Development of Supply Chain Risks Interrelationships Model Using Interpretive Structural Modeling and Analytical Network Process

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Abstract—**Globalization and vast changing of business nature nowadays makes interdependence between organizations who shares the same supply network is becoming stronger. Any risk that occurs in one point of a supply chain could affect to the whole network. As a result, risk in supply chain is getting more complex and unpredictable. Since any kind of risk could potentially impede or even stop business activities of the whole supply chain therefore managing supply chain risk is essential. Moreover, to handle supply chain risk properly, the interrelationships between these risks should be identified. However, there is only few study which cover interrelationships between supply chain risks. This research is aiming to provide a proposed model of a supply chain interrelation risks based on case study in an petrochemical industry. Interpretive Approach Structural Modeling is utilized to develop the relationships between risks while weight determination for risk relationship is conducted using Analytical Network Process. The case study of this research identifies that there are 14 supply chain risks which are grouped as driver, dependent, autonomous and linkage. The weight of risk interrelations are then considered when quantify each risk. Calculation of risk priority number is not only taking into account its own probability and consequence but also the probability and weight of affected risk.**

Keywords— Supply chain Risk management, Risk interrelationships.

I. Introduction

All business always has risk. Risk and opportunity in business can be seen as two sides of a coin. Therefore, businesses should find a way to gain profit while handling related potential risks. Nowadays, business is not competing between organizations but between supply chains. In 1980s, terminology of Supply chain (SC) is introduced. This term is describing network interaction between suppliers, manufacturers, distributors, retailers and customers, with aim to fulfils customer needs at low cost by matching customer demand with supply flow [2, 3]. The benefit of supply chain is significantly encouraging for business who always aiming at increasing their revenue. To ensure good integration between hundreds of supply chain players, from the upstream to the downstream, a continuous flow of information, material and capital is required. Moreover, due to globalization, e-business and offshore production, these supply chain players are located in different sides of the globe. As a result, business operations now are becoming more complicated, uncertain and interdependent which lead to more complex and higher risks.

Any disruption happened in one of supply chain player could affect the whole network while the source of disruptions could be originated from internal or external. This disruption potentially could lead to huge loss and even bankruptcy which can be seen in many cases as described in [4, 5]. Pholf, Gallus and Thomas [6] define risk in supply chain as " disturbances and interruptions of the flows within the goods, information, and financial network as well as the social and institutional network and may negatively effect the objective accomplishment of the individual company, respectively, the entire supply chain, in regard of end user advantage, costs, time or quality". To minimize or avoid the consequence of any disturbances in supply chain, every organization should manage potential risks in their supply chain.

Supply chain risk management (SCRM) is "process of systematically identifying, analyzing, and dealing with risks to SC" [7]. It is basically comprised of four steps, namely: risk identification, risk analysis, risk evaluation and risk mitigation. Identification of risk is the first and most important steps in SCRM. To be able to develop proper risk mitigation depends on the correctness of risk identification. Failure to recognize most of potential risks in supply chain could lead to incorrect risk analysis and risk evaluation which leads to ineffective mitigation strategy. Furthermore, due to complex and interdependent relations between supply chain players, the interrelationship of risks in supply chain should be considered [8, 9]. Therefore, it does not only identify potential risks but also recognizes the connection between these supply chain risks.

There are many research has been conducted in identifying risks in supply chain. Norrman and Jansson [4] utilised supply chain risk and structure map to plot business flow between a manufacturer and its suppliers to identify risk source at each process. However, only fewer research which take supply chain risk interrelationship into consideration. Hallikas et al. [10] presents risk interrelationships using combination of hierarchical forms and causal relations for assessing risks in small and medium-size enterprises (SMEs) network. Basu et al. [11] identified risk by mapping business processes and resource and then develop interrelationship between SC risks by using influence diagrams. While, Supply chain Management Process

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(SCMP) utilized to identify risks and Interpretive Structural Method (ISM) is used to model the relationships between risks in two case studies by Pfohl et al. [6]. This research shows that ISM can be applied to structure supply chain risks interdependencies which could be occurred in different SC players (e.q. third party logistics, first tier supplier, focal manufacturer, etc).

Even though, there are few studies that have accommodated identification of supply chain and mapping their interrelationships, none of these studies has done further by quantifying the weight of these risk interrelations. By doing so, it gives better data support to develop more proper supply chain risk mitigation plan. Thus, this research propose a framework to identify supply chain risks, then to develop risk interdependencies model as well as to quantify the weight between those interrelationships. This framework is applied in one of Indonesian chemical industry (Company X) and one of their main products (product Y) is chosen as case study for this research.

II. Method

The supply chain interrelationship is developed using Interpretive Structural Modeling (ISM) and it is integrated with Analytical Network Process (ANP) to quantify the weight which will be described in detail next.

ISM approach is consist of seven steps [6], they are: (1) Selection of elements relevant to the problem, (2) Establishing contextual relation type, (3) Construction of structural self-interaction matrix (SSIM) by pairwise comparison, (4) Developing a reachability matrix from the SSIM and checking for transitivity, (5) Level partitioning of reachability matrix, (6) Drawing of digraph with removed transitivity links, (7) Conversion of digraph into an ISM and checking of conceptual inconsistency. Output of ISM is then utilized in ANP to quantify the weight of supply chain risk interrelationship and it is followed these steps: (1) Classifying elements and alternatives, (2) Pairwise comparisons, (3) Developing Super matrix, (4) Synthesizing the result, (5) Determining the priority and weight. The integration between ISM and ANP of this research refers to Thakkar et al. [1] which can be seen in figure 1.

The first steps of ISM is conducted by identifying potential supply chain risk in Company X which will be the element of the problem. Supply Chain Operations Reference (SCOR) [12] model is utilized to assist researcher in identifying and structuring the potential supply chain risks. SCOR model consists of five operations namely: Plan, Source, Make, Deliver, and Return. To begin with, related primary and secondary data from the selected industry is gathered such as operations flow and potential supply chain risk in manufacturing product Y. Based on these data, all potential supply chain risks are divided into five operations stages according to SCOR model. There are five risks in Plan, six risks in Source, six risk in Make, ten risks in Deliver and two risks in Return. Some of those risks can be seen in table 1 below. Three expert of Company X, which are working in Planning, Warehouse and Material department, Production department, and Risk management department, are involved in this research to assist in confirming company's supply chain risks and their connections as well as the respondent in determining the weight.

After determining potential supply chain risks in the previous steps then its relationships are established through interview and discuss with respondents in Company X. These interrelationships then are mapped into Structural Self-Interaction Matrix (SSIM) which shows relation category between risk elements. They are four categories which is represent by different symbols, they are: (1) V = for the relation from i to j but not in both directions; (2) A = for the relation from j to i but not in both directions; (3) X = for both direction relations from i to j and j to i; and (4) O = if the relation between the elements does not appear to be valid. The next step is to develop Reachability Matrix based on SSIM by converting four symbols into binary number 0 and 1 based on these rules:

a. If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
b. If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
c. If the (i, j) entry in the SSIM is X, then both the (i, j) and (j, i) entries of the reachability matrix become 1.
d. If the (i, j) entry of the SSIM is O, then both the (i, j) and (j, i) entries of the reachability matrix become 0.

Checking for transitivity is conducted following reachability matrix development and the outcome is utilized for developing level partitioning of reachability matrix which takes several iterations. The result of these steps can be seen on table 2. Figure 2 shows classification of supply chain risks elements in driver dependence matrix as the result of mapping final reachability matrix output. It consists of four groups: driver, linkage, autonomous and dependent.

Conical matrix is developed based on partitioning of reachability matrix by rearranging the elements according to their level. The hierarchy resulted from conical matrix is utilized to develop ISM model (figure 3).

Before determining priority of supply chain risk elements which are linked to each other based on ISM model, the weight of each risk element should be established first. This is conducted by multiplying probability and consequence of each risk element. Then, the weight is determined by measuring the distance of risk driver with the affected risks. Then, pair wise comparisons for supply chain risk interrelationships is conducted and the partial result can be seen in table 3.

III. Result and Discussion

There is 14 risks has potentially occurs in Company X's supply chain. Driver-dependence matrix (figure 2) shows that supply chain risks in Company X fall into three groups, namely: autonomous, dependent, driver and linkage. "Delay/lateness of purchasing service" (risk #05) is risk which has maximum driver power (DP) value and fall in group "driver". It shows that if this risk occurs could cause many other risks in Company X's supply chain even though, the causes could be originated from external supply chain. While, risk that has the lowest driver power and dependence value is "over dependence to multiple sourcing" (risk #04), and fall in group “autonomous”. Thus, if this risk happens, it will have very low impact and/or low dependency to other risk in supply chain. “Storing final product in open storage” is risk that fall in group “dependent” which has lowest driver power but highest dependency to other supply chain risk. Supply chain risk of Company X that is fall in Linkage group is “lateness of incoming material”. Risk in Company X which have high driving force and dependency to others may lead production shut down or any other catastrophic to company’s or supply chain player’s operations. Briefly, by understanding the characteristics of each risk, it can be accommodated when developing mitigation strategy, since minimizing risk in “driver” group will automatically reduce risk in “dependent” group.

Further analysis using ANP has resulted on the weight of supply chain risk interrelationships between risk driver and its affected risks. By knowing the weight, proportion of affected risk can be measured more proper. For example, as can be seen on table 3, if the risk of lateness of incoming raw material (risk element #01) happens, then it will lead to the occurrence of two potentially affected risks with different fractions. Risk of process disruption due to material shortage (risk element #11) has the largest fraction that is 0.83. Then, it is followed by inadequate stock monitoring system (risk element # 10 = 0.17). Based on this weight (proportion), it can be inferred that if the arrival of incoming raw material is late in Company X will lead to process disruption due to material shortage with a probability of 83%. While the other risk that is inappropriate stock monitoring system will be also occur with a probability of 17%.

This weight will be considered in Risk Priority Number (RPN) calculation. For example: if probability and consequences for risk element (RE) # 01 are 4 and 4 consecutively. RPN is usually measured by multiple probability and consequence. Therefore, RPN for RE #01 is 16. By understanding that the occurrence of RE #01 will generate RE #10 and RE #11 as has been explained previously, then the probability and the weight for those risk to occur also considered. If probability for risk element (RE) # 10 and RE # 11are 2 and 3 consecutively then RPN for RE #01 become 16 + (0.17*2) + (0.83*3) = 18.83. In general, when calculating RPN only by taking into account probability and consequence of its own risk than the result will be smaller than if it also considers probability of affected risk. In view of risks in supply chain are interrelated, thus one risk could create other risk to happen. Therefore, calculation of RPN should also consider that interconnection in supply chain risk. By doing so, the risk evaluation which will prioritize risk based on the RPN will have a proper result and it will lead to better risk mitigation strategy.

IV. Conclusion

ISM is utilized in this research to develop supply chain risk interrelationship model and also to classify risk into four characteristics (groups) namely driver, dependent, autonomous and linkage. Whilst, ANP with Superdecision software are used to gain the weight of each relation between risks (risk driver and its affected risk).

As interrelationship of supply chain risks and the weight of each relation are known then these information are considered in RPN calculation. Accordingly supply chain risk should be determined not only by its own probability and consequence but also probability and the weight of its affected risk.

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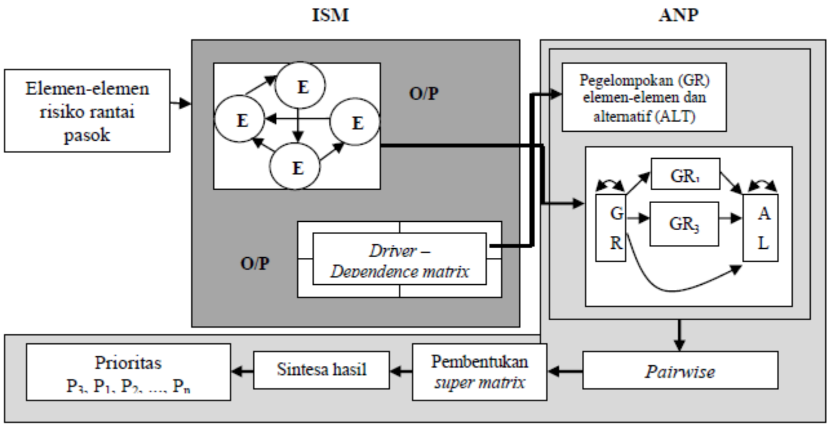

Figure 1. ISM and ANP integrated approach [1]

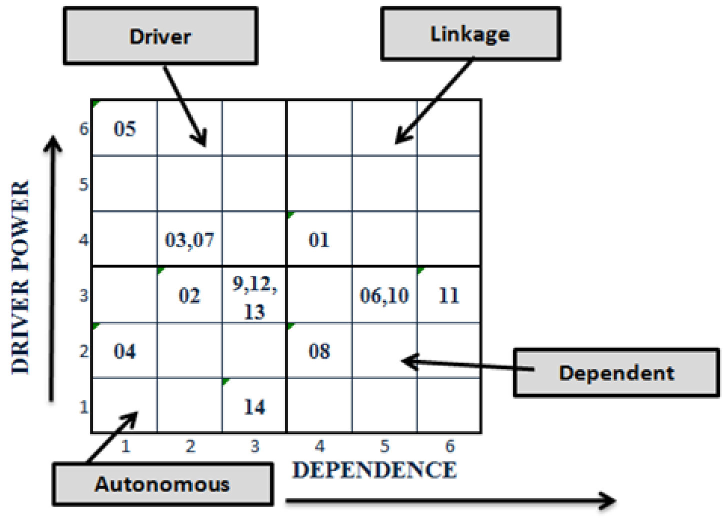

Figure 2. Driver dependence matrix of supply chain risk interrelationships

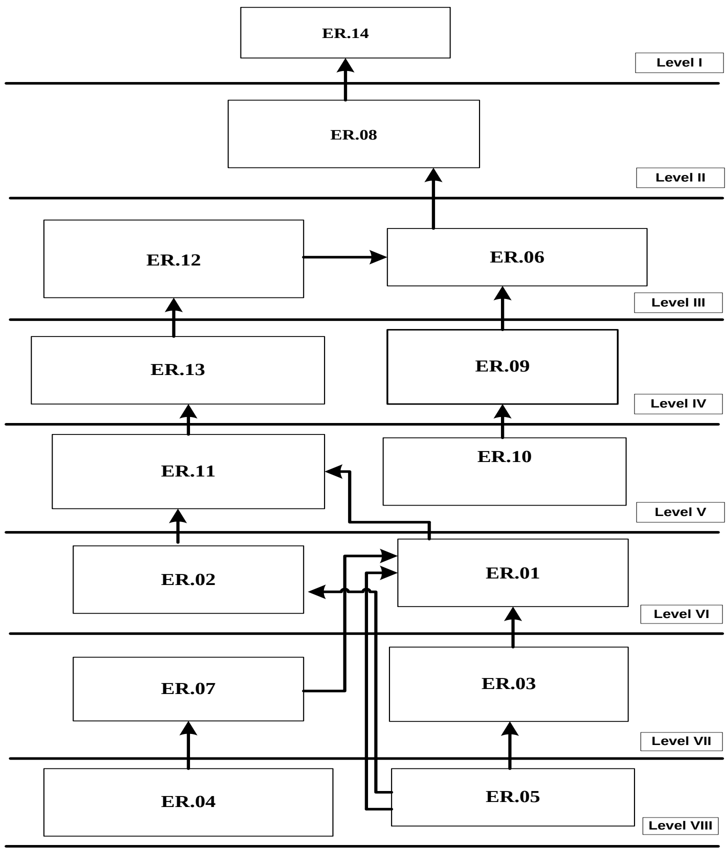

Figure 3. ISM Model

TABLE 1.
SUPPLY CHAIN RISK ELEMENT

Risk types	No	Description
Source	Risk Element 1	Inappropriate incoming raw material and supporting material arrival date (late)
	Risk Element 2	Inappropriate incoming spare parts arrival date (late)
	Risk Element 3	Overdependence to single supplier
	Risk Element 4	Multiple sourcing (too many suppliers)
	Risk Element 5	Lateness of service procurement

TABLE 2.
PARTIAL RESULT OF LEVEL PARTITIONING OF REACHABILITY MATRIX

Level	Element Risk numbers	Description
I	14	Defective or shrinkage final product
II	08	Open storage for storing final product
III	06	Inadequate warehouse space
IV	12	Increasing of consumption rare
	11	Stock difference
	28	Decrease in productivity

TABLE 3.
PARTIAL RESULT OF WEIGHT FOR EACH RISK INTERRELATIONS (ANP)

No	Risk Driver	Affected Risk	Weight
1	Delay/lateness of incoming material (ER 01)	Inadequate stock monitoring system (ER 10)	0.17
		Process interruption due to shortage of raw material (ER 11)	0.83