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Ripple effect of disruptions on performance in supply chains: an empirical study

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Received 2 October 2022
Revised 11 February 2023
3 March 2023
Accepted 8 March 2023

Abstract

Purpose – The present study is performed to identify the propagation mechanism of the ripple effect as well as examine the simultaneous impact of risks on supply chain (SC) performance.

Design/methodology/approach – A theoretical framework with many hypotheses regarding the relationships between SC risk types and performance is established. The data are collected from a large-scale survey supported by a project of the Japanese government to promote sustainable socioeconomic development for the Association of Southeast Asian Nations (ASEAN) region, with the participation of 207 firms. Structural equation modeling (SEM) is used to test the hypotheses of the theoretical framework.

Findings – It is indicated that human-made risk causes operational risk, while natural risk causes both supply risk and operational risk. Furthermore, the impacts of human-made risk and natural risk on performance are amplified through operational risk.

Funding: The authors would like to thank Van Lang University, Ho Chi Minh City, Vietnam for funding this research. This research is funded by the University of Economics Ho Chi Minh City, Vietnam.

Engineering, Construction and Architectural Management
Vol. 31 No. 13, 2024
pp. 1-22
Emerald Publishing Limited
0969-9988
DOI 10.1108/ECAM-10-2022-0924

Research limitations/implications – This study is one of the first attempts that identifies the propagation mechanism of the ripple effect and examines the simultaneous impact of risks on performance in construction SCs.
Originality/value – Although many studies on risk management in construction SCs have been carried out, they mainly focus on risk identification or quantification of risk impact. It is observed that research on the ripple effect of disruptions has been very scarce.

Keywords Ripple effect, Disruptions, Performance, Supply chains
Paper type Research paper

1. Introduction

Due to distinctive peculiarities, the construction industry often lags behind other industries in terms of performance, productivity and efficiency (Costa *et al.*, 2019). Construction projects are always characterized by short-term relationships, rapidly changing environments, inherent complexities, time and cost overruns, and interruptions due to unforeseen conditions (Koc and Gurgun, 2021). These characteristics lead to the existence of risks in construction projects (Dikmen *et al.*, 2018). All projects always have a certain degree of uncertainty and risk, and construction projects are also not an exception (Pham *et al.*, 2022). Goh *et al.* (2013) conclude that risks are unavoidable during the progress of construction projects. Interruptions in any phase of the SC could cause extreme losses (Niu *et al.*, 2017). According to Koushki and Kartam (2004), approximately a quarter of project delays are associated with the late delivery of construction materials. Hence, efficient risk management in construction SCs is essential for increasing work efficiency, reducing environmental impacts and adding values for all partners (Aloini *et al.*, 2012). The development of a SC risk management plan has become more critical for construction firms in complex projects today to increase their presence and competitiveness in this industry (Koc and Gurgun, 2021).

In recent years, many studies on risks in construction SCs have been carried out, for example, Naderpajouh *et al.* (2015), Rudolf and Spinler (2018), Panova and Hilletofth (2018), Shojaei and Haeri (2019), Zhao (2019), Abas *et al.* (2022), Obayi and Ebrahimi (2021), Ekanayake *et al.* (2021a), and Ekanayake *et al.* (2022). These studies highlight the challenges (e.g. maintaining operations and improving performance) that construction firms have to face regarding the propagation of disruption. However, the above studies have not identified the propagation mechanism of the ripple effect as well as examined the simultaneous impact of all risk types on performance. The occurrence of some risks (e.g. late delivery from suppliers) may lead to shortage of inventory and delay of construction schedule, and then it may seriously impact the operations process of construction firms. In the same vein, Zheng *et al.* (2021) concluded it is vital to investigate the risk propagation because it may affect the planning, inventory and production schedule which are not directly at risk in some periods. This study is conducted to fill these gaps in the literature. Dolgui and Ivanov (2021) posit that one or more disruptions can propagate throughout the SC and have impacts on performance, hence the emphasis is increasingly placed on the ripple effect. Ripple effect is a specific topic in SCM and a strong stressor to SC resilience. The ripple effect is defined as disruption propagation of an initial disruption toward other SC stages namely supply, production and distribution. In this situation, the occurrence of a disruption risk (e.g. terrorism and war, political instability, epidemics and natural catastrophes) can cause the occurrence of internal risks (e.g. supply risk, operational risk and demand risk). In other words, the ripple effect occurs when a disruption risk, rather than being contained in one SC part, cascades downstream and affects the entire SC performance (Dolgui *et al.*, 2018).

The propagating impacts of a disruption make local disruptions unpredictable, thus it is hard for managing them. Traditional SC risk management begins with risk identification and ends with various strategies to reduce the impacts of identified risks (Craighead *et al.*, 2007). This approach is only effective in dealing with anticipated disruptions, but less effective in dealing with unexpected disruptions. It is vital for firms to develop resilience which allows them quickly respond to and recover from unexpected disruptions (Baghersad and Zobel, 2021). In this case, an understanding of the disruption propagation and how it impacts the whole SC can support various decision-making levels in terms of resilience investment. The whole SC performance is the integrated performance of individual firms inside that SC network, which can be measured by network health (i.e. the number of healthy firms at a specific time) (Li and Zobel, 2020). Thus, investigating how disruptions propagate throughout the SC network and affect the network health allows managers to optimally allocate resources, effectively manage disruption propagation and attain higher SC performance (Li *et al.*, 2021). These arguments from the literature have highlighted the importance of studying the effects of disruption propagation on SC performance. This motivated us to carry out the present study.

In summary, the two specific objectives of the present study include: (1) Identifying the propagation mechanism of the ripple effect in construction SCs and (2) examining the simultaneous impact of SC risks on performance. This study is carried out through two steps. At the first step, SC risks are identified and then, the ripple effect between them is defined. In the second step, an empirical study is conducted with data collected from the construction industry in order to examine the propagation mechanism of the ripple effect.

2. Literature review

2.1 Gaps

Many works on risk management in construction SCs have been performed in recent years. For example, the aim of Naderpajouh *et al.* (2015) is to study governance of risks related to counterfeit, fraudulent and suspect items in SCs of construction projects, while Rudolf and Spinler (2018) present a prioritized and structured view on the SC risk portfolio in the construction industry. Moreover, the work of Panova and Hilletofth (2018) is aimed at investigating methods and models to manage SC risks and delays in construction projects. Shojaei and Haeri (2019) propose a comprehensive SC risk management approach for construction projects that applies fuzzy cognitive mapping, grounded theory and grey relational analysis. Zhao (2019) defines the risk interconnectivity, propagation density and risk propagation speed; and distinguishes infectious risks from conventional risks in mega project SCs. In addition, the study of Abas *et al.* (2022) is aimed at identifying critical risk and success factors that have effects on SC performance, whereas the study of Obayi and Ebrahimi (2021) aims to explore the role of external neo-institutional pressures in shaping the risk management strategies implemented to reduce transaction cost risks in construction SCs. It is observed the above studies still mainly focus on the identification and assessment of risks. Two gaps of knowledge emerged from the analysis of these studies. First, they have not identified the propagation mechanism of the ripple effect. Second, they have not assessed the simultaneous impact of all SC risks on performance. In most of real-life situations, firms often face not only a single risk, but also multiple risks (Wu *et al.*, 2017). Various risks in a SC are linked in complex patterns in which the occurrence of one risk can lead to the occurrence of other risks (Song *et al.*, 2017).

In this study, the ripple effect refers that the occurrence of external risks can cause the occurrence of internal risks. The ripple effect is an increase in the degree of impact each and all risks have on performance through the mutual interactions between risks. To the best of our knowledge, evidence for this kind of effect has not yet been found in the literature. As supported by Ho *et al.* (2015), further investigations on the interrelationships among different risks rather than standalone risks can support the process of SC risk management. Thus, the first contribution of our study is to identify the propagation mechanism of the ripple effect in construction SCs.

Identifying inherent SC risks is one of the main tasks of managers because it allows them to better understand risks and enhance the effectiveness of risk management (Lin and

Zhou, 2011). From the perspective of SC managers, it is not easy to justify investments in risk reduction strategies if they are not directly associated with the payoff (Rajagopal *et al.*, 2017). In order to promote best risk mitigation practices, the impacts of risk on performance need to be examined (Colicchia and Strozzi, 2012). Therefore, many studies in various industries have empirically investigated the relationships between SC risks and performance such as Zhao *et al.* (2013), Mishra *et al.* (2016), Wiengarten *et al.* (2016), Brusset and Teller (2017), Chen (2018), and Wang (2018). However, evidence for the simultaneous impact of all risk types on performance in construction SCs is still limited. This is also the second knowledge gap found in the literature; and this study attempts to fill this gap. Kumar *et al.* (2018) argue that SC risks have been widely explored by individual case studies or standalone models, while research on their simultaneous impacts (i.e. ripple effect of risks on performance) on performance through empirical research has been scarce. The assessment and treatment of a single risk in isolation is ineffective due to the interdependent nature of risks. Risks are propagated and exert a systemic effect on the SC network. The impact of risk propagation is reflected by some performance criteria such as quality, time and cost (Jayasinghe *et al.*, 2022).

Research on the relationships between the ripple effect and performance has gained much attention from researchers in recent years. Ivanov *et al.* (2016) describe the ripple effect in general and one example of the ripple effect in the dairy SC, present a model for reactive recovery policies under conditions of the ripple effect and exemplify them on a simulation example. Hosseini and Ivanov (2022) theorize a new measure to quantify the resilience of an original equipment manufacturer with a multi-stage assessment of suppliers' proneness to disruptions and the SC exposure to the ripple effect. The contribution of Pavlov *et al.* (2019) lies in a conceptualization of a new methodical approach to the detection of disruption scenarios, ripple effect dispersal and recovery paths in SCs on the basis of structural genomes. In the study of Birkie and Trucco (2020), resilience capability has direct positive effect in mitigating disruptions when SC complexity is taken into account. Hosseini *et al.* (2020) construct a new model based on integration of Discrete-Time Markov Chain and a Dynamic Bayesian Network to quantify the ripple effect. Kinra *et al.* (2020) develop a new model to assess the ripple effect of a supplier disruption, based on possible maximum loss. Özçelik *et al.* (2021) examines the ripple effect on the system performance of the reverse SC network and introduces a robust optimization model for designing strong reverse SC networks to cope with the uncertainties caused by the ripple effect. Liu *et al.* (2021) propose a new robust Dynamic Bayesian network approach to analyze the worst-case oriented disruption propagation in the SC. Park *et al.* (2022) examines the ripple effect in SCs due to circular flows embedded in SC design. Ivanov (2022) performs a simulation analysis using anyLogistix digital SC twin to identify potential impacts of blackouts on SCs for scenarios of different severity. It is found that researchers have paid considerable attention to the optimization and modeling of the ripple effect, while research on the relationship between the ripple effect and performance with survey data is rather limited. Craighead and Meredith (2008) note that the use of empirical data (e.g. survey) can supplement modeling, simulation and mathematics for developing and testing theories. Many researchers (e.g. Scudder and Hill, 1998) have called for this type of empirical research since operations management became an established study field in the management discipline. Thus, our study attempts to empirically examine the impacts of risks on performance in SCs.

2.2 Risks in supply chains

Jüttner (2005) analyzed risks both in processes of a firm and in SC flows (e.g. information and products flows), and basically SC risks can be divided into two categories: internal risk and external risk (or disruption risk). In an empirical study with the participation of 67 German automotive firms, Thun and Hoenig (2011) demonstrated that there are significant differences between internal and external risks with regard to the impact on performance. Previous studies on construction SC risks have also classified risks into disruption and internal risks such as Pham *et al.* (2022).

Disruption risks (e.g. natural catastrophes, war and terrorism, epidemics, fire accidents, external legal issues, economic downturns, political instability, social and cultural grievances) always have a comprehensive effect on all activities in the SC network. Internal risks include three sub-categories: operational risk, supply risk and demand risk. These risks are daily issues that can directly affect the SC in various ways (Truong Quang and Hara, 2018). The current study conducted a review of the literature to identify all specific risks of sub-categories. Categories, sub-categories and risks are summarized in Table 1.

Categories	Sub-categories	Risks	References
Internal risk	Supply risk	• Supplier opportunism • Unstable quality of inputs • Price fluctuations • Inflexibility of suppliers • Supplier bankruptcy • Suppliers' dependency • Unstable quantity of inputs • Delays in supply activities	Abdel-Basset and Mohamed (2020), Moktadir *et al.* (2021), Rostamzadeh *et al.* (2018), Truong and Hara (2018), Wagner and Bode (2008)
	Operational risk	• Design changes • Poor planning and scheduling • Technological changes • Dissatisfaction with work • Accidents • Inflexibility in layout for free flow of materials • Labor disputes/strikes • Lack of experience or training	Abdel-Basset and Mohamed (2020), Cunha *et al.* (2019), Rostamzadeh *et al.* (2018), Song *et al.* (2017), Truong Quang and Hara (2018)
	Demand risk	• Demand variability • Deficient or missing customer relation management function • Customer bankruptcy • Customer dependency • High competition in the market • Customer fragmentation	Abdel-Basset and Mohamed (2020), George *et al.* (2004), Ho *et al.* (2015), Moktadir *et al.* (2021), Quang and Hara (2019), Rostamzadeh *et al.* (2018), Song *et al.* (2017), Thun and Hoenig (2011), Wagner and Bode (2008), Xu *et al.* (2019)
Disruption risk	Human-made risk	• Economic downturns • Social and cultural grievances • External legal issues • War and terrorism • Political instability	Abdel-Basset and Mohamed (2020), Contreras *et al.* (2021), Hansen *et al.* (2013), Manuj and Mentzer (2008), Moktadir *et al.* (2021), Rostamzadeh *et al.* (2018), Song *et al.* (2017), Truong Quang and Hara (2018), Wu *et al.* (2017), Xu *et al.* (2019)
	Natural risk	• Epidemics • Earthquakes • Natural catastrophes • Tsunami	

Source(s): Compiled by the authors

Table 1.
Supply chain risks

2.3 Supply chain performance

Kaplan and Norton (1992) argue the performance of a firm should be reflected by both short and long term measures, leading to the development of two indicators: lagging and leading ones. Lagging indicators describe what actually happened in the past such as financial variables while leading indicators give an early warning of what might happen in the future (e.g. human resource-oriented variables, customer-oriented variables). Financial measures always have a crucial role, yet in order to have a comprehensive performance scale, intangible and strategic-oriented measures need to be balanced with financial measures.

This study uses many aspects for measuring performance including finance, customer service, innovation and learning, internal business and supplier performance, as the inheritance from Kaplan and Norton (1992). Developed by Kaplan and Norton (1992), the Balanced Scorecard model recognizes the limitations of traditional firm performance measurement and then, translates the strategy of a firm into performance objectives, particularly focusing on intangible assets such as supplier and customer relationships, skills and knowledge levels of employees, value chain and innovation. This approach shifts the traditional focus on physical assets to emphasize both physical and intangible assets of a firm for long term development. The present study defines a set of performance measures based on the Balanced Scorecard model comprising five main dimensions: finance, customer service, innovation and learning, supplier performance and internal business.

3. Hypotheses development

3.1 The impacts of external risk on internal risk and supply chain performance

Risks such as natural catastrophes, war and terrorism, political and economical issues, social and cultural grievances, and epidemics are known as external risks (or disruption risks). These risks rarely appear but can strongly impact SC performance (Abdel-Basset and Mohamed, 2020; Moktadir *et al.*, 2021; Rostamzadeh *et al.*, 2018; Song *et al.*, 2017; Wu *et al.*, 2017; Xu *et al.*, 2019). For example, Hansen *et al.* (2013) found that economic downturns changed financial results and market demand as well as created a difficult business environment, even breaking the supplier-buyer relationship. Furthermore, the existence of a large number of procedures causes delays and difficulties in transactions between members in the SC (Truong Quang and Hara, 2018).

In particular, the recent Covid-19 pandemic has gained great attention from practitioners and academics as a fatal health crisis (Contreras *et al.*, 2021). Non-pharmaceutical measures have caused the supply and demand problems for SCs. Indeed, Barichello (2020) notes that social distancing has severely damaged the economic activities and financial instability. Members at the downstream side of the SC have greatly suffered due to demand-side shocks (e.g. panic buying, excessive inventory), even many companies have to stop operations. This pandemic also caused an economic shock with more than 170 countries having negative GDP per capita growth, as well as impacted exchange rates and monetary policies on the market.

H1a,b,c,d. External risk causes supply risk, operational risk, and demand risk and adversely affects supply chain (SC) performance.

3.2 The impacts of supply risk and demand risk on operational risk and supply chain performance

Supply risk is related to adverse upstream activities in SCs that impact the ability of the focal firm in meeting customer demands (both in quality and quantity), causing threats to the customer's life and safety (Wagner and Bode, 2008). In this situation, the focal firm faces risks associated with the supply side, for example, unstable quantity and quality of inputs, price fluctuations and supplier bankruptcy (Abdel-Basset and Mohamed, 2020;

Moktadir *et al.*, 2021; Rostamzadeh *et al.*, 2018). These risks cause failure in providing goods or services to the purchasing company and downstream operations of the SC (Truong and Hara, 2018). Therefore, the following hypotheses are proposed:

H2a,b. Supply risk causes operational risk and adversely affects SC performance.

Demand risk is associated with adverse downstream events in the SC that affect the fulfillment of customers orders or variance in the volume desired by customers (Ho *et al.*, 2015). This type of risk derives from uncertainties related to the customer side such as customer fragmentation, customer bankruptcy, high market competition and demand variability (Abdel-Basset and Mohamed, 2020; Moktadir *et al.*, 2021; Rostamzadeh *et al.*, 2018; Song *et al.*, 2017; Thun and Hoenig, 2011; Wagner and Bode, 2008; Xu *et al.*, 2019). As a result, the SC network is highly influenced by the customers ability to order with the focal firm and/or differences in the volume and variety that customers expect (Quang and Hara, 2019). Moreover, when these risks arise, businesses will not be able to forecast the actual demand of the market. This leads to product shortages, product obsolescence, inefficient use of capacity, dysfunctional operations and poor customer service (Wagner and Bode, 2008). It is seen that uncertain demand gives rise to backlogs or shortages of orders, errors in planning and the bullwhip effect (George *et al.*, 2004). In addition, rapid changes in customer expectations increase costs of products. On the other hand, fluctuations in customers' demand negatively impact performance of the inventory system.

In construction, the SC process begins with the requirements of services, products and materials by clients, which is always followed by a demand. This step is particularly important because of its unique project-specific requirements (Behera *et al.*, 2015). Additionally, the role of clients is significant in terms of information sharing, trust and collaboration throughout the SC because they are associated with a higher number of risks compared to other stakeholders (Koc and Gurgun, 2021). Pham *et al.* (2022) imply that demand risk causes operational risk which in turn impacts the performance of construction SCs. Since evidence for such impacts is still limited in construction, the present study proposes that:

H3a,b. Demand risk causes operational risk and adversely affects SC performance.

3.3 The impact of operational risk on supply chain performance

Operational risk directly affects SC performance and receives resonant effects from other risks, namely supply risk, demand risk and external risk. Operational risk refers to disruptions caused by adverse events within a firm that affect the SC ability in producing goods and services, profitability, timeliness of production and quality. Some examples of operational risk include labor disputes, accidents, or changes in technology and design (Song *et al.*, 2017; Abdel-Basset and Mohamed, 2020; Cunha *et al.*, 2019; Rostamzadeh *et al.*, 2018). These risks lead to the challenge of determining optimal production quantity, optimal order quantity, safety level of inventory and other inventory policies. As a result, they have significant impacts on SC performance both in cost and profit (Truong Quang and Hara, 2018). Kate (2013) states that the majority of work accidents affect the ability of employees to perform their usual duties. Approximately 27 million work days in a year are lost due to occupational disease or personal injury, proving that these incidents can have serious consequences. Although the above studies in various industries have shown the effects of operational risk on performance, empirical evidence for such effects in construction SCs has been scarce. Koc and Gurgun (2021) conclude that operational risks such as lack of skilled workers, safety accidents, technological issues and lack of planning directly affect performance of construction SCs. Therefore, the following hypothesis is proposed Figure 1:

H4. Operational risk adversely affects SC performance.

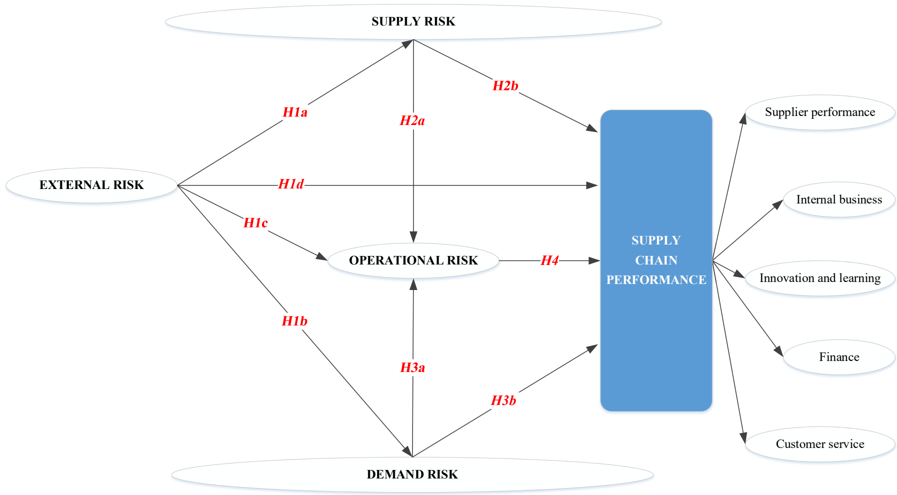


Figure 1.
Theoretical framework

Source(s): Compiled by the authors

4. Data collection

The data used in this study are collected from a large-scale survey supported by a project of the Japanese government to promote sustainable socioeconomic development for the ASEAN (Association of Southeast Asian Nations) region. Through the Vietnam General Statistics Office, a list of construction firms for our survey was firstly compiled. The survey was conducted in Vietnam's construction industry with a total of 3,601 firms. The target respondents are managers of firms who have knowledge and experience in risk management and SC management. Because the scales drawn from the literature were in English, the initial questionnaire was developed in English and subsequently translated into Vietnamese by our research team members. The Vietnamese version of the questionnaire was used for data collection. The content of the survey questionnaire is presented in the Appendix.

An invitation was sent to emails of all firms to ask them to take part in our survey. The invitation presented the purpose and objectives of this study as well as a request for firms to join the survey. Moreover, it is mentioned in the survey that the firm information is confidential and used only for the objectives of the study. After that, questionnaires were sent to firms that agreed to respond to the survey. Respondents were asked to rate the influences of SC risks on their firms in the past 5 years as well as estimate their SC performance. A five-point Likert scale was used in order to capture the different attitudes of the respondents, ranging from one (strongly disagree) to five (strongly agree). An official questionnaire link was sent to all firms via email. 354 responses were subsequently returned, representing a response rate of 9.83%. After excluding 147 incomplete responses, a total of 207 responses were used for the analyses. Characteristics of the sample are described in Table 2.

5. Results

A *t*-test estimate of non-response bias was undertaken in order to examine the difference in items between early and late responses (Armstrong and Overton, 1977). The results indicated that there were no statistically significant differences in the average scores of all observed items (internal confidence of 99%), hence non-response bias is not a problem in this study.

	Percent
Business field	
Building material manufacturing (sand, stone, additive)	15.5
Building material distribution	23.2
Concrete production	19.3
Construction executive	34.8
Design (architecture and construction)	7.2
Authorized capital	
Less than 1 million dollars	5.3
From 1 to 5 million dollars	16.4
Above 5 million dollars	78.3
Job title	
Top-level manager	7.7
Middle-level manager	22.7
First-level manager	51.2
Coordinator	10.6
Others	7.7

Source(s): Compiled by the authors

Table 2. Survey sample characteristics

In addition, each firm's independent and dependent variables were collected from the same respondent. This may result in the emergence of common method variance (CMV). Harman's single-factor test was conducted to examine this emergence (Podsakoff *et al.*, 2003). All observed items were subjected to a non-rotated factor analysis. If just one factor emerges (i.e. a generic factor can explain covariance in all variables), it is reasonable to assume that the CMV is substantial. The findings suggested that eleven factors occurred. However, when there are too many factors, this method of testing is not accurate (Podsakoff *et al.*, 2003). Therefore, items from each independent factor (i.e. risk constructs) were factorically analyzed with items from the scale of the dependent factor (i.e. performance construct). Factor analysis revealed that two or more components appeared, indicating that there is no significant CMV.

Traditional methods are used to assess the validity and reliability of constructs (Hair *et al.*, 1995). This study uses exploratory factor analysis (EFA) for detecting underlying dimensions. After removing measures that did not achieve the threshold value of 0.50, the remaining measures load on the corresponding components with factor loadings greater than 0.734, eigenvalue $\geq$1.623 and variance extracted $\geq$63.278. All item – total correlations are above 0.483, the Cronbach's alpha coefficients range from 0.700 to 0.845 (higher than 0.7). Hence, the reliability of the risk constructs is ensured (Table 3). Moreover, the degree of multicollinearity should be examined by calculating the variance inflation factor (VIF). A VIF value of 5.0 indicates potential problems of multicollinearity (Hair *et al.*, 2011). In this study, VIF values calculated are less than the threshold of 5.0, thus the constructs are free from the multicollinearity. Table 4 presents EFA results for performance constructs.

In the next step, SEM is employed for estimating the relationships among the constructs. Our study uses a two-step model building approach in which the measurement model is examined before testing the structural model (Anderson and Gerbing, 1988). Confirmatory factor analysis (CFA) is used to test the constructs validity including convergent and discriminant validity. CFA results from Table 5 show that composite reliability (CR) and average variance extracted (AVE) of all constructs are higher than 0.7 and 50% respectively, thus confirming the convergent validity.

Table 6 shows the evaluation of discriminant validity. It is seen that the square root of AVE for each construct located in the diagonal is greater than correlations between any two

Constructs	Observed items	Supply risk	Operational risk	Demand risk	External risk: Human-made risk	External risk: Natural risk	Item – total correlation
Supply risk	Supplier bankruptcy	0.870					0.727
	Price fluctuations	0.797					0.608
	Unstable quality of inputs	0.744					0.555
	Unstable quantity of inputs	0.767					0.586
Operational risk	Design changes		0.928				0.731
	Technological changes		0.932				0.731
	Accidents		0.921				0.697
	Labor disputes/ strikes		0.920				0.697
Demand risk	Demand variability			0.793			0.618
	High competition in the market			0.734			0.550
	Customer bankruptcy			0.819			0.656
	Customer fragmentation			0.832			0.669
External risk	Economic downturns				0.808		0.540
	External legal issues				0.794		0.521
	War and terrorism				0.770		0.483
	Epidemics					0.909	0.682
	Natural catastrophes					0.920	0.682
Cronbach's alpha		0.801	0.845	0.805	0.700	0.81	
Eigenvalue		2.533	1.651	2.531	1.623		
Variance extracted		63.325	86.141	63.278	71.441		

Source(s): Calculated by the authors

Table 3.
EFA results for risk constructs

constructs. This result indicates that the discriminant validity of the constructs was satisfactory (Fornell and Larcker, 1981).

The results of the SEM model are schematically depicted in Figure 2, with χ^2/df = 1.726, CFI = 0.902, RMSEA = 0.059, indicating that the model suits the data. In addition, the coefficient of R^2 is 0.54, meaning that our model can explain 54% variance of SC performance. Table 7 summarizes the results of hypotheses testing.

6. Discussion

The literature has given little attention to the combined impacts of disruptions and internal risks (e.g. supply, demand and operational risks). During the COVID-19 pandemic, firms have

	Observed items	1	2	3	4	Item – total correlation
Supplier performance	Reliability				0.891	0.623
	Response time				0.700	0.623
Internal business	Amount of waste		0.517			0.551
	Costs of inventory management		0.765			0.635
	Workforce productivity		0.806			0.58
Innovation and learning	Number of new products developed per year			0.778		0.635
	Workforce flexibility			0.871		0.635
Customer service	Delivery timeliness			Deleted		
	Percentage of "perfect orders" delivered			Deleted		
	Product value perceived by customers	0.658				0.552
	Product quality	0.939				0.673
	Response time to customers queries	0.473				0.481
Finance	Market share growth			Deleted		
	Return on Investments (ROI)			Deleted		
Cronbach's alpha		0.738	0.757	0.746	0.767	
Eigenvalue			1.131			
Variance extracted			74.661			

Source(s): Calculated by the authors

Table 4. EFA results for performance constructs

experienced severe supply–demand disruptions, causing shortages in production capacity (Xu *et al.*, 2020). Thus, they are unable to meet customer needs for essential products during lockdowns. Because of supply and demand disruptions, many firms have suffered from financial losses (Gholami-Zanjani *et al.*, 2021). As a result, such risks and disruptions have caused the ripple effect in SCs. Many previous studies have been done on risk management in construction SCs such as Naderpajouh *et al.* (2015), Rudolf and Spinler (2018), Panova and Hilletofth (2018), Shojaei and Haeri (2019), Zhao (2019), Abas *et al.* (2022), Obayi and Ebrahimi (2021), Ekanayake *et al.* (2021a), and Ekanayake *et al.* (2022). However, the findings of this study differ from those of these studies in some ways. First, some studies such as Shojaei and Haeri (2019), Zhao (2019), and Ekanayake *et al.* (2021a) have not provided evidence for the impact of all risks on performance. Second, other studies (e.g. Naderpajouh *et al.*, 2015; Panova and Hilletofth, 2018; Rudolf and Spinler, 2018; Abas *et al.*, 2022; Obayi and Ebrahimi, 2021; Ekanayake *et al.*, 2022) partially identify the types of risks while the propagation mechanism of risks has not been established.

The present study has two important contributions to the literature. The first contribution of this study is to identify the mechanism of the ripple effect in construction SCs. A good SC risk management strategy needs to evaluate the severity of risks. Ho *et al.* (2015) conclude that the majority of studies only consider the impact of each risk on various performance outputs. For this reason, the overall picture of the impacts of all risks in the SC is still lacking. However, the literature (e.g. Wagner and Bode, 2008; Truong Quang and Hara, 2018) indicates that risks do not independently occur, but simultaneously occur. This can explain why hedging solutions do not achieve the desired results because plans for mitigating and controlling risks only focus on a single risk. Worse, in an adverse situation, many risks that simultaneously occur without appropriate contingency plans inevitably have devastating consequences for SC operations. It is proven that a risk, when it occurs, can create a ripple effect. Indeed, using empirical data from 760 firms in Germany, Wagner and Bode (2008)

Constructs	Observed items	Standardized regression weights	Standard errors	R^2	Composite reliability	Variance extracted
Supply risk	Supplier bankruptcy	0.920	0.052	0.846	0.800	0.510
	Price fluctuations	0.733	0.061	0.538		
	Unstable quality of inputs	0.573	0.059	0.329		
	Unstable quantity of inputs	0.572	0.074	0.327		
Operational risk	Design changes	0.863	0.058	0.746	0.918	0.737
	Technological changes	0.901	0.054	0.812		
	Accidents	0.848	0.055	0.720		
	Labor disputes/ strikes	0.820	0.059	0.672		
Demand risk	Demand variability	0.641	0.045	0.410	0.804	0.513
	High competition in the market	0.549	0.034	0.301		
	Customer bankruptcy	0.786	0.035	0.618		
	Customer fragmentation	0.850	0.042	0.723		
External risk	Economic downturns	0.713	0.045	0.509	0.889	0.543
	External legal issues	0.672	0.053	0.451		
	Corruption	0.686	0.064	0.470		
	Epidemics	0.862	0.046	0.743		
	Natural catastrophes	0.884	0.044	0.782		
Threshold values		Standardized Regression Coefficients >0.5 Standardized Regression Coefficient >2 × standard error $R^2 > 0.3$ Composite reliability >0.7 Variance Extracted >50%				

Source(s): Calculated by the authors

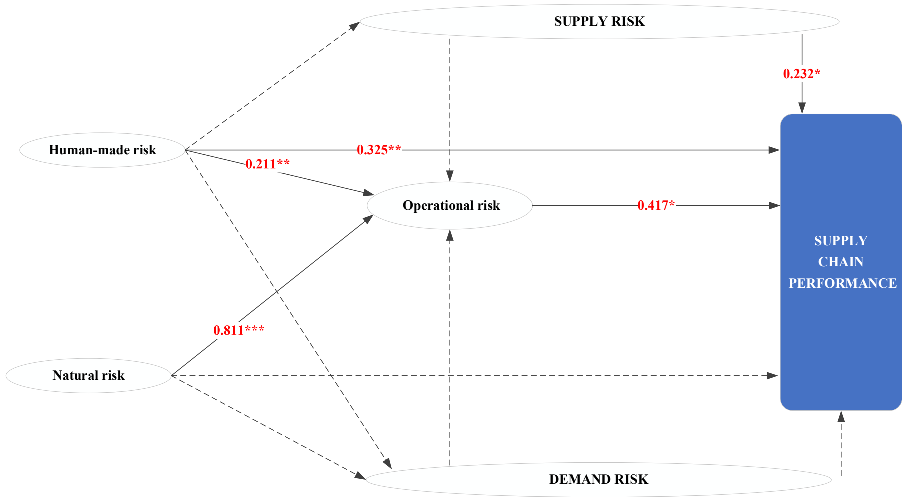
Table 5.
CFA results

	Supply risk	Operational risk	Demand risk	External risk
Supply risk	*0.796*			
Operational risk	−0.201**	*0.928*		
Demand risk	0.181**	−0.079	*0.795*	
External risk	0.186**	−0.054	0.043	*0.845*

Source(s): Calculated by the authors

Table 6.
Discriminant validity results

conclude the occurrence of financial and information risks leads to the occurrence of supply, manufacturing and demand risks. This view is also supported by Klüppelberg *et al.* (2014) that firms should understand how to model and describe the dependency structure of risks. Obviously, if all risks are interrelated, they tend to occur together and increase the severity of the overall risk impact.



Note(s): Chi-square/df = 1.726, CFI = 0.902, RMSEA = 0.059 R^2 = 54%
Source(s): Compiled by the authors

Figure 2. SEM results

Table 7. Hypotheses testing results

Hypotheses	Statements			Standardized regression weights
H1a	Human-made risk	→	Supply risk	Unsupported
H1b	Human-made risk	→	Demand risk	Unsupported
H1c	Human-made risk	→	Operational risk	0.211**
H1d	Human-made risk	→	Supply chain performance	0.325**
H1e	Natural risk	→	Supply risk	*0.225***
H1f	Natural risk	→	Demand risk	Unsupported
H1g	Natural risk	→	Operational risk	0.811***
H1h	Natural risk	→	Supply chain performance	*Unsupported*
H2a	Supply risk	→	Operational risk	Unsupported
H2b	Supply risk	→	Supply chain performance	0.232*
H3a	Demand risk	→	Operational risk	Unsupported
H3b	Demand risk	→	Supply chain performance	Unsupported
H4	Operational risk	→	Supply chain performance	0.417**

Source(s): Calculated by the authors

Our results indicate that human-made risk causes operational risk. Moreover, natural risk causes both supply risk and operational risk. It is remarkable to see that operational risk is the main risk that amplifies the impacts of human-made risk and natural risk on performance. Operational risk which is referred to uncertainties inherent in SCs (e.g. uncertain demand/supply/cost) is mostly ignored by the literature on the ripple effect. However, operational risk can create the ripple effect because firms often engage in the creation of customized products with suppliers. Hence, firms are highly dependent on single suppliers, causing delays in operations (Xu, 2020). In addition, due to high costs related to inventory holding, many firms adopt lean practices for keeping minimum inventory. This renders firms more susceptible to operational risk and the ripple effect along the SC (Papadakis, 2006). Although it is hypothesized that human-made risk leads to supply risk and demand risk, natural risk leads to demand risk, and supply risk and demand risk cause operational risk; the results do not support these hypotheses. A possible explanation for these unsupported hypotheses is that the data of this study are only obtained from construction firms in Vietnam. Because the construction industry in each country has specific characteristics that differ from those in other countries, such differences may be one reason that some hypotheses in our theoretical framework have not been supported.

The second contribution of this study is to demonstrate the ripple effect of risk on performance. As observed in Figure 2, human-made risk, supply risk and operational risk have direct impacts on SC performance, yet natural risk and demand risk have no such direct impacts. However, it is found that the impacts of human-made risk and natural risk on performance are amplified through operational risk. It means that human-made risk and natural risk lead to the occurrence of operational risk which in turn has negative effect on performance. Hence, the findings demonstrated the ripple effects of both human-made risk and natural risk on performance. In addition, the ripple effect of natural risk on performance is also confirmed by this study. Specifically, natural risk causes the occurrence of supply risk which then adversely affects performance. In this case, it is concluded that the impacts of natural risk on performance are propagated through supply risk and operational risk.

Recently, there is a growing interest from both practitioners and academics in managing disruptions through the development of SC resilience (Ambulkar *et al.*, 2015; Ekanayake *et al.*, 2020, 2021b). Resilience is an adaptive capability of a SC for preparing for unexpected events, responding to disruptions and recovering from them by maintaining the operations continuity (Yu *et al.*, 2019). It is claimed that resilience enables firms to better manage disruptions and maintain high performance through the continuance of products deliveries to customers (Brusset and Teller, 2017). In uncertain and turbulent environments, it is more crucial for firms to develop resilient SCs for managing unforeseen (Ali *et al.*, 2017). Although many previous studies on risk management in construction SCs have been conducted such as Naderpajouh *et al.* (2015), Rudolf and Spinler (2018), Panova and Hilletofth (2018), Shojaei and Haeri (2019), Zhao (2019), Abas *et al.* (2022), and Obayi and Ebrahimi (2021), their aims mainly focus on the risk identification and quantification of risk impact. It is concluded that research on resilience is still very limited. It is pivotal to nurture and embed resilience at appropriate levels in construction SCs because the performance targets and planned sustainability cannot be achieved without successfully overcoming disruptions and their ripple effect through the enhanced resilience (Ekanayake *et al.*, 2021c).

Whenever a SC is impacted by disruptions, resilience becomes important (Golan *et al.*, 2020). The comprehensive development of a SC resilience strategy consists of three stages: preparedness, response and recovery aimed at mitigating disruptions. Hence, in responding to severe impacts of disruptions, it is seen that the extant literature is increasingly focusing on the topic of resilience. For this reason, our study suggests that further studies should pay more attention in studying resilience in construction SCs since it helps firms effectively manage disruptions, thus operations can be restored to the previous or even improved performance level (Scholten *et al.*, 2014). Vertical collaborative strategies (e.g. inter-firm collaboration) and horizontal collaborative strategies (e.g. intra-firm collaboration) can help firms articulate rapid actions in responding to global disruptions, for example, the Covid-19 pandemic (Rahman *et al.*, 2022). In this situation, our study suggests that firms need to develop collaboration and operational flexibility along their SC when dealing with disruptions. Further investigation is needed to understand how and to what extent collaborative strategies can help firms reduce the impacts of large-scale disruptions.

7. Implications and limitations

With regard to theoretical implications, this study broadens the understanding of relationships between SC risks and performance with efforts to define, develop and examine the ripple effect. This is a new approach in the SC risk management literature, which simultaneously considers risks in an interactive system. Therefore, if firms are able to manage the mechanism of the ripple effect, they can significantly reduce the impact of risks on performance. Efforts should start with operational risks because they receive ripple effects from other risks namely human-made risk and natural risk. Then, the attention should be focused on supply risk which is also pushed by natural risk. In this situation, the severity of external risks would be significantly reduced if supply risk and operational risk are controlled.

It is really important to develop resilience in construction SCs since performance results can only be achieved if the effect of disruptions and their ripple effect are controlled through better resilience (Ekanayake *et al.*, 2021c). In this regard, this study has some practical implications. In order to maintain high performance, managers should implement various mitigation strategies namely SC resilience to enhance the ability of their firm in absorbing disruptions and rapidly returning to the stable condition (Yu *et al.*, 2019). Indeed, it is posited that in a highly changing environment, firms that strongly develop resilience are able to quickly recover from unforeseeable disruptions and still maintain the high level of performance (Hohenstein *et al.*, 2015). In an uncertain environment, firms in the SC always face many disruptions. Nevertheless, being exposed to disruptions is not necessarily a threat but potentially an opportunity for firms to develop resilient SC. Developing robust SC initiatives such as resilience can provide managers with an effective strategy to cope with risks and recover from disruptions.

Despite its own contributions, the present study still has several limitations that should be considered by further studies. The first limitation concerns the unsupported hypotheses in our theoretical model. Future research in Vietnam should apply other research methods such as case study and focus groups to examine why these hypotheses have not been supported. In this way, future studies can enhance the generalization of our model and establish more clearly the ripple effect of SC risks. Second, the data of the present study are cross-sectional in nature. This did not allow us to evaluate the long-term impacts of risks on performance. Hence, it is more interesting to conduct a longitudinal study to better understand the long-term impacts of risks. Third, toward a broader perspective, it is essential to examine the overall validity of the results in nations with different characteristics (developing countries/developed countries). Thus, an international survey may provide interesting insights into risk attitudes in other countries and may identify cultural differences in SC risk management.

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Appendix
Survey questionnaire

Part I: Company information

1. Business field:

☐ Building materials manufacturing ☐ Building materials distribution

☐ Concrete production ☐ Construction executive

☐ Design (architecture and construction) ☐ Others:

2. Type of business:

☐ Less than 1 million dollars

☐ From 1 to 5 million dollars

☐ Above 5 million dollars

Part II: Risks in construction supply chains

Please describe the occurrence and evaluate the likelihood of each risk as well as to what extent your firm in the past five years has experienced a negative impact in supply chain management, based on a five-point Likert scale: one (not at all) – to five (very large extent).

Occurrence		Probability					Risks	Degree of danger				
Yes	No	Very low				Very high		Not at all				Very large extent
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Supplier opportunism	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Unstable quality of inputs	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Price fluctuations	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Inflexibility of suppliers	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Supplier bankruptcy	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Suppliers' dependency	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Unstable quantity of inputs	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Delays in supply activities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Design changes	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Poor planning and scheduling	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Technological changes	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Dissatisfaction with work	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Accidents	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Inflexibility in layout for free flow of materials	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Labor disputes/strikes	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Lack of experience or training	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Demand variability	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Deficient or missing customer relation management function	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
☐	☐	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Customer bankruptcy	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Customer dependency	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	High competition in the market	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Customer fragmentation	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Economic downturns	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Social and cultural grievances	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	External legal issues	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	War and terrorism	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Political instability	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Epidemics	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Earthquakes	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Natural catastrophes	□ 1	□ 2	□ 3	□ 4	□ 5
□	□	□ 1	□ 2	□ 3	□ 4	□ 5	Tsunami	□ 1	□ 2	□ 3	□ 4	□ 5

PART III: SUPPLY CHAIN PERFORMANCE

Evaluate the following supply chain performance indicators compared to your major competitor (5-point scale: significantly worse - significantly better).

		Significantly worse			Significantly better	
1	Response time of our suppliers	□ 1	□ 2	□ 3	□ 4	□ 5
2	The degree of reliability on our suppliers	□ 1	□ 2	□ 3	□ 4	□ 5
3	Workforce productivity	□ 1	□ 2	□ 3	□ 4	□ 5
4	Amount of waste	□ 1	□ 2	□ 3	□ 4	□ 5
5	Costs of inventory management	□ 1	□ 2	□ 3	□ 4	□ 5
6	Number of new product developed per year	□ 1	□ 2	□ 3	□ 4	□ 5
7	Workforce flexibility	□ 1	□ 2	□ 3	□ 4	□ 5
8	Delivery timeliness	□ 1	□ 2	□ 3	□ 4	□ 5
9	Response time to customer queries	□ 1	□ 2	□ 3	□ 4	□ 5
10	Percentage of "perfect orders" delivered	□ 1	□ 2	□ 3	□ 4	□ 5
11	Product/service quality	□ 1	□ 2	□ 3	□ 4	□ 5
12	Product value perceived by the customer	□ 1	□ 2	□ 3	□ 4	□ 5
13	Market share growth	□ 1	□ 2	□ 3	□ 4	□ 5
14	Return on Investments (ROI)	□ 1	□ 2	□ 3	□ 4	□ 5

Part III: General information

What is your job title?

□ Top-level manager □ Middle-level manager □ First-level manager

□ Coordinator □ Others: