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Supply Chain Risk Management in The Fertilizer Company Using Interpretive Structural Modelling (ISM) And House Of Risk (HOR)

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ABSTRAK

Pertanian memegang peran penting di Indonesia, khususnya dalam pembangunan ekonomi. Untuk memastikan keberlanjutan sektor pertanian di Indonesia, potensi risiko terhadap keseluruhan proses produksi dan distribusi harus dikelola dengan tepat. Pupuk merupakan salah satu komponen kunci yang sangat dibutuhkan dalam kegiatan agraria. Namun, risiko dalam rantai pasok pupuk dapat mempengaruhi ketersediaan produk dan perlu dimitigasi untuk memastikan aliran produk yang efektif dan efisien. Penelitian ini bertujuan untuk mengidentifikasi risiko dalam rantai pasok pupuk dan keterkaitan antara risiko tersebut. Dengan menggunakan studi kasus PT X, salah satu perusahaan pupuk di Indonesia, penelitian ini mengevaluasi kejadian dan penyebab risiko tersebut, mengidentifikasi area prioritas untuk manajemen risiko, dan memberikan rekomendasi untuk tindakan mitigasi risiko dalam proses bisnis PT X. Model Supply Chain Operations Reference (SCOR) digunakan untuk mengidentifikasi proses bisnis dalam rantai pasokan PT X. Dari proses bisnis, 46 peristiwa risiko diidentifikasi. Setelah itu, Interpretive Structural Modeling (ISM) dilakukan untuk menilai keterkaitan antara elemen risiko dan menentukan elemen risiko prioritas di antara peristiwa risiko. Proses ini menghasilkan 21 peristiwa risiko prioritas utama. Peristiwa risiko ini kemudian diprioritaskan menggunakan House of Risk (HOR) Tahap I, yang menghasilkan tiga agen risiko prioritas. Langkah terakhir adalah HOR Tahap II, di mana enam tindakan preventif dirumuskan sebagai strategi mitigasi risiko.

Kata kunci: supply chain, risk management, interpretive structural modeling, house of risk

ABSTRACT

Agriculture holds a critical role in Indonesia, particularly in economic development. To ensure the sustainability of the agricultural sector in Indonesia, potential risks to the overall production and distribution processes must be appropriately managed. Fertilizer is one key component that is fundamentally required in agrarian activities. However, risks in the fertilizer supply chain could affect the availability of the product and need to be mitigated to ensure the effective and efficient flow of the product. This research aims to identify the risks in the fertilizer supply chain and the interrelationships between these risks. Using a case study of PT X, one of the fertilizer companies in Indonesia, this research evaluates the occurrences and causes of these risks, identifies priority areas for risk management, and provides recommendations for risk mitigation actions in PT X's business processes. The Supply Chain Operations Reference (SCOR) model is used to identify the business processes in PT X's supply chain. From the business process, 46 risk events are identified. Afterward, Interpretive Structural Modeling (ISM) is performed to assess the interrelationships between the risk elements and determine the priority risk elements among the risk events. This results in 21 key priority risk events. These risk events are then prioritized using House of Risk (HOR) Phase I, which results in three priority risk agents. The final step is HOR Phase II, where six preventive actions are formulated as risk mitigation strategies.

Keywords: supply chain, risk management, interpretive structural modeling, house of risk

INTRODUCTION

Agribusiness is essential in the world's economy as a key source of food supplies (Behzadi *et al.*, 2018). The agricultural sector plays an important role in the economic development and income of most of the Indonesian population. However, various limiting factors still encounter efforts to achieve optimal agricultural production (Rozaki, 2020). Contemporary agriculture relies on external inputs such as fertilizers and pesticides. This makes agriculture more at risk from pest attacks, climate change, and pandemics (Altieri and Nicholls, 2020). During the pandemic, stock availability and accessibility, in terms of price, became uncertain, conditions that had the potential to force farmers to stop production, affecting food supply (Rozaki, 2020). Agricultural success is affected by land conditions and the amount and quality of inputs such as fertilizer, seed, and pesticides (Funk and Brown, 2009).

There are five regular types of risk commonly appear in the supply chain: supply, process, demand, intellectual property, and behavioral, political, and social (Tang and Tomlin, 2008). Further supply risks can stem from the failure or unavailability of some inexpensive items. Risk management is important for agriculture supply chains because they often involve more sources of uncertainties than manufacturing supply chains (Behzadi *et al.*, 2018).

Supply chain risk is all risks from the flow of information, materials, products, or disruptions caused by the complexity of the company's relationships with external parties (Pujawan and Geraldin, 2009). Supply Chain Risk Management (SCRM) is the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole (Jüttner, Peck and Christopher, 2003). Supply chain risk management is defined as 'an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain (Ho *et al.*, 2015). Various research on risk assessment has been conducted in different industry sector.

(Agung S, Kusrini and Gafur, 2018) conducted risk assessment on the supply chain of cooking oil using Interpretive Structuring Modeling (ISM) combined with cross-impact matrix multiplication applied to the classification (MICMAC). The ISM methodology was applied to evaluate the relationships between risk elements. The risk elements were classified using MICMAC based on the values of Driver Power (DP) and Dependent Variable (D) obtained from the results of ISM. There were four levels of influence on factors influencing the supply of used cooking oil and five (5) elements of key success factors.

(Nguyen *et al.*, 2018) proposed a model for the risk mapping and priority calculation using House of Risk (HOR) and Interpretive Structural Modeling (ISM) for the fisheries supply chain. Results showed that 22 risk events and 20 risk agents are identified, and the two most important risks are A1 "Do not have long-term plan" and A13 "Strict product requirement". (Natalia *et al.*, 2020) conducted risk assessment using HOR and ISM at the conducted at a printing company that produce bottle molds and anti-sealed bottles. The result identified four key risks: the number of goods and specifications, product specifications desired by the customer, frequent changes in customer design and requests, and revisions to the design drawings.

(Dehdar, Azizi and Aghabeigi, 2019) investigates about the types of risks that threaten automotive supply chain. The identified risks are clustered inbound logistics which is about the process of material and relationship between supplier and manufacturer, and outbound which is the flow of finished goods and also interactions between manufacturer and customer.

(Babu and Yadav, 2023) uses the fuzzy set theory to present a conceptual framework for a comprehensive supply chain risk assessment in SMEs during uncertain times. A case study illustrates the efficacy of the proposed conceptual framework for post-covid-19 risk assessment in SMEs in a developing country. The proposed framework evaluates the overall risk index in SMEs based on seven Supply Chain Risk (SCR) factors and 42 associated attributes. In addition, twenty SCR attributes are identified as the main SCR obstacles according to their fuzzy supply chain risk index. (Vafadarnikjoo *et al.*, 2023) an integrated modified risk mitigation matrix (M-RMM) is developed to analyze the mitigation strategies for dealing with various risks in the context of the agri-food supply chain. The M-RMM is integrated with the grey multi-objective binary linear programming (GMOBLP) model to obtain the optimal risk mitigation strategies related to the three objective functions of risk, cost, and time minimization.

The research was conducted to identify the risks in the fertilizer supply chain at PT X. Based on the identified risks, the root causes were determined, and a mitigation plan will be proposed for the prioritized key risks. Interpretive Structural Modelling (ISM) is selected as a research methodology since it can identify relationships between variables, which later on define a problem. This enables the identification of the relationship between the risk variables, which helps to pinpoint the key risks that most significantly influence the emergence of other risks. This can support the improvement of risk management actions at PT X, encompassing both corrective and preventive measures. In addition to the ISM method, the study also employed the House of Risk (HOR) methodology, which combines the Failure Mode and Effects Analysis (FMEA) model with the House of Quality (HOQ) model. This methodology is used to design supply chain risk mitigation strategies by identifying risk events and minimizing the likelihood of risk causes. This research contributes to the literature by addressing the complex and interrelated risks in the fertilizer supply chain using a structured ISM-HOR framework. Previous studies often examined risks in isolation, whereas our approach provides a systemic understanding that enables more targeted and effective risk mitigation.

METHODOLOGY

Data Collection

During the data collection stage, a general overview of the company's business processes was first identified, followed by a detailed mapping of the supply chain processes using the Supply Chain Operations Reference (SCOR) model. Subsequently, potential risks at each stage of the business process were identified. Data collection involved two expert respondents representing key organizational functions: management and operations. These respondents were deemed sufficient to provide the necessary insights and explanations relevant to the study's objectives.

Although this study involved only two expert respondents, their participation was deemed sufficient due to their extensive knowledge and strategic roles within the organization, which represented both management and operational functions. These individuals have direct oversight and deep understanding of the business and supply chain processes, enabling them to provide informed and holistic perspectives on risk identification and prioritization. To ensure the credibility of the qualitative data, a consensus-based validation step was applied. Both experts were invited to review and refine their inputs collaboratively, resolving any inconsistencies and aligning on the interpretation of risk relationships and prioritization.

Data Analysis

At the data processing stage, the data obtained from respondents will be processed using the selected methods, namely Interpretive Structural Modelling (ISM) and House of Risk (HOR) with the following exposure. The use of the ISM method has several advantages when compared to other methods, including that ISM only involves a set of criteria that are interconnected, can establish contextual relationships leading to between criteria, capture the complexity of real world problems and has a higher ability to capture dynamic complexity. Where the first step in ISM modeling is to identify risk elements where the identification of elements that are related to problems in an organization or company is carried out, where this can be done with survey techniques, interviews to brainstorming, then the creation of contextual relationships between elements that have a relationship with the pair of elements that are following the purpose of the modeling, Furthermore, the development of SSIM from elements that have been combined to show pairwise relationships between elements in the system is carried out where the filling at this stage is based on the assessment of experts who understand the condition of the problem that is the topic of discussion.

According to Pujawan & Geraldin (2009), there are two processes in the implementation of HOR, namely HOR phase 1 and HOR phase 2 [7]. In the HOR stage 1, the focus is on the identification of risk events and risk agents. These will then be used to identify risk management priorities based on Aggregate Risk Potential (ARP). Meanwhile, HOR phase 2 focuses more on follow-up actions in handling risk priorities to develop appropriate risk mitigation strategies based on the level of relationship between mitigation strategies and risks, total effectiveness, and the level of difficulty in implementing risk mitigation strategies. In the first stage of HORO, what is needed to be calculated is the severity of the risk, the value of the frequency of the risk event (occurrence), and the value of the correlation between each risk event and the risk agent where the calculation of these various values will produce the value of Aggregate Risk Potential (ARP) which will result in the priority of handling the risk agent.

RESULT AND DISCUSSION

The supply chain business process is identified and mapped using the SCOR (Supply Chain Operations Reference) framework. According to SCOR, there are six main processes: Plan, Source, Make, Deliver, Return, and Enable. The mapping was prepared based on interviews and discussions with management representatives. Afterward, the risk events are identified for each main process. Table 1 illustrates the identified risks in all stages.

Table 1. Identified Risk Events

Code	*Risk Events*
E1	There are differences between demand and production capacity
E2	The warehouse stock record is not accurate
E3	Error calculation of on-hand raw material
E4	Ordering time is not suitable
E5	The order quantity is not optimal
E6	PR rejected by the procurement manager
E7	Suppliers could not fulfill raw material requirement
E8	Suppliers reject the purchase request
E9	Price increase
E10	Material stock out
E11	Unexpected change in raw material
E12	The material is not ordered
E13	No suitable supplier
E14	Material price is too high
E15	Transportation unit is not aligned with quantity order
E16	New shipping regulation
E17	Delay in delivery
E18	Inappropriate material handling during transportation
E19	Defect on ordered material

Code	*Risk Events*
E20	Incorrect type and quantity of materials ordered
E21	Miscalculation of material requirement
E22	Degrading quality of raw material
E23	Warehouse overcapacity
E24	Material shortage
E25	Insufficient mixing process
E26	Machine breakdown
E27	Production failure
E28	Human error in quality control
E29	Product spilled during packing process
E30	Fertilizer sack is torn or leaking
E31	The product did not pass test sampling
E32	Damaged product during moving process
E33	Sudden changes on delivery schedule
E34	Delivery could not be performed
E35	Product quantity that is transported is not aligned with order
E36	Miscommunication between couriers with management
E37	Delay in truck arrival
E38	Delay arrival at customer
E39	The received products are not aligned with complain letter
E40	Cannot receive goods complain
E41	Defective product inspection errors for repair
E42	Incorrect recording of product quality
E43	Quantity of received goods not aligned with return letter
E44	Report is not aligned with actual condition
E45	Error calculation on product cost
E46	SOP implementation is not optimal

The next phase is measuring the correlation between risk events using ISM analysis. In this analysis, the relationship between risks event are identified using a structural self-interaction matrix, which is later converted to a reachability matrix.

The Structural Self-Interaction Matrix (SSIM) is constructed to see the relationship between 46 variables that have been previously identified. It is developed using the notation V, A, X, O, which is defined as follows:

V = The relationship of factor i will affect factor j

A = The relationship of the j factor will affect the i factor

X = Two-way interrelation relationship (mutually influential)

O = Indicates that the i and j factors are not related

The SSIM matrix outlines the contextual influence among variables, which is then transformed into a reachability matrix (RM) to facilitate the hierarchical structuring process in ISM.

Table 2. Structural Self-Interaction Matrix

Risk Element	Ej1	Ej2	Ej3	Ej4	Ej…	Ej46
Ei1	-	V	V	O	V	O
Ei2	V	-	V	O	A	O
Ei3	V	V	-	O	A	O
Ei4	O	O	O	-	O	O
Ei…	V	A	A	O	-	O
Ei46	O	O	O	O	O	-

The transformation process of the Structural Self-Interaction Matrix (SSIM) into a reachability matrix (RM) involves converting the values into binary codes that can be quantitatively processed later. The steps to convert SSIM to RM are as follows:

- If the relation Ei to Ej = V in SSIM, then the elements Eij = 1 and Eji = 0 in RM
- If the relation of Ei to Ej = A in SSIM, then the elements Eij = 0 and Eji = 1 in RM
- If the relation Ei to Ej = X in SSIM, then the elements Eij = 1 and Eji = 1 in RM
- If the relation Ei to Ej = O in SSIM, then the elements Eij = 0 and Eji = 0 in RM

Table 3 presents the reachability matrix, which illustrates the directional relationships among the identified risk events. These relationships have been codified based on the standard SSIM-to-reachability matrix conversion rules.

Table 3. Reachability Matrix

Risk Element	Ej 1	Ej 2	Ej 3	Ej 4	Ej …	Ej46	Driver Power
Ei1	1	1	1	0	..	0	5
Ei2	0	1	1	0	..	0	4
Ei3	0	0	1	0	..	0	1
Ei4	0	0	0	1	..	0	1
Ei…	0	0	0	0	..	1	4
Ei46	0	0	0	0	..	1	1
Dep. Power	4	8	11	9	..	10	464

After the Reachability Matrix (RM) is established, the next step is to create the partition level. This step is performed by summarizing the non-zero data on RM and classifying them into two sets, namely the Reachability Set (R_i), which is taken from the results of non-zero element data in the Ei row, and second is the Attendance Set (A_i), which is obtained from the results of non-zero element data in the Ej column. The results of the data classification from A_i and R_i will be included in the iteration column, together with the intersection between Ai and Ri. If A_i and R_i is fully intersected, then a partition level is created. This process will be continued until all variables are fully intersected. Table 4 illustrates the summary of the iteration process, which creates 13 partition levels.

Table 4. Summary of Level Partition in ISM

Risk Element	Ri	Ai	Intersect	Level
3	3	1,2,3,5,6,10,11,12,21,23,24	3	I
4	4	4,6,9,10,12,13,14,17,24	4	I
16	16	6,9,12,13,14,15,16,17	16	I
36	36	33,34,35,36,37,38	36	I
46	46	25,27,28,29,30,31,32,44,45,46	46	I
9	9,14	6,9,14,22,45	9,14	II
11	1,10,11	1,2,5,7,8,10,11,12,13,14,15,21,24,31	1,10,11	II
17	17	10,17,19,22,24,27,33,34	17	II
30	30,32	28,29,30,32,34	30,32	II
32	30,32	30,32,34,35	30,32	II
44	44	39,40,41,42,43,44	44	II
2	2	1,2,5,6,10,21,23,24	2	III
14	9,10,14	6,9,10,12,13,14,45	9,10,14	III
29	29	28,29	29	III
35	35	35,38	35	III
41	41,42	39,40,41,42	41,42	III
42	41,42	39,40,41,42	41,42	III
43	43	39,40,43	43	III
45	45	45	45	III
..	..	..	..	..
34	33,34	33,34,38,44	33,34	XIII
38	38	38,44	38	XIII

The calculation process continued with the preparation of the final RM in a conical or lower triangular format called a Conical Matrix. This matrix was sorted based on the order of levels in each risk element. Level 1 represents the key risk events which have strong connection and considered as primary risk. This research also includes level 2 and 3 considering the relevance of these risk events based on the feedback from respondents.

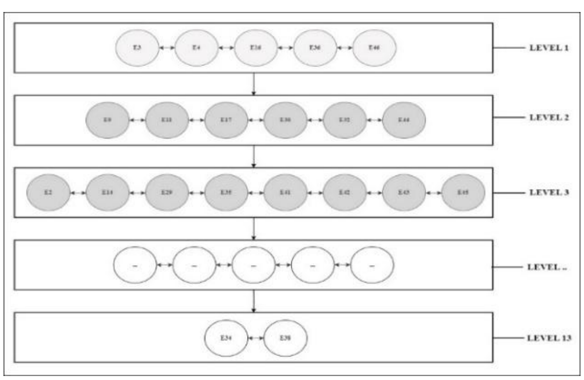

Figure 1. ISM Model Diagram

The result of ISM analysis becomes the input for the House of Risk (HOR) analysis. There are 19 priority risk elements, comprising 5 key risks and 14 secondary risks, derived from the preference of the observed object, along with the risk agent. These risk elements were validated based on confirmation with the supply chain manager representative.

Table 5. Summary of Level Partition in ISM

Priority Risk Event	Code
E2	Warehouse stock recording is not appropriate.
E3	There is an error when counting on-hand raw material.
E4	Raw material ordering time is not right.
E9	Price increase
E14	Supplier sets too high a price.
E16	The existence of the latest shipping regulations from the country concerned
E17	There was a delay in delivery.
E29	Product spillage during the pouring process on the packaging
E30	Fertilizer bags torn or leaking.
E32	Products damaged during the process of moving or placing in the warehouse
E35	The quantity of goods transported does not match the order.
E36	Miscommunication between the courier and the central management
E41	Defective product inspection errors to be corrected
E42	Product condition recording error
E43	The quantity of goods received does not correspond to the return letter.
E45	Calculation error in the supposed HPP
E46	Implementation of SOPs in sub-optimal subsidiaries

Referring to the identified 19 risk events, the cause or risk agents of the events are then defined. Based on the interview and discussion with the companies' management representatives, it is agreed that there are 27 risk agents that are considered driving the risk events. Table 6 presents the list of risk agenst related to the identified risk events.

Table 6. Risk Agents based on 19 prioritized risk events

Risk Agent	*Code*
The inspection process was not performed thoroughly.	A1
Historical data is not representative.	A2
Error in material planning	A3
Error in material forecasting	A4
High demand fluctuation	A5
Sudden purchase request with short delivery time	A6
Too many import purchases	A7
Issue with transportation (truck) during delivery	A8
Traffic congestion upon delivery	A9
Machines malfunction	A10
Packaging (sack) material is too thin	A11
Product weight is beyond the packaging capacity	A12

Risk Agent	*Code*
Pallet is obsolete	A13
Material handling is not optimal.	A14
Overcapacity in finished goods warehouse	A15
Warehouse temperature is not sufficient.	A16
Order picking is not aligned with order letter	A17
Lack coordination between staff	A18
Number of staff is not sufficient.	A19
Transportation is not available.	A20
Damaged transportation unit	A21
Error onthe complaint letter	A22
Inappropriate composition of raw material	A23
Human error on the data recording	A24
Incident during transportation that affect product shape or availability	A25
Lack of accuracy on financial management	A26
Lack of control from holding company towards the subsidiary company	A27

After the risk agents are identified, the severity level of risk events and the occurrence level of risk agents are measured. The measurement of severity and occurrence is performed using questionnaires that are distributed to the representative respondents. The severity level indicates the level of severity associated with each risk event, while occurrence level indicates the potential frequency of the risk agent. The correlation between risk event and risk agent is then calculated based on the feedback from management. After measuring the correlation, the next step is to calculate the Aggregate Risk Potential (ARP) to determine the priority risk agent. The ARP is calculated with the following formula:

$$ARP_j = O_j \Sigma_i S_i R_i \qquad (1)$$

Based on the ARP calculation, the three main risk agents are identified: A24 (human error in the process recording), A1 (the Inspection process not being performed thoroughly), and A27 (a Lack of control from the holding company towards the subsidiary company). Table 3 presents the ARP value from each risk agent.

Table 7 Risk agents' priority based on the HOR stage 1

Rank	Code	ARP	Percentage	Accumulated Percentage
1	A24	2583	8,71%	8,71%
2	A1	2520	17,20%	17,20%
3	A27	2310	24,99%	24,99%

In stage 2 of HOR, the preventive actions (PA) are identified together with their correlation with the risk agents. Total effectiveness (TE) and Effectiveness to Difficulty (ETD) are calculated based on the correlation value for each preventive action. Table 4 presents the preventive actions for each risk agent, based on interviews and discussions with management representatives of the holding company.

Table 8. Preventive actions based on the priority of risk agents priority

No	Risk Agent Code	Preventive Action	Preventive Action Code
1	A24	Detailing the cross-check mechanism for each part of the process	PA1
2	A1	Creating digital systems, such as e-procurement, for the entire production area for raw material recording	PA2
3	A27	Implementation of controls and audits regularly and evenly	PA3
		Making monthly reports related to project progress and constraints	PA4
		Implementation of a reward and punishment system	PA5
		Technical skill training	PA6

After determining the correlation value between the preventive actions and risk agents, the next step is to calculate the Total Effectiveness (TE) and Effectiveness to Difficulty (ETD).

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

$$ETD_k = \frac{TE_k}{D_k} \qquad (3)$$

Based on the calculation, the preventive actions will be ranked based on the highest ETD value. PA1 is ranked in the first position based on the highest ETD value of 15309, while PA5 is ranked as the last PA due to its lowest ETD value of 2310. Table 5 illustrates the ranking of preventive actions.

Table 9. Preventive actions ranking

No	Preventive Action Code	Preventive Action
1	PA1	Detailing the cross-check mechanism for each part of the process
2	PA3	Implementation of controls and audits regularly and evenly
3	PA2	Creating digital systems, such as e-procurement, for the entire production area for raw material recording

No	Preventive Action Code	Preventive Action
4	PA4	Making monthly reports related to project progress and constraints
5	PA6	Technical skill training
6	PA5	Implementation of a reward and punishment system

CONCLUSION

This research aims to identify and assess potential risks in the fertilizer supply chain, using a case study of a fertilizer holding company. Through the ISM model, 19 risk events were identified and structured based on 27 associated risk agents. The HOR model was then applied to prioritize these risk agents, resulting in three key risks: A24 (human error in process recording), A1 (inadequate inspection processes), and A27 (lack of centralized management control over subsidiaries). To mitigate these, six preventive actions were proposed, with PA1 (strengthening the crosscheck mechanism throughout the process) identified as the top priority. Additional actions include implementing routine audits and control mechanisms, developing integrated digital systems (e.g., e-procurement), enhancing project monitoring through monthly reports, providing technical training, and enforcing a structured reward-and-punishment system.

The findings of this study have practical implications for supply chain risk managers in fertilizer companies, providing a structured framework to prioritize and mitigate operational risks effectively. By applying a dual-method approach (ISM and HOR), this study offers a replicable model that can be adapted in other agricultural input industries facing complex, interrelated risks.

However, the study's limitation is driven by the low number of respondents. The ISM and HOR models were constructed based on the input of two experts. While these experts hold key roles in management and operations and possess comprehensive knowledge of the company's processes, the limited number may constrain the diversity of perspectives captured. Future research is encouraged to involve a broader panel of stakeholders to enhance model validation and generalizability.

Additionally, this research is limited by its focus on a single case study, which may affect the generalizability of the findings. Additionally, the ISM-HOR framework primarily captures interrelated risks but may overlook emerging or external risk factors not included in the initial classification. Future research could expand the scope by integrating expert judgment across multiple companies or regions, incorporating quantitative risk assessment methods, or exploring dynamic risk evaluation models over time. Assessing both key and non-key risks—especially those external to internal operations—may further support the development of more robust and adaptive risk mitigation strategies.

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