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A COLD CHAIN PACKAGING RISK MANAGEMENT SYSTEM BASED ON BAYESIAN NETWORK

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Abstract - Cold chain packaging failure can lead to serious cold chain disruptions, and the management of the cold chain packaging related risks is essential. The purpose of this paper is to develop a risk management model for cold chain packaging. The risk management model is designed based on literature review on the related topics. Bayesian Network is applied in the model, which key risk factors are identified. Risk factors of the cold chain packaging are identified and assessed. The risks are categorised into external, supply chain, logistical, information and shipping solution selection related risks. The study contributes to provide the knowledge needed of understanding the risks of cold chain packaging. It can serve as a guideline for all the stakeholders in the cold chain industry, e.g. for cold chain logistic managers and consultants, to manage risk regarding the packaging along the cold chain. This is the first risk management model proposed on the field of cold chain packaging, which concerns with both packaging itself and also with its impact on the overall cold chain. Industry practitioners can apply this model to assess the effectiveness of their cold chain packaging.

Keywords - Cold Chain, Packaging, Shipping Solutions, Risk Management, Bayesian Network, Supply Chain Risk Management

I. INTRODUCTION

There is an increasing demand of cold chain products today due to the advancement of the living standards and health care needs. Typical cold chain products are perishable food and pharmaceutical products, which usually have higher transportation and storage standards than non-perishable products. Cold chains have some unique characteristics compared to other supply chains, like seasonality in production and low temperature transportation and storage (Joshi et al., 2011). A functional cold chain can prevent the products from quality or safety deteriorations. Therefore, it is important to manage the cold chain effectively and efficiently to ensure product quality and the shelf life. However, there are still many obstacles faced by cold chain management. Inefficient packaging and packing method is identified as one of the main risks for cold chain disruptions (Cerchione et al., 2018).

Packaging plays an important role in the cold chain performance since it contains and protects the products along the entire cold chain, from right after production/processing all the way to the hands of end-users/consumers. There are several levels of supply chain packaging, including primary, secondary, tertiary and quaternary levels. Research on cold chain packaging mostly concerns with the primary level of packaging which offers basic features like containment and protection from the environment. However, secondary, tertiary and quaternary levels of packaging also have great impact on the performance of the entire supply chain. Secondary packaging refers to the shipping units, e.g. the shipping parcels. Tertiary and quaternary packaging are refers to the logistical units, concerning with providing extra protection along the cold chain, and examples include the shipping pallets and accessories (Hanson et al., 2017). Failure of any levels of the cold chain packaging will lead to adverse impact on the product quality. The complexity of the cold chain and packaging makes it difficult to find a universal solution for all cold chain products. Therefore, it is important to assess and manage the uncertainty and risk of the cold chain packaging, so risk mitigation strategies can be found to absorb potential and unresolved risks, therefore improving the overall cold chain performance (Beker et al., 2015 & Ho et al., 2015).Risk management is a useful tool in assisting with understanding, assessing and managing complicated problems, making it a good tool to be applied in the field of cold chain packaging due to its complex and perishable nature. Supply chain risk management (SCRM) and cold chain risk management (CCRM) have both received some research attentions, with the emergence of many frameworks and models. However, no previous literatures have studied the risk management of the cold chain packaging. Due to its significant role in the overall cold chain performance, it is of great importance to assess the risks related to cold chain packaging. Therefore, this paper aims to identify and assess the risk factors of the cold chain packaging, and a cold chain packaging risk management (CCPRM) model is proposed. The rest of the paper include methodology section demonstrating the research approaches and method, results and discussion section detailing the constructing of the CCPRMS, and finally the conclusion section summarizing the research.

II. METHODOLOGY

Since very few literatures study the risk or disruptions of the cold chain packaging, literature review is done

on the topics of cold chain disruptions and risk management. Key search words like 'cold chain disruption' and 'cold chain risk' are used in the web of science database. All the risk factors of the cold chain packaging are identified through literature review. Due to the complexity of the cold chain packaging system, Bayesian network (BN) is selected to be the decision-making method for the risk management system. BNs are used to represent casual relationships and probabilistic dependencies in a diverse range of studies. The nodes represent the different variables, and the arcs indicate the casual relationship of the nodes. Each causal relationship is assigned with a probability based on data or expert opinions. For studies on fraud risk management.

III. RESULTS AND DISCUSSION

Most literature in the field of cold chain disruption and risk management use 'risk' or 'hazard' as the term describing the unexpected disruptions, while some use other terms like 'risk index', 'risk event', 'risk agent', 'risk level', 'vulnerability' depending on the specific research concentration. The cold chain risk management consists of 3 main segments: risk identification, risk assessment and risk mitigation. The risk management segments coverage, targeting cold chain products, decision-making methods used and research methodology of the literature review on cold chain disruptions and risk management are summarized and shown in Table 1.

Source	Decision-making methods	Cold chain products	Risk identification	Risk assessment	Risk mitigation
(Zheng et al., 2021)	Bayesian network (BN)	Fresh produce	✓	✓	○
(Zhang and Han, 2020)	Interpretative structure modelling (ISM)	Medical products	✓	✓	✓
(Dagsuyu et al., 2021)	Failure mode and effect analysis (FMEA), Analytic Hierarchy Process(AHP)	\	✓	✓	✓
(Shashi et al., 2018)	\	Food	✓	○	○
(Zhang et al., 2017)	Catastrophe progression, max deviation	Agricultural food	✓	✓	✓
(Sastra et al., 2019)	House of risk(HOR), fuzzy inference system(FIS)	Frozen tuna	✓	✓	✓
(Nakandala et al., 2017)	Fuzzy logic, hierarchical holographic modelling	Fresh food and vegetables	✓	✓	○
(Zhang et al., 2020a)	Support vector machine	Strawberry	✓	✓	○
(Ali and Gurd, 2020)	\	Australian horticultural industry	✓	✓	✓
(Beker et al., 2015)	\	Food	✓	✓	✓
(Khan et al., 2022)	Fuzzy AHP	Halal food	✓	✓	○
(Wu and Hsiao, 2021)	FMEA	Food	○	○	✓
(Ridwan et al., 2019)	HOR	Fish at Karangantu Fisheries Port at Banten	✓	✓	✓
(Joshi et al., 2011)	AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Food	✓	✓	✓
(Zhao et al., 2020)	Fuzzy MICMAC	Agricultural food	✓	✓	✓
(Sharma et al.,	FIS, fuzzy MICMAC	\	✓	○	✓

2021)					
(Ali et al., 2018)	Contingency theory, resource based theory	\	✓	✓	✓
(Chen et al., 2021)	Bayesian network	Fresh cold chain	✓	✓	✓
(Zhang et al., 2019)	Fault tree, Bayesian network, fuzzy evaluation	Agricultural product	✓	✓	○
(Sharma and Pai, 2015)	BN	Food	✓	✓	✓
(Yang and Liu, 2018)	Bow-tie, fault tree, BN	Agricultural food	✓	✓	✓
(Soon and Abdul Wahab, 2022)	BN	Food	✓	✓	✓
(Zhang et al., 2020b)	BN	Fresh food	✓	✓	○
(Soon, 2020)	BN	Food	✓	✓	✓
(Bai et al., 2018)	Fuzzy comprehension evaluation, FMEA	Food	✓	✓	○
(Tsang et al., 2018)	Fuzzy logic	\	✓	✓	○
(Singh et al., 2017)	AHP, TOPSIS	\			
(Mercier et al., 2017)	\	Food			
(Ndraha et al., 2018)	\	Food			

Table 1 Literature review on cold chain risk management and disruption studies: methodologies, decision-making techniques, cold chain products, risk management process.

Regarding the targeted cold chain products, food products are the most popular cold chain products in the fields of cold chain disruptions and risk management. Some studies concentrate on specific types of food, e.g. Sastra et al. (2019) focusing on frozen tuna and Zhang et al.(2020a) focusing on strawberry, which both analyze the quality risks including contamination, moisture content, mechanical damages, etc. Only one study focuses on pharmaceutical products which analyses the risk control factors in a medical service provider (Zhang and Han, 2020). Some studies do not specify specific cold chain products but analyse the cold chain risks in general, such as Dagsuyu et al. (2021), Sharma et al. (2021), Ali et al. (2018), Tsang et al. (2018). Tsang et al. (2018) focus on the occupational safety risk of the cold chain, therefore do not need to distinguish between specific cold chain products.

Theoretical CCRM studies often identify risk factors from literature review and expert opinions and then propose a conceptual framework or model, while empirical studies conduct risk identification and assessment directly on a specific scenario, e.g. in a company or a specific region. Most CCRM studies use the theoretical methodology, and the models are sometimes further validated by case studies, numerical modelling or comparisons in some cases. Dagsuyuet al.(2021) applied the proposed risk assessment model on a third party cold chain logistics company, which the hazards are identified by company occupational health and safety specialists. Zhang et al.(2017) compare the historical data of fresh agricultural cold chain logistics from Shuanghui Group and Beijing Xinfadi using the constructed risk assessment model. The results are proven to be consistent with the recent company ranking in the industry and other reality factors. Apart from the risk model being applied on specific companies or locations, some models are applied on macro-level scenarios. The model of analysing the effectiveness of cold chain by Sharma and Pai (2015) is validated by a case study comparing the cold chain performance between a developed nation and a developing nation. Besides validating by empirical studies, benchmarking is also sometimes used in the risk management process. Joshi et al. (2011)'s food cold chain risk management model compares companies with the benchmarking data of the market leader. Studies utilising the empirical methodology conduct risk identification directly from real life scenarios, e.g. in a specific port, company, etc. Ridwan et al. (2019) construct a risk management model for the fish cold chain at the Karangantu fisheries port in Serang, Banten based on direct observations, interviews and local expert opinions. Zhang and Han (2020) analyse the risk control factors

from the RK pharmaceutical Co. Ltd in Shandong, China.

Regarding the risk management models themselves, the models proposed by CCRM studies mostly contain the risk identification and assessment steps, with only a few suggesting related mitigation strategies or actions. The risk identification is usually done through literature review and expert opinions, and then the identified risk factors are further assessed. The most commonly used term is risk or hazard referring to the unexpected macro- or micro-level events or activities that have negative impact to the cold chain, causing operational, financial, strategic or tactical failures (Ho et al., 2015). Some studies use the term risk level that specifies the degree or extent of the risks, therefore a hieratical risk structure is proposed (Zhao et al., 2020; Zhao et al., 2020). The term risk index is also used which intends to indicate the size of the risk reflecting the levels of the risk and to locate the key risk factors (Zhang et al., 2017). Other terms used include risk events, vulnerability, etc. Risk events are the adverse activities/incidents, and risk agents are triggers or causes of the risk events (Zhang et al., 2017). Vulnerability refers to the factors causing fragility to the cold chain (Yang and Liu, 2018). Apart from risk identification and assessment, risk mitigations or actions are also proposed in some risk management models. Some risk mitigations are at the strategic level, e.g. Zhang and Han (2020) conducting risk management in medical cold chains and proposing mitigation strategies such as encouraging marketization, learning from more advanced logistic information system and developing logistic information platform using new technologies. Other strategic suggestions include changing suppliers, improving inventory systems, more personnel training, increasing knowledge sharing, improving integrity of supply chains, improving related technologies and management systems, etc (Ali and Gurd, 2020; Zhang and Han, 2020; Chen et al., 2021; Dagsuyu et al., 2021). Operational level strategies are also provided by some models that involve making banners in rooms, give penalties to fishermen who do not handle catching results properly, unloading the results of fishing on the dock, etc (Ridwan et al., 2019; Sastra et al., 2019). Ali and Gurd (2020) propose knowledge sharing risk mitigation strategies to manage the operational risks for food cold chains, and the strategies include supply chain partners share integrated knowledge, information and data regularly, jointly developing R&D, etc. Time and cost constraints are sometimes considered when conducting the risk mitigation strategies/actions (Dagsuyu et al., 2021; Ridwan et al., 2019).

There are many different types of risks in supply chain risk management, and Ho et al. (2015) summarise the risk types in SCRM studies that include supply, demand, manufacturing, financial, macro, information and transportation risks. And the supply and demand risks have received most research attention. In the field of CCRM, due to its low temperature characteristics, the concentrations of the risks differ from SCRM. Most of the CCRM studies focus on all types of risks, but some concentrate specifically on operational, quality, safety or fraud risks of the cold chain. Categorising risk according to the logistical links is common in CCRM, and some studies categorise packaging as a separate link of the cold chain (Zhang et al., 2020b, Zhang et al., 2019, Dagsuyu et al., 2021, Zheng et al., 2021). Another way to classify the cold chain risks are dividing them into external, internal and network risks which external risks refer to environmental disruptions; internal risks refer to risks that occur inside the company/provider; network risks focus on the supply chain or market perspectives. Chen et al. (2021) categorize risks of fresh cold chain into external, internal and network risks which external risks are further subcategorized into social, political, natural and market risks; Internal risks are further subcategorized into management, financial and technical risks; network risks are further subcategorized into credit, logistics and information risks. Some studies use risk levels to impact level of each risk which demonstrates a hierarchical structure with indication of the casual relationship of the risks. Zhang et al. (2019) use 9 risk levels to model the risk of food supply chain which level 1 to 4 risks include all the market related risks; level 7 risks relates to lack of information management; level 8 risks relates to poor infrastructures; level 9 risks include all the external risks. Zhao et al. (2020) construct a reliability analysis model using 3 risk levels: delivery delay, quantity and variety inadequacy and unqualified products.

The technologies used in the cold chain also impact its effectiveness and efficiency greatly. The risk management model on strawberry cold chain by Zhang et al. (2020) group all technology related risks into a separate risk category which include factors like temperature, humidity, pre-cooling time, vibration, etc. Also since no perfect cold chain is guaranteed, monitoring along the cold chain is also essential for preserving the perishability of the products and safety of the personnel. Tsang et al., (2018) construct a risk monitoring system based on Internet of Things (IoT) to management cold chain risks focusing on the occupational safety risks. Depend on each companies' supply chain and logistical strategies, many choose third-party logistic providers for their cold chain products. For instance, Singh et al. (2017) propose a third party logistics selected model considering cost, facilities, network management, etc. Apart from technology risks, risk monitoring and third party logistics, sustainability risks are also studied, mostly focusing on the

packaging safety and CO2 emissions. Zhang et al. (2020a) identify sustainability risks of the cold chain which involve packaging related risks, carbon dioxide concentration, preservations, oxygen concentration, etc. Monitoring or indicator devices (on e.g. temperature, humidity, etc.) are often incorporated in the packaging, so the passive cooling mechanisms of the packaging can maintain its temperature during loading and unloading when refrigeration is not present. Therefore the packaging used along the cold chain has significant impact on the overall cold chain performance and the overall sustainability. However, there are still many uncertainties in cold chain packaging (CCP) and need more research attention. Assessing and managing the risk of cold chain packaging is essential.

Each CCRM study has different concentrations on the cold chain, including on the technologies used in the cold chain, on the risk factors during different cold chain links, on the supply chain side, on the information and financial flow, etc. The performance metrics of the cold chain include product quality & safety, overall efficiency of the cold chain, cost, customer satisfaction, company development & image, shelf life of the products, temperature disruptions, occupational safety, etc (Zheng et al., 2021). This paper aims to include CCP risk factors from all perspectives, and the risk factors are further categorized into external, supply chain, logistic, processing/packaging, information, quality and occupational safety risks, shown in table 2. All the risk factors in each category are specified below.

Risk category	Risk factors	Sources
External	Natural disasters, climate instability, traffic instability, political instability (government regulations, strikes), emergency events (power blackouts)	(Cerchione et al., 2018)(Zhang et al., 2017)(Sastra et al., 2019)(Nakandala et al., 2017)(Zhang et al., 2020a)(Beker et al., 2015)(Khan et al., 2022)(Zhao et al., 2020)(Ali et al., 2018)(Chen et al., 2021)(Zhang et al., 2019)(Sharma and Pai, 2015)(Zhang et al., 2020b)(Bai et al., 2018)
Supply chain	Supply failure, supply delay, market/demand instability, bullwhip effect, lack of supply chain integration, unable to meet required quality, forecasting errors, economic instability (lack of investment), payment delay, high capital cost, lack of standardisation, lack of customer knowledge, reliability of third-party logistics	(Zhang and Han, 2020)(Dagsuyu et al., 2021)(Cerchione et al., 2018)(Zhang et al., 2017)(Sastra et al., 2019)(Nakandala et al., 2017)(Ali and Gurd, 2020)(Khan et al., 2022)(Wu and Hsiao, 2021)(Ridwan et al., 2019)(Zhao et al., 2020)(Sharma et al., 2021)(Chen et al., 2021)(Zhang et al., 2019)(Yang and Liu, 2018)(Bai et al., 2018)(Singh et al., 2017)
Logistics	Improper loading/unloading/handling, poor or shortage of infrastructure/facilities/equipment (vehicle breakdowns, cold room breakdown, counting mistakes, improper/failed temperature control equipment, improper/failed monitor devices, GPS broken, unqualified technology), insufficient temperature control, unavailability of power, inefficient detection equipment, cold storage capacity, improper humidity, temperature uniformity, vibration errors, human errors (counting errors, poor driving, wrong storage location)	(Zheng et al., 2021)(Zhang and Han, 2020)(Dagsuyu et al., 2021)(Cerchione et al., 2018)(Zhang et al., 2017)(Sastra et al., 2019)(Zhang et al., 2020a)(Khan et al., 2022)(Wu and Hsiao, 2021)(Ridwan et al., 2019)(Zhao et al., 2020)(Sharma et al., 2021)(Chen et al., 2021)(Zhang et al.,

		2019)(Sharma and Pai, 2015)(Yang and Liu, 2018)(Zhang et al., 2020b)(Bai et al., 2018)(Tsang et al., 2018)(Singh et al., 2017)(Mercier et al., 2017)
Information	Lack of awareness of using IT, improper traceability, insufficient supply chain information sharing, lack of product temperature information, inadequate information system infrastructure, hidden information of transmission or storage dangers	(Zheng et al., 2021)(Zheng et al., 2021)(Khan et al., 2022) (Wu and Hsiao, 2021)(Joshi et al., 2011)(Zhao et al., 2020)(Sharma et al., 2021)(Chen et al., 2021)(Zhang et al., 2019)(Sharma and Pai, 2015)(Yang and Liu, 2018)(Zhang et al., 2020b)
Quality	Contaminated with other substances, presence of bacteria, mechanical damage and integrity	(Sastra et al., 2019)(Zhang et al., 2020a)(Beker et al., 2015)(Joshi et al., 2011)(Ali et al., 2018)(Sharma and Pai, 2015)(Soon and Abdul Wahab, 2022)(Soon, 2020)(Bai et al., 2018)(Tsang et al., 2018)(Mercier et al., 2017)(Ndraha et al., 2018)
Packaging/ processing	unsuitable packaging material/effect, lack of sanitation, improper processing and packing, unsafe packaging materials, packaging lacks sustainability, damaged packaging, poor quality after processing	(Zheng et al., 2021)(Zhang and Han, 2020)(Dagsuyu et al., 2021)(Cerchione et al., 2018)(Sastra et al., 2019)(Nakandala et al., 2017)(Khan et al., 2022)(Ali et al., 2018)(Zhang et al., 2019)(Zhang et al., 2020b)(Bai et al., 2018)

Table 2 Categories of risk based on literature review on cold chain disruptions and risk management

Failure of the cold chains can lead to quality decay of the cold chain products. Quality decay of food and pharmaceutical products are usually caused by temperature disruptions, leading to detrimental damages directly on human health and safety. Many studies have identified quality related risks of the cold chain. Zhang et al. (2020a) analyse the biological risks of the food cold chain, and popular risks include 'contamination', 'presence of bacteria', etc. All studies of cold chain quality risks focus on food cold chains (Sastra et al., 2019; Zhang et al., 2020a; Beker et al., 2015; Joshi et al., 2011; Ali et al., 2018; Sharma and Pai, 2015; Soon and Abdul Wahab, 2022; Soon, 2020; Bai et al., 2018; Tsang et al., 2018; Mercier et al., 2017; Ndraha et al., 2018). Studies concerning quality decay of pharmaceutical products are very few so far. However, it is found that not all temperature disruptions lead to vaccine damages (Ren et al., 2021). Therefore it is important to study the quality decay process of pharmaceutical product to alleviate false alarms from the cold chain monitor devices and to improve the overall CC efficiency.

Packaging and processing risk concerns with the original quality of the products, pre-treatment methods, packaging, etc. In SCRM studies, packaging related risks are often grouped under the manufacturing risk category, along with other production risks. In CCRM, some studies make packaging as a separate risk category (Zheng et al.,2020 &Dagsuyu et al., 2021 & Zhang et al., 2020), and 'packaging material' and 'packaging processing' are the most popular risk factors within the category. Apart from the materials and processing of the packaging, other packaging related risk factors are also identified. For example, Dagsuyu et al. (2021) mention 'occupational accidents during packaging' and 'lack of sanitation' risks under the packaging risk category. Zhang et al. (2020) present several packaging related risk factors under the sustainability category that include 'safety of packaging materials', 'packaging reliability and strength' and 'packaging sustainability'. Khan et al. (2019) put the 'packaging issues' risk under the risk category of outsourcing.

All the packaging related risk factors are general terms. Therefore, it is important to study the risks focusing detailly on the cold chain packaging.

The cold chain packaging normally consists of two systems: the temperature control systems and the monitoring system, both contributing preventing products from cold chain disruptions. The passive cooling system is mainly based on the phase change materials (PCM) used in the packaging that can provide additional cooling especially under external, supply chain or logistical disruptions. Also the monitoring or indication devices are often attached in the packaging. Therefore, failure of the cold chain packaging can lead to serious damages and losses of the cold chain. However, packaging sometimes is not considered in the product design phase and lacks integration of the entire cold chain. Sohrabpour et al. (2016) present methods to decrease the gap between supply chain needs and the packaging of the products by three propositions, using an expanded operational life cycle and four domains of design (customer, functional, physical, process) when designing the packaging and integrating the product and packaging system with the overall supply chain process. Also since CCP concerns with all levels of packaging including the logistical level shipping containers, the shipping solution selection is also important and have great impact on the overall cold chain performance (Singh et al., 2018). The risk factors contributing to the failure of the cold chain packaging are specified in table 3, which include external, supply chain, logistical, information and shipping solution selection related risks. The sub risk factors under each risk category are further detailed.

Explanatory variable	Details
External risk	Natural disasters(earthquakes, volcano disruptions), climate instability(extreme weather), traffic instability, political instability (government regulations, strikes), other disruptions (power blackouts, pandemic)
Supply chain risk	Supply failure, supply delay, market/demand instability, lack of supply chain integration, unable to meet required quality, skill shortage, lack of investment, payment delay, high capital cost, lack of standardisation, lack of customer knowledge, uncertain reliability of third-party logistics
Logistical risk	Poor or shortage of infrastructure/facilities/equipment (vehicle breakdowns, cold room breakdown, counting mistakes, improper/failed temperature control equipment, improper/failed monitor devices, GPS broken, unqualified technology, unavailability of power), insufficient temperature control, inefficient monitoring, cold storage capacity, improper humidity control, temperature uniformity, vibration errors, human errors (counting errors, poor driving, wrong storage location, improper loading/unloading/handling, lack of sanitation, improper processing and packing)
Information risk	Lack of awareness of using IT, improper traceability, lack of product temperature information, inadequate information system infrastructure, hidden information of transmission or storage dangers
Shipping solution selection risk	Wrong quantity/capacity selection, Inappropriate phase change material selection, inadequate accessories, wrong service selection

Table 3 Details of CCP risk factors

Popular decision-making techniques used in cold chain risk management are Bayesian Network (BN), Failure mode and effect analysis (FMEA), analytical hierarchical process (AHP), fuzzy inference system (FIS), etc. The decision-making techniques used will have an impact on the way the risks are categorised. For example, risk models using AHP will have a hierarchy structure, and risk models using BN will indicate the casual relationships between the risk factors. For studies focusing on supply chain risks, the house of risk (HOR) is often used, and pareto diagrams are drawn to prioritise the risk agents. Also the method of supply chain operation system (SCOR) in these studies is also used to map out supply chain activities (Sastra et al., 2019; Ridwan et al., 2019). For studies on fraud risk management, BNs are often used as the decision-making techniques for the model and 'food fraud types' is used as the targeted/child nodes. The parent nodes include food categories, year, hazards, notified by, point of adulterants, point of detection, origin or distributed via, action, etc (Soon and Abdul Wahab, 2022; Soon, 2020). BN is selected as the decision-making method for the risk management model in this paper due to its suitability for the complex cold chain packaging system. The variables in table 3 are the independent variables of BN while cold chain packaging failure serves as the dependent variable. Figure 1 shows the cold chain packaging risk management model.

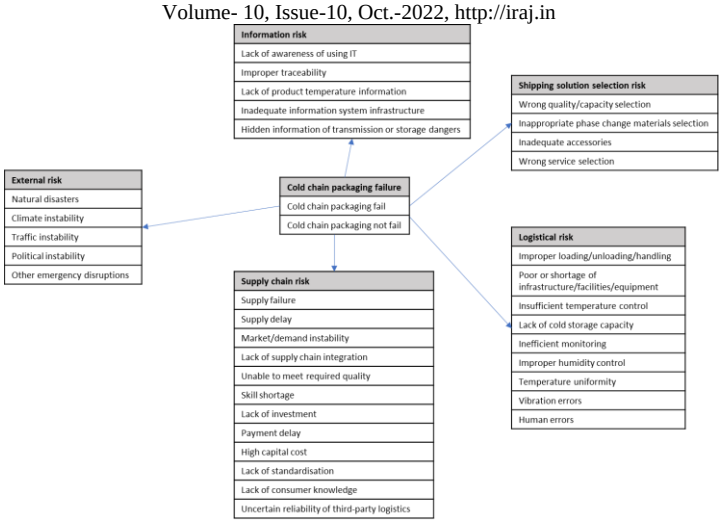

Fig. 1.Cold chain packaging risk management model based on Bayesian network

Like all other SCRM studies, cold chain is not immune to external, supply chain, logistical, information risks. Most of the studies in CCRM focus on supply chain and logistical risks. Supply chain risk refers to the unforeseen market fluctuations, e.g. sudden increase in demand, supplier failure, etc. Most common supply chain risks in the cold chain include supply delay, market instability, quality not meeting requirement, lack of integration, forecasting errors, etc. Zhao et al. (2020) studying agricultural food supply chain risk categorise supply chain related risks into 4 levels, including market fluctuations, lack of investment and high energy costs, delay in payment and imbalance of supply and demand. Zhang and Han (2022), Dagsuyu et al. (2021), Satatra et al. (2019), Nakandala et al. (2017), Ali and Gurd (2020), Khan et al. (2022), Joshi et al. (2011), Chen et al. (2021) and Zhao et al. (2020) all identify demand instability or market fluctuation risk in the cold chain. Supply relayed risks are also identified by many studies (Zhang and Han, 2020; Dagsuyu et al., 2021; Zhang et al., 2017; Nakandala et al., 2017; Khan et al., 2022, Wu and Hsiao, 2021; Chen et al., 2021). Khan et al. (2022) has found supply related risks as the major risk for the Halal food cold chain. Other supply related risk concerns with payment delay and the high capital cost (Ali and Guard, 2020; Sharma et al., 2021). Lack of integration and collaboration is another risk factor indicated by Zheng et al. (2021), Zhao et al. (2020), Sharma et al. (2021) and Zhang et al. (2019). Also lack of consumer awareness is found to be one of the key risks leading to temperature disruptions in the cold chain (Sharma et al., 2021; Sharma et al., 2021). Mercier et al. (2017) also find that domestic refrigeration is when temperature disruptions occur the most. Also, sometimes different cold chain products are transported and stored in same logistical containers due to convenience and cost considerations. Since different temperature requirements exist for different cold chain products, e.g. diary, fruit, vegetables, meat, seafood, medical and pharmaceutical products, etc., it is challenging to manage and standardize the temperature requirements. Therefore it is important to carry out related regulations that specify a standardization for cold chain temperature managements for different products. Other risks include ‘unable to meet required quality’, ‘skill shortage’, etc.

Logistical risk refers to the hazards that may occur during transportation and storage, and ‘poor loading/unloading/handling’ and ‘insufficient temperature control’ are the most common studied logistical risk factors in CCRM. Very few SCRM studies focus on this type of risk, but it has received great attention in CCRM due to the perishability nature of the cold chain products which have stricter requirements during transportation and storage. Poor or shortage of cold chain infrastructures and related devices are the most common risk factors causing cold chain logistical failures (Zheng et al., 2021; Shashi et al., 2018; Zhang et al., 2017; Sastra et al., 2019; Zhang et al., 2020a; Wu and Hsiao, 2021; Zhao et al., 2020;Sharma et al., 2021; Ridwan et al., 2019; Zhang et al., 2019). Apart from the cold chain transportation vehicles and storage rooms, monitoring of the cold chain is also important to detect any temperature disruptions. Insufficient amount of detection or monitor devices can lead to temperature abuse (Zhang et al., 2017). Moreover, lack of personnel awareness or related skills may lead to improper handling of the packaged products, causing potential risks of product quality decay (Dagsuyu et al., 2021; Zheng et al., 2021; Sharma et al., 2021; Khan et al., 2022). Many companies choose to use third party logistic for the transportation and storage of their cold chain products which can have potential risks as well. Sharma et al. (2021) identify reliability of the third party logistics as one of the inhibitors of the cold chain, and Khan et al. (2022) identify the risks of outsourcing. Singh et al. (2018) analyse how to select third-party logistics for cold chain products, considering logistic infrastructure and warehousing facilities, quality control and inspection, tracking,

customer service, etc. Since cold chains require constant temperature monitor along transportation and storage, information and data management are of equal importance. Information related risk concerns with managing the information flow of the entire cold chain. Yang and Liu (2018) model the information and financial flow of cold chain vulnerabilities in short term and long term for upstream, midstream and downstream links. Information system process related risks are identified by some studies (Zheng et al., 2021; Khan et al., 2022; Sharma et al., 2021; Sharma and Pai, 2015; Joshi et al., 2011). Lack of awareness of information technology and management systems is another risk identified (Shashi et al., 2018). Also, the product temperature data is sometimes not sufficient due to improper monitoring or lack of related devices (Wu and Hsiao, 2021). Mismatched, missed or damaged product information are also found to be present during the cold chain and have the potential of damaging the cold chain product quality (Chen et al., 2021; Zhang et al., 2020b).

Besides logistic, supply chain management and information risks, unexpected disruptive activities also have dramatic negative effects on the cold chain. Therefore it is crucial to analyse the external risks, which refer to events or activities not within control of companies and individuals that include natural disasters, pandemic, political instability and all other emergent events. Emergency related risk factors identified by Zhang et al. (2020) involve equipment maintenance capacity, emergency plan management, etc. Other natural disaster risks include earthquakes, extreme weather, etc (Nakandala et al., 2017; Sastra et al., 2019; Ali et al., 2018). Zheng et al. (2020) have identified 'extreme weather' as the riskiest event of the cold chain. Besides natural disasters, other unforeseen risks also have great impact on the cold chain. Beker et al. (2016) have found 'intentionally contamination' risk in food cold chain, and the food fraud risks are analysed by a few studies (Soon, 2020; Soon et al., 2021). Political instability such as government regulations, labor strikes also affect the overall effectiveness of the cold chain (Shashi et al., 2018; Nakandala et al., 2017; Khan et al., 2022; Zhao et al., 2020; Chen et al., 2021; Sharma and Pai, 2015). Also, unavailability of power or power outage may lead to vehicle and cold room breakdowns, damaging the temperature control of the cold chain (Shashi et al., 2018; Sastra et al., 2019; Zhang et al., 2019).

Regarding the shipping solution selection related risks, since there are many cold chain shipping solutions with various temperature ranges, sizes, capacities and other services available, inappropriate selections may lead to cold chain packaging failure. The selection of the phase change material is essential since it regulates the temperature range of the cold chain packaging. For example, deep frozen cold chain shipping solutions especially designed for some vaccines are provided by companies (Chen et al., n.d.). For the logistical shipping containers, besides the parcel and the pallet, accessories, e.g. pallet covers, vacuum insulation, etc., are often available to provide additional temperature maintaining or physical protection (Cold Chain Technologies, 2022a). Choosing suitable accessories affect the performance of the packaging. Apart from PCM and accessory selections, choosing suitable the size and capacity can minimize waste and increase the overall cold chain sustainability. Also, add-on services are sometimes provided with the shipping containers. For example, Cold Chain Technologies, a cold chain shipping solution company, provide services such as reusable/return service programs, thermal modelling, thermal packaging design, logistic management assistance, training sessions, etc (Cold Chain Technologies, 2022b). Selecting appropriate services that fits the overall cold chain goal is important for the cold chain packaging performance and effectiveness.

IV. CONCLUSION

Failure of cold chain packaging has great impact on the cold chain performance and is one of the main risk factors contributing to cold chain disruptions. This paper reviews the literature on cold chain disruptions and risk management to study the role of packaging in the cold chain and identify risk factors that may potentially cause packaging failure. A cold chain packaging risk management model is then constructed and assessed using the Bayesian Network. The risk factors contributing to the cold chain packaging failure are categorised into external, supply chain, logistical, information and shipping solution selection related risks. External, supply chain, logistical and information risks are similar to the risk factors causing cold chain disruptions, while the selection of the shipping solutions are the unique risk factor concerning the cold chain packaging. Inappropriate phase change material selection, capacity and quantity, services and other accessories can lead to cold chain packaging failures. This paper contributes to the literature by providing new theoretical knowledge in the field of cold chain packaging and can be used as guidelines for industry practitioners. In the future, each risk category can be further analysed in detail, and the conditional probabilities can be calculated in the risk management model. Also more research attention should focus on studying the pharmaceutical cold chains since it has received limited amount of attention so far.

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