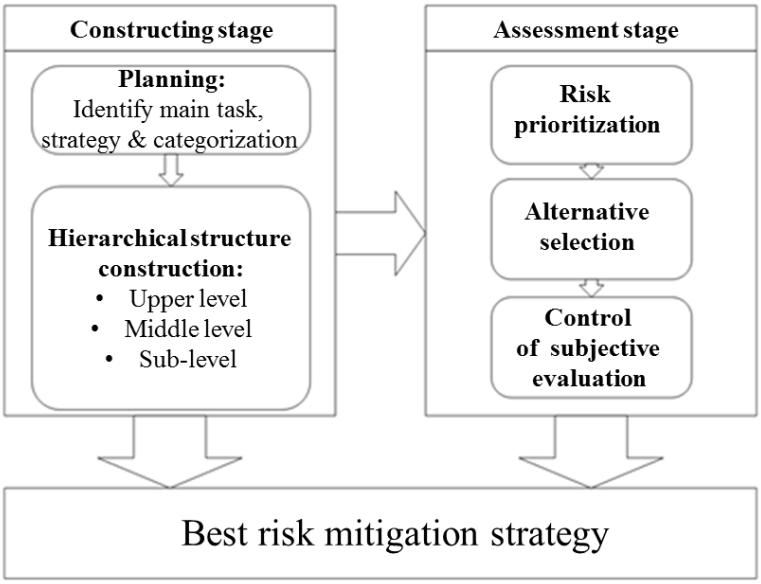


Figure 6. The AHP framework proposed in this work for assessment of supply chain risk

3.2 Exemplary Implementation of Analytical Hierarchy Process for Risk Assessment

Many works already implemented the AHP for risk assessment. Darmawan *et al.* [11] and Badea *et al.* [14] implemented the AHP for risk assessment of the collaborative supply chain. Furthermore, the AHP was implemented for sustainable supply chain in the renewable energy sector [20], supply chain product risk in

multi-product categories [19], bread product supply chain [16] implemented the AHP, onions supply chain [23], waste oil to biodiesel [24]. These examples for various fields show the AHP's flexibility and easiness as a risk assessment tool. Nevertheless, the risk should be identified prior to the AHP implementation for risk assessment.

The AHP implementation on the SCR assessment commences with the hierarchy structure construction. This AHP hierarchical structure construction is easy and flexible depending on the purpose of its implementation. The construction of hierarchical structure in the AHP method depends on risk criteria and sub-criteria. Suhaeni and Andayani [22] reported that risk identification can be worked out by data collecting using surveys, interviews, and questionnaires from expert respondents in the shallots supply chain. Susanawati *et al*. [23] proposed a discussion with experts in the related supply chain for risk identification. The experts related to the supply chain can be market players or employees that involve in the supply chain operation [9]. A discussion group can also be created to identify risks using experiences, knowledge, and personal judgment [17,18].

The AHP is one of the most popular methods to solve a multi-criteria problem and is widely used to assess a SCR problem that has multi-criteria as well. Frequently used criteria in SCR research are risk source criteria. Some works applied risk source criteria in SCR, e.g. SCR of bread product by Orzáez and Moreno [16], collaborative supply chain implementation by Darmawan *et al*. [11] and sustainable SCR by Ganguly and Chatterjee [13]. Risk source criteria that are often used in the SCR assessment are presented in Table 1.

Table 1. Risk source criteria

Risk Source Criteria	Reference
Product risk	[10,12,16,18]
Supplier risk	[10,12,14,16,18]
Consumer risk	[10,12]
Service risk	[10,12]
Information & technology risk	[10,12]
Environmental risk	[10,12]
Legal risk	[14,18]
Logistic risk	[14]
Human sources/labor risk	[14,16]
Eol/waste	[14]

Table 2. Collaborative supply chain risk's sub-criteria [12]

Criteria	Sub-criteria
Product	Competitive cost risk
	Delivery risk
Supplier	Procurement risk
	Material risk
	Order fulfillment risk
Customer	Delay risk
	System risk
	Demand risk
	Forecast risk
Service	Customer
	Satisfaction risk
	Guaranty risk
Information technology	Databases risk
	Software risk
Environment	Man-made disruption risk
	Transportation risk
	Natural disasters

Other criteria widely used in research's risk categorization are internal and external risks. Dong and Cooper [18] investigated risks from the company's internal and external parties. Another risk criteria categorization that will be used as assessment criteria in AHP is related parties involved in the supply chain [23]. Product criteria can also be used in criteria categorization, e.g. worked out by Mital *et al*. [19] when they investigated the risk assessment in the multi-categories supply chain, i.e. product's SCR of the

perishable product (milk), the non-perishable product (rice), durable product (mobile phone) and non-durable product (cigarette). Criteria based on the product are focused on product supply in a retail store. The criteria are therefore about quality, cost, continuity of supply, supplier, service, and buyer-supplier partnership [19]. These risk categorization criteria serve below the top level, i.e. the level 1, in the AHP hierarchal structure.

For every risk criteria categorization, there will be sub-criteria as risk explanation. These sub-criteria stand on the next level after the level 1. These sub-criteria provide more detailed information for every risk criterion. Exemplary sub-criteria from risk source criteria was worked out by Badea *et al.* [14] and is depicted in Table 2. Sub-criteria from similar criteria are compared by using pairwise comparison and the importance weights are then calculated by using a square matrix. After that, the criteria are compared by using pairwise comparison to calculate the overall risk weight.

The last level in the AHP hierarchal structure describes alternatives to solve the estimated risk. The alternatives are then connected with sub-criteria according to the correlation. There are many types of alternatives that can be elaborated in the last level. Alternatives in the AHP can be the mitigation strategy of SCR, i.e. in-house SCRSM strategy, collaborative SCRSM strategy, multi-function SCRSM strategy, and logistics SCRSM strategy [10]. The alternative level can be flexibly developed by using many sources. Darmawan *et al.* [11] used a literature review to construct the alternative level. Saxena and Seth [10] constructed the alternative level based on a literature review and expert opinions regarding SCR solutions and security management. Matrocinque *et al.* [20] used survey data to implement a sustainable supply chain in the renewable energy sector. Badea *et al.* [14] used their own thinking to develop the alternative level.

The AHP calculates alternative value based on the weighted risk so that the decision can be made. Another alternatives type is selection of product vendors as worked out by Mital *et al.* [19]. However, the alternative level in AHP hierarchal structure can also be eliminated, or not proposed, e.g. as worked out by Orzáez and Moreno [16] when the AHP is applied only to assess the risk and to acquire the weighted importance to rank the risk's importance. In this case, the solution for the risk with the heavier weight is then analysed by using another tool. The tool, e.g. the fishbone diagram, is used to identify sources of most weighted risk and to develop the supply chain operation procedure and corrective procedure [16]. All these works confirmed the AHP flexibility since the AHP is used as the risk and alternative assessment or used only as the risk assessment. The last one should be then followed by the use of other tools to search for the solution, mitigation or control.

3.3 Risk Relative Importance Weighted Using AHP

After the construction of the AHP hierarchical structure, a pairwise comparison is then worked out for each element in every hierarchy's level [10]. This pairwise comparison's aim is to define the order of importance of criteria and sub-criteria in risk problems based on the hierarchical structure that was previously constructed [10,14]. Pairwise comparison is worked out by comparing each dimension with another dimension at the same level by using the Saaty's scale [20]. A pairwise comparison matrix then is formed with n×n size (square matrix) as an assessment tool to get the relative importance [23]. A pairwise comparison to define relative importance steps can be worked out by experts, researchers, or with the help of a software application. Mastrocinque *et al.* [20], Ganguly and Chatterjee [13], and Mital *et al.* [19] developed a pairwise comparison through questionnaires spreading to the related supply chain experts. Experts involved can be the analyst in the related supply chain. On the other hand, Badea *et al.* [14] and Orzáez and Moreno [16] constructed the pairwise comparison by forming a group discussion among researchers. The software application as a pairwise comparison assessment was worked out by Saxena and Seth [10], Darmawan *et al.* [11], Susanawati *et al.* [23], and Suhaeni and Andayani [22].

In the beginning, the pairwise comparison commences at the sub-criteria level by comparing each sub-criteria and their correlation with the criteria at the higher level [13,23]. The assessment of relatives' importance weight at each hierarchy's level generates a rank of overall weight. This rank shows which risk is more important and strongly influences the supply chain. An exemplary pairwise comparison was worked out by Darmawan *et al.* [11] in which the criteria were weighted by comparing criteria at the level 1 in the mid-level. The pairwise comparison was done only at each sub-criteria at the same criteria, while sub-criteria from different criteria was not compared [11]. Meanwhile, Saaty [26] used experts' opinion which was then weighted using the scale ranging from 1 to 9 point. After the criteria and sub-criteria are weighted, the weight score is then evaluated by using a pairwise comparison matrix in n×n size (Figure 7) [26]. There are two weighted ratings in pairwise comparison. The first one is locally weighted, i.e. multiplicating among sub-criteria at the similar criteria level, and globally weighted, i.e. multiplicating the sub-criteria with its criteria from the higher level [11].

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & \cdot & \cdot & a_{\infty n} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdot & a_{1n} \\ 1/a_{12} & 1 & \cdot & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ 1/a_{1n} & 1/a_{2n} & \cdot & 1 \end{bmatrix}$$

Figure 7. A pairwise comparison matrix [10]

The alternative assessment is worked out similarly to the risk factor assessment. In the alternative assessment, a pairwise comparison also exists among alternatives with every risk factor [14]. The alternatives have to be compared one by one using criterion weight which was previously calculated at the last step. The assessment of 5 alternatives done with 16 risk factors by Badea *et al*. [14] resulted in 340 evaluations on two concepts (vertical and horizontal). Meanwhile, Orzáez and Moreno [16] did not assess the alternatives since their work did not propose any alternative in the AHP structure. This circumstance occurred since the AHP was only used to order the risk and alternative order of importance. The alternatives for this problem were then solved by using other methods or tools based on the risk order defined.

When using the AHP as decision-making tool, a subjective evaluation in defining the relative importance weighted cannot be avoided. In consequence, maintaining research consistency, whereas high consistency is important to create an accurate decision, remains a challenge [22]. This occurs since people may inconsistent when answering questions [15]. Therefore, consistency should be quantitatively determined to justify the consistency of the risk assessment using the AHP. The consistency index (CI) (eq. 1) measuring the assessment consistency rate in subjective evaluations depends on the size of the assessment matrix size (n) and the largest Eigen value of the (λ_{max}) [26]. The consistency ratio (CR) is a function of CI and the random index (RI) which depends on n value for each matrix (Table 3). If the CR value is less than 10%, consistency can be then accepted. In contrary, if the CI value is higher than 10%, the assessment should be repeated [26]. The equation for consistency ratio is depicted in equation (2). The use of a nine-point scale on AHP pairwise comparison may result in ambiguity in risk uncertainty and the prioritization of subjective evaluation can be biased due to several reasons [15]. Therefore, more attention is when assessing the risk by using the pairwise comparison.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

Table 3. Exemplary values of the random index (RI) for various assessment matrix sizes (n x n) [26]

Matrix size	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

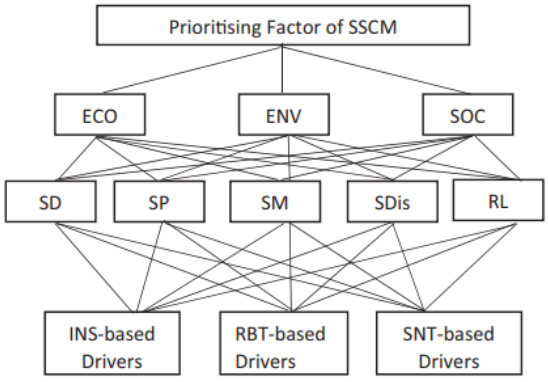
4. RISK ASSESSMENT FOR SUPPLY CHAIN SUSTAINABILITY

In recent years, awareness about sustainability in the supply chain problem has increased [20]. This occurs since more stakeholders start to consider sustainability as a key decision factor regarding the supply chain strategy and operation [13]. Many works already considered the sustainability in their SCR assessment, e.g. risk in sustainable supply chain by Ganguly and Chatterjee [13], supply chain's AHP model in the renewable energy sector by Mastrocinque *et al*. [20], and risks assessment to maintain shallot supply chain sustainability by Suhaeni and Andayani [22]. They concluded that a sustainable supply chain is strongly related to operation strategies in company's supply chain sustainability. The performance of the sustainability in supply chain can be measured through its social, environmental and economic aspects [25]. These dimensions are widely known as the triple bottom line (TBL) of supply chain sustainability. The implementation of SCRM as risks problem-solving in a sustainable supply chain is an integrated method so that the management team can achieve sustainable competitive advantages [5].

The TBL of supply chain sustainability consists of economic, environmental and social performance impact on the supply chain [27]. This TBL concept has been an important dimension for assessing sustainability in the supply chain [25]. However, many SCRM assessments still do not consider the TBL importance for supply chain sustainability [27]. Most ASCRM assessments merely measure supply chain sustainability using a single performance measure. This circumstance is due to additional challenges when

the management team adds the TBL dimension to the supply chain. The TBL dimension causes difficulties to attribute performance to a particular SCM. Of many MCDM methods, the AHP method can be strongly suggested to address this challenge.

The hierarchal structure of AHP can support the management team to construct any correlation between each sustainability performance dimension. Figure 8 depicts an exemplary hierarchal structure of sustainable supply chain management (SSCM) practices to measure sustainability performance [27]. This AHP structure has three criteria of the TBL concept, i.e. economic dimension, environmental dimension and social dimension, to achieve the SSCM. This exemplary framework can be used as based research structure for assessing the TBL dimension of SSCM.



Dimension Criteria	Codes
Performance: The Triple Bottom Line	
Economic Dimension	ECO
Environment Dimension	ENV
Social Dimension	SOC
Sustainable supply Chain Practice	
Sustainable Design	SD
Sustainable Procurement	SP
Sustainable Manufacturing	SM
Sustainable Distribution	SDis
Reverse Logistics	RL
Organisational theory-based Drivers	
Institutional Theory-based Drivers	INS-D
Resource Based Theory-based Drivers	RBT-D
Social Network Theory-based Drivers	SNT-D

Figure 8. The AHP hierarchal structure of TBL measurement in SSCM [27]

Some works applied the AHP to address this SSCM issue. Ganguly and Chatterjee [13] researched the most influential issues to achieve the SSCM. Five risk categories were identified, i.e. supplier side, legal risk, transportation, human resources and waste management [13]. The risk assessment by using the AHP concluded that the most important risk associated with the SSCM is the supplier risk. Therefore, the important thing to achieve the SSCM is to select the best sustainable supplier, not only related to the financial aspect but also related to other issues in the TBL dimension. Meanwhile, Suhaeni and Andayani [22] concluded that the production risk is the best risk affecting the SSCM in the SCR of shallot farming.

5. FUTURE CHALLENGE AND OPPORTUNITY

The SCR due to any uncertainty cannot be avoided in the supply chain operation. The use of SCRM to manage risk becomes an important strategy to maintain supply chain profitability and competitiveness. Many works are therefore devoted to research, analysis and construct the risk assessment since it is an important part of SCRM. The AHP discussed in this paper is widely known as the most popular and most-widely used for SCR assessment. However, most works merely discuss the supply chain in general. Only limited works offered a general hierarchy structure which can be applied generally in SCR assessment, e.g. by Mital *et al.* [15] when discussed complex analysis of the AHP hierarchy structure to be widely used in the SCR assessment of many products. Of many interesting discussions, technology product, e.g. mobile phone, computer, etc., is an interesting topic since it need fast product development. The faster the process needs to be worked out, the bigger probability of risks will arise in supply chain. The presence of online marketplaces, e.g. Shoppee, Tokopedia, Lazada, can be also an interesting discussion topic since they are strong game changers for the supply chain operation. These marketplaces can quickly offer many competitive products which can be easily seen by many people and companies.

Sustainability issues, e.g. social conflict, safety and health in working place, use of herbicide and preservative for food industries, company and employees' relation, social justice and environmental impact, have increased in recent years. These SSCM issues should be carefully addressed by the company, particularly due to increasing use of social media, e.g. Facebook, Instagram, Twitter, in this modern society. Any issue related to sustainability issues can be easily spread out through the social media. The author suggests that the company should increase awareness when dealing with a sensitive supply chain problem. The AHP method can be then implemented to address this issue since one key advantage of the AHP lays on its flexibility to gather information required for risk analysis, e.g. discussion with related experts, questionnaires, own thinking of the management team, etc. For example, Santoso *et al.* [28] used questionnaires technique to discuss supply chain management in cluster development of fisheries industry

6. CONCLUSION

Uncertain and unreliable circumstance affecting supply chain's performance in negative ways can be addressed by a systematic approach called as a supply chain risk management (SCRM) to reduce the probability of risks occurrence. Although many decision-making methods that can be used to assess risk, an important process of SCRM, the analytical hierarchy process (AHP) is discussed in this paper since it becomes the most popular one for multi criteria problem assessment. The ability of AHP to construct a hierarchal structure of problems can be used as a structure for future research. This paper also offers a new AHP framework which can be used to analyze supply chain risk.

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