SERIAL-INTEGRATED MULTI-CRITERIA DECISION-MAKING TECHNIQUE FOR RESILIENT SUPPLIER SELECTION IN THE MANUFACTURING INDUSTRY

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ABSTRACT

A supply chain is an entire system of producing and delivering a product or service, from the very beginning stage of sourcing raw material to the final stage of delivering a product or service to end-users. Several global risks and disruptions brought massive and devastating impacts on the world economy including the Small and Medium Enterprises (SMEs). Since the supplier is one of the important elements in a supply chain, economic resilience can be implemented by selecting a resilient supplier. However, the literature shows that previous supplier selections only focused on traditional, green and sustainable suppliers' criteria but resilience was rare to be discussed. Thus, the first objective of the study is to identify the generic criteria for selecting resilient suppliers. At the same time, there are problems in dealing with uncertainties and incomplete information while selecting suppliers. The second objective is to develop a new integrated Multi-Criteria Decision-Making (MCDM) model that considers incomplete data and uncertainties in selecting resilient suppliers. In this study, the proposed criteria were quality, lead time, cost, flexibility, visibility, responsiveness and financial stability. A serial-integrated MCDM technique was proposed by combining Grey Relational Analysis (GRA) from the grey theory and the Best Worst Method-Technique for Order Preference by Similarity to an Ideal Solution (BMW-TOPSIS) technique in serial to assess the suppliers and select the best alternative. The proposed criteria and technique were applied in the metal manufacturing company (Case 1) and the food manufacturing company (Case 2) which were facing economic problems to demonstrate its effectiveness. The result was generated using MATLAB. The result for Case 1 shows that Financial Stability has the largest weight and Supplier 1 is the best supplier for the company. For Case 2, Cost shows the largest weight, and the best supplier is Supplier 4. Then, the result was verified through manual calculation and validated with Analytic Hierarchy Process-VlseKriterijumska Optimizacija I Kompromisno Resenje (AHP-VIKOR). Through the identification of the generic resilience criteria and the suitable MCDM model, the managers can focus on resilience with the consideration of uncertainties and incomplete information to improve the supplier selection process. This can help to raise the supply chain performance of the companies.

ABSTRAK

Rantaian bekalan adalah keseluruhan sistem penghasilan dan penyampaian produk atau perkhidmatan, dari peringkat awal penyediaan bahan mentah hingga peringkat akhir penyampaian produk atau perkhidmatan kepada pengguna akhir. Beberapa risiko dan gangguan global membawa impak besar dan dahsyat kepada ekonomi dunia termasuk Perusahaan Kecil dan Sederhana (PKS). Memandangkan pembekal merupakan salah satu elemen penting dalam rantaian bekalan, daya tahan ekonomi boleh dilaksanakan dengan memilih pembekal yang berdaya tahan. Walau bagaimanapun, literatur menunjukkan bahawa pemilihan pembekal terdahulu hanya tertumpu pada kriteria pembekal tradisional, hijau dan mampan tetapi daya tahan jarang dibincangkan. Oleh itu, objektif pertama kajian adalah untuk mengenal pasti kriteria generik untuk memilih pembekal yang berdaya tahan. Pada masa yang sama, terdapat masalah dalam menangani ketidakpastian dan maklumat yang tidak lengkap semasa memilih pembekal. Objektif kedua ialah untuk membangunkan model Pembuatan Keputusan Berbilang Kriteria (MCDM) bersepadu baharu yang mempertimbangkan data yang tidak lengkap dan ketidakpastian dalam memilih pembekal yang berdaya tahan. Dalam kajian ini, kriteria yang dicadangkan ialah kualiti, masa utama, kos, fleksibiliti, keterlihatan, responsif dan kestabilan kewangan. Teknik MCDM bersepadu bersiri baharu telah dicadangkan dengan menggabungkan Analisis Hubungan Kelabu (GRA) dari teori kelabu dan teknik Kaedah-Teknik Terburuk Terbaik untuk Keutamaan Pesanan mengikut Persamaan dengan Penyelesaian Ideal (BWM-TOPSIS) secara bersiri untuk menilai pembekal dan memilih alternatif terbaik. Kriteria dan teknik yang dicadangkan telah digunakan dalam syarikat pembuatan logam (Kes 1) dan syarikat pembuatan makanan (Kes 2) yang menghadapi masalah ekonomi untuk menunjukkan keberkesanannya. Hasilnya kemudian dihasilkan dengan menggunakan MATLAB. Keputusan Kes 1 menunjukkan bahawa Kestabilan Kewangan mempunyai berat terbesar dan Pembekal 1 adalah pembekal terbaik untuk syarikat. Bagi Kes 2, Kos menunjukkan beban terbesar dan pembekal terbaik ialah Pembekal 4. Kemudian, keputusan telah disahkan melalui pengiraan manual dan disahkan dengan Proses Hierarki Analitik-VlseKriterijumska Optimizacija I Kompromisno Resenje (AHP-VIKOR). Melalui pengenalpastian kriteria daya tahan generik dan model MCDM yang sesuai, pengurus dapat memberi tumpuan kepada daya tahan dengan pertimbangan ketidakpastian dan maklumat yang tidak lengkap untuk menambah baik proses pemilihan pembekal. Hal ini dapat meningkatkan prestasi rantaian bekalan syarikat.

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CHAPTER 1

INTRODUCTION

1.1   Introduction

Due to global risks and disruptions, many Small and Medium Enterprises (SMEs) faced an economic crisis and some of them ended up with bankruptcy. To overcome the problem, a new integrated MCDM model was developed by applying the knowledge of Multi-Criteria Decision-Making (MCDM) in Industrial Engineering. This chapter discusses the study background, problem statement, research questions, research objectives, research scope, research significance, and finally chapter summary.

1.2   Research Background

A supply chain is a whole system that produces and delivers a product or service, from the starting stage of sourcing raw materials to the last stage of delivering products or services. A supply chain involves all the aspects of the production process, including the activities of transforming natural resources into finished products. A supply chain consists of five main elements which are suppliers, manufacturers, distributors, retailers and customers. Along the supply chain, there are uncertain risks and interruptions that can affect many areas of work.

Generally, there are two categories of supply chain risks which are operational and disruption (Ivanov, 2018). Operational risk refers to the inherent events that occur in a supply chain, such as transportation cost uncertainties, fluctuation in demand of the customer, and changes in the workforce (Hosseini & Barker, 2016a). Disruption risk refers to serious disruptive activities including natural disasters, human-made threats, or employee strikes such as pandemics,

earthquakes, tsunamis, fires, floods, logistics accidents, and labor strikes. These events may bring short-term or long-term negative effects on supply chain financial status or economic crisis in more serious cases. An economic crisis is a situation in which the country's economy experiences a sudden downturn in its aggregate output or real gross domestic product (GDP). The economic crisis brings a decline in the real income per capita and an increase in the rate of unemployment and poverty. This brought a strong impact to the world industries and they took a long period to recover. There are several cases of economic crisis in the past decades.

In 1997, the Asian economic crisis happened due to the speculative attacks on the Thai Baht. Malaysian Ringgit depreciated against the dollar by nearly 50 percent. The collapse of the stock market was even more drastic than the plunge in the exchange rate. The property bubble burst and it was accompanied by the massive capital outflows. The drop in stock prices, the slump of the property market and the depreciation of Malaysia Ringgit together led to the contraction of the economy. It resulted in a slowdown of economic growth which brought an inevitable impact on Malaysia's social sphere. The gross domestic product (GDP) contracted and resulted in the retardation of the growth of employment and the increase in the rate of unemployment. In 1998, the declined economy plunged the country into the first time of recession and caused all the economic sectors to shrink. Consequently, Malaysia's GDP dropped 6.2%. Among all the sectors, the construction sector contracted 23.5%, the manufacturing sector shrunk 9% and the agriculture sector dropped 5.9%. The economic shrinkage was then led to industries' bankruptcy. This crisis took several years to recover the economy (Ariff & Abubakar, 1999). This scenario implies the importance of resilience to deal with the economic crisis.

The attack of the Japanese earthquake and tsunami in 2011 have caused another economic crisis around the world. The suspension of Toyota in much of its production at Japan plants caused a worldwide shortage of components from suppliers (Reuters, 2016). The segregation of geography among suppliers has been practiced as a resilience driver for most of the automotive manufacturing companies after the disasters, where many of Toyota's auto part suppliers failed to fulfil the demand due to their location in the disruption zone. Toyota since then tried to collaborate with suppliers who were geographically dispersed, rather than being in a

short-distance zone. The unfulfillment of some critical suppliers led to a significant loss in profit during disruption due to the problem of replacing the suppliers. This shows that suppliers play an important role to deal with world disruptions.

In 2020, the worldwide pandemic COVID-19 which is not only an operational risk but also a disruption risk has brought a great global impact upon supply chain logistics, suppliers, and workforces. In Malaysia, Entrepreneurship Development and Cooperatives Ministry stated that a total of 50,269 SMEs faced an economic crisis and most of the companies faced bankruptcy when the Movement Control Order (MCO) was first implemented to stem the Covid-19 pandemic in March 2020 (Carvalho et al., 2020). Companies Commission of Malaysia provided a statistic that there were 9,675 SMEs shutting down from March 18 to June 9 in 2020 which was the first phase of MCO. From June to September 2020 which was the recovery MCO phase, 22,794 SMEs have folded (Carvalho et al., 2020). From the global view, supply chain risks and market disruptions were at an alarmingly high level. Based on a survey in April 2020, Institute for Supply Management reported that the reason 95% of businesses experienced operational problems was due to the pandemic (Ventura, 2020). US economy suffered the most severe contraction due to COVID-19 in December 2020. Because of lockdowns, social distancing measures, and travel restrictions, most of the companies found themselves losing workers and customers thus unable to operate the companies. As a result, there was a typical impact against financial insolvencies such as budget cuts and employee layoffs, which finally ended up with bankruptcy (Ventura, 2020).

COVID-19 hit the world economy including all the manufacturing industries. The metal manufacturing industry experienced a serious economy downturn which affected demand, production and revenues as the pandemic intensified. Although several countries have reported steel as one of the metal categories is an essential item, but the demand for steel production has dropped dramatically during the pandemic. Many minor construction projects have been halted as a consequence of the COVID-19 outbreak which has also negatively affected demand for steel (Research and Markets, 2020). On the other hand, as the government restricted the goods' movement locally and across countries, the problem of lack of materials

caused the manufacturers to halt their production (GlobeNewswire, 2021). This caused several problems along the supply chain. To deal with these, resilience is necessary to be considered in a supply chain to avoid the deterioration of the problems.

Other than that, manufacturers from food manufacturing industry also faced financial problems. However, the food manufacturing industry is slightly different from other industries in that it is producing essential needs (Food and Agriculture Organization, 2020a). The issue of factory shutdown causes consequences along the food manufacturing supply chain. If one factory closes, a certain number of workers at the factory face the risk to get unemployed and get starved, but if the suppliers and manufacturers are infected, more people are at risk (Staniforth, 2020). As the consequence, some food companies are working hard to meet the growing demand of retailers, whereas others are facing various challenges due to a drop in income. Due to the pandemic, governments around the world have made significant restrictions on the transportation of goods, as well as in the migration of labor. Therefore, the supply chain is significantly affected by the absence of local or migrant workers due to sickness or travel restrictions imposed by the lockdown. Resilience is required to be incorporated to deal with sudden changes in supply chains.

A resilient supply chain has a good flow of materials, information, and capital, with the collaboration between suppliers and customers by considering dimensions of having the ability to quickly respond to disruptions and possessing a flexible contingency plan to get ready with any disruptions. A definition of resilient from the National Association of Counties (NACo) (2013) stated that an economy resilient supply chain is able to foresee, adapt to, and leverage the uncertain conditions to the economic advantage. Similarly, U.S. Economic Development Administration's Comprehensive Economic Development Strategy Content Guidelines reported that there are three main attributes of resiliency which are the ability to withstand a shock, the ability to recover quickly from a shock, and the ability to avoid a shock altogether. There are different kinds of shocks such as any downturns in the national or global economy affecting local goods' demands and spending, external impacts such as a major changing climate, natural or man-made disasters, or military base

closures and any downturns of particular industries due to local economic activities (EDA, 2016). SAP Insights (2020) stated that a resilient supply chain is defined by its capacity for resistance and recovery which are the capability to resist supply chain disturbances and the ability to recover from disruptions within a short duration. A supply chain should be resilient enough from the economic perspective to respond to the supply chain challenges (Aday & Seckin Aday, 2020). In this case, Supply Chain Management (SCM) is very important. SCM is complicated and it includes all kinds of processes such as evaluation and selection of suppliers, negotiations of pricing and delivery and sharing of demand and supply (Chopra & Meindl, 2007). Rajesh and Ravi (2015) reported that supplier is one of the main elements in a supply chain whereas Munir et al. (2020) stated that supplier acts as the main source in developing a supply chain economy resiliency. Therefore, suppliers are the main concern in managing a resilient SCM.

A supplier can be a person, company, or organization that sells or supplies goods or equipment to customers. In this study, a supplier is a party that provides the raw materials by ensuring that the communications between all the parties are forthcoming and the stocks are of satisfactory quality. Suppliers play a vital role at each stage of the production process. Overall, suppliers are an inevitable source of economic issues. To deal with the economic crisis, an appropriate supplier selection is one of the effective ways. Generally, the selection can be carried out through a regular review of the financial and business performance of the suppliers. This can raise the confidence of customers about the suppliers and ensure the appropriate continuity plans are in place. By establishing certain performance indicators for suppliers, the managers will find it easier in building up a resilient supply chain.

In achieving a competitive supply chain, Supplier Selection Process (SSP) is one of the key activities, which further becomes a challenge for decision-makers (DMs) within today's globalized and strategic sourcing business framework (Li et al., 2007). SSP is important to improve future development and organizational competitiveness (Ahmed et al., 2018). SSP involves four subprocesses which are defining the problem, identifying the evaluation criteria, determining the potential suppliers, and selecting the best suppliers (Chen et al., 2018). Over the decades, SSP

has become more complicated due to the occurrence of more uncertainties, in addition to the traditional criteria such as cost, lead time, and quality. Accordingly, the literature is strengthened with a new approach that incorporates resilience criteria into the assessment process. This shows that decision-making is vital in SCM (Achilles, 2021). As such, Multi-Criteria Decision Making (MCDM) which is a user-friendly decision-making tool is conceptualized and developed, theorizing, and proposing to evaluate and select the best suppliers among the potential alternatives based on several traditional and resilience performance attributes.

SSP is a MCDM problem since the process deals with more than one criterion. To manage the whole supply chain, companies have to determine the relationship between each criterion, which in turn impacts the performance of the supply chain. MCDM method is a decision-making technique that combines supplier's performance across numerous, contradicting, qualitative and quantitative criteria and requires a solution with consensus (Seydel, 2006). The objective of MCDM is not only to suggest the best decision but also to aid decision-makers in selecting alternatives that are in line with their requirements. Belton & Stewart (2002) mentioned that at early stages, knowledge of MCDM methods and an appropriate understanding of the perspectives of decision-makers themselves are important for efficient and effective decision-makers.

MCDM is one of the fast-growing problem areas in supplier selection (Triantaphyllou, 2000). Instead of restricting its application to a specific MCDM approach, another idea is employing several MCDM techniques to improve the evaluation process. There are several MCDM methods available including Analytical Hierarchal Process (AHP), Analytical Network Process (ANP), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Previously, many researchers have applied these techniques in the field of supplier selection. Some of the researchers have integrated different MCDM techniques to form a new technique such as AHP-TOPSIS, GRA-TOPSIS and VIKOR-DEMATEL. However, some techniques faced difficulties to deal with uncertainties and incomplete data. In this

study, a new serial-integrated MCDM technique is proposed to solve the difficulties in resilient supplier selection.

1.3 Problem Statement

Along with unexpected global disruptions such as pandemics, people are accustomed to surviving in their comfort zones as they enter the globalization period. As a result, there is a lack of preparedness and readiness in dealing with unforeseen risks and disruptions, which pose several supply chain problems, causing most of the manufacturing sectors to face financial issues. To deal with the financial problem, resilience is very important to be incorporated to select suitable suppliers. The literature shows that most of the previous supply chains only emphasized on traditional, green and sustainable supply chain elements whereas less resilient supply chains have been explored. Therefore, resilience was focused in supplier selection to deal with various SC challenges. However, from the review on previous resilient supplier selection, each of the studies has introduced different sets of resilience criteria respectively and the sets are only suitable for certain industries rather than all, thus, there is a lack of a generic set of resilience criteria in supplier assessment and selection process. Generic criteria are defined as the characteristics relating to a whole group or class which can be generally applied in all kinds of situations. In this study, a generic set of resilience criteria was proposed to be applied in all kinds of manufacturing industries.

From the literature, MCDM techniques have been applied widely in solving previous supplier selection problems. Previous resilient supplier selection studies have utilized several MCDM methods either individual technique or integrated technique of AHP, ANP, TOPSIS, DEMATEL, and VIKOR in selecting resilient suppliers. After a comparison between the previous techniques, there is still room to improve the supplier selection process. In this study, the literature review was studied and the supply chain requirements were analyzed, finally a new serial-integrated MCDM method was proposed to improve the resilient supplier selection process. On the other hand, there are problems of uncertainties and incomplete

information in the supplier selection process. Unexpected risks and disruptions bring various uncertainties to the supply chain. In this case, the scorings on suppliers are usually incommensurate and fuzzy in nature. At the same time, decision-makers may have varying levels of knowledge and opinions when it comes to evaluating the suppliers. Also, there may be insufficient information due to data confidentiality which causes difficulties for the evaluation process. To deal with this, most of the studies have introduced fuzzy theory but the fuzzy theory was repaired to solve the uncertainties rather than incomplete information. Thus, the grey theory was applied. Also, literature shows that grey theory is still new and not yet being explored widely. Therefore, this study is proposing a serial-integrated MCDM technique and combining it with the grey theory which is not yet being investigated. The technique is applied to the manufacturing industries and the choice of case company is based on the impact of pandemic towards the supply chain.

1.4   Research Questions

The research questions are:

(a)   What are the generic criteria for selecting resilient suppliers?

(b)   What is the suitable MCDM model that considers incomplete and uncertain information in selecting suppliers?

1.5   Research Objectives

The objectives of the research are:

(a)   To identify the generic criteria of selecting resilient suppliers.

(b)   To develop a new integrated MCDM model that considers incomplete and uncertain information in selecting suppliers.

1.6   Research Scopes

There are several kinds of resilience in the supply chain. This study is focusing on the economic aspect of a resilient SC. To deal with this, a set of resilience criteria is determined. The resilience criteria set identified is generic rather than specific to a particular industry. Traditional criteria, as well as resilience criteria, are considered in the supplier selection process. In this study, two case studies were carried out in the manufacturing industries to validate the results. MATLAB is the tool applied for programming the technique.

1.7   Research Significance

It is highly crucial to introduce the resilience element into the supplier selection process rather than only conventional, green and sustainable elements due to its ability to deal with unforeseen risks and disruptions. Resilience can reduce the supply chain vulnerability towards the worldwide crisis and manage to recover from impact within a short period. In this case, a resilient supplier can make sure that the supply chain is free of economic disturbance and all the production line processes can be carried out as usual. Other than that, uncertainties factor is needed to be focused on the supplier selection process to deal with incomplete data and various uncertainties. In the case of pandemics which has brought uncertain disruptions to the supply chains, the impact is clearly shown from the economic problem. Before the pandemic, traditional criteria were being focused and resilience has been neglected in the supplier selection process which caused several economic effects and industries bankruptcy after the pandemic. To deal with the problem, resilience was incorporated in supplier selection. Other than that, the proposed set of resilience criteria was identified based on the review of literature and consideration of current supply chain needs. A set of generic resilience criteria was identified and a serial-integrated MCDM method was proposed to select resilient suppliers. The proposed criteria do not only consider the basic traditional elements, but also resilience and financial elements. With this, the company's managers could focus on different aspects by clearly identifying the resilience criteria with their importance to be

prioritized in the assessment process. Also, a more effective technique was proposed to improve the supplier selection process. Therefore, this study is significant to overcome the current needs of the metal and the food manufacturing industries and the proposed solution can enhance competitive advantages for organizations in the way of improving supply chain resiliency through resilient supplier selection. With this, future supply chain managers can assess the suppliers easily based on the proposed generic criteria and the new technique, thus saving time and effort in improving the supply chain performance. By applying the knowledge, the case company would be able to achieve its objective of building up a resilient supply chain through resilient supplier selection.

1.8   Outline of Thesis

Chapter 1 introduced the thesis, and the left of chapters are discussed as follows: Chapter 2 explains the literature review of the study. Chapter 3 presents the methodology of the study while Chapter 4 describes the data collection process for this study. The outcomes of the study were presented in Chapter 5 while Chapter 6 concludes the whole study.

1.9   Summary

This chapter has illustrated a brief understanding of the project. A supply chain includes the beginning process of providing raw materials by suppliers until the end process of delivering products to customers. Supplier is the main element of a supply chain and its selection is vital to improve the supply chain performance to deal with uncertain risks and disruptions. The next chapter is going to explain about literature review of the study on SCM, type of supplier selection, supplier selection criteria and methods, research gap and finally chapter summary.

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LIST OF PUBLICATIONS

Indexed Journal

1.   Leong, W.Y.; Wong, K.Y.; Wong, W.P. A New Integrated Multi-Criteria Decision-Making Model for Resilient Supplier Selection. *Appl. Syst. Innov.* **2022**, *5(1)*, 8. https://doi.org/10.3390/asi5010008 **(indexed by Scopus and Web of Science)**

Conference Proceeding

1.   Leong, W.Y.; Wong, K.Y. Trend and Assessment of Resilience. *2nd International Professional Doctorate and Postgraduate Symposium 2021 (iPDOCs'21)*, Universiti Teknologi Malaysia, 25 Sept 2021

2.   Leong, W.Y.; Wong, K.Y. Review on Resilient Supplier Selection. *International Conference on Applied Computing 2021 (ICAC'21)*, Universiti Teknologi Malaysia, 2-6 February 2021