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Abstract

Cross-border multi-modal and railway transportation often faces different risks and problems creating delays, sometimes driven of technical or administrative discontents between countries. For cold supply chains, the risks of such delays get even more important to understand and handle, due to the perishable characteristics of the goods. While some previous research has dealt with risk assessment of either cold supply chains or railway transportation, none seems to have combined those and the issue of cross-border transportation. To address this research gap, we first review related literature and identify what risks previously have been discussed in the different fields.

To empirically explore this in practice, we also identify and assess the risk factors occurring for cold supply chains using a new cross-border railway route between Thailand and Laos. The risk assessment used a Failure mode, effects, and criticality analysis (FMECA) methodology to analyze risks from both previous literature and expert's suggestion. The result showed that the quality and safety in uncertain situation was firstly concerned.

The study contributes by pointing out previous gaps in research, especially related to combining the important areas of cross-border transport, multi-modal railway transport and cold supply chain. Those three aspects are all important to handle growing trade of food in a sustainable and safe way. The study thus not only identifies important general risks, but also applies this practically. Finally, we outline issues for future research.

Keywords: risk assessment, multi-modal transportation, cold chain, cross border, FMECA

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1 Introduction

Cross border trade rises between Thai-Laos-China as a new Laos-China medium speed railway (MSR) has opened. The Thai-Laos-China cross border is a part of the Belt and Road Initiative (BRI) which aims to develop a global transport network connecting Europe, Africa, Central Asia, and the rest of Asia to China. The route for railway transport from Thailand to China starts from Nong Khai railway station, via Lao, to China. The merchandises are transported using multimodal transport modes ranging from truck, to train and to MSR. The merchandises are dispatched from the distribution center to the Nong Khai railway station, then carried by freight train to Laos, and lastly transported by MSR to China. Due to the fact that MSR helps to reduce transit time from 2 days to 15 hours and freight fee to a half of road transportation (World Bank,2020), this route is considered to be an option for cross border trade (Wei,2021). It is in line with the work of Zhao and Gua (2022) who studied high speed railway (HSR) and concluded that it improved transportation time and eased the access to other zones.

The merchandises to be transported via Thai-Laos-China cross borders are varied, but the most popular ones are fresh fruits, vegetables, frozen food and other perishable products. These products are temperature-sensitive and the temperature-controlled are need to maintain along the transportation period until the products arrive at the destination or it is called 'cold chain.' The cold chain must remain unbroken in order to keep the safety and quality of food and perishable products. Chen et al.(2014) indicated the importance of managing food chain quality and risks and Makule et al. (2022) supported that 50 percent of food losses came from many factors including perishability, poor post-production handling and storage, and processing infrastructures. Shaharudin and Fernando (2023) studied and proposed suitable technology to reduce food quality issues. Dan Li and Kang Li (2023) emphasized that cold chain products may get worse in quality during distribution. Tang (2023) determined correct temperature range for maintaining the cold chain for fresh food transport. Therefore, keeping the cold chain during transportation is an important and challenging issue for food quality.

Many research have been studied about cold chain logistics for fresh products including reviews of current research status, shortcomings, and future trends (Han et al., 2021). Peide Liu and Ying Li (2021) investigated risks of the cold chain green logistics (CCGL) using Failure Mode and Effect Analysis (FMEA). Gazcon-Rivera et al. (2021) also concluded mitigate strategies to reduce risk elements in process, design and improvement of transportation services using FMEA.

Cross-border multi-modal and railway transportation often faces different risks and problems creating delays, sometimes driven of technical or administrative discontents between countries. For cold chains, the risks of such delays get even more important to understand and handle, due to the perishable characteristics of the goods. While some previous research has dealt with risk assessment of either cold supply chains or railway transportation, none seems to have combined those and the issue of cross-border transportation. Therefore, to address this research gap, this research is interested in exploring and assessing risks with respect to cross-border and multi-modal cold chain. First, literature review on the risks related to the cold chain and multimodal transportation has been conducted, followed by the application of the Failure Mode and Effect Analysis and Critical Analysis (FMECA) on the case study of new Thai-Laos cross border cold chain. The focus area of this study is shown in Figure 1.

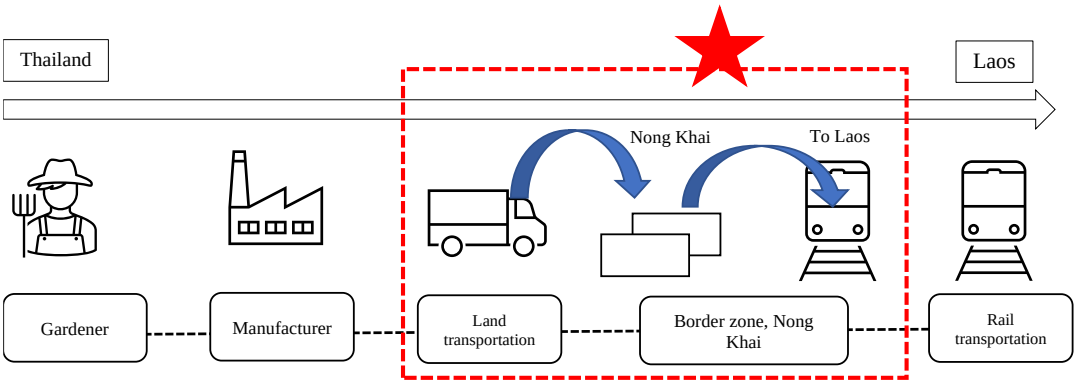

Figure 1: Focus area

2 Literature Review

To specify search strategy and search database, literature review analysis was based on the search string "cold chain", "cold chain risk", "railway cold chain", "rail freight supply chain", "cold supply chain", and "cold supply chain risk". The papers used data retrieved from ScienceDirect and Scopus databases to identify relevant articles. After scanning through all abstracts, more than 30 publications and theses were selected for reading in detail.

Among relevant literatures, Wei (2016) compared advantages and disadvantages between existing and new routes for China-Laos Railway. Wu and Hsiao (2021) conducted research on food quality and safety risk diagnosis in the food cold chain through failure mode and effect analysis. Trafialek and Kolanowski (2023) also applied Failure Mode and Effect Analysis (FMEA) for bakery and audit of HACCP system. The selected risks summarized from literature review is shown in Table 1. The definition of the risk is also described. The risk assessment tools used in the food industry is shown in Table 2. Other tools used in other industries are Sneak analysis and Reliability centered maintenance.

2.1 Risk factors for cross border and multimodal cold chain

After literature analysis, the summarized risk factors observed in literature related to cold chain, cross border and multimodal chain are shown in Table 3-5. Totally, fifteen risk factors have been identified including R1 Food quality, R2 Safety, R3 Technologies, R4 Equipment, R5 Operations, R6 Environment, R7 Personal, R8 Organization, R9 Supply hazards, R10 Storing hazards, R11 Packaging hazards, R12 Transportations hazards, R13 Temperature, R14 Time, and R15 Business strategy. From the tables, in total for all three literature areas, the risk factors R12 Transportation hazards, R3 Technologies, R14 Time were most mentioned followed by the following four on the same level: R2 Safety, R4 Equipment, R5 Operations, and R8 Organization.

An interesting observation is that the risk factors R8 Organization (as well as R1 Food quality, R9 Supply hazards and R13 Temperature) were almost only mentioned in the Cold chain literature. The other more frequently mentioned risk factors, especially R3 Technologies, R12 Transportations hazards and R14 Time were more balanced between the three literature areas.

Failure Mode	Risk factors	Definition	References
FM1	Quality and safety risk in uncertain situation	Uuncertainty in ffood quality and safety due to disconnection of supply chain or uncertain situation such as COVID19 pandemic	Hsiao and Huang(2016), Masadin and Safitri(2020), expert interview
FM2	Quality and safety risk in certain situation	Quality and safety risk in certain situation such as wrong Custom document. or less than quality standard.	Wu and Hsiao(2021), Šolc(2021), Goransson et al.(2018), Bartezzaghia et al.(2022), expert interview
FM3	Technology risk	Risk of technology change and comply with the new technology.	Ashok et al.(2017), Hassan et al.(2021), Masudin(2021), expert interview
FM4	Equipment and operations risk	Risk about poor equipment and operations process	Bartezzaghi et al.(2022), Hassan et al.(2021), expert interview
FM5	Organization and personal risk	Risk related to organization and personal issues such as lack of knowledge and training. human errors. lack of cooperation. lack of skills.	Wu and Hsiao(2021), Šolc(2021), Hsiao and Huang(2016), Liebchen and Schülldorf(2019), Hassan et al.(2021), expert interview
FM6	Time and temperature risk	Risk of uncontrolled temperature or long cargo handling time.	Wu and Hsiao(2021), Hsiao and Huang(2016), Goedhals-Gerber et al.(2020), Goransson et al.(2018)
FM7	Storage hazards risk	Risk in term of hazard storage or delay in schedule.	Wu and Hsiao(2021), Masudin(2020), expert interview
FM8	Packaging hazards risk	Risk of unsuitable package for product	Dagsuyu et al.(2021), expert interview
FM9	Transportation hazards risk	Risk related to transportation and infrastructure condition for delivery	Wu and Hsiao(2021), expert interview

Table 1 : The selected risks and details summarized from literature review.

Method	Reference
FMEA	Wu and Hsiao(2021), Peddi et al.(2023), Filz(2021), Varzakas(2016), Kardos(2021), Mangeli et al.(2019), Trafialek and Kolanowski(2014), Kudláč et al.(2017), Gazcon-Rivera(2021), Liu(2016)
FMECA	Bertolini. Bevilacqua and Massini(2006), Nardo et al.(2022), Michaels(2019)
HAZOP (Hazard and operability studies)	Herrer (2015), Lim et al.(2021), Solukloei(2022)
HACCP (Hazard analysis and critical control points)	Trafialek and Kolanowski(2014), Scipioni et al.(2002), Liu et al.(2021), Feng et al.(2019), Hasnan and S. Ramli(2020)

Table 2 : The risk assessment tools used in the food industry

Author / Risk	Wu and Hsiao (2021)	Goransson et al. (2018)	Goedhals-Gerber et al. (2020)	Mercier et al. (2018)	Ashok et al. (2017)	Hsiao and Huang. (2016)	Hassan et al.(2021)	Trafialek and Kolanowski (2014)	Lau et al. (2021)	Dagsuyu et al. (2021)
R1 Food quality	✓			✓	✓	✓				
R2 Safety	✓				✓					
R3 Technologies					✓		✓	✓	✓	
R4 Equipment					✓		✓	✓	✓	
R5 Operations							✓		✓	
R6 Environment									✓	
R7 Personal									✓	
R8 Organization	✓					✓		✓	✓	✓
R9 Supply hazards	✓			✓				✓		
R10 Storing hazards					✓					
R11 Packaging hazards										
R12 Transportations hazards	✓			✓						
R13 Temperature		✓	✓		✓	✓				
R14 Time		✓	✓	✓		✓				
R15 Business strategy										

Table 3 : Summary of risk factors from cold chain literature review

3 Research Methodology

3.1 Step 1: Identify risk factors for cross border, multimodal transportation and cold chain and get expert confirmation

The result from literature review conducted, based on risk factors found for cross border, multimodal transportation, and cold chain research, are shown in the Literature section. The relationship of the three risk factor groups is shown in Fig. 2. The factors were confirmed by three experts who have more than 10-year experience in cold chain and cross border transportation as shown in Fig. 3. Eleven factors were confirmed including FM1 Quality and safety risk in uncertain situation, FM2 Quality and safety risk in certain situation, FM3 Technology risk, FM4 Equipment and operations risk, FM5 Organization and personal risk, FM6 Time and temperature risk, FM7 Storage hazards risk, FM8 Packaging hazards risk, and FM9 Transportation hazards risk.

3.2 Step 2: Case study selection

In order to verify and assess the risks associated with the cross border and multimodal transportation for cold chain, a case study of Thai-Laos cross border was selected. The selection was based on the fact that the Thai-Laos cross border involve multimodal transportation as the new MSR has just launched and the major products to transport at the cross border are food produced and perishable products which require cold chain logistics. All three countries (Thailand. Laos. and China) will get benefit from the rail freight via the new route from the Nong Khai railway station. The obvious and challenging problem is the difference on the rail gauges in which railway track from Nong Khai station in Thailand to Thanaleng station in Laos uses meter gauge, but the MSR from Laos to Mohan in China uses standard gauge.

3.3 Step 3:. Risk analysis using FMECA

The method of Failure modes. effects. and criticality analysis (FMECA) has been applied in this research. FMECA requires the application of FMEA and builds upon the FMEA process by not only identifying potential failure modes, but also investigating and isolating any potential failure through a series of actions. FMECA provides more accurate results as it uses both quantitative and qualitative information where FMEA only uses qualitative information. FMECA allows researchers to measure a level of criticality to failure modes and order them according to importance. Apart from risk ranking using Risk Priority Number (RPN) of each failure mode as per the FMEA, the risk level and critical ranking are also analyzed which is the part of Criticality Analysis (CA). This is often used as an alternative for the Risk Priority Number (RPN) in FMEA. Criticality Matrix, which identifies severity on the horizontal axis and qualitatively derived occurrence on the vertical axis as shown in Figure 4.

Author / Risk	Wei (2021)	Fuggate (2020)	Kenadee (2013)	Liebchen and Schülldorf (2019)	Reis (2013)
R1 Food quality					
R2 Safety		✓	✓		
R3 Technologies	✓	✓	✓		
R4 Equipment	✓				
R5 Operations	✓			✓	✓
R6 Environment	✓				✓
R7 Personal				✓	✓
R8 Organization				✓	
R9 Supply hazards					
R10 Storing hazards					
R11 Packaging hazards					
R12 Transportations hazards	✓	✓	✓		✓
R13 Temperature					
R14 Time		✓	✓		
R15 Business strategy				✓	

Table 4 : Summary of risk factors from multimodal transportation literature review

In total, six respondents answered the questionnaires survey. The survey consisted of two parts. The first part contained information on personal characteristics of the respondents and the second part asked about their perspectives on the occurrence (O), severity (S), and detection (D) level of each risk factor. Then the RPN of each failure mode was calculated by multiplying O by S by D.

3.4 Step 4: Risk assessment summary

The result from Step 3 has been analyzed and concluded. The risk priority for cross border and multimodal cold chain has been identified.

Author / Risk	Wei (2021)	Fuggate (2020)	Kongdee (2013)
R1 Food quality			
R2 Safety		✓	✓
R3 Technologies	✓	✓	✓
R4 Equipment	✓		
R5 Operations	✓		
R6 Environment	✓		
R7 Personal			
R8 Organization			
R9 Supply hazards			
R10 Storing hazards			
R11 Packaging hazards			
R12 Transportations hazards	✓	✓	✓
R13 Temperature			
R14 Time		✓	✓
R15 Business strategy			

Table 5 : Summary of risk factors from cross border literature review

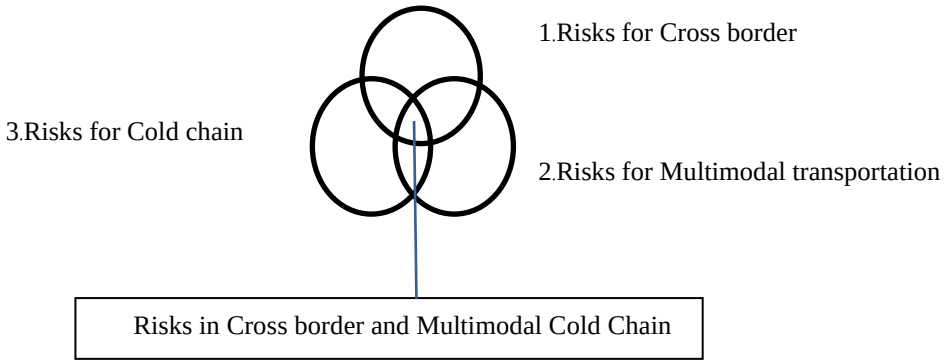

Figure 2 : The relationship of the three risk factor groups

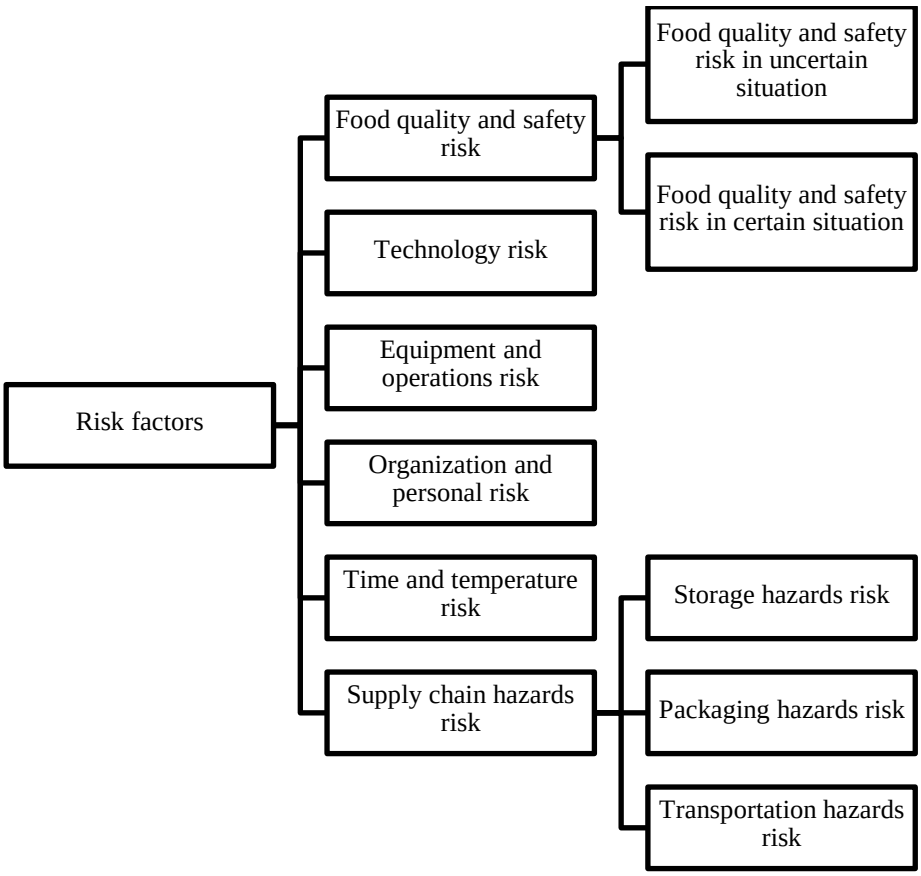

Figure 3 : Risk factors for cross border and multimodal transportation for cold chain confirmed by experts

Severity / Probability		Catastrophic	Critical	Marginal	Negligible
		1	2	3	4
Frequent	A	High	High	Serious	Medium
Probable	B	High	High	Serious	Medium
Occasional	C	High	Serious	Medium	Low
Remote	D	Serious	Medium	Medium	Low
Improbable	E	Medium	Medium	Medium	Low
Eliminated	F	Eliminated			

Figure 4 : Critically Matrix (adapted from MIL-STD-882E)

4 Findings

The RPN results from the study is shown in Table 6. In term of severity, FM1, FM2, FM6 and FM7 are the high risks, while in term of occurrence, FM1, FM2, and FM6 are occurred frequently. For the likelihood of detection of the failure modes, FM1, FM3, and FM8 are uncertainty. Overall, in terms of FMEA, the highest RPN is FM1, followed by FM6, FM2, FM3, and FM4. Figure 5 shows the high failure modes based RPN results.

As an alternative to RPN calculations, the criticality analysis has been conducted to analyze the risk level and determine critical ranking. The new result is shown in Table 7. From the analysis, FM1 and FM6 are considered high critical and FM2, FM4, and FM5 are serious critical. The result from critical analysis is in line with the RPN ranking in which FM1, FM2, FM4 and FM6 are critical. For FM3 Technology risk, based on CA, it is in medium rank, while based on RPN, it is high risk. This is because technology may not change frequently, so experts did not think it is high risk. Another difference is on FM5 Organization and personal risk, in which experts justified that it is serious critical, but from RPN calculation, it does not that serious.

Designation	Failure Mode	$\bar{S}$	$\bar{D}$	$\bar{O}$	RPNs
FM1	Quality and safety risk in uncertain situation	3.833	4.500	4.167	71.875
FM2	Quality and safety risk in certain situation	3.667	3.833	3.500	49.194
FM3	Technology risk	2.833	4.500	3.167	40.375
FM4	Equipment and operations risk	3.333	3.500	3.333	38.889
FM5	Organization and personal risk	3.333	3.167	3.000	31.667
FM6	Time and temperature risk	3.667	3.833	3.667	51.537
FM7	Storage hazards risk	4.000	3.500	2.500	35.000
FM8	Packaging hazards risk	2.833	4.000	2.667	30.222
FM9	Transportation hazards risk	2.667	3.667	2.500	24.444

Table 6 : Rating of failure modes and calculation of RPN

FM	Risk	Criticality ranking
FM1	Quality and safety risk in uncertain situation	High
FM2	Quality and safety risk in certain situation	Serious
FM3	Technology risk	Medium
FM4	Equipment and operations risk	Serious

FM5	Organization and personal risk	Serious
FM6	Time and temperature risk	High
FM7	Storage hazards risk	Medium
FM8	Packaging hazards risk	Medium
FM9	Transportation hazards risk	Medium

Table 7 : The level and determine critical ranking

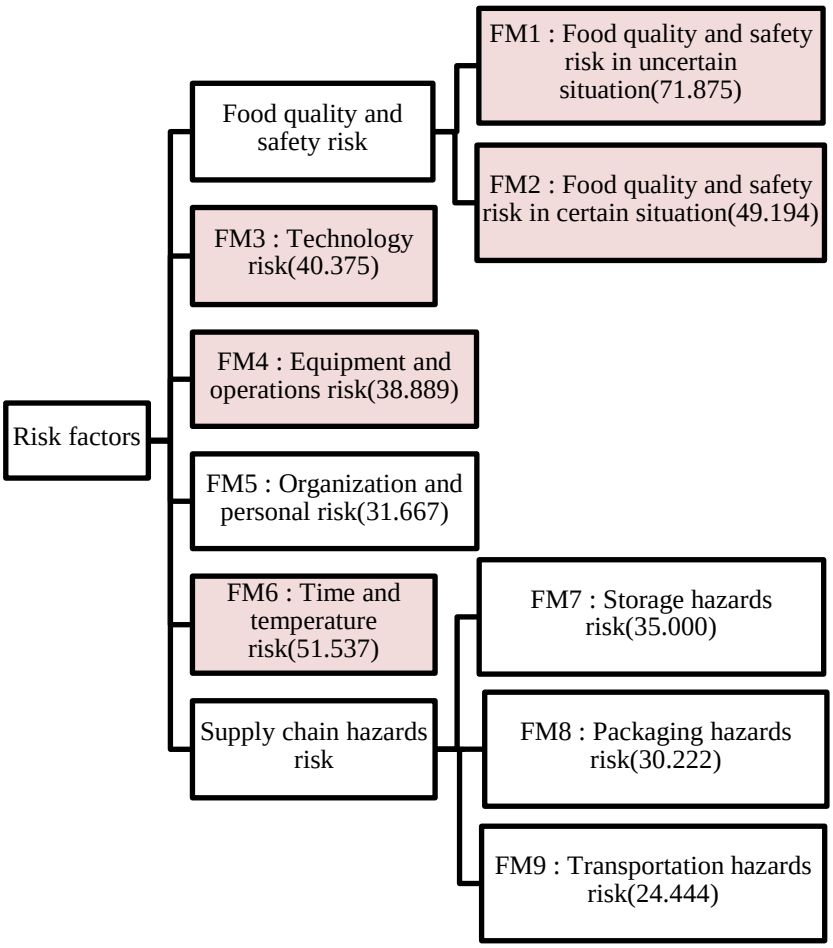

Figure 5 : The high risks based on the RPN results.

5 Conclusion

This research studied the risks associated with the cross border, multimodal and cold chain. The literature review showed that while some risks are identified in all three literature areas, risks related to organization, food quality, temperature, and supply hazards are most focused in cold chain literature and less in the others. All three areas find risks related to technology, transportation hazards and time

very important. This gap between different literature areas, indicates a contribution of this paper to combine them, as the current trend in many geographical areas are going toward increased use of cross border, multimodal cold chains.

To empirically investigate a cross border, multimodal cold chain, this research studied the new route from Thailand to China via new MSR Laos-China as a case study. The FMECA results confirmed that the FM1 Quality and safety risk in uncertain situation and FM6 Time and temperature risk are high risks and in need of priority focus. FM2 Quality and safety risk in certain situation, FM4 Equipment and operations risk and FM5 Organization and personal risk are serious risks. Therefore, it is suggested that immediate actions should be taken in order to mitigate these high and serious risks. The other risks including FM3 Technology risk and Supply chain hazards risk should be monitored.

Further research could be identifying mitigation strategies to manage the risks. The 4T strategies including tolerate, terminate, treat and transfer of risk management are suggested to be implemented. The guidelines for cold chain efficiency enhancement, especially for cross border and multimodal transportation should be developed. To increase generalizability, we suggest that other case studies with different settings should apply the same research method and see the results. Cross comparison among cases will be beneficial to better understanding on the risks of cross border, multimodal cold chains and their supply chain development.

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