科技部補助專題研究計畫成果報告
期末報告

考量環境易損性之山區公路脆弱度解構分析

計 畫 類 別 ： 個別型計畫
計 畫 編 號 ： MOST 104-2410-H-263-009-
執 行 期 間 ： 104年08月01日至105年07月31日
執 行 單 位 ： 致理學校財團法人致理科技大學行銷與流通管理系

計畫主持人： 謝承憲

計畫參與人員： 碩士班研究生-兼任助理人員：傅少君
大專生-兼任助理人員：楊雅婷
大專生-兼任助理人員：李玠佑

報 告 附 件 ： 出席國際學術會議心得報告

中 華 民 國 105 年 08 月 22 日

中 文 摘 要 ： 社會進步與人口成長使運輸路網日愈繁雜，社經活動更有賴運輸系統連結，運輸系統中斷將導致用路人耗費較高之金錢與時間成本以利用替代運具或路徑完成旅次目的，更有甚者將因受困而被迫取消旅次，所產生直接災損與間接社會經濟損失甚鉅。運輸脆弱度與回復力概念已引起廣泛討論，但仍難產生共識性定義，多數研究考量系統內各元素之空間關聯性，少部分納入元素功能間之相依性，然而，對於環境與運輸脆弱度間之關係，卻難有明確之界定。據此，本研究解構脆弱度與回復力之功能與內涵，據以建立路網脆弱度與回復力模式，並利用逆向工程概念協助決策者了解山區主要聯外公路系統以釐清脆弱度與回復力之關鍵影響因子。本研究以颱風強降雨為例，引入環境脆弱指標解構分析方法，建構防災與復原階段資源配置模式。據此，與山區景點聯外公路相關之脆弱度分析，包括自然條件、基礎設施、服務及社會經濟條件，有助於相關路網關鍵脆弱因子之界定、及減少相關災害損失策略之發展。本研究利用六項影響山區景點聯外道路之脆弱度因子於評估區域永續性，並以阿里山與日月潭為實例進行探討。分析結果顯示阿里山之永續性較日月潭為脆弱，較脆弱的山區聯外道路應優先考量減緩其受衝擊之強度，為同時考量臺灣山區景點之可及性、機動性與永續性，管制私有運具之進入有助於確保疏散時之道路容受度，但應以公共運輸提供充足的接駁運輸服務。除了以預疏散減緩受災並降低救援之成本外，公部門應透過土地使用管制及發展權轉移之方式，限制高脆弱地區之開發，以降低脆弱因子之暴露並改善脆弱度。此外，除救援物資配置外，日常生活所需用品之備援，有助於減緩因災害導致之孤島效應其負面影響。

中文關鍵詞： 公路脆弱度、環境脆弱因子、指標解構分析、資源配置

英 文 摘 要 ： The disconnection results considerable direct damage as well as indirect socioeconomic losses. Previous literature discussed the determination of vulnerability and resilience of transportation systems, however, it is difficult to build a consensual definition. However, the determination of relationships between environmental sensitivity and transportation vulnerability is absent from previous literature. Accordingly, this study deconstructs the functions and components and to integrate a network and resilience model. Moreover, a concept of reversed engineering is used to assist decision-makers in understanding the system of mountain highway networks and identifying the crucial influence factors of network vulnerability and resilience. The typhoon and heavy rain are applied as empirical study. Index decomposition analysis is introduced to construct resource allocation models in stages of disaster prevention and recovery, respectively. Therefore, this vulnerability analysis of the natural conditions, infrastructures, services, and socioeconomic factors that allow regional tourism to function is helpful for determining crucial vulnerability factors and developing strategies for mitigating losses in tourism areas. Six vulnerability factors affecting tourism areas are utilized to assess the sustainability of tourism areas. Alishan and Sun Moon Lake National Scenic Areas, two famous tourist sites in Taiwan, are employed as empirical cases. Analytical results reveal that sustainability in Alishan is more vulnerable than in Sun Moon Lake. The mountainous tourism areas with higher vulnerability should be of primary concern to mitigate impact intensity. To achieve the accessibility, mobility, and sustainability needed in the mountainous tourism areas of Taiwan, there must be regulation for controlling the entrance of private vehicles to ensure appropriate network loading during an evacuation. Simultaneously, the integrated public transportation network should provide sufficient connectivity to intra and inter tourism areas. In addition to pre-evacuation to mitigate damage and reduce the costs of rescue, governments should limit the development of vulnerable areas through land-use regulations and the transfer of development rights for reducing exposure and improving vulnerability. Along with the allocation of rescue resources, the redundancy of resources for supporting daily life should be improved to mitigate the impact of isolation caused by disasters.

英文關鍵詞： highway vulnerability, environmental vulnerability, index decomposition analysis, resource allocation

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）

考量環境易損性之山區公路脆弱度解構分析

計畫類別：■個別型計畫　□整合型計畫

計畫編號：MOST 104－2410－H－263－010－

執行期間：104 年 8 月 1 日至 105 年 7 月 31 日

執行機構及系所：致理學校財團法人致理科技大學 行銷與流通管理系

計畫主持人：謝承憲

共同主持人：

計畫參與人員：陳惠君、傅少君、楊雅婷、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：

□執行國際合作與移地研究心得報告

■出席國際學術會議心得報告

□出國參訪及考察心得報告

中　華　民　國　105　年　7　月　31　日

摘要

社會進步與人口成長使運輸路網日愈繁雜，社經活動更有賴運輸系統連結，運輸系統中斷將導致用路人耗費較高之金錢與時間成本以利用替代運具或路徑完成旅次目的，更有甚者將因受困而被迫取消旅次，所產生直接災損與間接社會經濟損失甚鉅。運輸脆弱度與回復力概念已引起廣泛討論，但仍難產生共識性定義，多數研究考量系統內各元素之空間關聯性，少部分納入元素功能間之相依性，然而，對於環境與運輸脆弱度間之關係，卻難有明確之界定。據此，本研究以過去研究所建議之系統動態方法解構脆弱度與回復力之功能與內涵，據以建立路網脆弱度與回復力模式，並利用逆向工程概念協助決策者了解山區主要聯外公路系統以釐清脆弱度與回復力之關鍵影響因子。本研究以颱風強降雨為例，引入環境脆弱指標解構分析方法，建構防災與復原階段資源配置模式。據此，與山區景點聯外公路相關之脆弱度分析，包括自然條件、基礎設施、服務及社會經濟條件，有助於相關路網關鍵脆弱因子之界定、及減少相關災害損失策略之發展。本研究利用六項影響山區景點聯外道路之脆弱度因子於評估區域永續性，並以阿里山與日月潭為實例進行探討。分析結果顯示阿里山之永續性較日月潭為脆弱，較脆弱的山區聯外道路應優先考量減緩其受衝擊之強度，為同時考量臺灣山區景點之可及性、機動性與永續性，管制私有運具之進入有助於確保疏散時之道路容受度，但應以公共運輸提供充足的接駁運輸服務。除了以預疏散減緩受災並降低救援之成本外，公部門應透過土地使用管制及發展權轉移之方式，限制高脆弱地區之開發，以降低脆弱因子之暴露並改善脆弱度。此外，除救援物資配置外，日常生活所需用品之備援，有助於減緩因災害導致之孤島效應其負面影響。

關鍵字：公路脆弱度、環境脆弱因子、指標解構分析、資源配置

Abstract

Transportation systems have become more complicated because of social progress and population growth. Numerous socio-economic activities are linked by transportation systems. Along with monetary costs, the costs of travel time of alternatives for users are steeply increased to achieve the original trip purpose due to the disconnected networks. In fact, some users are besieged with disconnection and forced to cancel their trips. The disconnection results considerable direct damage as well as indirect socio-economic losses. Previous literature discussed the determination of vulnerability and resilience of transportation systems, however, it is difficult to build a consensual definition. Some studies considered the spatial interaction among element in transportation systems, whereas little research discussed the functional interdependencies. However, the determination of relationships between environmental sensitivity and transportation vulnerability is absent from previous literatures. Accordingly, this study utilizes system dynamics proposed by previous literature to deconstruct the functions and components and to integrate a network and resilience model. Moreover, a concept of reversed engineering is used to assist decision-makers in understanding the system of mountain highway networks and identifying the crucial influence factors of network vulnerability and resilience. The typhoon and heavy rain are applied as empirical study. Index decomposition analysis is introduced to construct resource allocation models in stages of disaster prevention and recovery, respectively. Therefore, this vulnerability analysis of the natural conditions, infrastructures, services, and socioeconomic factors that allow regional tourism to function is helpful for determining crucial vulnerability factors and developing strategies for mitigating losses in tourism areas. Six vulnerability factors affecting tourism areas are utilized to assess the sustainability of tourism areas. Alishan and Sun Moon Lake National Scenic Areas, two famous tourist sites in Taiwan, are employed as empirical cases. Analytical results reveal that sustainability in Alishan is more vulnerable than in Sun Moon Lake. The mountainous tourism areas with higher vulnerability should be of primary concern to mitigate impact intensity. To achieve the accessibility, mobility, and sustainability needed in the mountainous tourism areas of Taiwan, there must be regulation for controlling the entrance of private vehicles to ensure appropriate network loading during an evacuation. Simultaneously, the integrated public transportation network should provide sufficient connectivity to intra and inter tourism areas. In addition to pre-evacuation to mitigate damage and reduce the costs of rescue, governments should limit the development of vulnerable areas through land-use regulations and the transfer of development rights for reducing exposure and improving vulnerability. Along with the allocation of rescue resources, the redundancy of resources for supporting daily life should be improved to mitigate the impact of isolation caused by disasters.

Keywords: highway vulnerability, environmental vulnerability, index decomposition analysis, resource allocation

1. INTRODUCTION

Demand for scenic areas has increased in Taiwan because of developments in the economy and transportation, changes in social patterns, and increases in income and leisure time. Meanwhile, tourism industries play an essential role in the economic transition in Taiwan because of the growth of the tourism population and their expenditures on recreation. Following these economic trends, and to meet the increased demand of residents for leisure space, governments have heavily invested in tourism markets through the planning of recreational facilities, investment in and development of scenic spots, and the development of strategic alliances with tourism operators. These efforts improve tourism's value to tourists as well as the accessibility and utility rates of remote scenic spots.

Taiwan's many national parks, scenic areas, nature reserves, and conservation areas have individual natural, cultural, and socioeconomic assets to offer tourists. Tourism contributes to the development of sustainability in culture, the economy, and the environment. There are many stakeholders in this process, including those who work in tourism, local communities, and the tourists themselves. Tourism infrastructure and services assist the industry in satisfying tourists' demands. However, it is difficult for tourism destinations and industries to prevent negative impacts from factors such as changes in climate and the environment. An assessment framework of tourism vulnerabilities would help bring about the sustainability of Taiwan's tourist areas.

Disasters cause serious damage to quality of life by threatening people's lives and health, interfering with the rhythm of their social lives and creating barriers to economic development. Specifically, interactions between climate and environmental changes have gradually increased the magnitude, duration, and threat of disasters. The absence of disaster prevention, mitigation, preparedness, and relief all contribute to the adverse impacts that natural disasters can have on social mechanisms, lives, property, and economic development. The Yokohama Strategy, initiated at the World Conference on Natural Disaster Reduction held in May 1994, provided guidelines for shielding humans, infrastructure, social operations, and economic systems from natural disasters. In recent years, the focus of disaster research has shifted from disaster science to the relationships among disasters, environmental systems, and socioeconomic systems. In 2004, the United Nations International Strategy for Disaster Reduction (UNISDR) defined a disaster as the effects and consequences of hazards on vulnerable socioeconomic systems, in which the vulnerability limits the capability for coping with the influence of the hazard. In addition, the Hyogo Declaration suggested that the suffering caused by hazards could be mitigated by reducing vulnerability. Furthermore, people must increase their resilience to disasters through early warning systems, risk assessments, and education as well as integrated approaches (UNISDR, 2005).

Taiwan, an island located between the Eurasia plate and the Philippine Sea plate, is part of the circum-Pacific seismic belt. Taiwan has high mountains with steep slopes and frequent earthquakes, which bring heavy rainfalls and geohazards such as landslides and other debris. Climate change may lead to even more severe damage if disaster areas are not adequately prepared. This will not only cause huge financial losses but also heavy casualties since tourism sites in mountainous areas are in remote districts with higher environmental fragility and less ability to withstand disaster.

Thus, the vulnerability analysis of the natural conditions, infrastructures, services, and socioeconomic factors will help to determine the crucial vulnerability factors and to develop strategies for mitigating losses in tourism spots in mountainous areas. The remainder of this paper is organized as follows. Section 2 is a literature review where sustainability and vulnerability are defined. Section 3 illustrates the model construction by introducing the assessment framework. Section 4 provides a discussion of the empirical results of vulnerability for two famous tourism spots in mountainous areas of Taiwan. Finally, section 5 offers concluding remarks and directions for future research.

2. LITERATURE REVIEW

2.1 Sustainability

There is no one common identified definition of sustainability (Pope et al., 2004; Loo and Chow, 2006; Jeon et al., 2006). Yang (2002) argued that quality of life involves not only individual health, safety, social justice, income, and freedom but also relationships with salient features of the environment such as fresh air, clean water, and natural surroundings. Moreover, Shafer et al. (2000) identified sustainability as the ability to develop a good quality of life in both the present and the future. In addition to these indicators, the Commission of the European Communities (2002) introduced a sustainability impact assessment process for developing an integrated assessment system, based on existing fragmented sectoral systems, for identifying the impacts of certain policies and determining the trade-offs among competing objectives.

Sustainable development is generally conceived as finding a balance among environmental, social, and economic qualities (George, 2001; Kasemir et al., 2003; Steg and Gifford, 2005; Ness et al., 2007). Moreover, the World Commission of Environment and Development (1987) defined sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” Additionally, Pope et al. (2004) suggested that it is necessary to explore not only the direction to the sustainable target but also the distance from sustainability. Activities in tourism, travel, and leisure are important components of daily life, and tend to converge on developed scenic areas, which brings environmental pressures owing to overloaded development, inappropriate managemen,t and frequently inadequate tourist behavior. Environmental protection in tourism areas thus becomes one of the fundamental conditions for sustainable development in the tourism industry. Sustainable tourism depends on successfully managing natural resources consumed by tourism to reach the goal of resources and tourism activities coexisting sustainably (Stewart, 1993). Sustainable tourism is understood to satisfy the demands of tourists as well as local residents through appropriate managerial strategies based on nature conservation and to contribute to rational revenues (Valentine, 1993) for financial sustainability.

2.2 Vulnerability

Similar to sustainability, a precise and consistent definition of vulnerability is unavailable in the literature (Berdica, 2002; Holmgren, 2004). The Intergovernmental Panel on Climate Change (IPCC) reported that vulnerability is the degree to which a system is susceptible to, or unable to cope with, the adverse impacts of climate change (IPCC, 2001). Chambers (2006) suggested that vulnerability exists in systems with an inferior resistance to, and coping capacities for, insecure conditions. Vulnerability thus refers to a negative indicator of system performance during disaster management. A system deemed to have high vulnerability implies that it possesses low resistance to external influences.

Adger (2006) defined vulnerability as the level of sensitivity to damage owing to the absence of adaptive capacity, resulting from exposure to negative influences caused by environmental and societal changes. The

UNISDR (2004) defined vulnerability as comprising the elements involved in rendering a system susceptible to damage by a hazard. Turner II et al. (2003) discussed how vulnerability is influenced by factor exposure, sensitivity, and resilience, with resilience representing the ability of exposed individuals to resist and recover from damage caused by external threats (Clark et al., 2000). Cardona and Carreño (2011) assessed exposure using the people, property, systems, and other elements present in hazard zones.

Vulnerability is not a new concept in risk and hazard assessment. However, it is difficult to obtain an acceptable consensus of what exactly falls under transport vulnerability. Jenelius et al. (2006) employed an index of link importance and site exposure to represent the impact of a failure of a particular link on the general travel cost to examine road network vulnerability. Bana e Costa et al. (2008) analyzed the vulnerability of bridges and tunnels in Lisbon caused by earthquakes to identify critical infrastructures. Jenelius (2009) extended the road network vulnerability from the link to regional importance and exposure and concluded that a greater substitution distance and additional derived temporal costs indicate reduced accessibility and greater vulnerability. De Andrade et al. (2010) estimated the natural and socioeconomic vulnerability of oil spills in which the most vulnerable areas are directly related to fishing and have low income and education levels.

Moreover, Hsieh et al. (2011) examined bridge failure vulnerabilities by using 11 related vulnerability factors and deduced that accessibility and redundancy significantly affect vulnerability and risk. To determine a passenger transportation system's resilience to terrorism, Cox et al. (2011) constructed operational metrics that ranged from specific trips to more holistic measures, including the contribution of those trips on economic activities based on vulnerability, flexibility, and resource availability. The developed model indicated a reduction of 76.9% in total trips because of fear factor as opposed to a decrease in capacity. An "impact area" vulnerability analysis approach, which evaluated the consequences of a link closure within its impact area instead of the entire network, significantly improved the efficiency of determining the most critical links in large-scale and congested road networks with uncertain demand (Chen et al. 2012). Miller-Hooks et al. (2012) proposed techniques that would substantively increase the ability to assist in predisruption network vulnerability assessment and make predisaster vulnerability reduction investment decisions.

In accordance with the aforementioned literature, this study defines vulnerability as the ability to provide sufficient operational functions to stakeholders of tourism areas, based on resistant and coping capacities for impacts caused by hazards, along with resilience for assisting in the recovery from negative impacts.

3. MODEL CONSTRUCTION

The emerging consensus is that sustainable systems should efficiently and effectively provide users with equitable and safe access to basic needs, stimulate economic development, and not cause environmental harm (Pope et al. 2004; Jeon et al. 2006). Sustainability has recently become a key planning objective. Items widely considered in measuring sustainability in relation to the transport system include social justice, accessibility, safety, universal design, economic health, and environmental quality (McMahon 2002; Ness et al. 2007).

Accordingly, this study develops the framework for assessing the sustainability of tourism spots in mountainous areas based on environmental capacity. The vulnerability factors proposed according to the aforementioned literature are classified into three dimensions referring to sustainable development, namely economic efficiency, social equity, and environmental quality. The construct of economic efficiency is composed of mobility, economic health, and reliability. Mobility refers to the efficiency of vehicle movement through the road system from tourism areas to intercity transportation systems. Moreover, mobility describes individual ease of movement (Levine and Garb 2002; Levinson 2003). As a result, satisfying users' need for mobility refers to developing the capability to overcome spatial resistance. Both short- and long-term cost efficiency should also be considered in the construct of economic health. Therefore, the ratio between traffic volume and highway capacity (V/C) in the ground access systems of tourism spots in mountainous areas is utilized as the substitution of mobility, and the revenues of tourism industries in scenic spots represents the economic health. Reliability describes consistent, stable, and standard outcomes when the experience is repeated under the same conditions. The key factor influencing needs satisfaction with regard to reliability is thus represented by the redundancies of resources for supporting daily life.

Social equity issues in sustainable tourism involve residents, income, social constructs, and accessibility. Exposure was assessed using people, property, systems, and other elements present in hazard zones (Cardona and Carreño, 2011), and the number of residents was used as a proxy for the exposure to road network failure. The resident population experiences the direct negative effects caused by road failure in daily life, including increased travel time, lack of access to the health care system, and inferior quality of life. A larger number of residents implies a greater number of potentially affected people and, thus, greater vulnerability.

From the socioeconomic perspective, the share of disadvantaged groups with a limited self-protection capacity is proportional to vulnerability, in which the criteria consist of the age of the population and number of disabled people (Messner and Meyer, 2006). Aging populations and low fertility rates have significantly influenced global demographics and increased the dependency ratio. The dependency ratio represents the ratio of the total population of people under 15 years and over 65 years of age to the working population aged between 15 and 65 years. A higher dependency ratio represents a higher loading on the working-age population and implies greater vulnerability. Accessibility is utilized to evaluate network development in transportation planning and to measure the potential of regional economic performance in urban planning. In fact, Martellato et al. (1998) demonstrated that accessibility refers to potential opportunities within interactions among urban spatial patterns. Levine and Garb (2002) measured accessibility using the ease of interactions between network nodes.

Governments have traditionally constructed extensive infrastructure to enhance the economic efficiency of tourism spots in mountainous areas. However, thermal power, the major electronic power generated in Taiwan, has contributed to the greenhouse effect and ozone hole and has consequently threatened the very ecological system on which human life depends. In response to such research, policies in developed countries have changed in recent years to mitigate adverse environmental impacts. Moreover, excessive use of resources, especially nonrenewable resources, should be considered in relation to environmental quality (McMahon, 2002; Pope et al., 2004; Steg and Gifford, 2005; Loo and Chow, 2006; Ness et al., 2007).

Environmental capacity is employed as the basis of the assessment framework, and other vulnerability factors influence the basic environmental capacity of tourism spots in mountainous areas. This assessment uses multiplication to indicate the adjustment of each vulnerability factor to the environmental capacity of tourism areas, overcoming the problem of the inconsistent units among vulnerable factors. Equation 1 illustrates the vulnerability of tourism spots in mountainous areas.

$$Vul = \frac{I}{R} \times \frac{R}{A} \times \frac{A}{W} \times \frac{D}{I} \times \frac{V}{C} \times \frac{E}{TR} \quad (1)$$

Where, *Vul*: vulnerability of the tourism area;

I: sum of annual income;

R: number of residents substituted to physical exposure;

A: accessibility of road system from the tourism areas to the intercity network;

W: redundant daily resource in the wholesalers and retailers;

D: dependency ratio;

V: traffic volume of the access network;

C: capacity of the access network;

E: emission of the tourism industry;

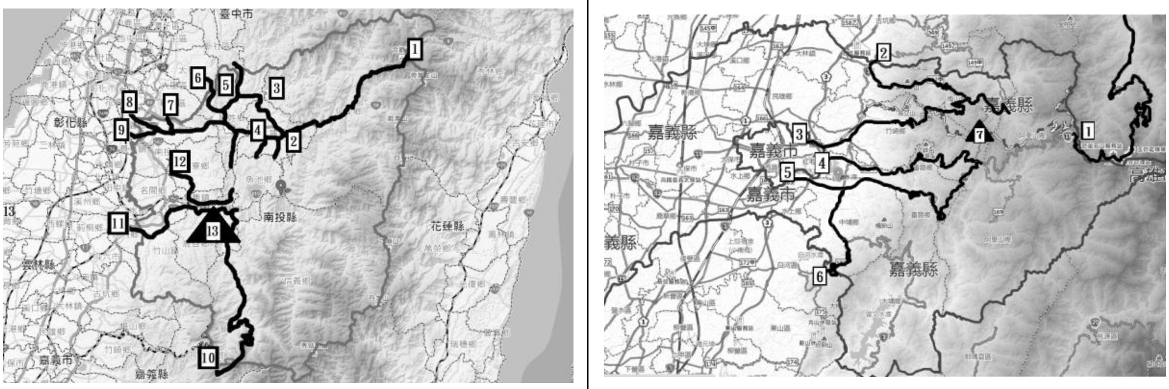
TR: total revenue of the tourism industry.

The first item on the right hand side of Eq. 1 expresses the average income of residents in tourism areas that might be damaged in the hazards as the exposure positively proportioned to vulnerability. The second item indicates the average loading of the access network, in which higher loading might cause a failure to evacuate. The third item represents the multiplicative inverse of redundant daily resources in an isolated area. Along with exposure to hazards, income refers to the resilience to rapidly recover from disaster losses, whereas a higher dependency ratio indicates that more rescue resources are needed to invest in a group without sufficient self-protection and response capacities. The fifth item denotes the network capacity around the tourism areas, and the last item shows the basis of tourism development, demonstrating how much emission per revenue is in the tourism industry.

4. EMPIRICAL RESULTS

Two famous mountainous tourism areas in Taiwan—Sun Moon Lake and Alishan—are utilized as empirical cases to analyze the sustainability of tourism areas and to verify the feasibility of vulnerability assessments. From the mesoscopic viewpoint, this study simplified the access road network into 13 links in Sun Moon Lake and 7 links in Alishan. Figure 1 shows the digitized spatial location of the selected links in the mountainous tourism areas. The selected links identified as main arteries are those in which sufficient traffic volumes are measured by authorities.

The preliminary data on vulnerability factors include published statistics, studies, and digitized data from the base year of 2013. The numbers of residents and the dependency ratio were sourced from the city’s annual statistical overview. The number of wholesalers and retailers were referenced from the national industry, commerce, and service census. The average annual household-consolidated income tax represents household disposable income.



Sun Moon Lake | Alishan

Figure 1. Access road network of the investigated tourism spots in mountainous areas

Emission was calculated according to the electric power consumption of tourism industries provided by the Taiwan Power Company; the emission of carbon dioxide (CO_2) in Sun Moon Lake and Alishan were 6.26 and 1.90 billion-grams, respectively. The number of wholesalers and retailers in Sun Moon Lake and Alishan were 371 and 104, and the total revenues of tourism industries in Sun Moon Lake and Alishan were 1.50 and 0.26 billion New Taiwan dollars (NTD). Moreover, the household-consolidated income tax collected by the Fiscal Information Agency, Ministry of Finance, shows that the total income in Sun Moon Lake and Alishan were 1.56 and 0.37 billion NTD, respectively. The population in Sun Moon Lake and Alishan were 16,686 and 5,732 persons, and the dependency ratio in Sun Moon Lake and Alishan were 29.45% and 27.84%, respectively.

Table 1. Analytical results of vulnerability in mountainous tourism areas

Vulnerability factors	Sun Moon Lake	Alishan
Overall vulnerability	29.11	101.23
Average income (10^3 NTD/person)	93.44	63.73
Highway loading (10^3 persons/link)	1.28	0.82
Daily resource deficiency	0.04	0.07
Dependency (10^{-10})	1.89	7.62
Level of service	0.88	0.52
Environmental impact (gram/NTD)	4.17	7.27

Table 1 lists the analytical results of vulnerability in the two mountainous tourism areas. The basic factor of sustainability in these areas listed in the last row in Table 1 (i.e., environmental impact) reveals that Sun Moon Lake is more sustainable than Alishan because the total revenue of the tourism industry in Sun Moon Lake is 5.74 times that of Alishan, whereas the emission of CO_2 in Sun Moon Lake is 3.29 times that of Alishan. Although the dependency ratio of Alishan is lower than that of Sun Moon Lake, the much lower disposable income leads Alishan to more vulnerable dependency. Furthermore, Alishan performs better in economic exposure (i.e., average income) and highway loading, as well as level of service (i.e., V/C); however, sustainability in Alishan is more vulnerable than in Sun Moon Lake.

The mountainous tourism areas with higher vulnerability should be of primary concern to mitigate impact intensity. Tourism spots in mountainous areas are more vulnerable due to longer distances to a well-connected intercity transportation systems in case of an emergency, because of the detour routes required and because more people do not have sufficient capacity for self-protection. However, along with costly rescues of disadvantaged residents, it is difficult to achieve the break-even point for constructing redundant physical infrastructures due to low demand. Reducing and limiting the number of livestock dependent on ground access systems to prevent further degradation from overutilization is critical in these vulnerable areas.

To achieve the accessibility, mobility, and sustainability needed in the mountainous tourism areas of Taiwan, there must be regulation for controlling the entrance of private vehicles to ensure appropriate network loading during an evacuation. Simultaneously, the integrated public transportation network should provide sufficient connectivity to intra and intertourism areas. Moreover, strategies based on transit-oriented development, such as a pedestrian-friendly environment, advanced traveler information systems and frequent public transit services, could assist tourism areas in mitigating traffic congestion in the access network and improving safety. From an environmental perspective, governments can subsidize green transit vehicles to increase the environmental benefits in tourism areas. Charging a higher congestion tax internalizes social costs in areas with remarkable environmental degradation and is helpful in limiting the development of highway systems in environmentally sensitive tourism areas.

In addition to pre-evacuation to mitigate damage and reduce the costs of rescue, governments should limit the development of vulnerable areas through land-use regulations and the transfer of development rights for reducing exposure and improving vulnerability. Along with the allocation of rescue resources, the redundancy of resources for supporting daily life should be improved to mitigate the impact of isolation caused by disasters. Furthermore, to encourage investment in environmentally friendly tourism, industries should be reducing emissions as well as waste and should be creating employment opportunities in local areas, which will lead to a return of working-age people and improvement of the dependency ratio.

5. CONCLUSIONS

Taiwan’s national parks, scenic areas, nature reserves, and culture conservation areas have many natural, cultural, and socioeconomic resources that are advantageous to tourism. Tourism development helps increase the sustainability of culture, the economy, and the environment, and depends on the relationships among tourists, tourism industries, the authorities, and area residents. It is difficult, however, for the tourism industry to prevent and deal with the negative impacts of catastrophic changes in the environment and climate, and these changes have increased in size, duration, and frequency. The absence of disaster prevention, mitigation, preparedness, and relief all contribute to the adverse impacts that a natural disaster has on social mechanisms, quality of life, property, and the economy. The absence of an assessment framework of tourism vulnerability might be negatively affecting the sustainability of tourism areas.

Accordingly, the vulnerability analysis of the natural conditions, infrastructures, services, and socioeconomic factors in regional tourism is helpful for determining the crucial vulnerability factors and for developing strategies to mitigate losses. The study combines vulnerability within tourist areas and access roads to construct a model for assessing vulnerability, where six vulnerability factors affecting tourism areas are utilized to assess the areas’ sustainability. Alishan and Sun Moon Lake, two popular scenic areas in Taiwan, are employed as the empirical cases. Along with identifying critical vulnerability factors, this study carries the managerial implications of threatened regional tourism and provides resource allocation strategies for mitigating the negative impacts of external forces on the regional tourism system.

The analytical results reveal that the basic environmental impact in Sun Moon Lake is more sustainable than in Alishan because of its higher ratio of total revenue from the tourism industry and its CO_2 emission level. Alishan performs better in economic exposure, highway loading, and level of service; however, the sustainability of Alishan is more vulnerable than that of Sun Moon Lake because of the more serious impact of tourism development and fewer disaster recovery resources. Accordingly, this study recommends strategies for reducing vulnerability in mountainous tourism areas, including regulations for controlling the entrance of private vehicles, transit-oriented development, increased redundancy of daily resources, the allocation of rescue resources, and the creation of employment opportunities.

REFERENCES

Adger, W.N., 2006. Vulnerability. Global Environmental Change, 16(3), 268-281.

Bana e Costa, C.A., Oliveira, C.S. and Vieira, V., 2008. Prioritization of bridges and tunnels in earthquake risk mitigation using multicriteria decision analysis: Application to Lisbon. Omega, 36(3), 442-450.

Berdica, K., 2002. An introduction to road vulnerability: What has been done, is done and should be done. Transport Policy, 9(2), 117-127.

Cardona, O.D. and Carreño, M.L., 2011. Updating the indicators of disaster risk and risk management for the Americas. Journal of Integrated Disaster Risk Management, 1(1), 1-21.

Chambers, R., 2006. Vulnerability, coping and policy. IDS Bulletin, 37(4), 33-40.

Chen, B.Y., Lam, W.H.K., Sumalee, A., Li, Q. and Li, Z.-C., 2012. Vulnerability analysis for large-scale and congested road networks with demand uncertainty. Transportation Research Part A, 46(3), 501-516.

Clark, W.C., Jäeger, J., Corell, R., Kasperson, R., McCarthy, J.J., Cash, D. et al., 2000. Assessing vulnerability to global environmental risks, Paper presented at the Workshop on Vulnerability to Global Environmental Change: Challenges for Research, Assessment and Decision Making, Airlie House, Warrenton, Virginia, May 22-25.

Commission of the European Communities, 2002. Communication from the commission on impact assessment. COM (2002) 276 final, Commission of the European Communities, Brussels.

Cox, A., Prager, F. and Rose, A., 2011. Transportation security and the role of resilience: a foundation for operational metrics. Transport Policy, 18(2), 307-317.

de Andrade, M.M.N., Szlafsztein C.F., Souza-Filho P.W.M., Araújo A.d.R. and Gomes M.K.T., 2010. A socioeconomic and natural vulnerability index for oil spills in an Amazonian harbor: A case study using GIS and remote sensing. Journal of Environmental Management, 91(10), 1972-1980.

George C., 2001. Sustainability appraisal for sustainable development: Integrating everything from jobs to climate change. Impact Assessment and Project Appraisal, 19(2), 95-106.

Holmgren, Å.J., 2004. Vulnerability Analysis of Electric Power Delivery Networks. Mark och vatten, Stockholm.

Hsieh, C.H., Su, J.L. and Feng, C.M., 2011. Disaster risk assessment of highway bridge from vulnerability perspective. Journal of the Eastern Asia Society for Transportation Studies, 9, 1-15.

Intergovernmental Panel on Climate Change (IPCC), 2001. Technical Summary – Climate Change 2001: Impacts, Adaptation, and Vulnerability. IPCC, Geneva.

Jenelius, E., 2009. Network structure and travel patterns: Explaining the geographical disparities of road network vulnerability. Journal of Transport Geography, 17(3), 234-244.

Jenelius, E., Petersen, T., Mattsson, L.G., 2006. Importance and exposure in road network vulnerability analysis. Transportation Research Part A: Policy and Practice, 40(7), 537-560.

Jeon, C.M., Amekudzi, A.A. and Vanegas, J., 2006. Transportation system sustainability issues in high-, middle-, and low-income economics: Case studies from Georgia (U.S.), South Korea, Colombia, and Ghana. Journal of Urban Planning and Development, 132(3), 172-186.

Kasemir, B., Jäger, J., Jaeger, C.C. and Gardner, M.T., 2003. Public Participation in Sustainability Science. Cambridge University Press, Cambridge.

Levine, J. and Garb, Y., 2002. Congestion pricing conditional promise: promotion of accessibility or mobility? Transport Policy, 9(3), 178-188.

Levinson, D., 2003. Perspectives on efficiency in transportation. International Journal of Transport Management, 1(3), 145-155.

Loo, B.P.Y. and Chow, S.Y., 2006. Sustainable urban transportation: Concepts, policies, and methodologies. Journal of Urban Planning and Development, 132(2), 76-79.

Martellato, D., Reggiani, A. and Nijkamp, P., 1998. Measurement and measures of network accessibility - economic perspectives. In K. Button, P. Nijkamp and H. Priemus (eds.) Transport Networks in Europe; Concepts, Analysis and Policies. Edward Elgar, London, 161-180.

McMahon, S.K., 2002. The development of quality of life indicators - a case study from the City of Bristol, UK. Ecological Indicators, 2(1-2), 177-185.

Messner, F. and Meyer, V., 2006. Flood damage, vulnerability and risk perception – Challenges for flood damage research. In J. Schanze, E. Zeman and J. Marsalek (eds.) Flood Risk Management: Hazards, Vulnerability and Mitigation Measures. Springer, Netherlands, 149-167.

Miller-Hooks, E., Zhang, X. and Faturechi, R., 2012. Measuring and maximizing resilience of freight transportation networks. Computers and Operations Research, 39(7), 1633-1643.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. and Olsson, L., 2007. Categorising tools for sustainability assessment. Ecological Economics, 60(3), 498-508.

Pope, J., Annandale, D. and Morrison-Saunders, A., 2004. Conceptualising sustainability assessment. Environmental Impact Assessment Review, 24(6), 595-616.

Shafer, C.S., Lee, B.K. and Turner, S., 2000. A tale of three greenway trails: User perceptions related to quality of life. Landscape and Urban Planning. 49(3-4), 163-178.

Steg, L. and Gifford, R., 2005. Sustainable transportation and quality of life. Journal of Transport Geography, 13(1), 59-69.

Stewart, M.C., 1993. Sustainable tourism development and marine conservation regimes. Ocean and Coastal Management, 20(3), 201-217.

Turner II, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L. et al., 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America, 100(14), 8074-8079.

United Nations, International Strategy for Disaster Reduction (UNISDR), 2004. Living with Risk: A Global Review of Disaster Reduction Initiatives. United Nations Publication, Geneva.

United Nations, International Strategy for Disaster Reduction (UNISDR), 2005. Hyogo Declaration. United Nations Publication, Geneva.

Valentine, P.S., 1993. Ecotourism and nature conservation: A definition with some recent developments in Micronesia. Tourism Management, 14(2), 107-115.

World Commission on Environment and Development, 1987. Our Common Future. Oxford University Press, Oxford.
Yang, Z., 2002. Microanalysis of shopping center location in terms of retail supply quality and environmental impact. Journal of Urban Planning and Development, 128(3), 139-149.

科技部補助專題研究計畫成果自評表

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（簡要敘述成果是否具有政策應用參考價值及具影響公共利益之重大發現）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(請於其他欄註明專利及技轉之證號、合約、申請及洽談等詳細資訊)

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 200 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，針對山區公路系統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偏遠地區道路與觀光系統因應風險之學術研究與實務規劃設計的參考。山區道路除產業需求與偏遠地區居民可及性服務外，更為臺灣觀光休閒產業重要利基之一，建置回復利評估模式為地方政府及觀光休閒業者進行山區景點聯外運輸系統之規劃重點，並有助於資源布局與區域業者策略聯盟之研擬。災害發生前，考量環境易損行之山區道路脆弱度有助於界定高風險地區、並執行預警及預疏散工作；災害發生時，觀光景點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，山區觀光景點聯外運輸系統脆弱度與回復力仍有助於減災階段之風險管理。本研究初步成果已投稿至 Asian Logistics Round Table 研討會並口頭發表，後續將尋求國際學術期刊發表之機會。

4. 主要發現

本研究具有政策應用參考價值： ■否 □是，建議提供機關________

(勾選「是」者，請列舉建議可提供施政參考之業務主管機關)

本研究具影響公共利益之重大發現：■否 □是

說明：(以 150 字為限)

科技部補助專題研究計畫出席國際學術會議心得報告

日期：105 年 5 月 20 日

<table>
<tr><td>計畫編號</td><td colspan="3">MOST 104－2410－H－263－010－</td></tr>
<tr><td>計畫名稱</td><td colspan="3">考量環境易損性之山區公路脆弱度解構分析</td></tr>
<tr><td>出國人員姓名</td><td>謝承憲</td><td>服務機構及職稱</td><td>致理科技大學 行銷與流通管理系
副教授</td></tr>
<tr><td>會議時間</td><td>105 年 1 月 10 日至
105 年 1 月 14 日</td><td>會議地點</td><td>Washington, D.C., U.S.A.</td></tr>
<tr><td>會議名稱</td><td colspan="3">(中文) 美國運輸研究委員會第 95 屆年會

(英文) The 95th Annual Meeting of Transportation Research Board</td></tr>
<tr><td>發表題目</td><td colspan="3">(中文) 跨境供應鏈營運者之回復力投資策略
(英文) The resilience investment of logistics operators in transnational supply chain</td></tr>
</table>

一、 參加會議經過

美國運輸研究委員會 (Transportation Research Board, TRB) 每年一月份買華盛頓特區舉辦之 TRB 年會為全球最盛大之運輸學術研討會之一，該年會每年吸引超過 12,000 名世界各地運輸學者專家與會，今年估計超過 5,000 篇研討會論文發表，會議內容包括各項先進之運輸科技、研究、應用與合作相關議題。五天的會議共有超過 800 場次的研討與工作坊，其中 35 場為今年聚焦的 “Research Convergence for a Multimodal Future”，另有 75 場次則用以發表 TRB 關注的變革性技術、運輸與健康、及運輸回復力等。

受補助者於美國東岸時間 1 月 10 日清晨抵達華盛頓杜勒斯國際機場，於當地時間下午 15 時前往 Walter E. Washington Convention Center 參加開幕儀式，當晚並參與 2016 Technical Information Exchange 學術交流會，針對運輸發展現況分享研究經驗、交換學術資訊、並促進與世界先進國家交流機會，並與駐美國台北經濟文化辦事處科技組 (Science and Technology Division, TECRO) 周家蓓教授進行意見交換。1 月 11 日上午前往 poster 論文區發掘新興議題並與論文作者進行討論，並針對所發表之跨國冷鏈回復力內涵進行說明，與相關學者於該議題進行意見交換。下午與國立東華大學陳正杰教授前往運輸部拜會。

1 月 12 日上午前往 Critical Transportation Infrastructure Protection Committee 旁聽來自產官學專家討論各國對於運輸基礎設施面臨危害，尤其是人為災害如恐怖攻擊時，可採取之防護計畫。下午則參與公共運輸設施之防護與回復力系列論文發表場次。1 月 13 日上午選擇 Advances in Intermodal Freight Terminal Design and Operations 場次聆聽複合運輸相關研究趨勢與產業動態，下午參與 Logistics of Disaster and Business Continuity Committee 討論，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

本次投稿以跨境冷鏈物流回復力之探討為主，參與交流場次亦以該類相關之主題為首要，研討會中所接觸主要探討主題包括供應鏈斷鏈 (supply chain disruption)，與會專家並以國際行動電話製造大廠 Nokia 及 Ericsson 為實際案例進行說明斷鏈狀況與相關衝擊，另外並針對回復力 (resilience) 與永續性 (sustainability) 之異同進行比較，但仍難獲得一致共識之定義與說明，此外，亦有學者提出供應鏈回復力與供應鏈安全 (supply chain security) 其概念與所關注議題之異同，多元觀點實獲益匪淺，並有助於受補助人未來相關研究之調整與可能之國際合作。

另外，除供應鏈回復力外，並參與關鍵基礎設施防護與回復力之相關發表與討論，主要強調受災之損害，甚至包括應受管制傳染疾病之影響，另外提及回復力應涵括快速之復原 (speed recovery) 及參與救援者其家庭，以卡崔娜颶風為例，參與救災者其本身亦為受災戶，在家庭受災情況不明朗前提下、甚至已知家庭成員生命之殞落，探究如何在其 shock recovery 過程中仍能維持救援能量。與臺灣狀況相同的部分，則係高齡化社會與身心障礙等弱勢團體之家庭面臨危害時之抵禦能力逐漸受到重視；此外，亦有學者以海地震災為例，說明土地使用與社會網路 (social networks，社群) 在回復及災後重建所扮演之角色，與過去受補助者多僅以亞洲民情與救災體系角度進行思考多有差異。

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

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. This 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 this 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, this study 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. This study 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. This study 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), this study 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.

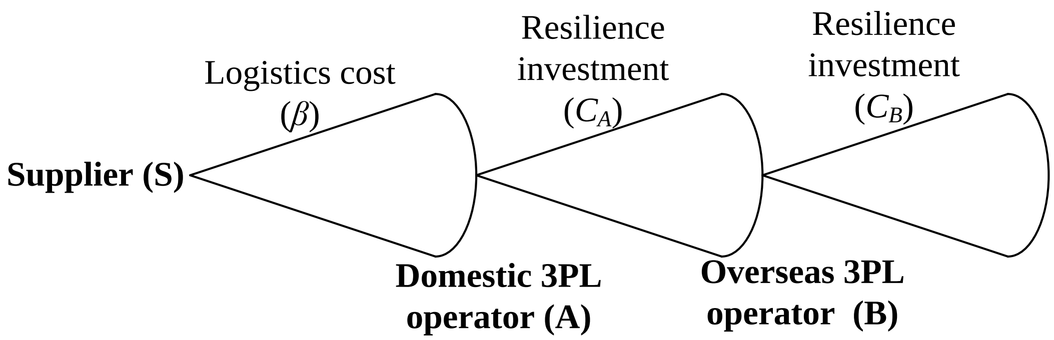


FIGURE 1 Framework of game tree.

All players aimed to minimize costs. This study 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, this study 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. This study 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, this study 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).

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

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.

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

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.

$$\tau = \Delta Q_s \times \alpha\beta \qquad (3)$$

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, this study 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).

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

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

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

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.

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

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.

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

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

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.

$$C_B^* = \frac{-\ln\left(\frac{1}{\Pr\times Q\beta(1-\gamma)c}\right)}{c} \tag{9}$$

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

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

This 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 this 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. This 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. This 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.

ACKNOWLEDGMENTS

The authors would like to thank the Ministry of Science and Technology of the Republic of China, Taiwan for financially supporting this research under Contract No. MOST 103-2410-H-263-002.

REFERENCES

1. Craighead, C. W., J. Blackhurst, M. J. Rungtusanatham, and R. B. Handfield. The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities. *Decision Sciences*, Vol. 38, No. 1, 2007, pp. 131–156.
2. Sheffi, Y., and J. B. Rice Jr. A Supply Chain View of the Resilient Enterprise. *Sloan Management Review*, Vol. 47, No. 1, 2005, pp. 41–48.
3. Tang, C. S. Robust Strategies for Mitigating Supply Chain Disruptions. *International Journal of Logistics Research and Applications*, Vol. 9, No. 1, 2006, pp. 33–45.
4. Soni, U., V. Jain, and S. Kumar. Measuring Supply Chain Resilience Using a Deterministic Modeling Approach. *Computers and Industrial Engineering*, Vol. 74, 2014, pp. 11–25.
5. Ponomarov, S. Y., and M. C. Holcomb. Understanding the Concept of Supply Chain Resilience.

International Journal of Logistics Management, Vol. 20, No. 1, 2009, pp.124–143.
6. Du, Q., K. Kishi, and T. Nakatsuji. Vulnerability Evaluation of Logistics Transportation Networks Under Seismic Disasters. In *Transportation Research Board 94th Annual Meeting, Transportation*, Research Board of the National Academies, Washington, D.C., 2015.
7. Christopher, M.and H. Peck. Building the Resilient Supply Chain. *International Journal of Logistics Management*, Vol. 15, No. 2, 2004, pp.1–14
8. Wagner, S. M., and C. Bode. An Empirical Examination of Supply Chain Performance along Several Dimensions of Risk. *Journal of Business Logistics*, Vol. 29, No. 1, 2008, pp. 307–325.
9. Wagner, S. M., N. Neshat. Assessing the Vulnerability of Supply Chains Using Graph Theory. *International Journal of Production Economics*, Vol. 126, No. 1, 2010, pp. 121–129.
10. Fazli, S., and A. Masoumi. Assessing the Vulnerability of Supply Chain Using Analytic Network Process Approach. *International Research Journal of Applied and Basic Sciences*, Vol. 3, No. 13, 2012, pp. 2763–2771.
11. Pettit, T. J., J. Fiksel, and K. L. Croxton. Ensuring Supply Chain Resilience: Development of a Conceptual Framework. *Journal of Business Logistics*, Vol. 31, No. 1, 2010, pp. 1–21.
12. Chen, C., C. Feng, Y. Tsai, and P. Wu. Modeling Resilience Enhancement Strategies for International Express Logistics. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2378*, Transportation Research Board of the National Academies, Washington, D.C., 2013, pp 92–98.
13. Du, Q., T. Nakatsuji, and K. Kishi.Transportation Network Vulnerability: Vulnerability Scanning Methodology Applied to Multiple Logistics Transport Networks. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2410*, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp 96–104.
14. Melnyk, S. A., E. W. Davis, R. E. Spekman, and J. Sandor. Outcome-driven Supply Chains. *Sloan Management Review*, Vol. 51, No. 2, 2010, pp. 33–38.
15. Ratick, S., B. Meacham, Y. Aoyama. Locating Backup Facilities to Enhance Supply Chain Disaster Resilience. *Growth and Change*, Vol. 39, No. 4, 2008, pp. 642–666.
16. Iakovou, E., D. Vlachos, and A. Xanthopoulos. An Analytical Methodological Framework for the Optimal Design of Resilient Supply Chains. International Journal of Logistics Economics and Globalisation, Vol. 1, No. 1, 2007, pp. 1–20.
17. Soni, U., and V. Jain, V. Minimizing the Vulnerabilities of Supply Chain: A New Framework for Enhancing the Resilience. *Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference on*, pp. 933–939.
18. Omer, M., A. Mostashari, R. Nilchiani, and M. Mansouri. Aframework for Assessing Resiliency of Maritime Transportation Systems. *Maritime Policy and Management*, Vol. 39, No. 7, 2012, pp. 685–703.
19. Dixit, A. K., and S. Skeath. *Games of Strategy* (2nd Edition). W. W. Norton & Company, Inc., New York, 2004.
20. Aust, G., and U. Buscher. Vertical Cooperative Advertising and Pricing Decisions in a Manufacturer–Retailer Supply Chain: A Game-theoretic Approach. *European Journal of Operational Research*, Vol. 223, No. 2, 2012, pp. 473–482
21. Sun, J., J. Lin, and Y. Qian. Game-theoretic Analysis of Competitive Agri-biomass Supply

Chain. *Journal of Cleaner Production*, 43, 2013, pp. 174–181.
22. Bakshi, N., and P. Kleindorfer. Co-opetition and Investment for Supply-Chain Resilience. *Production and Operations Management*, Vol. 18, No. 6, 2009, pp. 583–603.
23. Yue, D. and F. You. Game-theoretic Modeling and Optimization of Multi-echelon Supply Chain Design and Operation under Stackelberg Game and Market Equilibrium. *Computers and Chemical Engineering*, 71, 2014, pp. 347–361.

四、 建議

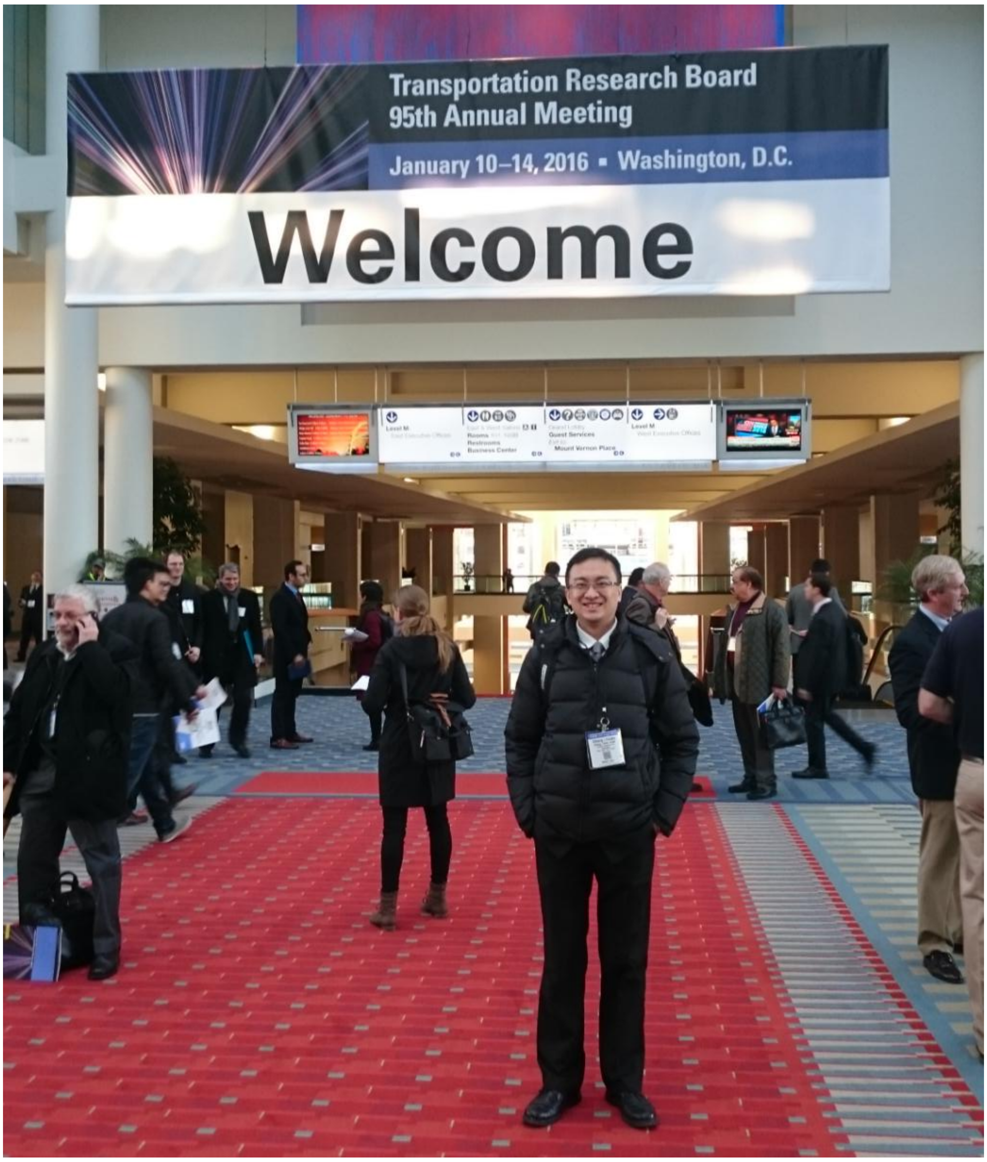
TRB 為世界最大規模運輸學術研討會之一，今年所接觸華人作者多來自於大陸地區，其留學生參與積極度增加，研究能量不可小覷，雖臺灣地區在相關的運輸研究仍具一定優勢，但學生多以參與國內活動為滿足，一方面可能也受限於英語能力較為不足，較缺乏與國際學術交流接軌之機會，未來若能在經費許可且甄選合適人選前提下，提供學生出國參與國際研討會，相信有助於提升學生的國際化視野。

五、攜回資料名稱及內容

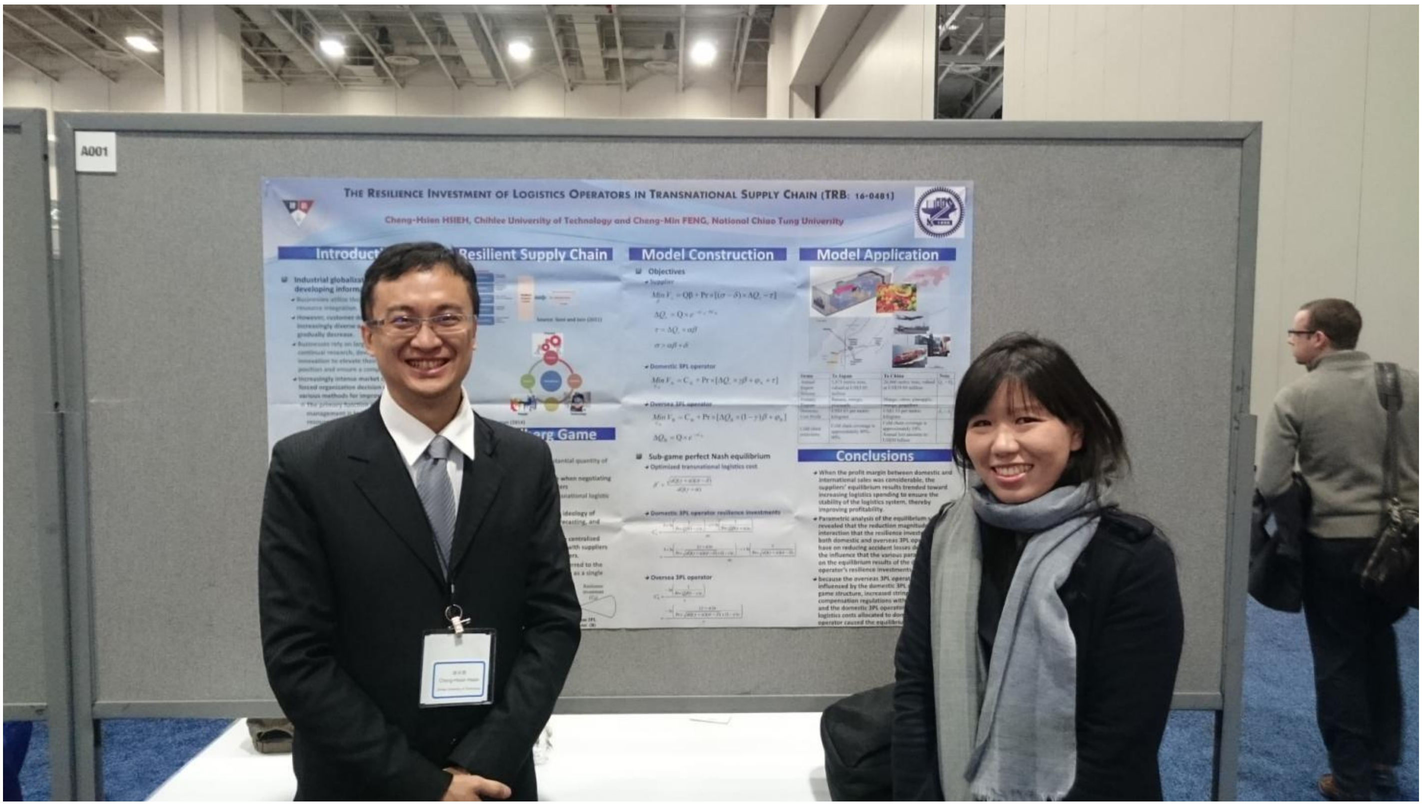
An abstract proceeding in electronic format, and the Conference Program including a wide spectrum of research topics, and the industrial exhibition information.

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



海報發表場次

Logistics of Disaster and Business Continuity Committee 會場

科技部補助計畫衍生研發成果推廣資料表

日期:2016/08/18

科技部補助計畫	計畫名稱: 考量環境易損性之山區公路脆弱度解構分析
	計畫主持人: 謝承憲
	計畫編號: 104-2410-H-263-009-　　學門領域: 交通運輸

無研發成果推廣資料

104年度專題研究計畫成果彙整表

計畫主持人：謝承憲	計畫編號：104-2410-H-263-009-
計畫名稱：考量環境易損性之山區公路脆弱度解構分析	

成果項目					量化	單位	質化（說明：各成果項目請附佐證資料或細項說明，如期刊名稱、年份、卷期、起訖頁數、證號...等）
國內	學術性論文	期刊論文			0	篇	
		研討會論文			0		
		專書			0	本	
		專書論文			0	章	
		技術報告			0	篇	
		其他			0	篇	
	智慧財產權及成果	專利權	發明專利	申請中	0	件	
				已獲得	0		
			新型/設計專利		0		
		商標權			0		
		營業秘密			0		
		積體電路電路布局權			0		
		著作權			0		
		品種權			0		
		其他			0		
	技術移轉	件數			0	件	
		收入			0	千元	
國外	學術性論文	期刊論文			0	篇	
		研討會論文			1		Oral presentation at the special section ""Sustainability development of transport ans logistics"" in the Asian Logistics Round Table.
		專書			0	本	
		專書論文			0	章	
		技術報告			0	篇	
		其他			0	篇	
	智慧財產權及成果	專利權	發明專利	申請中	0	件	
				已獲得	0		
			新型/設計專利		0		
		商標權			0		
		營業秘密			0		
		積體電路電路布局權			0		

		著作權	0		
		品種權	0		
		其他	0		
	技術移轉	件數	0	件	
		收入	0	千元	
參與計畫人力	本國籍	大專生	3	人次	
		碩士生	1		
		博士生	0		
		博士後研究員	0		
		專任助理	0		
	非本國籍	大專生	0		
		碩士生	0		
		博士生	0		
		博士後研究員	0		
		專任助理	0		
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。）					

科技部補助專題研究計畫成果自評表

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（簡要敘述成果是否具有政策應用參考價值及具影響公共利益之重大發現）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（請於其他欄註明專利及技轉之證號、合約、申請及洽談等詳細資訊）

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200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，針對山區公路系統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偏遠地區道路與觀光系統因應風險之學術研究與實務規劃設計的參考。山區道路除產業需求與偏遠地區居民可及性服務外，更為臺灣觀光休閒產業重要利基之一，建置回復利評估模式為地方政府及觀光休閒業者進行山區景點聯外運輸系統之規劃重點，並有助於資源布局與區域業者策略聯盟之研擬。災害發生前，考量環境易損行之山區道路脆弱度有助於界定高風險地區、並執行預警及預疏散工作；災害發生時，觀光景點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，山區觀光景點聯外運輸系統脆弱度與回復力仍有助於減災階段之風險管理。本研究初步成果已投稿至Asian Logistics Round Table研討會並口頭發表，後續將尋求國際學術期刊發表之機會。

4. 主要發現

本研究具有政策應用參考價值：■否　□是，建議提供機關

（勾選「是」者，請列舉建議可提供施政參考之業務主管機關）

本研究具影響公共利益之重大發現：■否　□是

說明：（以150字為限）

未影響重大公共利益