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INVESTIGATION OF THE CONSTRUCTION SUPPLY CHAIN VULNERABILITIES UNDER AN UNFAVORABLE MACRO-ENVIRONMENTAL CONTEXT

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ABSTRACT

International trades rely on robust supply chains. However, supply chains are vulnerable to disruptions. Before implementing lean construction, identifying construction supply chain vulnerabilities (CSCV) is crucial to avoid failure. Meanwhile, an unfavorable macro-environmental context (e.g., challenging economic and political situations) can potentially affect the behavior of CSCV. This paper aims to identify and prioritize CSCV under an unfavorable macro-environmental context in a real-world case and then analyze the changes in CSCV in a period coinciding with the Covid-19 outbreak. A literature review led us to extract 26 variables that were then prioritized using the responses from questionnaires distributed among 72 participants in the studied country. A descriptive statistical approach was used to analyze the results, which showed that unlike the normal contexts mentioned in previous studies, under an unfavorable context, such CSCV as "price and exchange rate fluctuations", "supply-demand volatility", "financial issues", and "political challenges" gained priority. Moreover, analyzing the changes in CSCV indicated that the studied construction supply chain has become more vulnerable in the mentioned period. Considering the identified CSCV, this paper suggests that managers focus more on tools such as the Last Planner System and value stream mapping when implementing lean.

KEYWORDS

Construction Supply Chain Vulnerabilities (CSCV), Lean Construction, Unfavorable macro-environmental context

INTRODUCTION

Instability or volatility of economic, political, environmental, technological, legal, and social factors worldwide can disrupt the performance of local and international supply chains (SCs). For example, war, pandemics outbreaks, imposing sanctions on a specific

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economy, or even climate can make the supply chains around the world vulnerable to disruption. On average, companies' losses on account of different sources of disruptions in supply chains equal 45% of one year's profits for a decade (McKinsey Global Institute, 2020). The construction industry is not an exception in facing supply chain vulnerabilities (SCV). Due to the nature of this industry, it can even be more complicated for it to manage such sources of disruption (Loosemore, 2000), especially if the industry plans to deploy lean principles. As discussed later in this paper, implementing lean construction practices exhibits varying relationships with the performance and vulnerability of construction supply chains. Thus, accounting for SCV before implementing lean construction practices can support making better managerial decisions in supply chains and a smoother transition from tradition to modernity.

The SCV can impact supply chains in interconnected global markets. However, there seem to be distinctions regarding the context of isolated economies where specific rules are applied. For instance, in a country like Iran, which has been under severe international sanctions and disconnected from the global markets for years, monopolies have become prevalent in different echelons of supply chains (Jahantigh et al., 2015). So, some severe macro-environmental factors (i.e., sanctions, economic isolation, corruption, fraud, and prevalence of monopolies) can affect the behavior of construction SCV and their importance in different economies and their associated contexts. However, no study has been conducted to date to consider the vulnerabilities of the construction supply chains under an unfavorable macro-environmental context.

In this study, we take Iran as a benchmark for an unfavorable macro-environmental context to identify and prioritize the construction supply chain vulnerabilities (CSCV). Then, we analyze the changes in CSCV in the past two years, which coincide with the Covid-19 outbreak. The results act as a decision-making tool for supply chain participants and researchers to consider lean practices or resilience concepts in the construction supply chains struggling with difficult macro-environmental situations.

LITERATURE REVIEW

LEAN CONSTRUCTION AND CONSTRUCTION SUPPLY CHAIN

Akintoye et al. (2000) considered construction supply chain management as a strategic management process that manages the information flow and activities among networks of organizations and linkages to deliver construction products and services to the clients. They introduced the upstream and downstream linkages in construction supply chain management. Upstream linkage is interpreted as activities related to the production preparation on site. On the other hand, the downstream linkage consists of activities in the delivery process of construction products. Each construction supply chain comprises different phases, including planning and design, procurement, and construction and delivery (Le et al., 2020). As Loosemore (2000) states, the supply chain in construction is different from that of other industries, as the construction industry has a transient nature and imposes broader risks than other sectors.

Some researchers have considered lean construction as a means for supply chain improvement. For instance, the application of some lean tools and aspects such as partnering and collaboration (Ballard & Howell, 2003; Green & May, 2005), the Last Planner System (Fernandez-Solis et al., 2013), and value stream mapping (Pasqualini & Zawislak, 2005) can improve SCs. Erik Eriksson (2010) showed that lean construction could result in monetary savings due to efficient coordination and utilization of shared

resources among SC partners. The maturity process of supply chains consists of six stages, and "lean" is the third stage of this process (Stevens & Johnson, 2016). On the other hand, since lean thinking focuses on eliminating waste through the minimization of resources, the implementation of lean construction principles can strain supply chains (Azevedo et al., 2008), as discussed in the rest of this study.

CONSTRUCTION SUPPLY CHAIN VULNERABILITIES (CSCV)

Pettit et al. (2010) proposed a two-dimensional outlook for assessing supply chain resilience: vulnerabilities and capabilities, the former of which will be considered in the context of Iran in this paper. Christopher & Peck (2004) considered the origins of supply chain vulnerabilities as internal and external factors. Internal factors rise within the organizations and their supply chains, while external factors are out of the control of the supply chain networks. Recently, determining the SCV and analyzing their impacts on the supply chains has motivated the interest of some researchers. For instance, Elleuch et al. (2016) and Ekanayake et al. (2020) have reviewed the related literature in this area.

The construction industry can be affected directly and indirectly by the vulnerabilities of its supply chains, as they play a crucial role in this industry; therefore, any SC disruption can cause irreparable costs in construction projects (Zainal Abidin & Ingirige, 2018a, 2018b). Zainal Abidin & Ingirige (2018b) studied the vulnerabilities affecting the construction supply chain of Malaysia by proposing a layered framework that shows the cascading impacts of SCV.

Another significance of CSCV can be sought in their role in applying lean construction principles. Previous research shows that lean practices will result in more vulnerabilities for construction supply chains (Ponomarov & Holcomb, 2009; Ruiz-Benítez et al., 2018). Applying lean practices means maintaining very little inventory and relying on integrating supplier relationships to decrease costs and create SC efficiencies. The supply/demand volatility, the cost minimization, and increased dependency among supply chain participants, which all result from lean, contribute to a lack of responsiveness to the adverse effects of disturbances. Consequently, commitment to lean principles can make the supply chains more vulnerable to disruptions (Azevedo et al., 2008). In other words, when implementing lean, a trade-off between lean practices and vulnerabilities should be established in supply chains (Maslaric et al., 2013; Govindan et al., 2015). Furthermore, Christopher & Rutherford (2004) mentioned that managing supply chain vulnerabilities will be a challenge for continuous improvements, a core element of lean (Green & May, 2005; Jørgensen & Emmitt, 2009). So, identifying construction SCV is critical before implementing lean concepts in the construction supply chains.

As mentioned previously, some specific tools and aspects of lean contribute to SC improvements when implementing lean. On the other hand, areas in which lean construction can cause SCV have been pointed out in the literature. So, identifying CSCV will provide the SC managers with a guide for an optimized selection of lean tools in such a way as to decrease the vulnerabilities of construction SCs.

IRANIAN CONSTRUCTION SUPPLY CHAIN

Located in the Middle East, Iran is a developing country whose construction industry accounted for 5.5% of Iran's GDP in 2019 (Central Bank of Iran, 2019). After a period of decline, the output value of the country's construction sector is expected to grow at an annual average rate of 4.4% until 2023. This growth is due to the government's efforts to

invest in transportation, energy, and infrastructure projects (GlobalData, 2019). However, official figures indicate that the industry is experiencing fluctuations throughout the Covid-19 outbreak, followed by a decline and contraction from November 2021 to January 2022 (Iran Chamber of Commerce, Industries, Mines and Agriculture, 2022). This underachievement can be rooted in chronic problems originating in Iran's political, economic, and regulatory bodies (Asnaashari et al., 2009).

In this paper, we identify and prioritize the vulnerabilities of the construction supply chains considering an unfavorable macro-environmental context to see the effects of such factors on the behavior of CSCV. We chose Iran as a country that best fits such situations. Then, we analyze the changes in these vulnerabilities over the past two years (coincident with the outbreak of Covid-19).

RESEARCH METHOD

This research conducted a review to extract the SCV in the global context. The authors utilized the keywords "*Construction*" AND "*Supply Chain*" AND "*Vulnerable*" and "*Supply Chain*" AND "*Resilient*" through the target databases of Scopus, Science Direct, and Google Scholar (as a searchable Engine) within a time bracket from 2000 onward. At this stage, 120 pieces of research, including journal and conference papers, thesis, and books, were collected. Afterward, the results were scrutinized by reading their abstracts, which excluded some of them for further consideration. The results were refined to those focused merely on supply chain vulnerabilities in this step. Then, a thematic analysis was conducted to obtain common SCV in the literature.

After determining the SCV using 40 pieces of research, a questionnaire containing the identified SCV was designed. Respondents were solicited to answer two questions regarding each SCV:

- The effect of CSCV in the past two years, and
- The effect of CSCV in general

The reason for separating the questions into two parts is that the outbreak of Covid-19 (in the past two years) impacted supply chains in different ways (Alicke et al., 2021), which can bias the respondents' minds on the general effects of CSCV. The responses were received using a five-point Likert comprising very low (1), low (2), moderate (3), high (4), and very high (5). The scores were then averaged and compared to identify how the priority of CSCV differs under the dominance of an unfavorable macro-environmental context. The scores were also utilized to realize how recent conditions (including the outbreak of the COVID-19) have changed the priority of CSCV.

In the last section of the questionnaire, respondents were also requested to declare a further three CSCV other than those presented by the questionnaire, allowing the authors to tune the results and recognize any factors not identified through the literature. Before distribution among respondents, the questionnaire was approved by an academic professional in the construction industry.

By analyzing the results through a descriptive statistical analysis method, a prioritized list of construction supply chain vulnerabilities and their changes in the last two years under an unfavorable macro-environmental context is obtained.

SAMPLING SPECIFICATIONS

The data-gathering period took place from December 2021 to January 2022, and the data were solicited from the respondents through online questionnaires based on a random

sampling approach. The online questionnaire was shared via the social networking platforms LinkedIn™, WhatsApp™, and Telegram™. The authors applied two criteria for selecting respondents: 1) being an active participant in the construction supply chain and 2) having more than two years of experience in this industry. The use of the online questionnaire made it impracticable to account for the response rate. A total number of 72 responses were received through the online questionnaire. Figure 1 shows the respondents' background information in the first section of the questionnaire. The charts indicate that most of the respondents were highly educated and experienced. They also show that the respondents were chosen from a wide array of Iranian construction sectors and were from multiple provinces indicating the validity and generalisability of the research results.

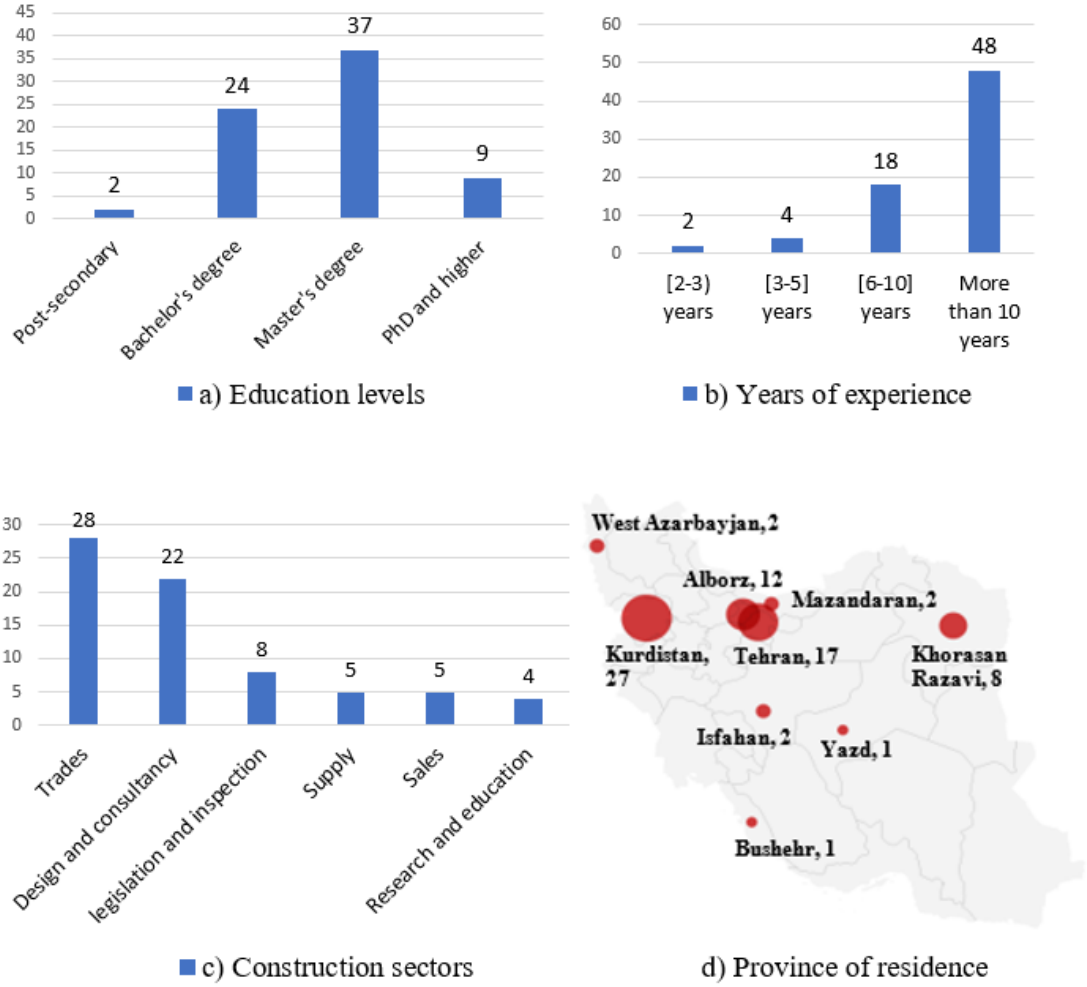

Figure 1- Information of Respondents

SCV IN THE LITERATURE

This study utilized 40 screened papers to extract a list of supply chain vulnerabilities. We scrutinized these papers to achieve a list of 26 vulnerabilities that were either precisely common or conveyed the same concept with nuances in expression among the screened papers. Consequently, we subsumed some vulnerabilities in the literature under more inclusive categories. The identified 26 vulnerabilities with their frequency in the reviewed literature are listed in Table 1.

Table 1- Categorized SCV extracted from the literature

Rank	SCV Category	Brief Description	Freq.	References No.
1	Natural disasters and environmental issues	e.g., flood, earthquake, famine, and environmental pollution leading to a lockdown	20	[1] [2] [4] [6] [7] [8] [15] [16] [17] [18] [19] [21] [23] [25] [28] [30] [32] [36] [37] [39]
2	Human resources issues	e.g., strikes, job-quitting, dissatisfaction, unskilled HR	14	[2] [3] [4] [7] [11] [12] [15] [20] [21] [23] [28] [29] [34] [39]
3	Machinery and IT breakdown	due to improper maintenance or no upgrading	14	[4] [7] [13] [15] [18] [21] [22] [23] [24] [25] [31] [33] [38] [40]
4	Political challenges	e.g., international sanctions, nepotism, lack of meritocracy, and mafia.	14	[4] [7] [8] [9] [10] [15] [19] [21] [23] [25] [27] [28] [29] [37]
5	Supply-demand volatility	market pressure due to supply and demand mismatch	12	[2] [4] [7] [8] [10] [11] [12] [15] [21] [23] [25] [37]
6	Inadequate communication and poor information flow	SC stakeholders fail to access up-to-date info. due to communication breakdowns	11	[1] [7] [10] [13] [15] [22] [23] [24] [33] [38] [40]
7	Data Breach	violating confidentiality protocols	11	[4] [7] [13] [18] [22] [24] [25] [33] [38] [39] [40]
8	Terrorism/war	war outbreak and terrorist attacks	10	[4] [14] [15] [19] [21] [28] [29] [34] [36] [37]
9	Disruption of logistics	inbound/outbound logistic and transportation problems	9	[3] [4] [5] [7] [12] [15] [18] [23] [39]
10	Information mishandling	inadequate data analysis and improper forecasting causing the bullwhip effect	9	[13] [18] [21] [22] [24] [25] [33] [38] [39]
11	Poor product quality	material, products, and services fail to meet customers' requirements	8	[3] [4] [7] [18] [21] [22] [23] [25]
12	Financial issues	e.g., bankruptcy, budget non-realization, problems in financing the projects	8	[3] [4] [7] [8] [9] [10] [12] [23]
13	Corporates dropout	closure of companies supplying materials, products, and services	7	[2] [3] [7] [11] [23] [27] [31]
14	Distrust among stakeholders	due to the prevalence of fraud and non-transparency among SC participants	7	[1] [7] [9] [15] [22] [23] [25]
15	Rework and change orders	due to changing customers' preferences in construction projects	7	[4] [11] [15] [21] [22] [29] [31]
16	Unreliable IT systems	IT systems fail to conform to project preferences	7	[4] [11] [12] [15] [21] [22] [25]
17	Severe weather	harsh climatic situations that disrupt construction projects	6	[4] [12] [15] [21] [27] [40]

Rank	SCV Category	Brief Description	Freq.	References No.
18	New legislation	the implication of new governmental rules	6	[4] [8] [10] [15] [18] [29]
19	Poor integration due to outsourcing	unmanaged outsourcings that lead to loss of SC connectivity	5	[7] [10] [15] [21] [37]
20	Utility disruptions and energy scarcity	power and Internet service outages, together with fuel shortages	5	[4] [7] [8] [11] [39]
21	Infrastructure damage due to accidents	accidents such as the explosion at the workshop or the supplier companies	5	[4] [7] [11] [23] [36]
22	Health and safety issues	occupational health and safety incidents, including accidents and near misses	4	[7] [9] [15] [21]
23	Theft and sabotage	e.g., cyber-attacks and deliberately damaging or thieving projects assets	4	[8] [15] [21] [25]
24	Biological threats	e.g., infectious diseases outbreak	3	[7] [15] [35]
25	Price and exchange rate fluctuations	unstable local currencies that affect the prices and cause an inflation bubble or recession	2	[3] [10]
26	Negative media	e.g., social media causing an interruption in SCs by the propagation of exaggerated or biased news	2	[4] [29]

References utilized are: 1=(Zavala-Alcívar et al., 2020); 2=(Wang et al., 2018); 3=(Truong & Hara, 2018); 4=(Bevilacqua et al., 2018); 5=(Zavala et al., 2018); 6=(Chaghooshi et al., 2018); 7=(Zainal Abidin & Ingirige, 2018b); 8=(Kochan & Nowicki, 2018); 9=(Zainal Abidin & Ingirige, 2018a); 10=(Zainal Abidin, 2018); 11=(Meinel & Abegg, 2017); 12=(Ali et al., 2017); 13=(Huong Tran et al., 2016); 14=(Annarelli & Nonino, 2016); 15=(Fiksel 2015); 16=(Mensah et al., 2015); 17=(Bruno & Clegg, 2015); 18=(Green, 2015); 19=(Bueno-Solano & Cedillo-Campos, 2014); 20=(Scholten et al., 2014); 21=(Pettit et al., 2013); 22=(Aloini et al., 2012); 23=(Chowdhury et al., 2012); 24=(Tummala & Schoenherr, 2011); 25=(Xiao et al., 2011); 26=(Wedawatta et al., 2011); 27=(Wedawatta et al., 2010); 28=(Boin et al., 2010); 29=(Pettit, 2008); 30=(Stolker et al., 2008); 31=(Berry & Collier, 2007); 32=(Kumar & Viswanadham, 2007); 33=(Cucchiella & Gastaldi, 2006); 34=(Tang, 2006); 35=(Peck, 2005); 36=(Sheffi & Rice Jr, 2005); 37=(Christopher & Peck, 2004); 38=(Chopras, 2004); 39=(Chopra & Sodhi, 2004); 40=(Handfield et al., 2002);

RESULTS AND ANALYSIS

In this section, the responses indicate that the four most and least concerning SCV have not changed during the past two years in the construction industry of the studied country. Accordingly, "price and exchange rate fluctuations", "supply-demand volatility", "financial issues", and "political challenges" are the prime disruptors of the country's construction supply chain in descending order. These are followed by "corporate dropouts", "distrust among stakeholders", and "poor product quality". However, in the case of the past two years, "biological threats" have taken the sixth position in the most prior CSCV in Table 2. On the other hand, the least concerning CSCV have not changed in the past two years. They include "natural disasters and environmental issues", "infrastructure damage", "data breach", and "terrorism/war" in descending order. The factors are sorted by their priority from highest to lowest. They are indicated by their rank in the literature -as the global context- in Figure 2.

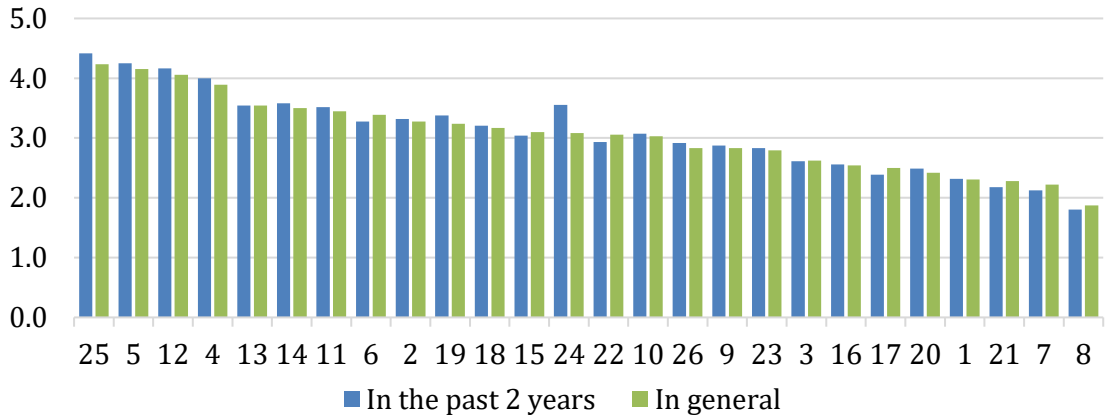

Figure 2- CSCV by their rank in general and the past two years in Iran

The data also shows that the priority of the majority of the CSCV has not considerably changed within the past two years. If one step change in rank is regarded as negligible, the priority of only five CSCV has changed over the past two years. Thereby, three CSCV have lost their priority which include "corporates dropout", "inadequate communication", and "rework and change orders". Also, two CSCV have gained priority during this period: "biological threats" and "information mishandling". The most considerable changes belong to "biological threats" and "inadequate communications". This information is indicated in Table 2.

Table 2- Factors with the most significant change in priority in the past two years

CSCV	General Rank	Rank in the past two years	Change
Biological threats	13	6	7 up ↑
Information mishandling	15	13	2 up ↑
Corporates dropout	5	7	2 down ↓
Rework and change orders	12	14	2 down ↓
Inadequate communication	8	11	3 down ↓

The changes in the score of CSCV are calculated to indicate the extent to which they have gained or lost significance. Hence the in-general scores are subtracted from the past-two-year score. Hence the average general and past two years' scores are subtracted for CSCV to calculate the change measure. It is illustrated in Figure 3. As can be seen, "biological threats" have gained the highest amount of importance in the past two years, and this is followed by "price and exchange rate fluctuations", "poor integration", "financial issues", and "supply-demand volatility". In contrast, concerns regarding certain CSCV have been reduced within the past two years. This group of CSCV is comprised of "health and safety issues", "inadequate communication", "severe weather", "infrastructure damage", "data breach", "terrorism/war", "rework and change orders", and "machinery and its breakdown" in ascending order of score change. Only "corporate dropout" exhibited no change in score in the study period. It should be noted here that the aforementioned score changes ranged from the lowest of -0.11 to the highest of 0.47.

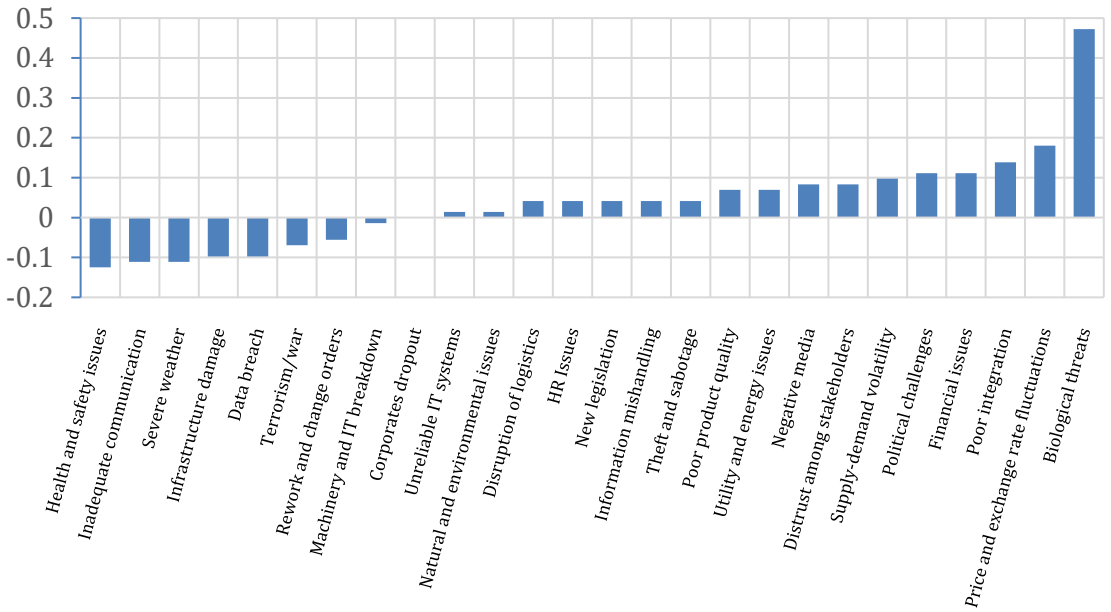

Figure 3- Change in the importance of CSCV in Iran in the past two years

The respondents were asked to point out any CSCV missing from the questionnaire through open-ended questions. A total of 16 responses were received, which were analyzed qualitatively. The most-cited concerns are listed below, respectively:

1) corruption of regulatory and supervisory bodies (typically referred to as bribery)
2) incompetency of the regulatory and supervisory entities to enact regulations and circulars
3) little use of new technology
4) the role of monopolists (especially in the supply of cement as a strategic material in the construction industry)
5) the role of intermediaries and middle persons.

It should be noted that, due to space limitations, only the top and bottom four CSCV are investigated and discussed in the rest of this essay.

DISCUSSION

The primary variable in the studied country was "price and exchange rate fluctuations". It can be attributed to the country's economic crisis due to international sanctions[5] that have caused the national currency to lose its value and drop by around eight times[6], resulting in massive inflation during recent past years[7]. This variable makes investors keep their capital in any form other than cash, which cannot sometimes be readily liquidated. Further, investors make significant losses due to these conversions in many cases. The second most crucial variable in the presence of an unfavorable macro-environmental context, "supply-demand volatility", also appears to have links with the economic crisis. This mainly happens due to the shortage of raw materials and the influence of monopolists, especially cement suppliers, limiting the market supply to

[5] Carnegie Endowment for International Peace. *The Geopolitical Roots of Iran's Economic Crisis*. (https://carnegieendowment.org/sada/83350)
[6] https://www.tgju.org/archive/price_dollar_rl
[7] Inflation, consumer prices (annual %) - Iran, Islamic Rep. (https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=IR)

increase the prices or export their products when they perceive higher profit in exports. These all cause the demand to react impulsively to supply fluctuations that deteriorate market balance. The third most important variable was "financial issues", which again stem from the country's economic situation. "Political challenges" was identified as the fourth most important variable associated mainly with the foreign policies of the studied country. Although these CSCV have not changed their priority during the past two years, their significance has increased in this period. It can be related to the deteriorating economic-political conditions of the studied country.

Another subject worth mentioning here is "biological threats", whose priority has changed meaningfully from 13 to 6 during the past two years. It has happened due to the outbreak of the COVID-19, indicating that the pandemic has resulted in higher vulnerability in the construction supply chain of the studied country. Other changes that occurred to the priority of the CSCV indicated in Table 2 do not appear to convey any meaningful information.

Moreover, the changes in the score of the CSCV in the past two years indicate that the COVID-19 has been a significant issue during this time. It is also evident that the most prior CSCV of the studied construction supply chain have gained the highest significance levels during this period. Thus, it can be inferred that the construction supply chain of the studied country has become more vulnerable in the past two years.

CONCLUSION AND FUTURE RESEARCH

In this paper, for the first time, we studied the construction supply chain vulnerabilities (CSCV) in the presence of an unfavorable macro-environmental context (e.g., difficult political, economic, and legal situations). Also, we analyzed the changes in such vulnerabilities in a period coincident with the outbreak of the Covid-19. The country which best fit the study's situation was Iran, where crippling international sanctions have brought about economic isolation and the prevalence of monopolists. The results showed that under unfavorable macro-environmental factors, such CSCV as "price and exchange rate fluctuations", "supply-demand volatility", "financial issues", and "political challenges" gained priority over others. These ramifications, which differ from those in normal contexts mentioned in previous research, imply the significance of considering the specific supply chain context in identifying the CSCV. They also provide a proper tool for supply chain decision-makers when facing challenging macro-environmental factors.

Furthermore, this study analyzed the changes of the identified CSCV in a period coincident with the outbreak of the Covid-19 pandemic. The results of analyzing these changes indicated that the impacts of the pandemic in line with the unfavorable macro-environmental context have made the studied construction supply chain more vulnerable to disruption. Moreover, this paper has introduced four more CSCV specific to the abovementioned context. The limitation of this study refers to considering only one country, i.e., Iran, to simulate an unfavorable macro-environmental context. However, the results can provide a decision-making tool for supply chain managers before implementing lean principles. In other words, since lean has twofold effects on SCs (i.e., improving SCs' performance while making them more vulnerable to disruption), the CSCV provided in this paper help managers focus more on lean tools such as the Last Planner System and value stream mapping which cause less vulnerability in SCs.

Further research can be done to determine the capabilities in supply chains operating under unfavorable macro-environmental contexts to counter the CSCV for making the

supply chain resilient. Moreover, future studies can focus on the role of each lean tool on the vulnerability of construction SCs and consider separating internal and external vulnerabilities.

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