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FRAMEWORK DEVELOPMENT FOR THE ASSESSMENT OF THE SUPPLY CHAIN RESILIENCE USING THE HOUSE OF RISK

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Abstract: The COVID-19 pandemic has created uncertainty and disruptions in Supply Chain (SC), which has caused many researchers to re-study Supply Chain Risk Management (SCRM) to deal with risks due to the pandemic. Moreover, the direction of post-pandemic SCRM research is more toward Supply Chain Resilience (SCRes) which is the ability of a supply chain to prepare for disruptions and return to normalcy. Many researchers have started researching SCRes to carry out SC recovery measures. However, research on the quantification of SCRes is still rare and is an opportunity. One of the risk quantification methods in the SCRM field is the House of Risk (HoR). This study develops a SCRes assessment framework with the help of the HoR. HoR has two stages, namely: HoR1 for identifying the risks and HoR2 for mitigating the risks. In this study, one step was added, namely the level assessment stage of resilience. The resilience profile is calculated based on the risk map and mitigation plan. This study succeeded in providing a framework for assessing the level of resilience using the help of HoR. Meanwhile, only an illustrative case study is used. Our future research is on how to apply the proposed resilience assessment framework to a real case.

Keywords: supply chain, risk management, supply chain resilience, house of risk

Abstrak: *Pandemi COVID-19 menciptakan ketidakpastian dan gangguan di berbagai bidang. Salah satunya adalah bidang Supply Chain (SC). Hal ini menyebabkan banyak peneliti yang kembali meneliti manajemen risiko rantai pasok (Supply Chain Risk Management/SCRM) untuk menangani risiko akibat pandemi. Arah penelitian SCRM pasca pandemi lebih ke arah ketahanan rantai pasok (Supply Chain Resilience/SCRes). SCRes adalah kemampuan rantai pasok untuk dapat bersiap menghadapi gangguan, dan pulih kembali ke keadaan normal. Banyak peneliti mulai meneliti SCRes untuk melakukan tindakan pemulihan SC pasca pandemi. Namun, penelitian mengenai kuantifikasi SCRes masih sangat kurang. Hal ini merupakan sebuah peluang. Salah satu metode kuantifikasi risiko di bidang SCRM adalah metode House of Risk (HoR). Oleh sebab itu, penelitian ini mengembangkan kerangka penilaian ketahanan rantai pasok dengan bantuan metode HoR. HoR memiliki dua tahap, yaitu: HoR1 untuk mengidentifikasi resiko dan HoR2 untuk memitigasi resiko. Sedangkan, pada penelitian ini, satu tahap ditambahkan yaitu tahap perhitungan tingkat resiliensi berdasarkan peta resiko dan rencana mitigasi. Penelitian ini berhasil memberikan kerangka penilaian tingkat resiliensi dengan mengembangkan metode HoR. Studi kasus yang digunakan dalam penelitian ini masih berupa kasus ilustrasi. Sehingga harapan pada penelitian selanjutnya adalah penerapan kerangka penilaian ketahanan yang diusulkan pada kasus nyata.*

Kata kunci: *rantai pasok, manajemen risiko, supply chain resilience, house of risk*

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INTRODUCTION

The rapid spread of COVID-19 has created uncertainty and disruption in many areas and many company scales. It affects not only the business performance (Wijayanti et al. 2022), but also other field. One of them is the field of Supply Chain (SC) (Yu and Aviso, 2020). The pandemic control measures taken by several countries in the world have also disrupted the flow of goods, both from China and around the world. For example, Wuhan, which is the epicenter of the COVID-19 outbreak, is also a hub for auto manufacturers of global brands such as GM, Hyundai, and Toyota have closed facilities across China (Ivanov and Das, 2020; Yu and Aviso, 2020). This results in the instability of global supply chains.

COVID-19 is categorized as a disruptive risk caused by natural disasters (Hosseini et al. 2019). This risk has a low probability of occurrence, but a high impact. The nature of this risk is unpredictable; vary in type, scale and nature; intermittent; not identified and not estimated properly; and has short- and long-term negative effects (Dolgui et al. 2018). Another example of disruptive risk is the case of the 2011 Japanese Earthquake. This case caused several Japanese manufacturers to temporarily stop their production (BBC, 2011) which also disrupted the world SC network.

To deal with the risk of disruption, several researchers propose risk management methods. Supply chain risk management is better known as Supply Chain Risk Management (SCRM). One part of SCRM that is now becoming important during a pandemic is Supply Chain Resilience (SCres) (Ali and Gölgeci, 2019; Gligor et al. 2019; Hosseini et al. 2019; Pournader et al. 2020; Schlegel and Trent, 2019; Scholten et al. 2019; Waters, 2011). SCRes is the supply chain's ability to prepare for and respond to unexpected risk events, recover quickly from the original situation, or grow and move to a new, more desirable state (Hohenstein et al. 2015).

Many researchers from various countries have started researching SCRes to carry out SC recovery actions due to COVID-19 (Golan et al. 2020; Hosseini et al. 2019). This is because many industries have been disrupted by the COVID-19 pandemic. These studies are generally conducted to assess the industry's ability to return to normal SC operations.

According to Hosseini et al. (2019), supply chain resilience (SCRes) is realized when SC networks are able to survive, adapt and recover from disruptions to meet customer demands and ensure their performance. Hosseini et al. (2019) conceptualize and comprehensively present a systematic review of the latest literature on quantitative modeling of SCRes while specifically dealing with the concept of Resilience Capacity. Managers and researchers can benefit from their surveys as they introduce structured analysis and recommendations on which quantitative methods can be used at different levels of capacity resilience.

Ali and Gölgeci (2019) found an exponential growth in the literature on SCRes over the last decade. However, there are still gaps for empirical research on triggers, barriers, theories, moderators, mediators, and research methods in constructing SCRes.

Gligor et al. (2019) examined concepts to distinguish between the concepts of agility and supply chain resilience (SCres). There is a complex relationship between these two things, causing the emergence of six main dimensions to capture the concept of agility and the concept of SCRes. In the concept of agility and resilience, three dimensions are found in common, namely the ability to adapt tactics and operations (flexibility), the speed of operation, and the ability to scan and anticipate environmental conditions.

Pournader et al. (2020) reviewed supply chain risk publications in nine prestigious journals in management, operations, and supply chain related to current trends and topics. Using a refined set of keywords, they extracted and filtered the most relevant Scopus supply chain risk management (SCRM) articles from 2001 to 2019. Based on the categories identified, they provided a detailed description of the formulation of future research in the SCRM field. One of them is SCRes.

According to Schlegel and Trent (2019), the future of supply chain risk management (SCRM) is promising and interesting to study because of the uncertainty in risk. The companies that will survive are those that not only accept risk but also understand how to anticipate and prepare for risk.

Based on Scholten et al. (2019), this SCRes concept has received significant attention in recent years. They reveal that more than 80% of businesses are concerned about the resilience of their supply chains and that

disruption can result in significant losses. As a result, SCRes are a topic of significant concern. Furthermore, SCRes as a theme has become important not only in industry but also as the government sector. Therefore, the achievement and improvement of SCRes have become the main agenda for researchers, organizations, supply chains, industry, governments, and economic institutions.

Waters (2011) discusses the concept of integrated SCRM, where all members of the supply chain work together to manage risk together. In practice, this is difficult to achieve. The result is a resilient supply chain that is risk-resistant or a resilient supply chain.

Although many studies have focused on SCRes, there are some shortcomings pointed out by Hosseini et al. (2019). One of them is the SCRes mathematical model and the quantification of SCRes (Ribeiro and Barbosa-Povoa, 2018).

One of the risk quantification methods in SCRM is the House of Risk (HoR) method. HoR is a framework that combines the House of Quality (HoQ) with the failure mode and effect analysis method (Pujawan and Geraldin, 2009).

Some of the applications of this HoR include: Rizqi and Khairunisa (2020) applying the HoR method to determine supply chain risk mitigation strategies for bag craft SMEs. Atmajaya et al. (2020) also applied HoR to MSMEs for banana chip snacks. Meanwhile, Octaviani et al. (2020) used HoR in organic fertilizer supply chains.

This study developed the HoR method from Pujawan and Geraldin (2009). HoR from Pujawan and Geraldin (2009) has two stages, namely HoR1 and HoR2. While in this study, there is one additional stage, namely the calculation of the level of resilience.

The organization of this article includes research methods, results and discussion, and conclusions. The research method will describe the concept of the proposed framework. This framework is a resilience assessment framework using the help of HoR. In the results and discussion, an example case taken from previous research will be used to show how to use the proposed framework. And ends with the last part of this article, namely the conclusion.

METHODS

This study developed the HoR method from Pujawan and Geraldin (2009). The HoR itself is a risk management development framework based on the House of Quality (HoQ) and failure modes and effects. HoR from Pujawan and Geraldin (2009) has two stages, namely HoR1 and HoR2. While in this study, there is one additional stage, namely the calculation of the level of resilience.

HoR1 was used to identify risk agents, assess the impact and possible risk of the incident, as well as compile a risk relationship matrix. This HoR1 stage identifies the risk agent (A_i), risk event (E_i), impact severity (S_i), and probability of occurrence (O_i).

Then, at HoR1, the aggregate risk potential of j risk agent (ARP_j) is calculated by equation (1).

$$ARP_j = O_i \Sigma_i S_i R_{ij} \quad (1)$$

O_j is the probability of the occurrence of risk agent j, S_i is the severity of the impact if risk i occurs, and R_{ij} is the correlation between risk agent j and risk event i. Information about the degree of correlation of R_{ij} is contained in Table 1.

Table 1. Correlation level

Weight	Relationship Information
0	None
1	Low
3	Medium
9	High

On the other hand, HoR2 focuses on risk mitigation. This HoR2 is used to determine which action should be taken first, taking into account the different effectiveness as well as the resources involved and the degree of difficulty in doing so.

In HoR2, there are several stages to carry out risk mitigation planning. Risks that have a high ARP are a priority to be mitigated. Preventive action (Preventive Action k or PA_k) is carried out to deal with the type of risk agent i. The level of effectiveness of risk management (TE_k) is calculated based on the relationship between PA_k and A_i, which is denoted by E_{jk}. The level of this relationship is as in Table 1. Then, the formula for calculating TE_k is found in equation 2.

$$TE_k = \Sigma_j ARP_j E_{jk} \quad \forall k \qquad (2)$$

There is also a level of difficulty in implementing risk mitigation, which is denoted as D_k. The total effectiveness compared to the level of difficulty is denoted by ET D_k, which is formulated in equation 3.

$$ET\ D_k = TE_k / D_k$$

Based on Rizqi and Khairunisa (2020), there are three levels of difficulty in implementing risk mitigation (Table 2).

Table 2. Difficulty of mitigation implementation (D_k)

Weight	Degree of Difficulty
3	Easy
4	Medium
5	Difficult

The third stage is the proposal stage from the author as a framework for assessing the level of resilience. To carry out an assessment of the level of resilience, it takes several steps. The first step, based on risk analysis with HoR1, is risk mapping. The risk map used is based on ISO 31000:2018 (ISO, 2018) and the National Standardization Agency (BSN, 2018) (Figure 1).

The probability level is adjusted to the value of O_j, or the probability of the occurrence of a risk agent j. At the same time, the level of impact is obtained from the largest S_i value of risk i, with a high correlation value or $R_{ij} = 9$.

To map resilience, resilience zones from Pettit et al. (2010) were used as the basis (Figure 2). To use this zone, a determination of the level of capability and vulnerability is required.

Capabilities are attributes that enable companies to anticipate and overcome disruptions (Pettit et al. 2010). The capabilities are classified based on the level of difficulty in implementing risk mitigation (D_k). The lower the D_k value, the higher the capability value. Broadly speaking, the level of capability is shown in Table 3. The value of the capability of risk agent i is obtained by calculating the average value of the level of mitigation application.

The level of vulnerability to risk is obtained from the level of risk contained in the risk map (Figure 1). In the research of Pettit et al. (2010), there are three levels of vulnerability to risk, while on the risk map there are five levels of risk. Based on these two things, the conversion of the risk level into the vulnerability level is formulated in Table 4.

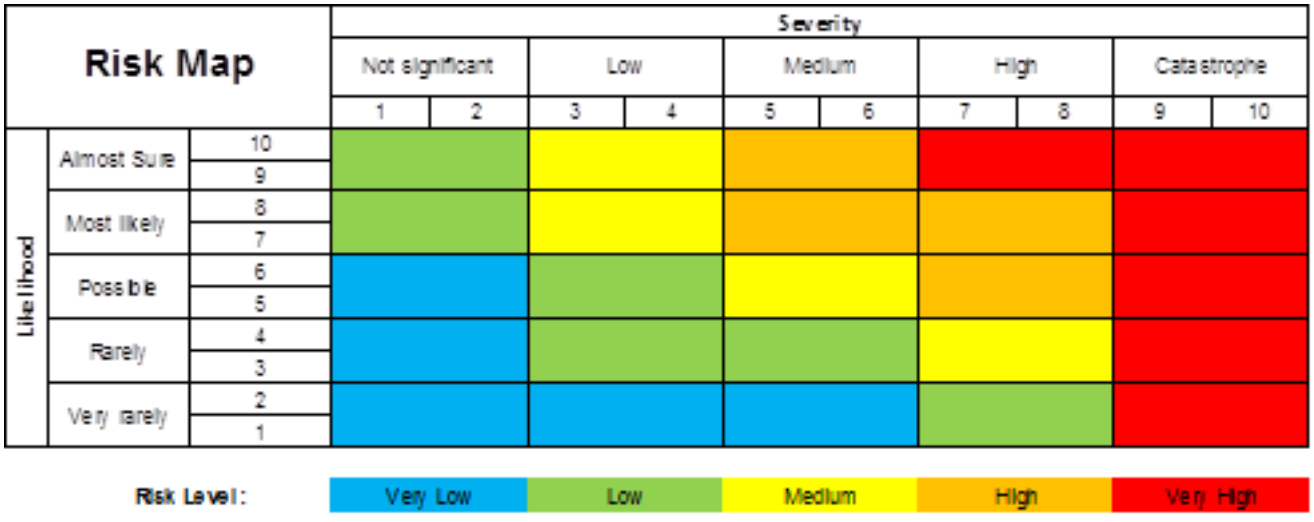

Figure 1. Risk map

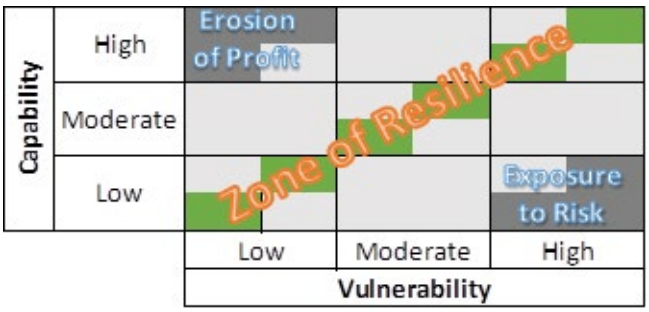

Figure 2. Resilience zone (Pettit et al. 2010)

Table 3. Capabilities level

Weight	Difficulty of Mitigation Implementation (D_k)	Capability Level
3	Easy	High
4	Medium	Medium
5	Difficult	Low

Table 4. Vulnerability level

Risk level	Vulnerability level
Very Low	Low
Low	
Medium	Medium
High	High
Very High	

With the capability level and vulnerability level obtained, the resilience zone map can be described as shown in Figure 2. This resilience map refers to the research of Pettit et al. (2010). In Figure 2, there are three types of zones. Erosion of profit zone: in this zone, the business or risk handling ability exceeds the impact of the risk, so the business is classified as a waste that can reduce profits. The second zone is the resilience zone. In this zone, the company is said to be resilient or resistant to risk. The third zone is the risk exposure zone (exposure to risk). In this zone, the company does not have the ability (capability) or effort to handle risks so that the company will be easily affected by risk.

Based on this framework, an experiment using data from Rizqi and Khairunisa (2020)'s research was conducted. In their research, Rizqi and Khairunisa (2020) only analyzed the HoR1 and HoR2 stages. Thus, in this study, an analysis of resilience will be carried out using the proposed framework.

RESULTS

Based on the case study we will discuss the assessment result of resilience level and the managerial implication this method.

Assessment Result of Resilience Level

In this study, we used data from Rizqi and Khairunisa (2020) 's research. In this study, the object observed was a bag-producing MSME. The risk agents from the MSMEs are listed in Table 5 and the risk events are in Table 6.

From Tables 5 and 6, they are combined into HOR1 by considering the relationship between risk agents and risk events (R_{ij}). Details of HOR1 are in Table 7.Then, the Pareto diagram is used to see the ranking of the urgency of risk based on the amount of ARP. This Pareto diagram is shown in Figure 3.

Table 5. Risk agents (Rizqi and Khairunisa, 2020)

Code	Description	Occurrence Level
A1	Workers' lack of interest and involvement in the company's supporting activities	3
A2	There seems to be no quality control process	7
A3	Suppliers are unable to match the company's requirements for quantity or quality	4
A4	Errors in the planning of production equipment and maintenance	2
A5	The internal communication system within the company isn't working properly	3
A6	The quantity of customer orders is uncertain	8
A7	Logistics firms' ability to deliver products to clients is uncertain	3
A8	During shipment, raw materials and/or supplementary materials may be damaged	2
A9	Supplier delivery delays	3

Based on Table 7, the relationship between risk agents and high-risk events was chosen to be the benchmark for the risk impact of these risk agents. Then, based on the probability of occurrence, each risk agent is mapped into a risk matrix as shown in Figure 4. From Figures 3 and 4, it can be concluded that risk agents A2, A3, and A6 are risks that must be addressed first (priority).

In Rizqi and Khairunisa (2020)'s research, the only risks that were mitigated were A2 and A3 risks. To reduce the impact of risk, several mitigation strategies are carried out. The mitigation plan for this risk agent is shown in Table 8.

Table 6. Risk events (Rizqi and Khairunisa, 2020)

Code	Description	Severity Level
E1	Mistakes in maintenance planning	6
E2	Design planning delays	8
E3	Production planning errors	4
E4	The company's requirements for raw materials and auxiliary supplies are not being met	8
E5	Raw resources and supporting supplies are in short supply	6
E6	The internal communication mechanism at the company is ineffective	3
E7	Planning the budget to be used incorrectly	6
E8	Customers' orders are uncertain	8
E9	Customers have delays in selecting and using transportation/logistics providers	6
E10	Production was delayed	4

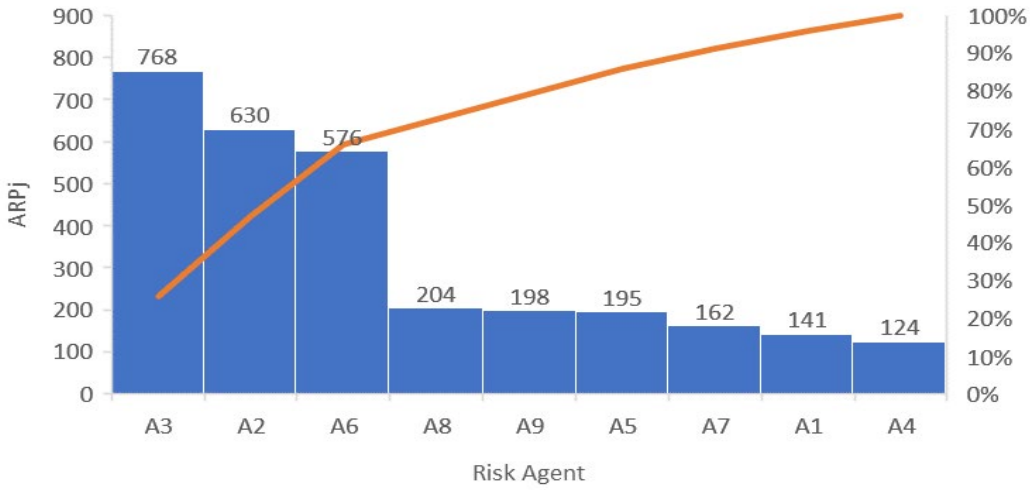

Figure 3. Pareto chart

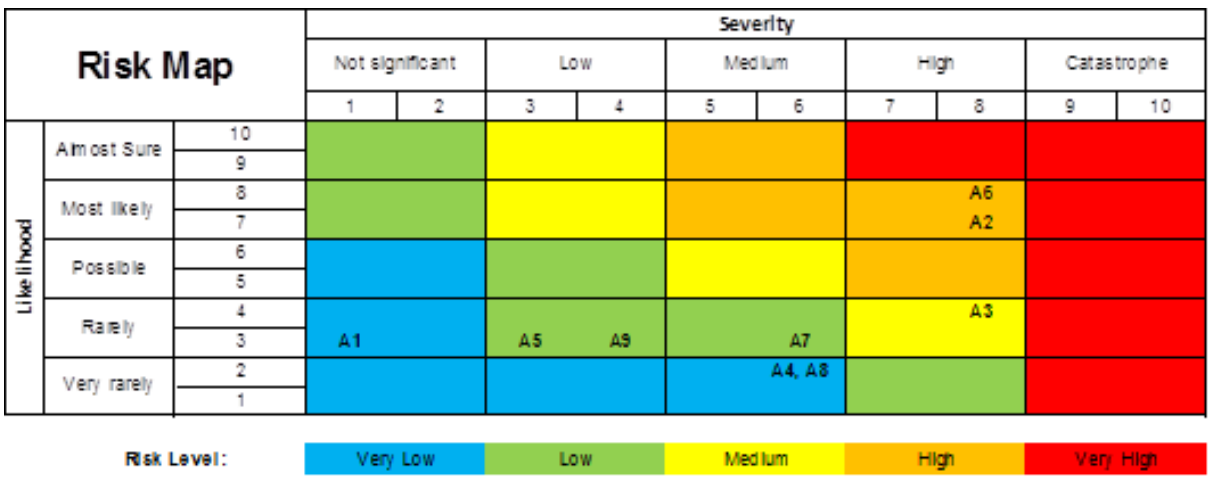

Figure 4. Risk map concluded that risk agents

Table 7. House of Risk 1 (HoR1)

Code	A1	A2	A3	A4	A5	A6	A7	A8	A9	Severity (Si)
E1	1			9	1					6
E2	1				3					8
E3	3		9	1	1			3	3	4
E4		9	9					3		8
E5			9					9	3	6
E6	3				9					3
E7		3	3							6
E8						9				8
E9							9			6
E10	3		3	1	1			3	9	4
Occurence (Oj)	3	7	4	2	3	8	3	2	3	Total
ARPj	141	630	768	124	195	576	162	204	198	2998
%	0.047	0.210	0.256	0.041	0.065	0.192	0.054	0.068	0.066	1
Rank	8	2	1	9	6	3	7	4	5	

Table 8. Mitigation plan

Code	Description	Mitigation Code (PA_i)
A3	Make a cooperation agreement (MoU) to ensure the availability of raw materials from suppliers	PA1
	Cooperate with more than 1 supplier	PA2
A2	Standardize product quality	PA3
	QC process for procuring raw materials before and during the production process	PA4

Based on the mitigation plan in Table 7, the analysis was carried out using HoR2. In HoR2, the value of effectiveness (TE_k) is calculated by equation 2. Then the difficulty level of implementation is mapped based on Table 9. And the value of ETD_k is calculated by equation 3.

Based on the capability value of the difficulty level (D_k). The capability level of A2 risk agents is in the high category, while A3 risk agents are in the medium category. The level of vulnerability of risk agent A2 is high, while that of agent A3 is moderate. A summary of the vulnerabilities and capabilities of A2 and A3 risk agents is provided in Table 10.

In this research, we improve the previous research of Rizqi and Khairunisa (2020). However, here we add the resilience assessment for their case. Thus resulting in a new step. Based on Table 10, risk agents A2 and A3 can be mapped as shown in Figure 5. Figure 5 shows that the mitigation carried out for Risk agents A2 and A3 is not yet optimal. This mitigation has not provided a number in the resilience zone.

Managerial Implications

The proposed framework adds new additions to map the resilience capabilities of a chain or company. Resilience zones from Pettit et al. (2010) were used as the basis. The resilience zone itself is divided into three types of zones. Erosion of profit zone: in this zone, the business or risk handling ability exceeds the impact of the risk, so the business is classified as a waste that can reduce profits. The second zone is the resilience zone. In this zone, the company is said to be resilient or resistant to risk. The third zone is the risk exposure zone (exposure to risk). In this zone, the company does not have the ability (capability) or effort to handle risks so that the company will be easily affected by risk.

Table 9. House of Risk 2 (HoR2)

Code	PA1	PA2	PA3	PA4	ARP
A2	3	9			768
A3			9	3	630
TEk	2304	6912	5670	1890	1398
Dk	4	4	3	3	
ETDk	576	1728	1890	630	
Rank of Priority (Rk)	4	2	1	3	

Table 10. Capabilities and vulnerability levels of risk agents i

Risk Agent	Average	Capability Level	Risk Level	Vulnerability Level
A2	4	Medium	High	High
A3	3	High	Medium	Medium

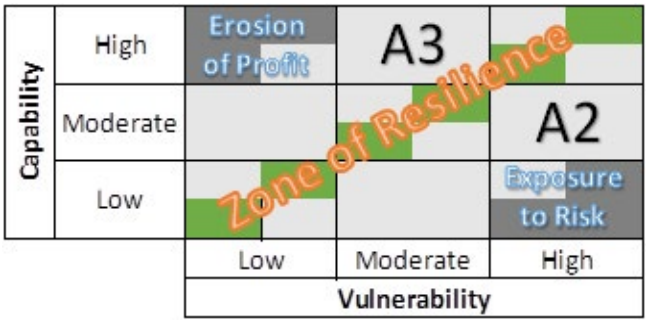

Figure 5. Resilience zone of the example case

Using this zone mapping, a company can assess its capability and vulnerability to see whether they are in the resilience zone or not. The company could also see whether its mitigation plan led to a waste of effort or an effective mitigation plan.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study aims to develop the HoR method from previous studies. HoR has two stages, namely, HoR1 and HoR2. In this study, one step was added, namely the stage of calculating the level of resilience.This study succeeded in providing a framework for assessing the level of resilience by developing the HoR method. However, in this study, the cases used were still in the form of sample cases taken from previous studies.

Recommendations

In future research, cases from real industries are expected to be used. In this study, verification has not been carried out on the idea of an assessment framework for resilience itself. So, in further research, new methods other than the method proposed in this study are expected to be developed.

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