**Supply Chain Sustainability Risk Assessment Model Using Integration of the Preference Selection Index (PSI) and the Shannon Entropy**

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Purpose

This study proposes a new model for assessing supply chain sustainability risk integrating subjectivity and objectivity of decision- maker. Research has shown the vacancy of study in dealing with above issue. To fill this research gap, a new decision support model considering subjectivity and objectivity of decision makers in assigning the weight of the supply chain risk reprioritization criteria is presented and demonstrated using a case example.

Design/Methodology/Approach

This study adopts a new decision support model for assessing supply chain sustainability risk based on additional Failure Mode and Effect Analysis (FMEA) parameters and its integration with Preference Selection Index (PSI) methodology and The Shannon entropy. A case example of the supply chain SME producing handy crafts has been used in this study.

Findings

The result of our study reveals critical sustainability risk dimensions and their risk elements demanding management attention to support realization to a more sustainable business operation.

Research limitations/implications

The use of a single case study is often associated as a limitation in the research studies, and this study is based on findings from Small and Medium Enterprise (SME) in the handy craft sector in a developing country. Nonetheless, future studies may focus on replicating this study using more samples. This preliminary study provides academics and practitioners with an exemplar of supply chain sustainability risk assessment from the SME in a developing country.

Practical implications

The result of this study is beneficial for practitioners, particularly owner-managers of SMEs who can use this study as guidance on how to identify and select the critical sustainability risks and plan mitigating strategies accordingly.

Originality/value

Scientific effort on appraising supply chain sustainability risk using the integration of the PSI and Shannon entropy method is missing in earlier studies. To the best of our knowledge, this is the first paper applying the PSI and Shannon entropy method and using it for evaluating supply chain risk based on five sustainability pillars. The findings and suggestions for future research initiatives will provide new insights for scholars and practitioners in managing SME supply chain sustainability risks.

1. **Introduction**

Small and medium enterprises are important contributors to the global economy not only because of their large economic contributions but also due to their role as a job absorbing sector in both developed and developing countries (Hanggraeni *et al.* 2019). However, due to inherent limitations of human and financial resources (Saad *et al.* 2017) it often makes their business prone to termination. Following the work of Tong *et al*. (2018), it is estimated that during the first decade of a business lifetime, only 13% of the SMEs will survive. This indication signals the importance of managing business risks in the context of SMEs to support their business standing in the long-time horizon. Government around the globe are currently enforcing organisations large or small to implement sustainable practices. Hence, improving methodology to aid SMEs to appraise the impact of sustainability risk will provide relevant sustainability risk mitigation strategies that in turn will improve its sustainability. Driven by the need to sustain global economic growth by reducing the adverse impact of business uncertainty, nowadays the theme of supply chain sustainability risk assessment is becoming one of the emerging research areas (Ghadge *et al*. 2012, Ho *et al*. 2015, Fahimnia *et al.* 2015; Kumar *et al*. 2018). Although the importance of sustainability risk assessment within supply chain context is getting more important, research attention devoted to improving methodology in Small and Medium Enterprises (SMEs) supply chain risk assessment approach are still scarce (Qazi and Gaudenzi, 2016), Vishnu *et al*. (2019) and Lima *et al.* (2020). As an aid to decision- makers in dealing with supply chain risk assessment within Small and Medium Enterprises, several studies have utilised various risk reprioritization methods. Anin *et al.* (2015) used traditional FMEA in which the determination of critical supply chain risks is based on multiplication among three risk indices namely, occurrence, detection and severity of risks without the utilization of any multi- criteria decision- making method. Fuzzy logic -based supply chain risk reprioritization approach has been reported by Rohmah *et al*. (2015) and Muchfirodin *et al*. (2015). Slamet *et al*. (2017) presented the integration of Fuzzy logic and the ANP for ranking critical SME supply chain risks, Mustaniroh *et al*. (2019) used the integration of the AHP and Fuzzy logic to select critical SME supply chain risks. Babu *et al.* (2020) presented the use of the Interpretive Structural Model (ISM)-based supply chain reprioritization approach to improving understanding in selecting the most critical risks considering their interrelationship. Alora and Barua (2021) by using the integration of the AHP and Fuzzy TOPSIS revealed critical SME supply chain risks. Despite versatility on studies applying varying supply chain risk assessment models in aforementioned works, efforts to appraise the impact of risk in above mentioned SME supply chain which use the AHP and ANP approach are still based on decision- makers subjectivity in which pairwise comparison among risk criteria and consistency checking of decision -makers are becoming investigation basis.

Although establishment of decision support model to assess criticality of supply chain risks considering both of subjective and objectivity of decision makers is believed advantageous instead of reliance on subjective or objective stand-alone approach, however to the best of our knowledge such effort is vacant in supply chain risk management studies. Among studies on compiling supply chain risk assessment models presented by Rathore *et al*. (2017), Tran *et al.* (2018) and Vishnu *et* *al.* (2019) are showing vacancy of studies dealing with the above issue. While efforts to consider decision- makers subjectivity and objectivity in assigning risk priority ranking are already reported by Wen *et al.* 2021 and Pintelon *et al.* 2021, studies intended to consider decision makers subjectivity and objectivity in the supply chain risk assessment area is vacant in references. Subjective evaluation of risk criteria occurred when decision maker uses his or her own preference in assigning the risk criteria score, meanwhile objective risk evaluation process is accomplished by calculating mathematically to the all-risk elements in the decision matrix (Chaitanya and Srinivas, 2021).

In an attempt to support decision- makers determining priority ranking in a multi -criteria decision making environment, Maniya and Bhatt ( 2010) introduced the Preference Selection Index (PSI) method. Considering its simplicity, this method is getting wider acceptance being used in various applications areas such as evaluating the performance of flexible manufacturing system evaluation (Jain, 2018), determining optimum process parameters ( Parizi *et al.* 2017 ), selecting the best accommodation (Aksoy and Ozbuk, 2017), maintenance planning ( Pancholi and Bhatt, 2018 ). However, the utilisation of this method in supply chain risk evaluation studies, to the best of our knowledge is vacant in literature. Along with the intention to develop a subjective and objective decision support model simultaneously for supply chain risk evaluation which is also missing in previous studies, this paper intends to develop a new decision support model for evaluating the criticality of supply chain sustainability risk of SME considering subjectivity and objectivity of decision- maker using the integration of the PSI and the Shannon entropy.

The objectives of this paper are as in the followings

* To present the objective and subjective supply chain sustainability risk assessment model based on the integration of the PSI and The Shannon entropy method.
* To determine critical supply chain sustainability risks based on the decision support model using the integration of the PSI and the Shannon entropy based on case example.
* To elaborate the theoretical and practical offering by this study.

The structure of this paper is as follows. In section 2, a short description of supply chain sustainability risks and followed by an overview of supply chain sustainability risks assessment and the state of the art of use of the supply chain risk assessment tool, the FMEA in the supply chain context. Section 3 relates to an overview of the PSI, state of the art in applying this method and establishment of supply chain sustainability risks assessment model based on integrating the PSI and The Shannon Entropy into supply chain FMEA framework. A case example applying the framework using SME Supply chain producing handy crafts based on five pillars of sustainability is presented in section 4. Findings, discussion, and limitations of the model used are presented in section 5. Finally, section 6 concludes this study with directions for future research.

1. **Literature review**

This section relates to the description of supply chain sustainability risks and compilation of earlier studies in supply chain sustainability risks and the implementation of supply chain FMEA as qualitative tool for assessing supply chain sustainability risks and outlines the research gaps motivating this research.

*2.1 Overview of supply chain sustainability risks and its advancement of studies*

Correlating to any factor brings negative consequences, risk is possessing two attributes namely, the likelihood of risk event occurrence and its adverse impact (Majumdar *et al*. 2020). In line with the growing importance of managing business operation against impact of business risks, Junaid *et al.* (2019) presented various definition of risk from scholars and yielding conclusion that supply chain risk can be defined as the adverse impact of risk events occurrence when companies doing business with their partners. Within the supply chain management discipline, supply chain risk assessment is one of the critical enablers of successful supply chain risk management (Prashar and Aggarwal, 2019). In improving understanding on the category of supply chain risks impact, Shafiq *et al*. (2017) presented categorization of supply chain risks into two broad categories; operational and sustainability type supply chain risks. The first supply chain risk category refers to any risk events bring negative impact temporarily to operational of supply chain and usually concentrated on cost, delivery and quality problems and sustainability risk as the risk events occurred bringing adverse environmental and social impacts. Other scholars, Louis and Pagel (2019) presented categorization of supply chain risk into two classes, ordinary and sustainability risk. The former risk focuses on typology of supply chain risk that have temporary impact on the company and has no consequences on the existential of the company in the long-time horizon. In the opposite, sustainability supply chain risk has longer adverse impact on the firm threatening the existential of business in longer time horizon and closely related with capability to provide the need of future generation. Departing from the adverse impact of sustainability risks, Iddirisu and Bhatarachaya (2015) suggested the expansion of sustainability pillars into five pillars namely, economical, technical, environmental, social, and institutional dimensions. Driven by growing interests in managing supply chain sustainability risk, studies dealing with improving methodology for prioritization of supply chain sustainability risks are growing recently. Table 1 presents scientific efforts which focusing on supply chain sustainability risk assessment.

Table 1. Studies focusing on supply chain sustainability risk assessment

|  |  |  |  |
| --- | --- | --- | --- |
| Author(s) | Description | Enterprise type | Author country of origin |
| Gianakis and Papadopoulos (2016) | Exploring categories of sustainability risks using case example from developed economy setting and proposing risk management approaches based of conventional FMEA | Large enterprise | France and UK |
| Rostamzadeh et al., (2018) | Evaluating critical supply chain sustainability risk using TOPSIS and CRITIC | Large enterprise | Iran and Denmark |
| Baseet and Mohammed  ( 2019) | Integrating TOPSIS and CRITIC methods to appraise criticality of sustainability risk | Large enterprise | Egypt |
| Song et al., (2019) | evaluating the impact of internal-and external supply chain risk factors using DEMATEL (Decision Making Trial and Evaluation Laboratory) | Large enterprise | China |
| Valinejad and Rahmani (2018) | Determining critical supply chain sustainability risks based on five pillars of sustainability | Large enterprise | Iran |
| Xu et al., (2019) | Development of a framework to quantify supply chain sustainability risks using risk assessment space and materiality analysis | Large enterprise | China |
| Rezgdeh and Shoukohyar (2020) | Inclusion of information technology dimension in assessing supply chain sustainability risk | Large enterprise | Iran |
| Chen et al., (2021) | Investigation on relationship of critical success factors for supply chain risk mitigation in telecommunication industry | Large Enterprise | India |
| Jianying *et al*. (2021) | Applying integrated neural network with Genetic Algorithm and Particle Swarm Optimization methods to determine the most critical supply chain sustainability risks | Large enterprise | China |
| Yang *et al.* (2021) | Evaluating sustainable SME credit risks within financial supply chain | Small enterprise | China |
| Raian et al.(2021) | Applying Fuzzy Synthetic method to evaluate sustainability risks in textile supply chain | Large enterprise | Bangladesh |
| Wang and Rani  (2021) | Integrating double normalization-based multiple aggregation (DNMA) model and fuzzy logic for ranking sustainable manufacturing supply chain risk | Large enterprise | China |
| Haji *et al*. (2021) | Applying integrated Best-Worst Method (BWM) and fuzzy-WASPAS Methods for ranking sustainable risks in food supply chain | Large enterprise | Iran |

At the other side, the use of FMEA as methodological approach to assess criticality of supply chain risk is continuously growing irrespective to the type of supply chain risk factors being evaluated. Table 2 presents compilation of studies on utilising the FMEA as means to evaluate criticality of supply chain risks.

Table 2. Studies pertaining on applying FMEA methodology for supply chain risk assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Author(s) | Content | Supply chain risk reprioritization tool | Risk reprioritization parameters | Supply chain type |
| Ghadge *et al*. (2017) | Solving root cause of quality risks in global supply chain | Fuzzy logic | Severity, detection and occurrence of risk | Electronics product supply chain |
| Nakandala *et al.* (2016) | Analysing criticality of risks in fresh food supply chain | Fuzzy logic and Hierarchical holographic modelling | Occurrence and severity | Food supply chain |
| Prakash *et* al.(2017) | Modelling interrelationship among risks in food supply chain | Interpretive structural modelling (ISM) | Occurrence, detection and severity | Food supply chain |
| Mohan (2017) | Selecting critical risk exposure index in pharmaceutical industry | AHP | Occurrence, detection and severity | Pharmaceutical products |
| Sheshe  (2018) | Evaluating criticality of risk factors in humanitarian supply chain | None | Occurrence, detection and severity | Humanitarian operation |
| Liu et al., (2018) | Determination of critical safety risk in gas station supply chain | Entropy | Occurrence, detection and severity | Gas station supply chain |
| Mangla et al., (2018) | Determining critical risk factors in green supply chain | Fuzzy Logic | Occurrence, detection and severity | Plastic Manufacturing |
| Alzubayer et al., (2019) | Evaluating criticality of supply chain risks in ceramic | Fuzzy TOPSIS | Quality of process control, probability of risk event occurrence and severity of risk effect | Ceramic |
| Olivos *et al.,* 2019 | Assessing criticality of risk factors in tools manufacturing | AHP | Occurrence, detection and severity | Fabricated Tools |
| Wu et al., (2019) | Assessing criticality of supply chain in automobile manufacturing | Fuzzy Synthetics evaluation | Occurrence and severity | Automobile product |
| Rathore *et al.* (2020) | Assessing critical supply chain risks in food grain supply chain | Fuzzy VIKOR | Occurrence, Detection and Severity | Food |
| Mzougui *et al.* (2020) | Identifying Critical supply chain risk in Automotive manufacturing supply chain | AHP and fuzzy DEMATEL | Occurrence, cost, dependence and strategic impact | Automotive product |
| Panahi *et al.* (2020) | Determining critical supply chain risks in Event Weather in the Artic | AHP and Bayesian Network | Occurrence, visibility | Maritime supply chain |
| Raghuram *et al.* (2020) | Determining supply chain risk maturity index | Ordered Magnitude-AHP | Probability and severity of risk | Distillery industry |
| Zhu *et al.* (2020) | Identifying critical risks in product deletion and its impact to supply chain | None | Occurrence, detection and severity scale | Consumer products |
| Moktadir *et al*. (2021) | Identifying critical supply chain sustainability risk | Pareto Analysis-Best Worst Method (BMW) | None | Leather |
| Anugerah *et al*., (2021) | Selecting critical sustainable supply chain risks | AHP | Occurrence, Detection and severity scale | Palm oil |

Referring to Table 1 dan table 2, it is evident that despite increasing number of studies reported the use of many multi-criteria decision-making approaches in supply chain risk evaluation using FMEA framework, it is clear that supply chain sustainability risks evaluation using the PSI method is vacant and motivating this study. Moreover, integrated model of the PSI and Shannon entropy as new offering approach to assess the magnitude of supply chain is absent in previous references.

*2.2. Integrating the PSI and Shannon entropy- the model*

The following notations are used to develop decision support model for ranking supply chain sustainability risk using FMEA methodology.

= Preference score of the risk occurrence attribute;

= Preference score of the detection of risk attribute;

= Preference Score of the severity impact of risk attribute;

= preference score of the sensitivity of supply chain attribute;

= preference score of the recoverability of supply chain attribute;

= objective weight of the risk occurrence attribute;

= objective weight of the risk detectability attribute;

= objective weight of the risk severity attribute;

= objective weight of the risk sensitivity attribute;

= objective weight of the risk recoverability attribute;

= Risk occurrence Scale of Risk variable i;

= Risk Detectability Scale of Risk variable i;

= Risk Severity Scale of Risk variable i;

= Sensitivity scale of supply chain under study against impact of risk element i;

= Recoverability scale of supply chain under study against adverse impact of risk element i;

= preference score of decision maker against risk reprioritization criteria j;

= Compromise weight of supply chain risk prioritization criteria j;

adjustment factor;

= Score of the entropy of the risk reprioritization attribute j;

= Relative weight of the risk element element i;

= Mean risk priority number of risk element i ;

= Standard deviation of risk priority number of risk element i;

Where i= 1,2,3…., m and j=1,2,3,….n.

*2.3. Overview of Preference Selection Index (PSI) method and its application area*

Preference Selection Index (PSI) methodology is firstly introduced by Maniya and Bhatt (2009). This method is a typology of multi criteria decision making method which simultaneously optimizes two or more conflicting attributes. In the PSI method, determination of the attribute for priority ranking is based on beneficial (profit) and non-beneficial attribute (cost). Beneficial attributes are those kind of attribute in which the larger is score is better. In reverse, the non-beneficial attributes are typical of attributes in which the lower of its score is better.

Due to its capability to aid decision makers in making less complicated reprioritization in decision-making process, the use of the PSI is becoming more versatile to various areas as reported in Table 3. As can be seen in Table 3, despite growing number of studies applying the PSI method into varying application area exist, however no previous studies reported it into supply chain risk assessment application.

Table 3. Compilation on studies in the use of PSI methodology

|  |  |  |  |
| --- | --- | --- | --- |
| No | Authors | Content | Country |
| 1 | Joseph and Sridharan (2011) | Using PSI method for selecting priority scheduling rules in flexible manufacturing system | India |
| 2 | Maniya and Bhatt (2011) | Selecting flexible manufacturing System | India |
| 3 | Attri et al., (2014) | Ranking cutting fluids using a novel decision-making method: preference selection index | India |
| 4 | Paul et al., (2014) | Ranking Priority Dispatching rules for assembly job shop scheduling | India |
| 5 | Singh et al., (2015) | Selecting optimum Brake material specification | India |
| 6 | Attri and Grover (2015) | Designing life cycle of production system | India |
| 7 | Chamoli (2015) | Determining optimal parameter design of Channel Flow | India |
| 8 | Sharma and Singhal (2016) | Selecting best plant lay out option | India |
| 9 | Chauhan et al.,(2016) | Optimising design parameter of Solar Thermal Collector | India |
| 10 | Khorsidhi and Hasani (2013) | Comparing Performance of PSI and TOPSIS method for selecting composite material properties | Iran |
| 11 | Mayyas et al., (2013) | Selecting eco-oriented automotive materials | USA |
| 12 | Parizi et al., (2017) | Determining process parameters in manufacturing composite materials | Iran |
| 13 | Nadda et al., (2018) | Determining the best mechanical design parameters of a solar air heater | India |
| 14 | Patel et al. (2018) | Selecting optimum process parameters for Polylactic Acid | India |
| 15 | Reddy et al., (2019) | Selecting optimum cementitious material properties | India |
| 16 | Ezatpour et al., (2016) | Selecting best combination material properties of Aluminium Nano composites | Iran |
| 19 | Borujeni and Gitinavard (2017) | Selecting sustainable mining contractor | Iran |
| 20 | Madic et al (2017) | Determining optimum Laser process condition | Serbia and Lithuania |
| 21 | Pathak et al., (2019) | Determining optimal scanning conditions | India |
| 22 | Jha et al., (2018) | Determining Optimum phase combination of biodegradable composite | India |
| 24 | Kumar and Kumar (2020) | Selecting best composite materials | India |
| 25 | Singh et al., (2020) | Selecting best composition of Polypropylene composite | Hungary and India |
| 26 | Biswas and Anand (2020) | Integrating Preference Selection Index (PSI) and Proximity Value Index (PVI) for evaluating logistics competitiveness scale between BRICS and G7 Countries | India |
| 27 | Kumar *et al*., (2021) | Selecting best composition for optimum performance of metallic alloy | India |
| 28 | Jain *et al*., (2021) | Selecting the rank of Flexible Manufacturing System (FMS) flexibility | India |
| 29 | Ulutas *et al*. (2021) | Combining Preference Selection Index (PSI) and Proximity Value Index (PVI) for warehouse selection | Turkey |

Intended to be used as means to determine the score of the subjective weight in appraising the weight of supply chain risk reprioritization criteria, steps to determine the subjective weight of risk reprioritization criteria is as follows.

Step 1. Determining the goal of applying the PSI.

Step 2. Identifying supply chain risk variables ( i=1, 2, 3, …., m) and risk reprioritization criteria ( j=1, 2, 3, … n).

Step 3. Constructing a risk decision matrix by arranging its column as risk reprioritization attributes and its rows as risk variable alternatives as below:

Table 4. A Typical Supply Chain Risk Decision Matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  | C1 | C2 | C3 | ……… | Cn |
| R1 | P11 | P12 | P13 | ……… | P1n |
| R2 | P21 | P22 | P23 | ……… | P2n |
| R3 | P31 | P32 | P33 | ……… | P3n |
| ……… | ……… | ……… | ……… | ……… | ……… |
| Rm | Pm1 | Pm2 | Pm3 | ……… | Pmn |
|  |  |  |  |  |  |

Step 4. Normalizing decision matrix. For determining the weight of risk criteria using the PSI, normalization of supply chain risk decision matrix can be accomplished by categorization of beneficial and non-beneficial attributes. For non-beneficial attribute, normalization of risk alternatives following equation 1.

………………………………………………………………… (1)

Meanwhile for beneficial type risk reprioritization attribute, equation 2 is used.

= ; ……………………………………………………………….. (2)

Step 5. Determining mean value of normalized data for risk attribute . Computation of the mean value of normalized data is accomplished by using equation 3.

………………………………………………………………………………… (3)

Step 6. Determining deviation preference value. Computation of the preference deviation value data is accomplished by using equation 4.

……………………………………………………………………………. (4)

Step 7. Determining deviation preference value of each risk attribute j using the equation 5.

𝞍j = ………………………………………………………………. (5)

Step 8. Calculating overall preference value of risk attribute j by using equation 6.

𝛙j = ………………………………………………………………………… (6)

The result of step (8) is the preference score of each risk reprioritization attributes which representing the decision maker preference. This preference is functioning as surrogate of the weight of the risk attributes. Let now 𝛙j becoming the preference score against risk reprioritization criteria j.

*2.4. Shannon entropy*

Following Ouyang et al., (2013), entropy represents the amount of information uncertainty from discrete probability distribution. The entropy method is useful to determine the objective weight of reprioritization criteria. If the data in the decision matrix is known, the weight of the criteria can be counted objectively. Becoming the method to determine the objective weight of supply chain risk reprioritization criteria, the Shannon entropy is adopted by many studies dealing with priority ranking in various areas such as evaluating the risk of equipment failure ( Sachdeva *et al*. 2009), selecting supplier (Liu and Zhang, 2011), managing public rental housing (Wu *et al*. 2017), materials selection (Bakhoum and Brown, 2013 and Hafezalkotob and Hafezalkotob, 2016), managing project (Moarefi *et al*. 2028), Beverage selection (Isik and Adali, 2017), selecting drivers for implementing lean construction (Dehdasht *et al.* 2020).

The procedure to determine the objective weight of the supply chain sustainability risk criteria by using the Shannon entropy can be described as in the followings.

Step 1. Determine decision matrix D which is containing n supply chain sustainability risk prioritization criteria and m risk variable.

D = ( i=1,2,3,…m) and j=1,2,3,…n).

presents the performance value of risk variable i for risk reprioritization attribute j.

Step 2. Normalizing the decision matrix. For beneficial risk reprioritization attributes, use equation (7) and for non-beneficial risk reprioritization attributes, use equation (8).

= ………………………………………………..(7)

= …………………………………………………(8)

Step 3. The entropy of the j risk reprioritization criteria is counted using equation 9.

= …………………………………………………….. (9)

Where = and (0,1).

Step 4. Calculating the objective weight of the risk reprioritization criteria using equation 10.

= and =1………………………………………….(10)

Pertaining to the use of the Shannon entropy to aid risk reprioritization decision making, Table 5 presents compilation of previous researches devoted to rank criticality of risk.

Table 5. Studies applying Shannon entropy for appraising the weight of risk reprioritization criteria

|  |  |  |  |
| --- | --- | --- | --- |
| No | Author(s) | Content | Application Area |
| 1 | Xin, J (2008) | Ranking risk of radioactive protective measures | Nuclear Power Plant |
| 2 | Yu, C., Zhang,B.,Yao, Y., Meng, F. and Zheng, C. (2013) | Determining most important risk factors of groundwater contamination | Groundwater vulnerability assessment |
| 3 | Josi, S.A.,Shafiee, M., Moradimaj, N., and Saffarian, S., (2012) | Determining relative weight on environmental risk reprioritization criteria | Environmental risk assessment |
| 4 | Mavi et al., (2016) | Appraising the weight of risk criteria in supplier selection | Motorcycle manufacturing |
| 6 | Sutrisno et al. (2018) | Evaluating relative importance of lean waste risk reprioritization criteria | Geothermal power generation Maintenance |
| 7 | Liu et al. (2018) | Determining risk relative importance risk criteria | Healthcare |
| 8 | Shahin et al. (2019) | Ranking supply chain risks using Shannon entropy and fuzzy TOPSIS | Home appliance |
| 8 | Gheib et al. (2019) | Estimating the weight of risk reprioritization criteria | Water treatment plan |
| 9 | Eshanifar, M. and Hemesy, M.(2021) | Appraising relative weight of risk variables in construction project | Construction Project |
| 10 | Pintelon, et al. (2021) | Determining relative weight of risk reprioritization attribute | Medical device development |
| 11 | Wang et al. (2021) | Determining relative weight of risk reprioritization attribute | Mechatronic production process |

Among eleven studies applying the Shannon entropy to assess criticality of risk only the works of Mavi *et al*., (2016) and Shahin *et al*., (2019) which deal with subjective determination of relative importance of risk criteria.

*2.5. Compromise weighting of risk criteria using preference selection index (PSI) index and the Shannon Entropy*

In an attempt to combine both of subjective and objective supply chain risk reprioritization method, subjective risk weightage process based on the PSI method and objective risk weightage process using the Shannon entropy is accomplished by combining equation 6 and 10. Next, a compromise weighting method used to represent combination of subjective and objective approach and formulated as in equation 11.

= ……………………………………………… (11)

With .

*2.6. Inclusion of the relative impact of supply chain risk element using relative weight method*

In evaluating the impact of risk, usually one risk element is having relative weight impact against other risk elements affecting the score of the risk priority number. In accommodating the impact of each risk element relative to other risks, the concept of relative weight can be used as an approach to consider the relative impact of risk to support decision making. The concept of relative weight has been used as means to consider the relative impact of factors affecting risk priority decision making. Researches applying the relative weight method is many such as investigating the impact of environmental factors for software development (Zhang *et al.* 2015), investigation on the impact of airline cabin environment (Jia *et al.* 2018), impact of failure factors to the wind turbine ( Li *et al.* 2020). Suppose that there are n risk element with i=1,2, 3,..,n; then the risk relative weight from risk element is expressed as equation 12.

= …………………………………………………………… (12)

2.7. Integrating the Shannon Entropy and The Preference Selection Index (PSI) -the model

2.7.1. Additional supply chain sustainability risk Reprioritization Criteria

Supply chain FMEA is a typical risk assessment method used to evaluate the impact of risk within supply chain scope. In evaluating the impact of risk, in similar with design and process FMEA, supply chain FMEA using three risk reprioritization criteria namely, occurrence, detection and severity of risk. Nevertheless, reliance on these three criteria is insufficient in quantifying the impact of risk element and in line with development of FMEA risk reprioritization model, additional criteria such cost as compiled by Liu *et al.* (2013), substitutability, production capability and profit contribution (Selim *et al*. (2015), experiences and profession hierarchy of decision makers (Fatahi *et al.* 2020) are added to comprehend risk assessment approaches. Considering that enterprise supply chain may have sensitivity against impact of a certain risk element and also capability to recover from impact of a particular risk, to improve comprehensiveness of supply chain risk assessment, Lahmar et al., (2018) suggest to consider sensitivity against impact of a risk. Following Behzadi et al., (2018), along with occurrence, detection and severity of risk, recoverability from impact of risk shall be taken into consideration in appraising criticality impact of risk becoming more comprehensive. Considering this situation, additional criteria for supply chain risk ranking is then presented in Table 6.

Table 6. Additional supply chain FMEA risk reprioritization criteria

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Score | Linguistic Interpretation | Sensitivity of supply chain | Occurrence  Of risk variables | Detectability occurrence of risk variables | Severity of risk effect | Recoverability of supply chain |
| 1 | Remote | Supply chain is insensitive against impact of risk | The chance of risk event occurrence is remote | The occurrence of risk variables is directly observable by no means of detection tool | The impact of risk is negligible | No effort needed to recover supply chain disruption |
| 2 | Small | Supply chain is small sensitive against impact of a risk | The chance of risk event occurrence is small | The occurrence of risk variables is moderate difficult detected using detection tool and method by the company | The impact of risk is little annoyance to the customers | Little effort needed to recover supply chain disruption |
| 3 | Medium | Supply chain is medium sensitive against impact of a risk | The chance of risk event occurrence is medium | The occurrence of risk variable is rather difficult to detect by any means of company detection method | The impact of risk is causing very high dissatisfaction to the customers | Medium effort needed to recover supply chain disruption. No need external resource for recoverability |
| 4 | high | Supply chain is highly sensitive against impact of a risk | The chance of risk event occurrence is high | The occurrence of risk variable is very difficult to detect by any means of company detection method | The impact of risk is having consequence to regulatory violation | Recoverability of supply chain is demanding intervention by external bodies outside of the company |
| 5 | Very high | Supply chain is very sensitive against impact of risk occurrence | The chance of risk occurrence is inevitable | The occurrence of risk variable is undetected by any means of company detection method and reported by the customers | The impact of risk is affecting health and safety and may be causing death | Recoverability of supply chain is demanding all out intervention by external bodies outside of the company |

A typical supply chain FMEA sheet presenting these additional risk reprioritization parameters is given in Table 7.

Table 7. A typical of Supply Chain FMEA sheet

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | Supply Chain Risk Reprioritization Attributes | | | | |  |
| Supply chain risk dimension | Supply chain risk element | Risk occurrence  (O) | Risk detection  (D) | Risk severity  (S) | Risk sensitivity  (SN) | Risk recoverability  (R) | Risk priority number |
|  |  |  |  |  |  |  |  |
| .  .  .  . |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| .  .  . | .  .  . | .  .  . | .  .  . | .  .  . | .  .  . | .  .  . |
|  |  |  |  |  |  |  |  |

2.7.2. New Risk Priority Number

In representing the metric as measure of risk criticality impact, FMEA using multiplication of the three risk reprioritization parameters namely, occurrence, detection and severity of risk. Mathematically, the metric of risk in FMEA which is named Risk Priority Number (RPN) is formulated by following equation 13.

= …………………………………………………….. (13)

Taking into account to emphasize on effectiveness to detect and prevent the reoccurrence of a risk event, Sahwney et al., (2010) suggest to modify equation 13 into equation 14 where detectability of a risk becomes a denominator in ranking a risk.

……………………………………………………… (14)

Next, Braglia ( 2000), Bevilacqua et al. (2000), Carmignani (2009), Taghipour et al. (2011) and Bojan and Blazic (2015) declared that the criticality of a particular risk can be quantitatively counted as the sum of the impact risk reprioritization criteria. Furthermore, Carmignani (2009) presented that risk priority score is also affected by the score of the relative weight of a risk element against other risks. As a manifestation of negative uncertainty, the company usually will take the form of a risk impact evaluation approach which emphasizes risk detectability to prevent the reoccurrence risk factors or reduce the impact of a risk. Taking into account the effect of the compromise weight of the risk priority criteria from equation 11, the relative weights among risk elements in equation 12 and the emphasis on the ability to detect and control risk as suggested by Sahwney et al., (2010) in equation 14, the new RPN index estimation model of a supply chain risk element is expressed by the equation 15.

= …………………… ……. (15)

As enterprises are having limited resources to mitigate the impact of a risk event, it is necessary to determine the cut off RPN score to delineate among critical risk elements demanding immediate preventative or corrective action and non-critical risks in which their risk mitigation efforts could be postponed later. Following suggestion of Rezgdeh and Shokouhyar (2020), if the mean RPN score is with deviation standard , then the critical risks and non-critical risk are counted by equation 16 and 17.

= µ + …………………………………………………………………. (16)

= µ ………………………………………………………………. (17)

**4. Research Methodology**

*4.1 Case study description*

To demonstrate the use of integrated PSI and The Shannon entropy into Supply Chain FMEA model as new offering method to assess criticality of supply chain sustainability risk, a case study (Yin, 2014). The framework of research approach as presented by Mangla *et al*., (2015) and Anugerah *et al.* (2021) is used as reference model. A case example focused on the SME sector selling wooden handicraft is chosen. In the context of Indonesia as developing country, among other type of SME operating sectors, handy craft sector is becoming the third rank contributor to the Indonesian GDP and acting role as workforce absorber since the number of handicraft SME is up to 19% from the whole of the number of SMEs in Indonesia (Badruddin and Siregar, 2018, Raya *et al*., 2021). In accordance to Shafi *et al*., (2019), this SME sector comparing to other SME sectors are having distinct characteristics’ such as creating jobs with least investment costs, consuming least energy and carrying cultural and traditional knowledge to the descendance generation. The locus of the study is located at an SME producing wooden handy crafts for tourism located in West Sumatera Province, Indonesia. The case study employed three stages of supply chain sustainability risk evaluation. The first step pertains to determination on the supply chain sustainability risk elements. Second step related to the determination of each supply chain sustainability risk element and counting the subjective and objective weight of supply chain risk reprioritization criteria. In the third step, determination of the cut of RPN and critical RPN suggested for becoming management attention is presented.

*4.1.1. Supply chain sustainability risk element determination*

In the first stage, construct validity of the research is determined based on literature reviews to supply chain literature with the aim to determine the category of supply chain sustainability risk dimensions and their risk elements. The result of this first step is categorization of sustainability risk dimensions and risk variables and its supporting references as depicted in Table 8.

Table 8. Categorization of supply chain sustainability risk dimension from various references

|  |  |  |  |
| --- | --- | --- | --- |
| Sustainability  Risk Dimension | Sustainability Risk category | References | Example of Risk element |
| Economical | Competition Risk | Schulte and Hallstadt (2017) | Price war |
|  | Knowledge Risk | Durst and Zieba (2020) | Insufficiency on risk management know how |
|  | Reputational Risk | Schulte and Hallstadt (2017) | Bad reputation, sabotage on competitors’ brand |
|  | Intellectual Property risk | Gianakis and Papadopoulos (2016) | low awareness on the importance of intellectual property right, Intellectual property piracy |
|  | Quality Risk | Ghadge *et al.* (2017) | Defective products and process |
|  | Corruption Risk | Monteiro *et al*. (2018) | Cost mark up, bribery, unofficial levies |
|  | Market Risk | Puniyamoorthy *et al.* (2013) | The change of customer preference |
|  | Delivery Risk | Gupta *et al.* (2014) | Failure in delivering products and service in timely manner |
| Environmental | Pollution | Gianakis and Papadopoulos (2016), Oliviera *et al.* (2019) | Air, water and soil pollutions |
|  | Waste | Gianakis and Papadopoulos (2016) | By product waste |
|  | Natural Disasters | Gianakis and Papadopoulos (2016) | Earthquake, hurricane and flood |
|  | Pandemic | Gianakis and Papadopoulos (2016) | Avian Influenza and Covid 19 |
| Social | Relationship Risk | Alamwaleh and Poppelwell (2012) | Distrust among business partners |
|  | Cultural Gap Risk | Jian and Rutherford (2010) | Failure to understand local culture, |
|  | Behavioural Risk | Ragunath and Devi (2018) | Bullying, sexual harassment, |
|  | Human Resource Risk | Cunha *et al*. (2019) | Employee turn over |
| Institutional | Regulatory / Compliance Risk | Hadiguna (2017) | Inflexible governmental regulations, inconsistency of governmental rules |
| Technical | Infrastructure Risk | Ebrahimi *et al.* (2019) | Lack of infrastructures, failure of infrastructure |

The second step of this research is checking relevancy and appropriateness of the supply chain risk variables in the context of the SME. To achieve this goal focus group discussion with SME experts is carried out to determine the elements of operational risk that will be used as the basis for evaluating sustainability risks. Furthermore, the various modes of operational risk variables were verified by interviewing and observing SME entrepreneurs’ business operation in the wood craft sector. Based on the five pillars of sustainability, the dimensions and elements of risk are determined by asking SME owner in the case study to determine the sustainability risk scale using an ordinal scale of 1 to 5. The results of determining the dimensions and risks are shown in Table 8. In this paper, subjectivity related to the evaluation of sustainability risk in the case study is the scoring that follows the preferences of MSME actors based on the experience of MSME actors in determining the sustainability risk scale, while the objective data for determining the risk displayed are the risk element scores contained in Table 9.

Table 9. The scale of supply chain risk reprioritization of case example

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Supply chain risk reprioritization attributes |  |  |  |  |
| Supply Chain Risk Dimension | Supply Chain Risk category | Supply Chain Risk Variable | Occurrence | Detection | Severity | Sensitivity | Recoverability |
| Economical | Reputational Risk | Unattractive product packaging | 1 | 5 | 1 | 2 | 3 |
|  |  | Product brand counterfeiting | 1 | 4 | 5 | 5 | 5 |
|  |  | Product re-packing | 1 | 2 | 5 | 5 | 4 |
|  | Competition Risk | Price war among competitors | 4 | 3 | 5 | 5 | 5 |
|  |  | Entrance of New Competitors | 4 | 3 | 3 | 5 | 5 |
|  |  | Change of customer preference | 3 | 5 | 3 | 3 | 3 |
|  |  | Competitors’ Unethical behaviour | 2 | 3 | 3 | 4 | 4 |
|  | Financial Risk | Avoiding Tax | 5 | 4 | 4 | 2 | 2 |
|  |  | Imitating competitor product | 4 | 3 | 5 | 4 | 4 |
|  |  | Bribery | 4 | 1 | 4 | 4 | 4 |
|  |  | Fix Pricing | 5 | 4 | 4 | 4 | 4 |
|  |  | Fluctuation of raw material price | 3 | 3 | 3 | 3 | 3 |
|  |  | Sudden order cancellation | 1 | 5 | 5 | 5 | 3 |
| Technical  /Operational | Technological Risk | Production Facility Risk | 5 | 2 | 4 | 4 | 4 |
|  | Supplier Risk | Unreliable suppliers | 4 | 2 | 3 | 5 | 3 |
|  | Demand risk | Demand Forecasting error | 5 | 2 | 4 | 5 | 5 |
|  | Quality Risk | The use of low-quality grade raw materials | 1 | 2 | 2 | 3 | 3 |
|  | Knowledge Risk | Very low awareness on the Intellectual property right | 4 | 4 | 4 | 3 | 3 |
|  |  | Very low knowledge on Risk in running business | 5 | 4 | 4 | 3 | 3 |
|  |  | Perception among SME owners that risk is merely linked to financial loss only | 5 | 4 | 4 | 4 | 4 |
|  |  | Lack of innovation capability | 3 | 5 | 3 | 3 | 3 |
|  |  | Low awareness on the importance of product certification | 1 | 4 | 2 | 3 | 3 |
|  | Human Resource Risk | Employ turn over | 3 | 2 | 2 | 2 | 4 |
|  |  | Very low educational level of employees | 5 | 2 | 1 | 1 | 1 |
|  |  | Low interest in upgrading employee skills | 4 | 2 | 4 | 2 | 3 |
|  |  | Scarcity of talent for creative type job | 4 | 2 | 4 | 2 | 3 |
|  |  | Low interest to continue family business | 5 | 2 | 2 | 3 | 4 |
| Environmental | Pollutant Risk | Noise | 1 | 1 | 1 | 2 | 1 |
|  |  | soil pollution | 1 | 4 | 4 | 4 | 4 |
|  | Waste Risk | By product garbage | 1 | 2 | 5 | 5 | 5 |
|  |  | Electricity wastage | 1 | 2 | 2 | 3 | 3 |
|  | Natural Hazard Risk | Pandemic | 1 | 4 | 5 | 4 | 4 |
|  |  | Earthquake | 1 | 5 | 5 | 5 | 5 |
|  | Man-made risk (Security Risk) | Burglary | 3 | 1 | 5 | 5 | 5 |
|  |  | Theft | 3 | 3 | 1 | 5 | 5 |
| Social Risk |  |  |  |  |  |  |  |
|  | Labour Practice and decent working condition Risk | Unclean and unsafe production facility | 5 | 1 | 3 | 3 | 4 |
|  |  | Sub-standard safety apparatus | 5 | 4 | 3 | 2 | 3 |
|  |  | The use of child workforce | 1 | 1 | 3 | 2 | 3 |
|  |  | Unfair wage | 4 | 4 | 4 | 3 | 3 |
|  |  | The absence of insurance coverage | 4 | 1 | 2 | 2 | 2 |
| Political Risk | Regulatory Risk | Difficulty to obtain banking credit | 1 | 2 | 1 | 2 | 3 |
|  |  | Product certification cost | 2 | 2 | 2 | 2 | 2 |
|  |  | Weak and Inflexible Governmental support | 3 | 2 | 3 | 4 | 4 |
|  | Compliance Risk | Regulatory tightness becoming supplier of big company | 4 | 2 | 3 | 4 | 4 |
|  |  | sum | 129 | 126 | 144 | 154 | 156 |

Under five pillars of sustainability, totally 44 risk elements are identified in this study. Reputational, competition and financial risks are three categories of economic risks. Reputational risk is typical risk closely related to the degrading product or company reputation due to various negative issues like product appearance problem, counterfeiting and product re-packing issues. Within Technical Risk dimension, six risk types are identified which is consisting of facility production risk, Demand Risk, Quality risk, Knowledge risk, supplier risk and human resource risks. In environmental risk, four categories of sustainability risks in the form of pollutant risk, waste, natural hazard and man-made risk are existing. In the social risk dimension, double category of sustainability risks, labour practices and working condition are revealed. At last, in institutional risk, regulatory and compliance risk are found as negative uncertainties affecting business standing of the enterprise under study.

*4.4. Determination on the score of the compromise weight of supply chain risk priority number*

The first step in determining the composite weight for each risk element is carried out by determining the subjective weighting of risk priority parameters using the PSI method, followed by determining the objective risk priority weights using the Shannon entropy method and combining the relative weights between risk elements. The descriptions of the explanation of the three stages are as follows:

The steps for determining the weight of priority risk subjectively using the PSI method are:

*4.4.1. Identification of beneficial and non-beneficial attributes*

In the PSI methodology, two categorical attributes, beneficial and non-beneficial are used as basis for calculating preference score. Beneficial attributes relate to supply chain sustainability risk reprioritization is detection and recoverability attributes while risk occurrence scale, severity of supply chain risk impact and sensitivity of risk are categorized as non – beneficial attributes. By using equation ( 1) until equation (6 ), the overall preference score for each risk attributes is presented in Table 10.

Table 10. Overall Preference variation value of each risk attribute

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No | Preference value of risk occurrence | Preference value of risk detection | Preference value of risk severity | Preference value of risk sensitivity | Preference value of risk recoverability |
| 1 | 0.361 | 0.180 | 0.189 | 0.108 | 0.162 |

The above overall preference scores are representing subjective weight of risk reprioritization parameters of case example. Therefore, the score of = 0.361, = 0.180, = 0.189, = 0.108 and = 0.162 respectively.

*4.5. Determination on the Objective weight of the supply chain risk reprioritization criteria using the Shannon Entropy*

The objective weight of supply chain sustainability risk reprioritization criteria is determined by using the Shannon entropy score. At first, normalization of the risk element scores from Table 8 is accomplished by using equation 7 and equation 8. Then, the entropy score of each risk criteria is counted by following equation 9 and equation 11. The objective weight of the risk criteria is = 0.187, =0.159, =0.183, = 0.313, and = 0.158.

*4.5.1 Determination of the weight of Subjective- Objective supply chain risk reprioritization criteria*

Above weight is determined by using equation 12 and the score of each compromise weighting are as in the followings; compromise weight of occurrence = 0.187, compromise weight of detection = 0.168, compromise weight of severity= 0.185, compromise weight of sensitivity = 0.210, and compromise weight of = 0.139.

4.6. Comparison on risk priority ranking using Subjective, Objective and Subjective-Objective risk prioritization approaches

Table 11 present the result on appraising supply chain risk score by using four different approaches.

Table 11. Risk priority evaluation comparison among the conventional FMEA, the PSI, the Shannon entropy and integrated Shannon entropy and PSI method.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Supply Chain Risk Dimension | Supply Chain Risk category | Supply Chain Risk Variable | RPN based on Conventional  Supply chain FMEA | RPN based on the PSI | RPN based on the Shannon Entropy | RPN-based on Integrated PSI and Shannon Entropy |
| Economical | Reputational Risk | Unattractive product packaging | 5 | 1.91 | 1.52 | 0.79 |
|  |  | Product brand counterfeiting | 20 | 4.03 | 4.56 | 2.75 |
|  |  | Product re-packing | 10 | 9.76 | 8.72 | 3.10 |
|  | Competition Risk | Price war among competitors | 60 | 5.56 | 7.32 | 5.71 |
|  |  | Entrance of New Competitors | 36 | 4.09 | 6.64 | 5.07 |
|  |  | Change of customer preference | 45 | 4.50 | 3.365 | 2.12 |
|  |  | Competitors’ Unethical behaviour | 18 | 3.84 | 4.21 | 3.80 |
|  | Financial Risk | Avoiding Tax | 80 | 3.97 | 7.24 | 3.97 |
|  |  | Imitating competitor product | 60 | 5.77 | 8.70 | 6. |
|  |  | Bribery | 16 | 16 | 19 | 6.60 |
|  |  | Fix Pricing | 80 | 4.55 | 4.86 | 3.81 |
|  |  | Fluctuation of raw material price | 27 | 4.09 | 4.61 | 3.55 |
|  |  | Sudden order cancellation | 25 | 2.23 | 3.30 | 4.35 |
| Technical  /Operational | Technological Risk | Production Facility Risk | 40 | 9.18 | 9.72 | 7.37 |
|  | Supplier Risk | Unreliable suppliers | 24 | 12.70 | 9.04 | 7.63 |
|  | Demand risk | Demand Forecasting error | 40 | 9.80 | 10.12 | 3.43 |
|  | Quality Risk | The use of low-quality grade raw materials | 4 | 6.21 | 6.16 | 3.01 |
|  | Knowledge Risk | Very low awareness on the Intellectual property right | 64 | 3.91 | 3.94 | 2.80 |
|  |  | Very low knowledge on risk in running business | 80 | 4.28 | 4.24 | 3.01 |
|  |  | Perception among SME owners that risk is merely linked to financial loss only | 80 | 4.57 | 4.86 | 2.0 |
|  |  | Lack of innovation capability | 45 | 3.64 | 2.71 | 1.31 |
|  |  | Low awareness on the importance of product certification | 8 | 1.86 | 2.58 | 6.46 |
|  | Human Resource Risk | Employ turn over | 12 | 5.77 | 4.0 | 4.16 |
|  |  | Very low educational level of employees | 10 | 5.97 | 4.56 | 3.10 |
|  |  | Low interest in upgrading employee skills | 32 | 7.60 | 7.08 | 4.96 |
|  |  | Scarcity of talent for creative type job | 32 | 7.60 | 7.08 | 4.36 |
|  |  | Low interest to continue family business | 20 | 8.10 | 7.88 | 2.71 |
| Environmental | Pollutant Risk | Noise | 1 | 4.07 | 6.33 | 1.13 |
|  |  | soil pollution | 16 | 1.00 | 3.70 | 1.47 |
|  | Waste Risk | By product garbage | 10 | 6.35 | 9.12 | 4.76 |
|  |  | Electricity wastage | 4 | 3.75 | 5.16 | 7.92 |
|  | Natural Hazard Risk | Pandemic | 20 | 2.82 | 3.96 | 3.20 |
|  |  | Earthquake | 25 | 2.057 | 3.73 | 2.78 |
|  | Man-made risk (Security Risk) | Burglary | 15 | 16.71 | 5.36 | 4.53 |
|  |  | Theft | 9 | 4.333 | 4.12 | 4.08 |
| Social Risk |  |  |  |  |  |  |
|  | Labour Practice and decent working condition Risk | Unclean and unsafe production facility | 15 | 17.14 | 17.5 | 4.13 |
|  |  | Sub-standard safety apparatus | 60 | 3.91 | 3.75 | 2.60 |
|  |  | The use of child workforce | 3 | 7.95 | 10.16 | 8 |
|  |  | Unfair wage | 64 | 6.32 | 3.94 | 6.93 |
|  |  | The absence of insurance coverage | 8 | 12.21 | 11.83 | 8.75 |
| Political Risk | Regulatory Risk | Difficulty to obtain banking credit | 2 | 3.035 | 3.84 | 2.26 |
|  |  | Product certification cost | 8 | 6.76 | 4.52 | 3.73 |
|  |  | Weak and Inflexible Governmental support | 18 | 6.07 | 8.08 | 5.5 |
|  | Compliance Risk | Regulatory tightness becoming supplier of big company | 24 | 6.82 | 8.64 | 5.93 |

Comparison of supply chain sustainability risk scoring shown in table 11 with four different approaches shows relatively different results. This is because each risk score is calculated using different approach where in conventional FMEA, the relative weight of the risk criteria is not taken into account and also ignores the sensitivity and recoverability aspects of the supply chain to the impact of a risk. Meanwhile, in calculating the risk score using the PSI approach, the subjectivity of decision makers is stressed in determining the risk score compared to using the Shannon entropy method which emphasizes the objectivity aspect of the risk contained in the risk criteria score contained in the decision matrix table score. To accommodate the integration of the subjectivity and objectivity aspect of decision makers, the integration between PSI and Shannon entropy methods is used together. This shows that the integration of the PSI and Shannon entropy methods offering advantage where decision makers can simultaneously consider their subjectivity and objectivity of the risk data in determining risk priorities.

*4.6. Determination of The Risk Priority Number of Risk Elements of case example*

This study intended to determine the score of the critical supply chain sustainability risks using integrated Shannon entropy and the PSI as represented in equation 15. The scale of the risk priority ranking of each risk element is presented in Table 12.

Table 12. The RPN Score of each risk elements

|  |  |  |  |
| --- | --- | --- | --- |
| Supply Chain sustainability risk dimension | Supply chain Risk category | Supply chain risk element | Risk priority number |
| Economical | Reputational | Unattractive product packaging | 0.79 |
|  |  | Product brand counterfeiting | 2.75 |
|  |  | Product re-packing | 3.10 |
|  | Competition | Price war among competitors | 5.71 |
|  |  | Entrance of new competitors | 5.07 |
|  |  | Change of customer preference | 2.12 |
|  |  | Competitors’ unethical behaviour | 3.80 |
|  | Financial | Avoiding Tax | 3.97 |
|  |  | Product imitation by competitors | 6. |
|  |  | Bribery | 6.60 |
|  |  | Fix Pricing | 3.81 |
|  |  | Fluctuation of raw material price | 3.55 |
|  |  | Sudden order cancellation | 4.35 |
| Technical  /Operational | Production facility | Production Facility failure | 7.37 |
|  | Demand | Demand Forecasting error | 7.63 |
|  | Quality | The use of low-quality grade raw materials | 3.43 |
|  | Knowledge | Very low awareness on the Intellectual property right | 3.01 |
|  |  | Very low knowledge on Risk in running business | 2.80 |
|  |  | Perception among SME owners that risk is merely linked to financial loss only | 3.01 |
|  |  | Lack of innovation capability | 2.0 |
|  |  | Low awareness on the importance of product certification | 1.31 |
|  | Supplier | Unreliable suppliers | 6.46 |
|  | Human Resource | Employ turn-over | 4.16 |
|  |  | Very low educational level of employees | 3.10 |
|  |  | Low interest in upgrading employee skills | 4.96 |
|  |  | Scarcity of talent for creative type job | 4.36 |
|  |  | Low interest to continue family business | 2.71 |
| Environmental | Pollutant | Noise | 1.13 |
|  |  | soil pollution | 1.47 |
|  | Waste | By product garbage | 4.76 |
|  |  | Electricity wastage | 7.92 |
|  | Natural Hazard | Flood | 3.20 |
|  |  | Earthquake | 2.78 |
|  | Man-made | Burglary | 4.53 |
|  |  | Theft | 4.08 |
| Social Risk |  |  |  |
|  | Working facility | Untidy and unclean production facility | 4.13 |
|  |  | Sub-standard safety apparatus | 2.60 |
|  | Labour practice | The absence of insurance coverage | 8 |
|  |  | The use of child workforce | 6.93 |
|  |  | Unfair wage | 8.75 |
| Political Risk/Regulation risk | Regulatory | Difficulty to obtain banking credit | 2.26 |
|  |  | Product certification cost | 3.73 |
|  |  | Weak and Inflexible Governmental policy | 5.5 |
|  | Compliance | Regulatory tightness becoming supplier of big company | 5.93 |
|  | N=44 risk variables, mean RPN= 4.25; standard deviation =1.89 |  |  |

*4.5.2. Economical risk*

Under economical sustainability risk dimension, reputational, competition and financial risk categories along with their risk elements are revealed. As a typical business which heavy reliance on the attractiveness of product sold to the potential buyer, packing attractiveness is also becoming vital factor which attract attention to other stakeholders such as new investors, partners and new employees ( Ambroise and Allaz, 2017). In reputational risk, product re-packing risk is becoming the most serious risk as reflected by its largest RPN score among two other reputational risk categories. This kind of risk is a typical risk occurred when competitors are selling their own product using competitors packing bag/label. This indicates that improving brand name of the company is influencing to the business continuation and shall be considered in making the product sold becoming more marketable against competitor brand. In competition risk category, the riskiest risk element is “price war” as it is having most impacting risk metric among other type of risk elements in competition risk category. This signals on the enterprises under study to keep on producing good quality merchandise while keep it price affordable to be sustained. In the financial risk, the risk type “Bribery” is still perceived as the riskiest risk since this kind of risk is causing high annoyance to the business owners due to the difficulty to estimate how much and how many times shall it should be paid to obtain services.

*4.5.3. Technical risks*

This second pillar of sustainability risk is concerning on negative uncertainty factors affecting business operability of the company. Under this pillar, six categories of sustainability risk are revealed which showing, that knowledge and human resource risks are having the most risky elements. Attribution of knowledge and human resource risk as one of the important risk elements in SME context is in line with study of Falkner and Hiebl (2015). In terms of its risk impact, “demand risk” is becoming the most critical risk element to the enterprises as that may lead decision makers take wrongly decision on resource allocation.

*4.5.4. Environmental risk*

The third sustainability risk pillar, the environmental risk refers to the adverse impact of negative uncertainty affecting negatively to the enterprise’s environments. The sub risk categories of environmental risk were based on the classification model of Pereira et al., (2020). Within this categorization waste risk, in the form of “by product waste” is perceived as most important risk as reflected by their RPN largest score compared to other categories of environmental risk. On considering situation in developing country, this is not surprising since business owners are less paying attention in dealing with by product wastage produced by their company’s operation. Low attention to the environmental impact of business operation is not surprising to the SME in Indonesia. (Fatimah *et al*. 2002). The second environmental risk, security risk is also perceived as the most important risk and one of the common risks in the context of developing country. This typical risk is in line with study of Kagwati et al., (2014) and(Sujka and Schulze, 2012).

*4.5.5. Social risk*

The social risk as the fourth sustainability pillar is consisting of two risk categories, working facility condition risk and working practice risk. Within social risk, “unfair wage” and “the absence of working insurance” are the riskiest social risks revealed. This type of risk is unsurprise as employee working in family type company as this study take place is not based on formal contract but often based on family relationship.

*4.5.6. Institutional risk*

The fifth sustainability risk, the institutional risks are consisting of two categories, the regulatory and compliance risk. Between these two categories of institutional risks, compliance with requirements to undertake business relationship with bigger companies is perceived as serious issues consider inherent limitations owned by the small and medium company pertaining to the availability of standard operating procedures etc. As owners of the SMEs are usually using relative loans for funding their operations, the bank ability problem is not perceived as serious issues. As this study found, dealing with around forty-four risk elements is demanding exhaustive effort for risk alleviation. Therefore, categorizing critical and non-critical risks are suggested to save resource owned by the company.

Based on the mean score of the RPN and its standard deviation obtained from Table 12, by using equation 16, the critical supply chain risk element from every risk dimension and each risk category of case example is presented in Table 13.

Table 13. Critical supply chain risk elements of case example

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Risk  Dimension | Risk category | Supply chain risk element | Risk Priority Number | Priority  rank | Cumulative RPN score |
| Economical | Competition | Price war among competitors | 5.71 | 1 | 27.66 |
| Entrance of new competitors | 5.07 | 2 |
| Financial | Product imitation by competitors | 6. | 2 |
| Bribery | 6.60 | 1 |
| Sudden order cancellation | 4.35 | 3 |
| Operational | Facility | Production Facility failure | 7.37 | 2 | 30.78 |
| Demand | Demand Forecasting error | 7.63 | 1 |
| Supply | Unreliable suppliers | 6.46 | 3 |
| Human resource | Low interest in upgrading employee skills | 4.96 | 4 |
| Scarcity of talent for creative type job | 4.36 | 5 |
| Environmental | Waste | By product garbage | 4.76 | 2 | 12.68 |
| Electricity wastage | 7.92 | 1 |
| Social | Security | Burglary | 4.53 | 1 | 23.68 |
| Labour practice | The absence of insurance coverage | 8.0 | 2 |
| The use of child workforce | 6.93 | 3 |
| Unfair wage | 8.75 | 1 |
| Institutional  risk | Regulatory | Weak and Inflexible Governmental policy | 5.5 | 2 | 11.43 |
| Compliance | Regulatory tightness becoming supplier of big company | 5.93 | 1 |

Referring to Table 13, concentration to deal with impact of economical risk, “price war” and “bribery” risk should be assigned as management top priority. Price wars as one of the important risks in the economic dimension are in line with a survey study by Shah and Patel (2017) in the context of developing countries that arises due to the absence of cooperation between handicraft business actors in determining price equality. In the technical dimension, production facility, demand, supply and human resource risks are becoming the four riskiest categories based on their risk impact. This is indicating that the contributing elements continuing business of the SME in the handicraft type business is strongly affected by reliable suppliers and production facility, error free demand forecasting, and availability of skilled labours. Finding this study is in line with a study from Shafi et al (2020) which noted that cooperating reliable suppliers will increase the continuity of the SMEs operation in the handy draft sector. The lack of human resources to become artisans in the handy craft industry, which is one of the sustainability issues is also in line with the findings of Chudasri *et al*. (2012). The decline in the interest of the younger generation to continue their business as handicrafts SME craftsmen also has a negative impact on the continuity of the craft business (Wondirad *et al*., 2021). The wood craft industry is a typical example of a demand driven industry. Thus, improvement in capability in predicting market demand will greatly affect production planning and supply of raw materials. Efforts to improve the ability to forecast consumer demand can be done by improving proficiency using quantitative demand forecasting tool since generally the SME decision makers only rely on their past experiences in forecasting market demand. Proficiency in using qualitative and quantitative demand forecasting tool will be greatly improving sustainability of the enterprise. In the environmental risk dimension, to support realization of sustainability practice, awareness to keep continuing working place cleanliness of working safety place to improve workers’ productivity and saving electrical energy usage shall be in decision makers’ mind. The result of scanning social risk element indicating that management of the company shall better improving workers wage scheme and considering allocation of worker working insurance. At last, from institutional risk dimension, capability to fulfil requirements partnering with bigger companies in particular to production capacity risk is becoming the most impacting risk since such requirement will be implying additional costs and technical requirements burdening to the SME. This compliance risk is evidently occurring to the SMEs intending to export its product overseas (Revindo, 2017).

*4.6. Contributions to the academic community*

Motivated by vacancy of studies on combining of both subjective and objective sustainability risk assessment studies in supply chain risk management field and also scarcity of empirical studies on evaluating supply chain sustainability risk of SME in developing country, this study presented an initial effort to fill in such gap by proposing a new risk assessment approach. The Preference Selection Index (PSI) method is used to estimate the subjective weight of the preference score of the risk reprioritization attributes and the Shannon entropy is employed to appraise the objective weight of supply chain risk reprioritization criteria. Next, complementing to the occurrence, detection and severity scale, sensitivity and recoverability scale are added as additional risk reprioritization criteria. A case study is presented to illustrate its applicability in practical situation.

Presenting the application of the integrating the PSI and the Shannon entropy method to appraise the weight of supply chain risk reprioritization attributes, this study offering contribution to academic community. The contributions offered by this study are in the followings.

Firstly, as reflected in Table 14, this study presented a new decision support model for appraising the impact of supply chain sustainability risk considering decision maker subjectivity and risk data objectivity in assigning the score of supply chain risk criteria which to the best of our knowledge never investigated by previous scholars.

Table 14 . Classification of studies dealing with weightage approach in determining the supply chain risk reprioritization criteria in the context of supply chain of small and medium enterprise

|  |  |  |  |
| --- | --- | --- | --- |
| Supply chain risk criteria weightage approach |  |  |  |
| Subjective | Technique(s) | Author(s) | Commodity |
|  | Analytical Hierarchy Process (AHP) | Ornaez and Moreno (2021) | Bakery |
|  | Analytical network priority (ANP) | Slamet *et al* (2017) | Papaya |
|  | Best -Worst Method (BWM) | Moktadir *et al*. (2021) | Leather |
| Subjective Hybrid | Fuzzy AHP-TOPSIS | Alora and Barua  (2020) | Miscellaneous |
|  | AHP-TOPSIS | Silva *et al*. (2021) | Spice |
|  | AHP-PROMETHEE | Venkatesan and Kumanan (2012) | Plastics |
| Objective | Shannon Entropy- TOPSIS | Shahin *et al*. (2019) | Home appliance |
| Subjective-Objective | Entropy-PSI | This paper | Wooden Handicrafts |

Our model presents an alternative approach to quantify the weight of risk reprioritization attributes instead on the reliance of consistency checking -based supply chain risk ranking reprioritization approach using the stand alone subjective risk prioritization approach using the AHP and or the Best Worst Method (BWM). Or using objective risk ranking approach using the Shannon entropy. Secondly, we have demonstrated that in undertaking supply chain risk criticality assessment, influence of supply chain sensitivity and recoverability from risk as other important risk criteria in risk priority making shall be taken into account which will make supply chain risk assessment process becoming more comprehensive. Thirdly, departing from the study on categorizing supply chain risk assessment methods by Tran *et al*., (2018) it is evident that based on our survey, adoption of the PSI method in supply chain risk assessment is vacant. Moreover, the study also has demonstrated on the promising usage of the PSI as one of simple supply chain risk reprioritization ranking methods can be used by SME practitioners.

*4.7. Contribution to the managerial practice*

This paper offers contributions to managerial purpose. At first, this paper presented derivation of supply chain sustainability risk variables at practical setting derived from five pillars of sustainability to improve understanding of typical supply chain sustainability risks toward a better risk identification and mitigation planning. At second, this paper also offers a practical use of the recent multi criteria decision making method, the PSI and the Shannon entropy in assigning the preference score of risk reprioritization criteria based on empirical study in the context of developing country. Some other offerings based on this empirical study are concerning on suggestions to improve financial, human resource, knowledge management and working practices to support realization of sustainable operational practice to the SMEs.

4.7. Limitations and Recommendations

Attempting to firstly present an empirical study in applying the integrated PSI and the Shannon entropy method into supply chain sustainability risk assessment based on single case study, validity of the study perhaps is only applicable to wooden handy craft sector only in a developing country. Next, sensitivity analysis to determine the influence of change in the weight of risk criteria and suggestion on sustainable risk mitigation strategies are not covered by this study. Furthermore, subjectivity of the SME owners of the case example which believed affects the accuracy in assigning the risk priority score of the supply chain risk elements is not taken into account. Departing from above limitations, recommendations are advised in the followings.

It is advised to replicate this early study using more respondents and other SME business types to improve its validity and generalisability. As the risk scores obtained from this study is coming from the owner of the enterprise, additional information from other stake holders in the supply chain sustainability risk assessment is suggested to improve comprehensiveness of the study. Also, relative weight of sustainability pillars and impact of practitioners’ working experiences which believed affecting the impact of supply chain risks should be considered in the decision support model.

**5. Conclusions and New Research Directions**

Driven by scarcity of empirical study on assessing supply chain sustainability risk in the context of developing country, this paper presented to use of integrated PSI method into supply chain FMEA to select the most critical risk using case example from creative industry sector. The result of the study pinpoints several critical risk elements from every sustainability pillars indicates that economic, social and operational type sustainability risks are perceived as the three most critical risks affecting business sustainability. Considering as an initial effort to integrate the PSI, the Shannon entropy and the relative weight method into supply chain FMEA method in selecting critical supply chain sustainability risks, future studies can focus on comparing the performance of the proposed model with other multi criteria decision making methods followed by sensitivity analysis. Additionally, future studies can also integrate the PSI, the Grey Relational Analysis (GRA) and the Principal Component Analysis (PCA) methods to reduce the number of risk dimensions and enable decision makers to focus on a few important sustainability risks elements. Determination on the score of supply chain sustainability risk index based on the categorization of supply chain risk elements is another research direction worth to be pursued in future research.

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