科技部補助專題研究計畫成果報告
期末報告

以回復力觀點評估我國低溫物流產業於全球冷鏈布局之最佳策略

計 畫 類 別 ： 個別型計畫
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執 行 單 位 ： 致理技術學院行銷與流通管理系

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報 告 附 件 ： 出席國際會議研究心得報告及發表論文

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中 華 民 國 104 年 08 月 13 日

中文摘要： 隨著運輸技術的發展，廠商欲將產品外銷至其他國家以爭取最大獲利須仰賴跨國物流系統進行產品的運輸與配送，若物流系統發生意外事故而導致供貨中斷容易對業者造成巨大的損失，且供應鏈具有連鎖反應之特性，各業者對於意外事故的應變能力會影響供應鏈上其他業者的獲利，物流合作夥伴是否具備良好的事故回復力遂成為各業者的重要考慮因素。本研究擬以完全資訊的Stackelberg動態賽局概念建構跨國物流回復力投資動態賽局模式，參賽者依照決策優先順序分別為供應商、本國物流服務商、他國物流服務商，本研究擬定各參賽者在考慮他國端可能發生意外事故的情境下的回復力投資成本函數，並且假設各參賽者均以成本極小化為目標進行決策，藉由分析各參數對賽局均衡結果的影響情形以探討各參賽者在不同情境下的投資策略，最後以我國水果產品外銷至日本與中國大陸的案例進行個案探討。分析結果顯示供應商在外銷產品數量越大、事故賠償規則越嚴苛、物流服務商的投資效果越良好、產品內外銷利潤差距越小的情況下，供應商均衡結果傾向降低物流費用支出以節省成本；物流服務商在產品數量越大、每單位貨品物流費用越高、事故賠償規則越嚴苛、他國端意外事故機率越高的情境下，物流服務商均衡結果傾向增加回復力投資，此外本國與他國物流服務商的回復力投資的效果的大小與交互關係是影響物流服務商投資均衡結果的重要決定因素。

中文關鍵詞： 回復力、跨國物流、Stackelberg賽局

英文摘要： With the development of the transportation technology, manufacturers need the transnational logistics systems to export products for maximizing the profit. If the accident happened, the disruption of supply chain is likely to cause huge losses. The coping and response abilities of supply chain members impact the benefits of other members due to the interdependency. To minimize the losses, suppliers may consider whether their logistics partners have great resilience. This study applies the Stackelberg game with perfect information to construct a dynamic game and analyze the resilience investment strategies of companies. Players include the suppliers, domestic logistics operator, along with overseas logistics operator. This study constructs the resilience investment cost function of each player considering the logistics accident which happens in the foreign site. This study assumed that minimizing the total cost is the goal for each player in decision making and applied the backward induction to assess the equilibrium. A low-temperature supply chain of fruit from Taiwan to Japan and China was employed as the empirical case. The results show that the larger volume of products, the higher logistics expenses paid by the supplier, the more stringent accident compensation rules, and the higher risk of accident in the foreign site, make logistics service providers increase their resilience investment to prevent additional costs caused by supply chain failure.

英文關鍵詞： Resilience, Transnational supply chain, Stackelberg game

科技部補助專題研究計畫成果報告

（□期中進度報告/■期末報告）

以回復力觀點評估我國低溫物流產業於全球冷鏈布局之最佳策略

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計畫主持人：謝承憲
共同主持人：
計畫參與人員：謝孟樺、傅少君、許雅斐、李玠佑

本計畫除繳交成果報告外，另含下列出國報告，共 1 份：
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中　華　民　國　104　年　7　月 31　日

摘要

隨著運輸技術的發展，廠商欲將產品外銷至其他國家以爭取最大獲利須仰賴跨國物流系統進行產品的運輸與配送，若物流系統發生意外事故而導致供貨中斷容易對業者造成巨大的損失，且供應鏈具有連鎖反應之特性，各業者對於意外事故的應變能力會影響供應鏈上其他業者的獲利，物流合作夥伴是否具備良好的事故回復力遂成為各業者的重要考慮因素。本研究擬以完全資訊的 Stackelberg 動態賽局概念建構跨國物流回復力投資動態賽局模式，參賽者依照決策優先順序分別為供應商、本國物流服務商、他國物流服務商，本研究擬定各參賽者在考慮他國端可能發生意外事故的情境下的回復力投資成本函數，並且假設各參賽者均以成本極小化為目標進行決策，藉由分析各參數對賽局均衡結果的影響情形以探討各參賽者在不同情境下的投資策略，最後以我國水果產品外銷至日本與中國大陸的案例進行個案探討。分析結果顯示供應商在外銷產品數量越大、事故賠償規則越嚴苛、物流服務商的投資效果越良好、產品內外銷利潤差距越小的情況下，供應商均衡結果傾向降低物流費用支出以節省成本；物流服務商在產品數量越大、每單位貨品物流費用越高、事故賠償規則越嚴苛、他國端意外事故機率越高的情境下，物流服務商均衡結果傾向增加回復力投資，此外本國與他國物流服務商的回復力投資的效果的大小與交互關係是影響物流服務商投資均衡結果的重要決定因素。

關鍵字：回復力、跨國物流、Stackelberg 賽局

Abstract

With the development of the transportation technology, manufacturers need the transnational logistics systems to export products for maximizing the profit. If the accident happened, the disruption of supply chain is likely to cause huge losses. The coping and response abilities of supply chain members impact the benefits of other members due to the interdependency. To minimize the losses, suppliers may consider whether their logistics partners have great resilience. This study applies the Stackelberg game with perfect information to construct a dynamic game and analyze the resilience investment strategies of companies. Players include the suppliers, domestic logistics operator, along with overseas logistics operator. This study constructs the resilience investment cost function of each player considering the logistics accident which happens in the foreign site. This study assumed that minimizing the total cost is the goal for each player in decision making and applied the backward induction to assess the equilibrium. A low-temperature supply chain of fruit from Taiwan to Japan and China was employed as the empirical case. The results show that the larger volume of products, the higher logistics expenses paid by the supplier, the more stringent accident compensation rules, and the higher risk of accident in the foreign site, make logistics service providers increase their resilience investment to prevent additional costs caused by supply chain failure.

Keywords: Resilience, Transnational supply chain, Stackelberg game

INTRODUCTION

Facing industrial globalization and rapidly developing information technology, conventional business models can no longer adapt to the quickly changing environment. In response, businesses utilize their advantages and resource integration to gradually form supply chain systems characterized by labor specialization. However, customer demands are becoming increasingly diverse as product lifecycles gradually decrease. Businesses rely on large supply systems and continual research, development, and innovation to elevate their overall market position and ensure a competitive advantage. Increasingly intense market competition has forced organization decision makers to attempt various methods for improving profitability. Common methods include cost reduction, quality improvement, just-in-time (JIT) management, high quality after-sales services, and diversified management. Since the introduction of integrated supply chain concepts, numerous companies have transitioned from single-business management models to overall supply chain management (SCM) models to improve profits. SCM encompasses the planning and management involved in procurement, production, and processing activities as well as all logistics management activities. The primary function of SCM is to integrate the internal resources of a business with cross-organizational supply and demand. SCM also entails coordination and collaboration with channel partners, which includes suppliers, intermediaries, third-party logistics (3PL) services providers, customers, and other stakeholders.

Supply chain vulnerability and the associated operational and financial risks represent the most pressing concern facing firms that compete in global markets nowadays because tiny events might dramatically disrupt operations of supply chain (*1*). Such disruptions spread throughout the entire supply chain, negatively affecting supply chain members and hindering order fulfillment. Lean supply chain model based on the perspective of competition may produce adverse effects in crisis situations. If companies are fragile and unable to recover promptly from such adverse effects, the entire supply chain may lose irrecoverable competitiveness. Therefore, the coping capacities and resilience of supply chain become a major issue in recent studies (*2, 3*).

Businesses have developed lean concepts that emphasize JIT management to improve their profitability in extremely competitive markets. However, these concepts have hindered the flexibility and adaptability of supply chains in reallocating resources when responding to crises or changes in the external environment. Instead, these concepts may create substantial losses for businesses if these problems are not controlled and overcome (*4*). Moreover, the occurrence of unexpected adverse events causes chain reactions. Events that hinder operations in one section of the chain may trigger a reaction throughout the entire supply chain, consequently causing chain-wide collapse. Disruptions within supply chains are generally instantaneous and without warning. Following the globalization of supply chains, the structures have become transnational, magnifying the repercussions of broken supply chains (*5*). Due to the extended scope of supply chain, rapid economic growth, globalization, and social changes, supply chain members have faced significantly increased uncertainties. Du et al. proposed a methodology to scan vulnerability of logistics transportation networks considering the difference caused by component degradation and probability of component degradation under seismic disaster (*6*).

However, most studies on resilience of supply chain and logistics have focused on the assessment of key factors influencing the resilience or the establishment of organizational structures and recovery mechanisms with favorable resilience. Subsequently, few studies have examined resilience improvement strategies for transnational supply chain members and their investment. Suppliers market their goods to other countries to improve profitability and thus require a comprehensive transnational logistics system for transportation and distribution. System disruptions caused by unexpected adverse events may result in substantial losses for the supplier and the logistics provider. To reduce the financial loss caused by unexpected adverse events, suppliers and their transnational logistics partners invest in relevant mechanisms for improving the resilience. Transnational supply chain members are required to share the risk and loss associated with disruptions. Thus, the resilience investment strategies adopted by businesses are affected by external factors and the investment strategies of their partner businesses. The present study aimed to examine the investment strategies that suppliers, domestic 3PL operators, and overseas 3PL operators implement to improve their resilience against potential overseas incidents. Game theory was adopted in the present study to establish a dynamic game model for the resilience investments of transnational logistics providers. Using a low-temperature supply chain (cold chain) as an empirical case, the researchers analyzed the equilibrium strategies of the key players in transnational logistics systems and the management implications of these strategies.

SUPPLY CHAIN VULNERABILITY AND RESILIENCE

Supply chain vulnerability represents an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain (*7*). Moreover, supply chain vulnerability indicates a susceptibility and sensitivity to threats and hazards that substantially reduce its ability to maintain its intended function referring to a function of certain supply chain characteristics and the losses to a given supply chain disruption (*8*).

Wanger and Neshat developed the quantitative supply chain vulnerability index considering the relationships among operation elements and impact factors using Graph theory (*9*). The vulnerability factors and their importance to a supply chain vary because of spatiotemporal and enterprise characteristics. Supply chain vulnerability can be calculated by a function of consequences and the probability of natural hazards, accidents, and intentional disruptions. Operators should concern in the highest vulnerability events with high probability along with severe consequences, for example, expelled partnership with critical supply chain members, conflicts between labor and capital, and insufficient quality control (*2*). The categories of supply chain vulnerability include demand side involving delay of delivery, interruption of distribution network, and uncertainty (*8, 9, 10*), supply side consisting of production capacity, quality, human resource, sensitivity, and resilience (*8, 11*), as well as structure of supply chain comprised of reliability, connectivity, lean storage, and agile operations (*10, 11*).

Chen et al. contributed a method for quantifying and optimizing resilience strategies based on integrated resource assignment concepts during the post-disruption phase considering a set of optimal actions from resilient strategies, including selecting alternative routes, switching shipping modes, renting other carriers' capacities, re-allocating local trucks, and prioritizing the order of shipments due to limited capacities (*12*). A generalized cost of logistics transport network considering both time value and transport cost represents the criterion used to evaluate the facilities vulnerability, in which the prior protected facilities are determined based on the risk of component failure and the structure of the network (*13*).

Businesses generally employ strategies for robustness within their supply chains to resolve problems regarding demand management. These strategies also enable businesses to effectively deploy their contingency plans when disruptions occur, thus increasing the resilience of the supply chain (*3*). Resilience originates from the theoretical basis of social psychology and is closely associated with ecological and social vulnerability, psychology and policies of disaster reconstruction, and risk management that are constantly faced within creasing threats (*5*). Businesses are frequently subject to environmental uncertainties and must therefore develop resilience to manage severe contingencies. Resilience entails the backup, absorption, and recovery abilities required to mitigate the impact of risk, manifesting cost-effectiveness and enables supply chains to recover rapidly from various functional failures (*14*).

Wal-Mart was able to respond rapidly to Hurricane Katrina because of the appropriate integration of its equipment, stores, and logistics centers to its data management center, suggesting that supply chain resilience facilitates businesses in achieving operations through resource redistribution (*15*). The intervention measures for improving resilience includes implementing flexible sourcing, demand-oriented management, and contingent stock, as well as creating total supply chain visibility and backing up procedures and knowledge (*16*). Improving the adaptability and preparation in face of unexpected disruptions is necessary for reducing risks; supply chains should endeavor to maintain control and continuity of business and system structures and functions to achieve uninterrupted operations in recovering from disruptions and resuming normal operations (*5*).

Resilient supply chains preparing for potentially risky events in advance are able to respond effectively to these events once they occur, and rapidly recover from collapse by improving the dimensions of flexibility, adaptability, collaboration, visibility, and sustainability (*17*). Resilient systems refers to those capable of absorbing impact, reorganizing following the impact to maintain functionality, adapting to hazards, dealing with hazards accordingly, and rapidly recovering following disruptions. The resilience can be improved by reducing vulnerability and improving adaptability. Generally, systems manifest favorable resilience when they are adaptable and less vulnerable (*18*).

GAME THEORY

Game theory is the study of mathematical models to explore the equilibrium in behaviors of intelligent rational decision-makers and their interactions and comprehensively used in economics, political science, psychology, and biology fields. The players represent decision makers in game theory whose behaviors are guided by individualism and rationality. There are two fundamental assumptions in game theory. First, players consider maximized utilization and are able to assess the outcomes according to their own decisions. Secondly, the behavior and decision of each player involves mutual interdependencies among other players. Therefore, a game consists of two or more players according to mentioned assumptions, who adopt a set of strategies based on the maximized payoff considering moves of other players (*19*).

Games can be classified based on interactions, move sequencing along with information accessibility of players. From the interaction perspective, the collusive, cooperative and competitive interactions of players divide games into cooperative and non-cooperative game. Dynamic games denote that player makes a decision at every decision point considering other player's move sequencing, and his payoffs for all possible game outcomes, whereas each player chooses his action without knowledge of the actions chosen by other players in simultaneous games. Based on information accessibility, complete information game expresses that every player understands the knowledge, payoffs and strategies available to other players, whereas players may or may not know some information, e.g. types, strategies, payoffs or preferences, about other participants in incomplete information game. A dynamic complete information game is utilized in this study.

A game tree, an extensive form, has been employed to illustrate dynamic games. A game tree comprising decision trees of players providing information about all possible strategies of players as well as probable outcomes in the game through nodes and branches. Terminal nodes indicating the payoffs of every player are connected with initial node by branches. A sub-game represents any singleton before terminal node along with its sequencing branches, information, decision point and payoffs. Players in dynamic game possessing interdependencies have to look forward and reason back for deciding optimal move at each singleton. The optimal strategy set of posterior player developed according to the best strategy of former player refer to the best response function to former player. Backward induction, the process of reasoning backwards in time, from all possible terminal nodes to determine a sequence of optimal actions is utilized to analyze a game tree. The equilibrium of dynamic complete information game solved by backward induction is named sub-game perfect Nash equilibrium (SPNE).

The effects of the channel authority distribution were elucidated more clearly without restricting the boundaries of the manufacturers and retailers and that overall profits were maximized when two members cooperated with each other based on a game analysis (*20*). An optimal strategy for yield management regarding competitive agricultural products was determined by coexisting conditions of industries and evaluated the model parameters of the equilibrium game to analyze the feasibility and operability of agricultural supply chain (*21*).A game model was employed to calculated the risk mitigation costs of the various vendors by summing the vendors' risk mitigation investments with their expected losses from unexpected adverse events. Subsequently, the expected losses caused by the unexpected adverse events were calculated by multiplying the probability of an unexpected adverse event with the loss incurred by the vendor. The probability of an unexpected adverse event was adversely proportional to the amount invested by the vendor for risk mitigation (*22*).

Moreover, Yue and You set one manufacturer as the game leader and several suppliers and dealers as the game followers to observe the outcome of a single leader–multiple follower game based on the Stackelberg competition model. In this game, the objective of the players was to maximize profits. Strategies were characterized into raw material shipment, factory location, raw material acquisition, yield, logistics costs, and sales. The researchers further assumed that vendors were able to sell surplus goods that could not be distributed successfully to downstream venders because of unexpected adverse events or to an external market at a premium lower than that of the primary market because of overproduction (*23*).

MODEL CONSTRUCTION

This study adopted the Stackelberg dynamic game framework. The players comprised suppliers, domestic logistics operators, and overseas logistics operators. Suppliers were vendors endeavoring to market their goods in other countries. The researchers hypothesized that suppliers possessed a substantial quantity of goods for export and therefore had a considerable advantage when negotiating rates with logistics providers. Domestic logistics operators referred to the domestic 3PL operators that directly undertake international shipping orders from suppliers, including the domestic freight and warehousing vendors that are responsible for providing domestic land transport, harbor warehousing and collection, transnational maritime transport, and customs and quarantine services. Based on the supply chain ideology of collaborative planning, forecasting, and replenishment (CPFR), the researchers regarded the various domestic 3PL of transnational logistic systems as a single player and hypothesized that these providers possessed a centralized window for communicating with suppliers and overseas logistics providers. Similarly, overseas logistics providers referred to the local 3PL operator in foreign site as a single player.

To understand the willingness to pay for global logistics of the supplier, and resilience investment strategies of both domestic and overseas 3PL operators, this study formulates a three-stage dynamic complete information game illustrated as Figure 1, indicating that supplier (S) locates at the initial node acting the transnational logistics costs (β). The second actor, domestic 3PL operator (A), determines the optimal resilience investment strategy at C_A as the best response to the supplier's willingness to pay for transnational logistics costs. According to the investment strategy, overseas 3PL operator (B) invests at C_B to improve the resilience of its local logistics service for preventing the probability of broken chain and the following compensation. After formulating utility functions of players, backward induction is employed to achieve SPNE in which the generalized solutions are discuss through empirical cases.

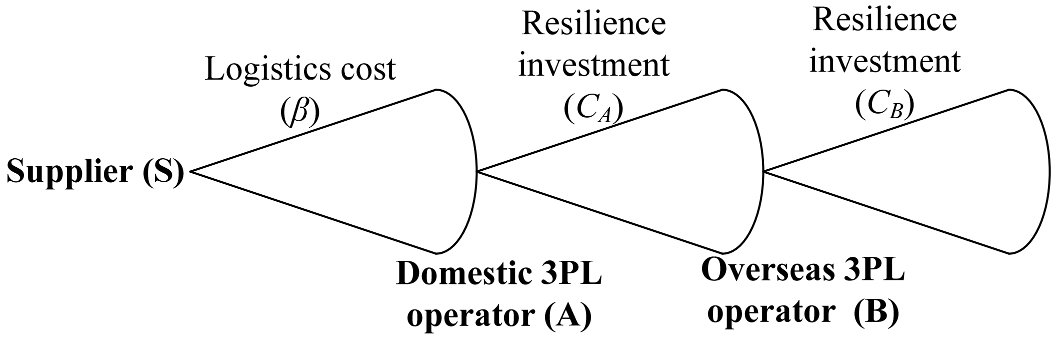

FIGURE 1 Framework of game tree.

All players aimed to minimize costs. The researchers regarded the function form of resilience investment cost, the quantities of products unable to distribute, and expected compensation as total cost of both 3PL operators according to Bakshi and Kleindorfer (*22*). To explore the occurrence of overseas disruptions in transnational logistics systems, it was hypothesized that the suppliers could provide an adequate and stable stream of goods. Furthermore, the researchers assumed that suppliers are able to sell non-exported goods caused by chain failure in the domestic market at a reduced premium during disruptions. In addition, in the occurrence of an unexpected adverse event, the domestic 3PL operator would be required to pay a percentage of the logistics cost (based on the predetermined logistics fees) as compensation to suppliers. The researchers only considered losses directly attributable to unexpected adverse events, including damage to goods and equipment, supply and delivery disruptions, and compensation.

Equation 1 indicates the objective of suppliers, in which these costs comprised decision-varying logistics costs and expected losses because of unexpected adverse events. For the occurrence rate of unexpected adverse events, the researchers considered only external factors, including natural disasters, society, and politics. The quantity of goods that could not be exported as a result of logistics disruptions was correlated with the resilience investment of the overseas logistics providers (Equation 2), and compensation was correlated with freight costs (Equation 3).

$$\underset{\beta}{Min}\, V_s = \mathrm{Q}\beta + \mathrm{Pr} \times [(\sigma - \delta) \times \Delta Q_s - \tau] \tag{1}$$

where Q represents overall export volume, β represents the unit logistics cost of the goods, Pr represents occurrence rate for unexpected adverse events affecting the overseas 3PL operator (0<Pr<1), σ represents the profit of overseas selling units from sale of goods, δ represents the profit of domestics selling units from sale of goods, ΔQ_s represents the quantity of goods that could not be exported as because of logistics disruptions, and τ represents the compensation payable by the domestic 3PL operator.

$$\Delta Q_s = \mathrm{Q} \times e^{-aC_A - bC_B} \tag{2}$$

where *a* and *b* represents the impact parameters from resilience investment of domestic and overseas 3PL operators, respectively, to the product volume unable to export caused by chain failure in foreign site.

$$\tau = \Delta Q_s \times \alpha\beta \tag{3}$$

where α represents the compensation–freight cost ratio (0< α <1).

To prevent the occurrence of illogical circumstances in which the increased severity of unexpected adverse events benefited the supplier, the researchers set $\sigma > \alpha\beta + \delta$. The domestic and overseas 3PL operators also aimed to minimize costs (Equations 4 and 5). These costs comprised resilience investments reliant on decision-making factors and expected losses from unexpected adverse events. The supply disruption losses of the overseas 3PL operator were correlated with its resilience investment (Equation 6).

$$\underset{\mathrm{C_A}}{Min}\ V_{\mathrm{A}} = \mathrm{C_A} + \mathrm{Pr} \times [\Delta Q_s \times \gamma\beta + \varphi_{\mathrm{A}} + \tau] \tag{4}$$

where γ represents the domestic 3PL operator's allocated portion of the logistics fees paid by the supplier (0< γ <1) and φ_{A} represents the losses (in terms of goods and equipment) incurred by the domestic 3PL operator because of disruptions.

$$\underset{\mathrm{C_B}}{Min}\ V_{\mathrm{B}} = \mathrm{C_B} + \mathrm{Pr} \times [\Delta Q_{\mathrm{B}} \times (1-\gamma)\beta + \varphi_{\mathrm{B}}] \tag{5}$$

where ΔQ_{B} represents the supply disruption losses of the overseas 3PL operator caused by unexpected adverse events and φ_{B} represents the losses (in terms of goods and equipment) incurred by the overseas 3PL operator because of disruptions.

$$\Delta Q_{\mathrm{B}} = \mathrm{Q} \times e^{-cC_B} \tag{6}$$

where *c* represents domestic performance of the overseas 3PL operator's resilience investment.

RESULTS AND DISCUSSION

According to backward induction, this study firstly analyzes the optimized resilience investment strategies of actor at terminal node, i.e. overseas 3PL operator, to keep the lowest cost considering the alternatives of leading actors. The analyzed best response function is substituted into utility function of domestic 3PL operator in which the optimized resilience investment would be determined. Finally, the best response in resilience investment of domestic 3PL operator is substituted into supplier's utility function to solve the optimized transnational logistics costs.

Results in SPNE

The SPNE solved by backward induction represents a generalized solution rather than specific solution analyzed based on behavior or data of each individual via questionnaires. Accordingly, the optimized transnational logistics cost of the supplier is illustrated in Equation 7.

$$\beta^* = \frac{\sqrt{a\text{Q}(\gamma+\alpha)(\sigma-\delta)}}{a\text{Q}(\gamma+\alpha)} \quad (7)$$

Based on the assumption mentioned above, the suppliers could sell surplus goods that were not successfully shipped overseas in the domestic market at a reduced premium ($\sigma > \delta$). Thus, $\beta > 0$.The results obtained from Equation 7 revealed that the supplier's logistics costs were positively correlated with overseas sales profits. Subsequently, the supplier manifested an increased willingness to pay higher logistic costs with an increased profit margin between domestic and overseas sales. However, increased overseas sales and stringency in supplier–logistics provider compensation regulations elevated the loss incurred by 3PL operator during supply chain failure, and the suppliers' equilibrium results shifted further toward reducing logistics spending to save costs. Moreover, the 3PL operator exhibited increased resilience investment willingness, and the suppliers' equilibrium results further trended toward reducing logistics spending to save costs when the logistics providers were allocated an increased proportion of the logistics costs or when the resilience investments of domestic 3PL operator manifested increased performance. The equilibrium results for the suppliers' logistics costs suggested that the occurrence rate of unexpected adverse events in overseas supply chains fails to affect the suppliers' logistics spending policies directly.

The results obtained from Equation 8 showed that the equilibrium results of the domestic 3PL operator shifted further toward increasing resilience investments in situations with increased logistics costs per unit of goods paid by the supplier, quantity of goods, stringency in the supplier–logistics provider compensation regulations, and the proportion of the logistics costs received. The rate of supply chain failure was elevated when the other country was prone to natural disasters or exhibited inadequate development of logistics technology. In addition, the equilibrium of the domestic 3PL operator shifted further toward increasing resilience investments in situations with increased overseas sales profits, which elevated suppliers' willingness to increase logistics costs.

$$\text{C}_\text{A}^* = \frac{b\times\ln\left(\dfrac{1}{\text{Pr}\times Q\beta(1-\gamma)c}\right) - c\times\ln\left(\dfrac{1}{\text{Pr}\times Q\beta(\gamma+\alpha)a}\right)}{ac} \quad (8)$$

$$= \frac{b\times\ln\left(\dfrac{(\gamma+\alpha)a}{\text{Pr}\times\sqrt{a\text{Q}(\gamma+\alpha)(\sigma-\delta)}\times(1-\gamma)c}\right) - c\times\ln\left(\dfrac{1}{\text{Pr}\times\sqrt{a\text{Q}(\gamma+\alpha)(\sigma-\delta)}}\right)}{ac}$$

The sizes of parameters *a, b,* and *c* were influenced by the logistic equipment and technology development of the two countries. Increased development of domestic logistic technology yielded a greater a value, and increased development of overseas logistic technology yielded greater *b* and *c* values, with denoting that the effect of the resilience investments of overseas 3PL operator on accident losses was far greater than the its effect on improving the resilience of the domestic 3PL operator. Subsequently, the domestic 3PL operator manifested decreased resilience investment willingness and increased domestic sales profits. The magnitude of the effect of logistics costs paid by the supplier, export quantity, and the disruption occurrence rate on the equilibrium of domestic 3PL operator's resilience investments become greater as the margin between the b and c values increased. Moreover, the magnitude of the effect of the compensation–logistics cost ratio and the proportion of the supplier's logistics costs allocated to the domestic 3PL operator on the equilibrium of domestic 3PL operator's resilience investments became greater as the technical development of the domestic 3PL operator increased.

The results obtained from Equation 9 showed that the equilibrium results of overseas 3PL operator shifted further toward increasing resilience investments in situations when logistics costs per unit of goods paid by the supplier and quantity of goods are both increased. Furthermore, when the supplier–logistics provider compensation regulations were relatively more stringent or if the domestic 3PL operator were allocated a larger proportion of the logistics costs, domestic 3PL operator were more likely to cooperate with the overseas 3PL operator with favorable resilience, thereby elevating the willingness of the overseas 3PL operator to increase their resilience investments.

$$\mathrm{C}_{\mathrm{B}}^{*} = \frac{-\ln\left(\dfrac{1}{\Pr\times Q\beta(1-\gamma)c}\right)}{c} \tag{9}$$

$$= \frac{-\ln\left(\dfrac{(\gamma+\alpha)a}{\Pr\times\sqrt{\mathrm{aQ}(\gamma+\alpha)(\sigma-\delta)}\times(1-\gamma)c}\right)}{c}$$

Similar to the results of the domestic3PL operator, the suppliers' willingness to increase logistics costs was demonstrated when profit margin between goods sold domestically and internationally was increased, with the supplier's logistics expense per unit of goods achieving a positive correlation with the resilience investments of the overseas 3PL operator. Therefore, the equilibrium results of the overseas 3PL operator trended more toward increasing resilience investments. This was also true for when the rate of supply chain failure was also elevated as a result of the other country being prone to natural disasters or manifested inadequate development of logistics technology.

Empirical Discussions

The present study conducted a case study on the export of fresh, chilled, and frozen fruits from Taiwan to China and Japan to elucidate resilience investment strategies of suppliers and transnational 3PL operators. The Taiwan Provincial Fruit Marketing Cooperative (TPFMC) was selected as the supplier. This cooperative is collectively managed by numerous Taiwanese farmer groups and is the largest agriculture-based cooperative in Taiwan. Table 1 shows a comparative overview of the low-temperature logistics (cold chain) of Japan and China and of Taiwan's fruit export situation.

In the global markets, the competitiveness of cold chain enterprise is impacted by the fluctuations in prices of products, the inefficiency in clearing customs and quarantine, as well as difficulty in controlling qualities. Especially, the insufficient infrastructures and technology of foreign cold chain members (e.g. unbalance between supply and demand caused by unsymmetrical information, along with the absence from integrated monitoring mechanism) increase the risk of broken cold chain. Cold chain is a subset of the total supply chain involving the production, storage and distribution of products that require temperature control for retaining their critical characteristics and associated value. Moreover, cold chain involves the transportation of temperature sensitive products in the supply chain through thermal and refrigerated packaging methods, along with logistics planning to protect the integrity of the shipments.

TABLE 1 Comparison of the Fruit Exports from Taiwan to China and Japan

Items	To Japan	To China	Note
2015 Annual Export Volume	Annual export volume for fresh, chilled, and frozen fruit is 1,871 metric tons, valued at US$3.054 million.	Annual export volume for fresh, chilled, and frozen fruit is 26,060 metric tons, valued at US$39.893 million.	$Q_J < Q_C$
Primary Exports	Banana, mango, pineapple	Mango, citrus, pineapple, orange, grapefruit, betelnut	
Domestic Unit Profit	Approximately US$1.63 per metric kilogram	Approximately US$1.53 per metric kilogram	$\delta_J > \delta_C$
Overview of Low-Temperature Logistics	Cold chain coverage is approximately 80%–90%. Mature cold chain technologies.	Cold chain coverage is approximately 10%. Cold chain technologies are in the developmental stage. Annual goods lost because of improper temperature control amounts to US$50 billion.	

The exportation of goods by Taiwanese fruit suppliers to China fosters developing into an economy of scale, in which incentives are provided to cross-strait 3PL operators to invest in supply chain resilience and TPFMC's logistics costs for exports to China can be lowered to minimize cost. Although the domestic unit prices for fruit exported from Taiwan to Japan are slightly higher than the prices for that to China, the quantity of fruit export from Taiwan to Japan has gradually decreased each year. The limited quantity of exports to Japan makes promoting resilience investments to 3PL operators extremely difficult. Thus, to minimize costs for suppliers, the TPFMC should pay higher logistics costs to 3PL operators to improve the resilience of fruit cold chain from Taiwan to Japan. The TPFMC can increase logistics budges or export goods to encourage domestic3PL operator to reinvest in supply chain resilience. Under identical circumstances, these approaches create a greater incentive for domestic 3PL operator to reinvest in the resilience of large-scale rather than small-scale disaster prevention. The TPFMC can alternatively employ the companion regulations to induce overseas 3PL operator to reinvest in supply chain resilience. Under identical circumstances, these approaches create a greater incentive for Chinese 3PL operators than for Japanese 3PL operators.

Disruptions often occur in Chinese fruit-export logistics systems because of excessive volume and cold-chain failure; thus, Taiwanese 3PL operators tend to invest more funds in improving resilience against overseas supply chain failures. Moreover, Chinese 3PL operators tend to invest more in improving resilience against domestic supply chain failures because of large export volumes from Taiwanese fruit suppliers to China and the frequent occurrence of disruptions in Chinese logistics systems caused by natural or human-made disasters. By contrast, the volume of fruit exports from Taiwan to Japan is comparatively small, with disruptions being less likely to occur. Consequently, although profits are slightly higher for exports to Japan than to China, Taiwanese 3PL operators tend to invest less funds for preventing disruptions in Japan, whereas Japanese 3PL operators tend to invest less in domestic disruption prevention. If the TPFMC increased its logistics budges and export volumes, or demands for greater compensation in its compensation agreements, then both domestic and overseas 3PL operators would increase their resilience investments in response.

CONCLUSION

The analytic findings indicated that the suppliers' equilibrium results trended towards reducing logistics spending to lower costs associated when export volume is increased, accident compensation regulations are stringent, and performance in logistics providers' resilience investments is favorable. When the profit margin between domestic and international sales was considerable, the suppliers' equilibrium results trended toward increasing logistics spending to ensure the stability of the logistics system, thereby improving profitability. Moreover, as favorable effects of the domestic logistics providers' resilience investments on reducing the suppliers' accident losses increased, the influence of the various parameters on the equilibrium results of the suppliers' logistics spending decreased.

The domestic 3PL operator's equilibrium results shifted further toward increasing resilience investments to reduce accident losses in situations with increased logistics profit per unit, product volume, stringency of the compensation regulations established by suppliers, suppliers export profits, or occurrences of unexpected adverse events overseas. In addition, a parametric analysis of the equilibrium solution revealed that the reduction magnitude and interaction that the resilience investments of both domestic and overseas 3PL operators have on reducing accident losses determine the influence that the various parameters have on the equilibrium results of the domestic 3PL operator's resilience investments. Overseas 3PL operator's equilibrium results shifted further toward increasing resilience investments to reduce accident losses in situations with increased logistics profit per unit, product volume, suppliers' profit margin between domestic and international sales, or occurrences of unexpected adverse events overseas. Subsequently, because the overseas 3PL operator was influenced by the domestic 3PL operator in the present game structure, increased stringency in the compensation regulations with the supplier and the domestic 3PL operator or increased logistics costs allocated to domestic 3PL operator caused the equilibrium results.

Future research could determine the effects of resilience investments for various providers in the form of function equations. The present study adopted a simplistic approach to characterize the key transnational players: suppliers, domestic 3PL operator, and overseas 3PL operator. However, a diverse number of operators are involved in transnational logistics. The present study suggests that the list of relevant players be expanded. The suppliers were set as the primary actors in the proposed dynamic game because they are the dominant decision makers among the three players. Future studies could examine situations in which logistics providers play the dominant role by setting the logistics providers as the primary actors and examining and comparing the resulting equilibrium solution. In addition, long-term observations could be performed to formulate a specific distribution curve for disruption occurrences, thus determining the equilibrium solutions based on the resilience of specific transnational supply chains.

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附件二

科技部補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現（簡要敘述成果是否有嚴重損及公共利益之發現）或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■ 達成目標

□ 未達成目標（請說明，以 100 字為限）

□ 實驗失敗

□ 因故實驗中斷

□ 其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 ■未發表之文稿 □撰寫中 □無

專利：□已獲得 □申請中 □無

技轉：□已技轉 □洽談中 □無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性），如已有嚴重損及公共利益之發現，請簡述可能損及之相關程度（以 500 字為限）

本研究內容與原計畫相符，針對跨國供應鏈脆弱度與回復能力之國內外相關文獻進行回顧與評析，以提供相關單位作為跨國物流系統因應風險之學術研究與實務規劃設計的參考。冷鏈目前為臺灣物流相關產業重要利基之一，建置回復利評估模式為業者進行跨國冷鏈服務之規劃重點，並有助於策略布局與聯盟整合之研擬。雖災害發生時，供應鏈脆弱度與回復力多涉及經濟面向損失之討論，並非災害應變之首要關心，然以國家經濟、社會運作及產業發展角度論之，供應鏈脆弱度與回復力仍有助於減災階段之風險管理，跨國冷鏈投資策略更有助於提升臺灣廠商營運之穩健性與國際競爭力。本研究初步成果已投稿至 Transportation Research Board 95th Annual Meeting 審查，後續將尋求國際學術期刊發表之機會。

附件五

國科會補助專題研究計畫出席國際學術會議心得報告

日期：104 年 1 月 7 日

計畫編號	NSC103－2410－H－263－002－		
計畫名稱	以回復力觀點評估我國低溫物流產業於全球冷鏈布局之最佳策略		
出國人員姓名	謝承憲	服務機構及職稱	致理技術學院行銷與流通管理系副教授
會議時間	103 年 12 月 13 日至 103 年 12 月 15 日	會議地點	香港海景嘉福酒店
會議名稱	(中文) 第 19 屆香港交通研究學會國際學術研討會 (英文) the 19th International Conference of Hong Kong Society for Transportation Studies		
發表題目	(中文) 以便利商店鮮食為例探討低溫供應鏈脆弱度 (英文) The vulnerability of cold chain: a case of fresh food at convenience store		

一、參加會議經過

香港交通研究學會國際學術研討會為每年 12 月舉辦之運輸領域研討會，本次為第 19 屆由香港理工大學承辦，於 2014 年 12 月 13 日至 15 日假海景嘉福酒店舉辦，國際化程度高，共有來自 26 個國家超過 240 篇論文投稿，最終接受發表論文篇數為 130 篇。除亞洲地區學者外，亦吸引來自於澳洲、紐西蘭、法國、德國、荷蘭、比利時、匈牙利、瑞士、瑞典、英國、美國、及加拿大與會者超過 220 位。

受補助者於 12 月 12 日抵港，12 月 13 日上午八時前往會場參與開幕與 keynote speech 及三場 plenary speech。午餐時與香港交通研究學會理事長 Prof. William H. K. Lam、研討會籌備委員 Prof. S. C. Wong 及國內學者進行交流。是日下午前往 poster 論文區發掘新興議題並與論文作者進行討論，並針對所發表之低溫供應鏈脆弱度進行說明，與相關學者於該議題進行意見交換。第二日參加大會安排之 Social tour，前往香港濕地公園 (Hong Kong Wetland Park) 參訪，了解在都會地區擴展下兼顧生物多樣性與保存之工程，第三日上午參加另外三場 plenary speech 後，並選取與永續運輸相關議題場次聆聽以汲取新進研究議題，隨後參與閉幕活動。參與會議所獲得之資訊彙整於「與會心得」、而相關活動照片於臚列於「其他」。

二、與會心得

Keynote speech 邀請香港特區政府運輸署署長楊何蓓茵太平紳士 (Mrs. YEUNG HO Poi Yan, Ingrid, JP) 以 Road Traffic Congestion in Hong Kong 為主題進行講演，針對香港公路建設規劃與拓展進行說明，此外，由於研討會期間正值香港佔中活動尾聲，楊何署長並以佔中時部分行車動線重新規劃與大眾運輸繞道等配套措施進行講解。今年香港運輸學會年會主題為運輸與建設 (Transportation and Infrastructure) 涵蓋永續運輸的軟硬體工程，在 plenary speech 部分，美國伊利諾大學香檳校區的 Professor Imad L. AL-QADI 以鋪面工程改良為主題，探討可再生的運輸系統與永續鋪面；瑞士蘇黎世聯邦技術學院運輸規劃與系統研究所的 Professor Kay AXHAUSEN (Transportation 期刊主編) 則回顧近年來以家戶活動產生為基礎所建構的連續模型，探討社會活動與運輸間的關係發展。

而新加坡國立大學土木與環境工程學系的 Professor T.F. FWA 亦針對其長期研究的環境永續鋪面之設計與建造進行分享;此外,日本京都大學經濟研究所的 Professor Se-il MUN 提出一套改良式的貨運之時間價值評估模式，相關參數之考量值得臺灣借鏡；美國伊利諾大學香檳校區土木與環境工程學系 Dr. Yanfeng OUYANG 介紹期發表於 2014 年 Transportation Research Part B 的一篇文章，以網路交通量均衡的概念，利用 bi-level mixed-integer non-linear program，進行貨運設備區位與鋪面設施修護的聯合最適化求解。最後，加拿大卡加利大學土木工程學系的 Professor S.C. (Chan) WIRASINGHE 則以都會區大眾運輸系統的分析模式進行剖析，並與與會學者針對新方法概念進行交流。

感謝科技部計畫對於本次國際研討會之經費補助與支持，除了吸收世界各地優秀學者所提供的研究資訊之外，對於這種直接面對面交流與觀摩的機會，與會者提出的最新成果和交流思想對運輸課題的研究開發有激盪的作用，且在不同國情下規劃管理的觀點都能促進更多方法的提升、也更能夠提升國內的研究水準，並提高臺灣在國際學術研究上的能見度。

三、發表論文全文或摘要

THE VULNERABILITY OF COLD CHAINS: A CASE OF FRESH FOOD AT CONVENIENCE STORES

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ABSTRACT

For people dining out, convenience stores are a new source of a diverse range of fresh food products that includes refrigerated, warm, and freshly made comestibles. The quality of perishable food products degrades with time because inappropriate logistics can increase the risk of foodborne illnesses. Cold chains, which involve the uninterrupted refrigerated handling of fresh food from manufacturers to the market, concern the processing, transportation, and storage of temperature-sensitive products. Accordingly, this study explores the essential impact factors of cold chain vulnerability by using a decision-making trial and evaluation laboratory (DEMATEL) method based on nine criteria. One of the major fresh food suppliers of FamilyMart in Taiwan was employed as the empirical case. The methodology can determine the critical vulnerability factors and the weakest link in the fresh food cold chain logistics system to improve the risk assessment and loss mitigation of cold chain systems.

Keywords: Cold chain, vulnerability, fresh food, convenience stores, decision-making trial and evaluation laboratory (DEMATEL)

1. INTRODUCTION

Supply chain vulnerability and the associated operational and financial risks represent the most pressing concern encountered by firms that currently compete in global markets because trivial incidents can considerably disrupt supply chain operation (Craighead et al., 2007). The coping capacities and resilience of supply chain has become a major concern in recent studies (Sheffi and Rice Jr., 2005; Tang, 2006; Colicchia, et al., 2010). Because of the more complicated supply chain operation, rapid economic growth, globalization, and social changes, supply chain members have faced substantially increased uncertainties. The supply chain might be vulnerable because vast amounts of variations of components and materials that consumer desire must be simultaneously delivered within short intervals (Svensson, 2000). In particular, changes in industrial structures, such as extended chain store systems, various distribution types, changing retail channels, popular low-temperature products, professional logistics services, dense inhabitation, and urbanization, facilitate the development of low-temperature supply chain (i.e., cold chain). Most of the products that cold chains serve are temperature sensitive; the alteration of temperature in transportation and storage, package stability, and pick-up and delivery times, substantially influence the quality of cold chain.

In the global market, the competitiveness of cold chain enterprises is affected by fluctuations in product prices, economies of scale, inefficiency in clearing customs and quarantine, as well as difficulty in controlling quality of agricultural products. The insufficient infrastructures and technology of foreign cold chain members (e.g., imbalance between supply and demand caused by asymmetrical information along with the absence of an integrated monitoring mechanism) substantially increase the risk of broken cold chain. Cold chain consists of a subset of total supply chain, involving the production, storage and distribution of products that require temperature control for retaining their essential characteristics and associated value (Reed, 2005). Moreover, cold chain involves the transportation of temperature-sensitive products in the supply chain through refrigerated packaging methods, accompanied by logistics planning to protect the integrity of the shipments (Rodrigue et al., 2013).

Previous studies regarding cold chains have focused on the technology in monitoring and controlling temperature condition, neglecting impact analyses on broken cold chains. Accordingly, this study examined the practical processes of cold chain operations to develop a framework using a decision-making trial and evaluation laboratory (DEMATEL) method for exploring the crucial impact factors of cold chain vulnerability based on the interdependencies among vulnerability factors, thus proposing improvement strategies for cold chain operators. The socioeconomic changes in Taiwan have resulted in an increase in the population that dines out, reaching 70% of the total population in 2007. Owing to the high density of convenience stores (CVSs) and their 24-hr operation, 90% of Taiwanese people have unlimited access to CVS services in their communities. For people dining out, CVSs provide a new source of diverse fresh food products, including refrigerated, warm, and freshly made comestibles.

Along with the convenience factor, increasing numbers of customers buy fresh food at CVSs because of the substantially improved quality and taste of these foods. The growth of food service at CVSs is facilitated not only by operators' focus on quality ingredients and preparation from scratch, but also by young consumers' willingness to try the fresh food that CVSs offer. Rather than because of densely spread channels, the market share of fresh food at CVSs has increased because of innovative new products, target marketing strategies, and the degree of dependence on CVSs. The annual revenue derived from sales of fresh food at CVSs exceeded US$1 billion in Taiwan with a growth of 10.1% in 2012 (Industry and Technology Intelligence Services, 2013). Thus, the cold chain operation of fresh food at CVSs was employed as the empirical case in this study. The following section presents a definition of cold chain vulnerability and clarifies the relevant factors, after which the DEMATEL method is described in detail. Subsequently, the empirical vulnerability of major fresh food suppliers of FamilyMart in Taiwan is discussed, and Section 5 provides the conclusion and recommendations for future research directions.

2. THE VULNERABILITY OF COLD CHAIN

2.1 Cold Chain

The cold chain is a physical process that is predominantly applied in the supply chain logistics of certain processed foods and can be applied to frozen, chilled and fresh perishable food products (Salin and Nayga, 2003). Cold chain logistics, comprising equipment and processes that maintain perishable products in controlled cold environments, involves the production and processing conducted in packaging stations, cold storage warehouses, transportation systems, distribution centers, and retailer operations (Casper, 2007). Any variation in temperature increases the risk of food poisoning and food spoilage, and each product requires a specific temperature-controlled environment in the distribution process for delivering the products to stores (James and James, 2010). Accordingly, temperature control is critical in cold chain logistics and for maintaining the quality and integrity of the products (Kuo and Chen, 2010). Moreover, because urban populations are rapidly growing, implementing cold chain logistics is a primary method for ensuring the quality and safety of food (Coulomb, 2008). Various problems in food safety have emphasized the need for the early identification of hazards that affect cold chains and the subsequent mitigation, control, and prevention of the associated risks (Marvin and Kleter 2009).

In fresh food cold chain system, a necessary temperature level is set to maintain the quality of fresh food at each link of the supply chain. To preserve the quality of fresh food products, professional and specialized facilities are required to control the correct temperatures from production to delivery for consumption. The facilities in a cold chain logistics system consist of precoolers, packing houses, refrigerated chambers, and refrigerated vehicles. Precoolers are used to quickly dissipate heat after harvest to obtain the required conditions, and packing houses are necessary for preparing fresh foods before they enter the market, which involves processes such as trimming, cleaning, and removing deficient products. Furthermore, refrigerated chambers create the required low-temperature storage environments for storing high-quality fresh food, whereas refrigerated container vans and trucks are used for distributing and delivering fresh food from such refrigerated chambers or packing houses (Yang and Cai, 2013). Fresh food cold chain enables suppliers to control the appropriate temperature for foodstuffs with short periods of freshness; to correctly store fresh food, the rule “first in, first out” must be followed (Likar and Jevšnik, 2006), and variations in temperature must be minimized.

The cold chain of fresh food at CVS refers to the uninterrupted refrigerated handling of fresh food from the manufacture to the market. These products require adequate treatments, such as processing, transporting, and storing, before selling. The qualities of perishable food products degrade with time because inappropriate logistics can increase the risk of microbial contamination, which not only reduces the shelf life of products but also causes foodborne illness. The cold chain system thus needs proper facilities, processes, as well as participants, such as packers, transport service suppliers, and workers to handle, store, and transport perishable produce. Cold chain management plays a strategic role in the quality of fresh food arriving to consumers.

2.2 Supply Chain Vulnerability

Vulnerability refers to susceptibility to damage without adaptation because of exposure to the negative effects caused by external changes (Adger, 2006). Chambers (2006) expressed that vulnerability exists in systems having inferior resistance and coping capacities in insecure conditions. In other words, a system is vulnerable when exposed to risks, impacts, or pressures from disasters when a contingency-mitigating capability does not exist. Based on the perspective of supply chain, Jüttner et al. (2003) defined supply chain vulnerability as the adverse consequence of risk sources in relation to the existing mitigation strategies. Christopher and Peck (2004) considered supply chain vulnerability represents as an exposure to severe disturbance, arising from risks that are internal and external to the supply chain. Moreover, supply chain vulnerability indicates a susceptibility and sensitivity to threats and hazards that substantially reduce its ability to maintain its intended function referring to the function of certain supply chain characteristics and the losses caused by a given supply chain disruption (Wagner and Bode, 2006).

Wanger and Neshat (2010) developed the quantitative supply chain vulnerability index by considering the relationships among operation elements and impact factors by using graph theory. The vulnerability factors and their importance to a supply chain vary because of spatiotemporal and enterprise characteristics. Sheffi and Rice (2005) calculated supply chain vulnerability by using a function of consequences and the probability of natural hazards, accidents, and intentional disruptions. Operators must be concerned with the highest vulnerability events with high probability and severe consequences; for example, dissolved partnerships with critical supply chain members, conflicts between labor and capital, and insufficient quality control. The categories of supply chain vulnerability, as related to demand, include delivery delays, an interruption of distribution networks, and demand uncertainty (Hallikas et al., 2004; Wagner and Bode, 2006; Wanger and Neshat, 2010; Fazli and Masoumi, 2012); vulnerability related to supply consists of production capacity, quality, human resources, sensitivity, and resilience (Wagner and Bode, 2006; Pettit et al., 2010), as well as the structure of supply chains, which comprises reliability, connectivity, lean storage, and agile operations (Pettit et al., 2010; Fazli and Masoumi, 2012).

Cold chain involving the processes, transportation, and storage of temperature-sensitive products through refrigeration technology, and logistical planning provides the necessary low-temperature environments to improve the quality and security of food. Controlling and recording temperatures is essential for cold chain (Montanari, 2008). Previous studies have determined that the primary condition necessary for successful cold chain is utilizing appropriate refrigerated facilities in processing, transporting, and storing products (Zhang et al., 2003; Kuo and Chen, 2010). Cold chain involving food is characterized by strict shelf life constraints, long lead times, and specific requirements for logistics processes such as warehousing and transportation (van der Vorst et al., 2005). Because performance enhancement is an ongoing requirement, devising a lean cold chain by eliminating low value-added activities and reducing inventory leads to an increased vulnerability to disruption (Vlajic et al., 2012).

3. METHODOLOGY

The decision-making trial and evaluation laboratory (DEMATEL) method, developed based on graph theory, has been used to discuss and solve complex and intertwined problem groups based on the improvement in the understanding of a specific problematique and a cluster of intertwined problems. Using the DEMATEL method enables planners and operators to determine and solve problems by visually confirming the interdependence among variables, which facilitates the development of a directed graph to reflect the interrelationships between variables (Huang et al., 2008). Employing the DEMATEL method involves four steps: calculating the average matrix, calculating the normalized initial direct-influence matrix, deriving the total relation matrix, and proposing the impact-relations map. The end product of the DEMATEL process (e.g., the impact-relations map) is a visual representation of the thought processes by which experts organize their actions in the world. This organizational process must occur for experts to maintain internal coherence and to achieve personal goals.

Respondents were asked to indicate the non-negative direct-influence that they believe each component in a given system exerts on each of the others, using a scale ranging from 0 to 1. A link v_{ij} from variable C_i to variable C_j determines to what extent C_i affects C_j. From any group of direct matrices of respondents, Eq. 1 represents the average matrix $\boldsymbol{V}$, where the diagonal elements of matrix $\boldsymbol{V}$ are all set to zero, and n denotes number of factors concerned in the system. Subsequently, the normalized initial direct-relation matrix $\boldsymbol{X}$ (shown in Eq. 2) generated based on $\boldsymbol{V}$ by using a simple matrix operation, shows the initial influence that a factor exerts on and receives from another factor, in which the normalization coefficient λ is indicated as in Eq. 3. Each element of matrix $\boldsymbol{X}$ portrays a contextual relationship among the elements of the system and can be converted into a visible structural model—an impact-relations map—of the system with respect to that relationship.

$$\boldsymbol{V} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_i \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_j & C_n \end{array} \\ \begin{bmatrix} 0 & v_{12} & \cdots & v_{1n} \\ v_{21} & 0 & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \cdots & 0 \end{bmatrix}_{n \times n} \end{array} \tag{1}$$

$$\boldsymbol{X} = \lambda \quad \boldsymbol{V} \tag{2}$$

$$\lambda = \frac{1}{\max\left(\max \sum_{i=1}^{n} v_{ij},\ \max \sum_{j=1}^{n} v_{ij}\right)} \tag{3}$$

A continuous decrease of the indirect effects of problems along the powers of matrix $\boldsymbol{X}$, (e.g., $\boldsymbol{X}^2$, $\boldsymbol{X}^3$, …, $\boldsymbol{X}^{\infty}$), guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix. The total relation matrix $\boldsymbol{T}$ is defined as Eq. 4, where $\boldsymbol{I}$ refers to the identity matrix. The element of the matrix $\boldsymbol{T}$, t_{ij}, denoting the full direct- and indirect-influence exerted by factor C_i on factor C_j is employed to calculate the active and reactive degree of each factor in the system.

$$\boldsymbol{T} = \sum_{k=1}^{\infty} X^k = \lim_{m\to\infty} X(I + X^2 + \cdots + X^{m-1}) = \lim_{m\to\infty} X\left(\frac{I - X^m}{I - X}\right) = X(I - X)^{-1} \tag{4}$$

Equation 5 shows the affecting ability of D_i, representing the sum of influence exerted by factor C_i on the other factors, whereas R_j is the sum of influence that factor C_j received from the other factors (shown in Eq. 6). $(D_i + R_j)_{j=i}$, namely prominence, reveals the degree of importance to the role of C_i in the system and also provides an index that shows the total effects both exerted and received by C_i. Moreover, $(D_i - R_j)_{j=i}$, namely relation, indicates the net effect that C_i contributes to the system. A positive relation denotes that C_i belongs to the cause group, whereas C_i is a net receiver if the relation is negative (Falatoonitoosi et al., 2013).

$$D_i = \sum_{j=1}^{n} t_{ij} \tag{5}$$

$$R_j = \sum_{i=1}^{n} t_{ij} \tag{6}$$

The DEMATEL method is widely applied in industrial planning, such as in the marketing strategies for LCD-televisions that are based on consumer behavior (Chiu et al., 2005), airline safety measurement and improvement strategies (Liou et al., 2007), human resource protocol based on global managers’ competencies (Wu and Lee, 2007), portfolio selection based on capital asset pricing models (Ho et al., 2011), and organic light-emitting diode technology selection (Shen et al., 2011).

4. EMPIRICAL RESULTS

A fresh food manufacturer providing instant food at 4 °C to FamilyMart in Taiwan was employed to analyze cold chain vulnerability and verify systematic interdependency assessments. Eleven experts, including scholars and managers responsible for information technology, quality management, research and development, as well as operation sites were invited to determine the causal relationships between pairs of vulnerability factors in fresh food cold chain operations. Based on a literature review and empirical processes illustrated in Fig. 1, facilities including food processing equipment and low-temperature vehicles, procedures including temperature control in processing and transportation, and human resource management including operational accuracy and crisis management skills were determined as the critical constructs in fresh food cold chain operations. The experts formed a consensus comprising nine vulnerability factors: idle time of low-temperature facilities, abnormality of refrigerated vehicles, abnormality of power supply, imperfect information, inadequate temperature control in food processing, inadequate temperature control in distribution and delivery, unqualified food products, error caused by frontline employees, and crisis handling ability of managers.

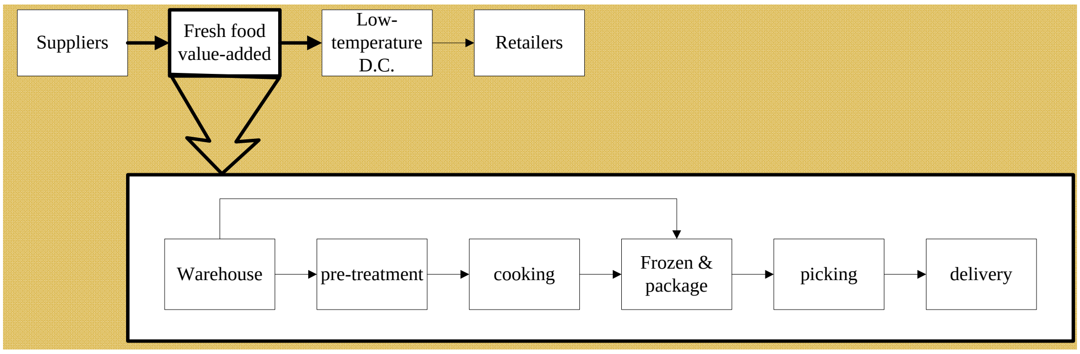


Figure 1. Operational processes of fresh food cold chain

Table 1 shows a 9×9 causal impact matrix ***V***, where the systematic relationship of each variable is identified. Each cell in the impact matrix reveals how the vertical variable directly influences the horizontal variable; for example, the cell corresponding to the fourth column and third row shows how abnormality of power supply influences imperfect information.

Table 1. Causal impact matrix

Active \ Passive	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Idle time of low-temperature facilities	0	0	0.2	0	0.1	0	0	0	0
(2) Abnormality of refrigeration vehicles	0.1	0	0	0	0	0.1	0.7	0	0
(3) Abnormality of power supply	0.3	0	0	0.6	0.6	0	0.6	0	0
(4) Imperfect information	0.3	0	0	0	0.6	0.6	0	0.6	0.5
(5) Inadequate food processing temperature	0	0.4	0	0	0	0	0.5	0.4	0
(6) Inadequate delivery temperature	0	0.7	0	0	0	0	0.8	0.2	0
(7) Unqualified food products	0	0.2	0	0	0	0	0	0.3	0
(8) Error caused by frontline employees	0.3	0.6	0	0.7	0.7	0.3	0.2	0	0
(9) Crisis handling ability of managers	0.7	0	0	0.6	0.5	0.3	0.2	0.4	0

Based on Eq. 2, $\lambda = 1/3$ was substituted into Eq. 3, calculated the inverse matrix by using Microsoft Excel 2007, and determined the total relation matrix ***T*** based on Eq. 4. Table 2 shows the total relation of each factor in matrix ***T***, which ranges from 0.001 to 0.356 with a mean value of 0.117, a median of 0.052, and a standard deviation of 0.115. To explain the structural relationship among the factors and maintaining the complexity of the system at a manageable level, identify a threshold level is necessary to filter the negligible effects (Li and

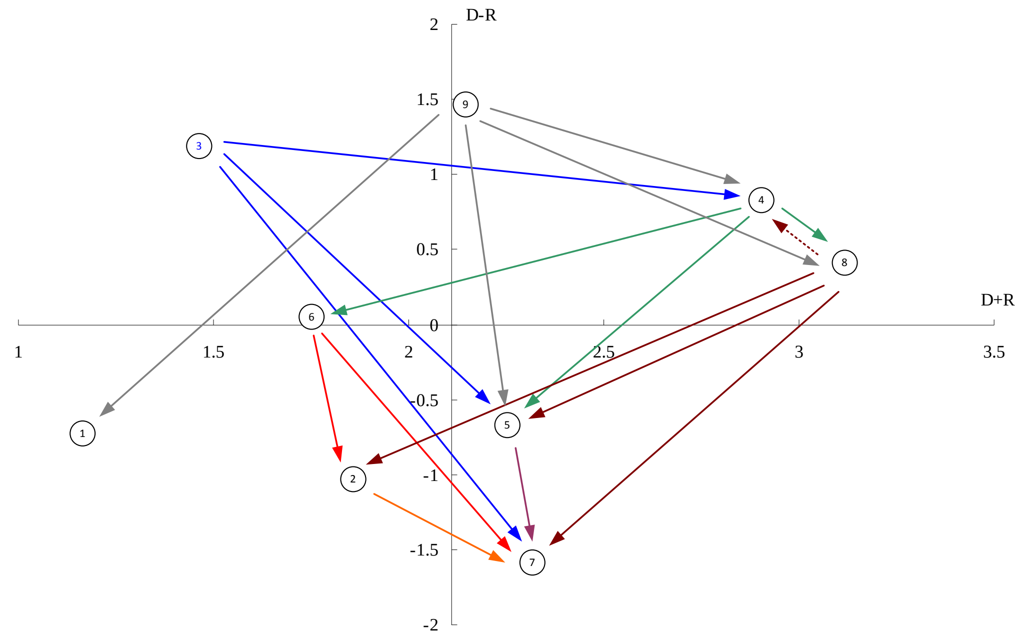
Tzeng, 2009). The experts formed a consensus regarding the threshold calculated using the mean value plus standard deviation (0.117 + 0.115 = 0.232) to assist in obtaining adequate information for simplifying the impact-relations map for further analysis and decision-making.

Table 2. The total relation matrix for cold chain vulnerability factors

Factor*	Total relation									$D+R$	$D-R$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		
(1)	0.011	0.013	0.067	0.017	0.054	0.006	0.028	0.014	0.003	**1.158**	**-0.729**
(2)	0.039	0.034	0.003	0.008	0.011	0.039	0.256	0.032	0.001	**1.848**	**-1.001**
(3)	0.150	0.100	0.010	0.240	0.291	0.068	0.303	0.127	0.040	**1.459**	**1.200**
(4)	0.196	0.193	0.013	0.118	0.342	0.282	0.214	0.334	0.186	**2.917**	**0.840**
(5)	0.030	0.200	0.002	0.043	0.052	0.034	0.244	0.176	0.007	**2.255**	**-0.677**
(6)	0.025	0.291	0.002	0.028	0.034	0.027	0.356	0.115	0.005	**1.739**	**0.027**
(7)	0.019	0.102	0.001	0.028	0.035	0.021	0.044	0.117	0.005	**2.315**	**-1.570**
(8)	0.166	0.336	0.011	0.279	0.339	0.186	0.266	0.146	0.046	**3.108**	**0.442**
(9)	0.306	0.156	0.020	0.277	0.307	0.192	0.231	0.272	0.046	**2.147**	**1.467**

** Note: Numbers in parentheses refer to the corresponding vulnerable factor mentioned in Table 1.*

Figure 2 reveals the impact-relations map with a direct and indirect influence in which unqualified food products (7) play a passive role (i.e., a performance index) in the fresh food cold chain operations, whereas abnormality of power supply (3) and the crisis handling ability of managers (9) represent the major factors that affect, but are rarely affected by, cold chain operations. The idle time of low-temperature facilities (1) plays a buffering role with unsubstantial relationships in the fresh food cold chain system. A sole feedback loop (dotted arrow) exists between imperfect information (4) and error caused by frontline employees (8), which were determined as critical vulnerability factors in fresh food cold chain operations because of high levels of prominence and relation.



** Note: Numbers in circles refer to the corresponding vulnerable factor mentioned in Table 1.*

Figure 2. Impact-relations map with direct/indirect influence

Although the efficiency and information of current cold chain operations have been improved, such operations remain relatively vulnerable because of interdependency among factors. The analytical results indicated that defective food products, the major reactive factors representing the outcomes of cold chain operations, are extremely vulnerable because any form of inappropriate operation negatively influences the security and quality of food products. Perfecting information collection and enhancing the training of frontline employees must be prioritized for mitigating the impact of inadequate temperature control in both processing and distribution as related to the performance of equipment and vehicles. Practically, it is recommended to enhance electronic data interchange to increase information accuracy, to invest in automatic temperature-monitoring facilities for issuing early warning notifications, and to adopt sufficient education and training methods for employees to improve the capacities for defect processing as well as mitigating unexpected crises.

5. CONCLUSION

This study utilizes the DEMATEL method to assist decision makers in determining the vulnerability of fresh food cold chain based on the causal relationships among operations. Based on a literature review and interviews with experts, this study proposed nine vulnerability factors in fresh food cold chain operations. One of the major fresh food suppliers of FamilyMart in Taiwan was employed as the empirical case. An impact-relations map was obtained to enable decision makers to understand how vulnerability factors affect cold chain vulnerability and subsequently adopt appropriate strategies for improving the performance of cold chain. Using the causal impact matrix is beneficial for determining which segment of operation requires additional protection.

According to the analytical results, imperfect information, inadequate temperature control in food processing, and frontline employee errors are the variables requiring critical attention in the operation of fresh food cold chain for Taiwanese CVSs. Failure to consider interdependency misdirects resource allocation to improve cold chain vulnerability. Based on the findings, enhancing electronic information processing and the education of frontline employees must be prioritized to mitigate the impact of inadequate temperature control in both processing and distribution. The developed method can be used to help decision makers prioritize resource allocation for improving fresh food cold chain serviceability, contributing to a semi-quantified assessment framework rather than traditional qualified interdependency analyses. The finding of this study must be treated with consideration because the results might partially reflect the method through which the data were collected.

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四、建議

香港交通年會雖僅為單一地區學會所主辦之研討會，但其國際化程度令人驚訝，與會人員來自於超過35個國家/地區，近年來大陸地區學生的參與積極度增加，其研究能量亦不可小覷，雖臺灣地區在相關的運輸研究仍具一定優勢，但學生 (尤以碩士班研究生以降較為明顯) 多以參與國內活動為滿足，一方面可能也受限於英語能力較為不足，較缺乏與國際學術交流接軌之機會，未來若能在經費許可且甄選合適人選前提下，提供學生出國參與國際研討會，相信有助於提升學生的國際化視野。

五、攜回資料名稱及內容

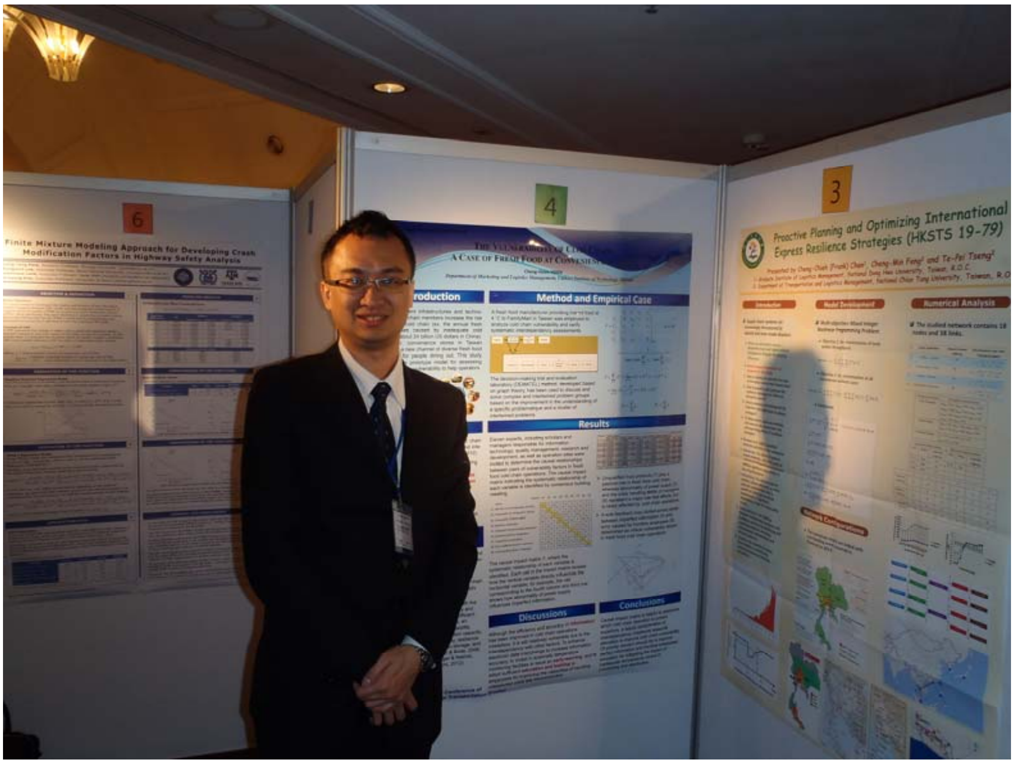
Proceedings in electronic format, Conference Programme including Abstract Compendium (hardcopy) with over 130 papers accepted for presentation at the conference, covering a wide spectrum of research topics.

六、其他

參與會議及發表照片

受補助人於會議主場地外留影

Keynote speech by Mrs. YEUNG HO Poi Yan, Ingrid, JP



海報發表場次

科技部補助計畫衍生研發成果推廣資料表

日期:2015/08/13

科技部補助計畫	計畫名稱: 以回復力觀點評估我國低溫物流產業於全球冷鏈布局之最佳策略
	計畫主持人: 謝承憲
	計畫編號: 103-2410-H-263-002- 學門領域: 交通運輸

無研發成果推廣資料

103 年度專題研究計畫研究成果彙整表

計畫主持人：謝承憲			計畫編號：103-2410-H-263-002-				
計畫名稱：以回復力觀點評估我國低溫物流產業於全球冷鏈布局之最佳策略							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	1	0%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	1	0%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	1	1	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

<table>
<tr><td>其他成果
(無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)</td><td>無</td></tr>
</table>

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

科技部補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估 ■達成目標 □未達成目標（請說明，以 100 字為限） 　　□實驗失敗 　　□因故實驗中斷 　　□其他原因 說明：
2. 研究成果在學術期刊發表或申請專利等情形： 論文：□已發表 ■未發表之文稿 □撰寫中 □無 專利：□已獲得 □申請中 ■無 技轉：□已技轉 □洽談中 ■無 其他：（以 100 字為限）
3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限） 本研究內容與原計畫相符，針對跨國供應鏈脆弱度與回復能力之國內外相關文獻進行回顧與評析，以提供相關單位作為跨國物流系統因應風險之學術研究與實務規劃設計的參考。冷鏈目前為臺灣物流相關產業重要利基之一，建置回復利評估模式為業者進行跨國冷鏈服務之規劃重點，並有助於策略布局與聯盟整合之研擬。雖災害發生時，供應鏈脆弱度與回復力多涉及經濟面向損失之討論，並非災害應變之首要關心，然以國家經濟、社會運作及產業發展角度論之，供應鏈脆弱度與回復力仍有助於減災階段之風險管理，跨國冷鏈投資策略更有助於提升臺灣廠商營運之穩健性與國際競爭力。本研究初步成果已投稿至 Transportation Research Board 95th Annual Meeting 審查，後續將尋求國際學術期刊發表之機會。