

Framework to mitigate supply chain disruptions in the apparel industry during an epidemic outbreak

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Abstract - Disruptions to a company supply chain, has serious implications, and if not addressed lead to even business closure. The article explores the supply chain risks faced by the apparel industry during an epidemic outbreak and the strategies that could be taken to mitigate them. A systematic review of the literature was initially conducted to identify the supply chain risks and mitigation strategies, and expert interviews were then used to reinforce the findings and then identify the focus areas. Supply chain risks were mapped in a vulnerability matrix with risk association, using a diagrammatic format, and a framework was developed using the supply chain risks and strategies. The developed framework shows that most of the risks can be mitigated by local sourcing and giving incentives to customers. A generalized model was developed based on cost and time considerations but using the same process it can be customized using different factors and risks depending on the experience and needs of the company.

Keywords - epidemic outbreak, mitigation strategies, supply chain disruptions, supply chain risks

I. INTRODUCTION

A Supply Chain (SC) disruption is any sudden change or crisis which negatively impacts the interconnectedness of a network of people, organizations, and activities where the movement of a product from a supplier to a final customer is affected [1]. This effect can be either local or global.

SC disruptions can occur in a company because of legal disputes, strikes, natural disasters and manmade catastrophes. In 2011, the Tsunami in Japan reduced its exports between 0.5% to 1.6% [2]. A brake-fluid proportioning valve supplier caught fire on 1st February 1997 which led Toyota to shut down all its plants and assembly lines and caused a sales loss of 70,000 vehicles ([3] [4]). Moreover, special cases like epidemic outbreaks (Ebola, SARS, MERS, Swine flu, and coronavirus/ COVID-19) also severely disrupts the supply chain [5]. Due to COVID-19, China's industrial production had decreased by 13.5% for the month of January and February 2020, compared to the previous year [6]. More than 75% of U.S. businesses have experienced SC disruption as a result of the COVID-19 outbreak [1] [7] [8]).

The apparel SC aims to provide the right fashion product to satisfy the market needs, with the lowest possible cost, fastest speed and maximized profit [9]. "No-one wants to buy clothes to sit at home in," says Simon Wolfson [10]. Due to the pandemic the fashion industry has been negatively impacted on every imaginable level where production has ceased, retailers have closed and demand has decreased to 34% in March because apparel is not a basic human need [10]. Therefore, the demand for apparels during the pandemic was very low. However, its contribution to the economy is significant. In 2018, the global clothing and apparel market reached a value of \$758.4 billion and has been growing at a compound annual growth rate (CAGR) of 7.5% since 2014

[11]. Moreover, the target for 2022 which was set before the onset of COVID-19 was a CAGR of 11.8% to nearly \$1,182.9 [11]. Furthermore, the Sri Lankan apparel industry which contributes 6% to its country's GDP and 44% to its national export revenue, had set itself a target of \$8 billion export revenue by 2025, prior to the onset of COVID- 19 [12] [13].

The experience faced by the Sri Lankan apparel manufacturing companies was very similar to the global context as most of the apparel manufacturing companies were struggling without raw materials for the upcoming orders. With the spread of the virus over 65 countries, lockdown procedures were implemented, including Sri Lanka where companies went through a temporary shutdown [14]. Because revenue was severely curtailed, companies faced severe cash flow constraints, with companies forced to cut non-essential costs, and even enforcing salary reductions among its staff.

According to [2][3][4][5][6] and [15] SC disruption has negatively affected the world's economy. The study focuses on SC risks, in this challenging scenario of an epidemic outbreak, in order to assess how such SC disruptions could be handled and mitigated. Because of the importance of the apparel industry to the local economy, being the single largest export revenue earner, the scope of the study was restricted to identify SC risks during an epidemic outbreak in the context of the Sri Lankan apparel industry. The study proposes a model to identify the SC risks and vulnerabilities during an epidemic outbreak and the possible mitigation strategies that could be adopted.

II. LITERATURE REVIEW

According to [16] managing SC disruptions revolves around, thoroughly understanding the identified risks, mitigating and then if needed, increasing the capacity of the SC.

Risk can be defined as "uncertainty of outcomes", "probability of lost or lost occurrence", "deviation of outcomes from expectation", "change leading to loss" or "danger of harm loss" [16]. Using the mentioned risk definitions, [16] has identified the following basic risk characteristics; risk is an attitude towards future, rooted in uncertainty, occurred because of lack of information and disadvantage to the company. It means that time, uncertainty, information and loss are key factors. Moreover, [16] [17] have identified single port closure, multiple port closure, transportation link disruption, loss of key supplier, labor unrest, economic recession, visible quality problems, computer virus, workplace violence, flood, wind damage, IT system failure, accounting irregularity, earthquake, employee sabotage, technological change and product tampering as SC risks and developed a vulnerability matrix using disruption probability and consequences (shown in Figure 1). Further,

they have discussed that the SC could be resilient if the company follows a mixed approach of flexibility and redundancy.

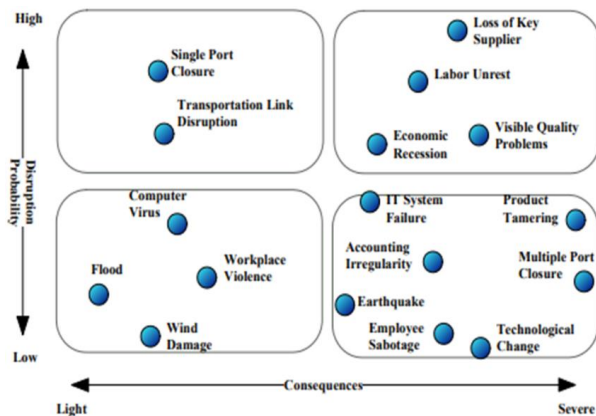


Fig 1. Vulnerability map for a single firm [16] [17]

According to [18], they have discussed, selected risks which are associated with the apparel retail SCs in India by structural analysis of the controllable risks that are identified. The risks they have selected and the background of it are shown in Table I.

TABLE I. RISK ASSUMPTIONS [18]

Risk no.	Risk	Background of risks
R1	Globalization	Currency fluctuations; design transfers, competition; legal and political risk; policy changes; etc.
R2	Raw material and product quality standards	Retailers do not have the complete SOP of the product quality and it varies from season to season/ and product to product
R3	Scarcity of resources	Scarcity of raw material; power shortage; labor shortage; resource cost; the cost of technology etc.
R4	Supplier uncertainty	Failure to deliver on time; supplier bankruptcy; unreliable supplier; Cost and quality not reliable/ consistent; etc.
R5	Lack of co-ordination/ alignment	Lack of communication; no cross-functional teams; no transparency between partners/departments; etc.
R6	Behavioral aspect of employees	Employee disputes; inefficient/ unskilled employee; resistance to change; unavailability of labor due to absence; etc.
R7	Infrastructure risks	Transport breakdown; inadequate means of transport; inconsistent warehouse facility; IT failure; etc.
R8	Delay in schedule/ lead time	Order fulfillment error; change in production schedules; machine breakdown; delay in delivery; change in design; etc.
R9	Demand uncertainty	Error in demand forecast (short term or long term); bullwhip effect; short product life cycle; risk from new entrants; etc.
R10	Customer dissatisfaction	Product returns; customer complaints; reduced demand; stock out; poor quality; wrong product delivery; etc.
R11	Financial risk	High cash conversion cycle; low market share; low-profit margins; decreasing revenues; etc.
R12	Security and safety	Pilferages and shrinkage of the materials in the warehouse/losses in transit, performance of the product, cyber-attack; etc.

Article in [18], has revealed the use of Interpretative Structural Modeling (ISM) to establish the interdependencies

between the risks (Table I), spread across various SC functions where they have classified the risk factors based on their driving and dependence power. They have identified that globalization, labor issues and security and safety of resources as the strong drivers of other SC uncertainties which will lead the company to a financial crisis [18]. The variables they have considered are limited, generic and the costs, frequency of occurrences of disruptions can be used to prioritize risk where strategies can be formulated to mitigate the risks.

According to [19], they have used 45 face to face interviews with open-ended questions to analyse 20 manufacturing firms in Uganda. They have identified, classified the SC risks/threats as Endogenous (supply-side, firm-level, demand-level), Exogenous (geopolitics, economic) using the collected data and it is shown in Table II. They have further analysed to identify the interconnectedness of SC threats, strategies and outcomes.

TABLE II. SUPPLY CHAIN RISKS CLASSIFICATION [19]

Threats	Supply-side	Long-distance sourcing triggered threats, limited local supply market, product counterfeiting, poor-quality raw materials, dishonest suppliers, raw material delays and shortages, financial difficulties of suppliers, supplier delivery failure, reputational risk
	Demand-level	Power asymmetries, dishonest customers/distributors, payment threat, financial difficulties of customers, order cancellations, demand variations, customer characteristics, reputational risk
	Geo-politic	Political instabilities, geographical location (landlockedness), national politics, government policy, the weak legal system, corruption, product counterfeiting, in-transit raw material theft, communication barriers, natural disasters
Supply Chain Resilience Strategies	Supply management	Backward integration, outsourcing, appropriate supplier selection, alternative transportation, multiple sourcing, supplier development, maintaining strategic stocks, buying instead of making (temporarily), effective contracting, local sourcing, order splitting, enhancing proximity to suppliers, procurement management, quality management, exclusive sourcing, inter-branch stock transfer
	Demand management	Creating customer flexibility, customer incentives, inventory management, product recalls, demand forecasting
	Relationship management	Co-opetition, collaboration with government, collaboration with customers, collaboration with suppliers, Informal networking
	Information management	Risk communication, market intelligence, increasing product knowledge, improving visibility, using information communication technology
Outcomes	To the supply-side	Poor-quality raw materials, limited flexibility to switch suppliers, supplier complacency, raw material delays and shortages
	To demand-side	Distributor complacency, reduced customer base, poor customer delivery performance
	To entire supply chain	Product counterfeiting, reputational risk

Risk assessment and operational approaches to managing risks in global SCs were addressed using a Canadian pet products company operation [20]. The study was based on a compilation of research and interactions with

SC managers in 15 different industries. A framework (Figure 2) was created according to the likelihood of disruptions and its consequences. They have provided scores considering the risk, affected part/product based on the likelihood and impact. It is also stated that attempting to scope one's risk is a challenge based on the supplier information. Moreover, reflecting upon the case study, it should be considered that the risk averseness of the company and the investment they are willing to make to mitigate the risk [20]. However, the study takes an overall view of SC risks and its mitigation strategies and not an in-depth analysis.

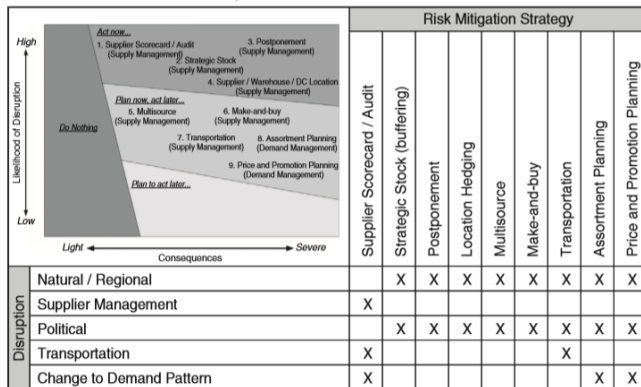


Fig 2. Common disruptions and the strategies that mitigate their impact [20]

Perspectives in SC Risk Management is addressed by reviewing quantitative models that deal with SC risks. A unified framework is developed to classify SC risk management articles. Moreover, SC risk management is approached in two ways; SC Risk (operational risks or disruption risks) and Mitigation Approach (supply management, demand management, product management and information management). The identified strategic and tactical plans to manage SC risks are shown in Table III. It is stated that managing SC risks can be addressed using the manager's attitude towards risks and initiatives for managing SC disruption. Furthermore, robust strategies to mitigate operational and disruption risks are identified. They are robust supply management strategies (multi-supplier strategy from multiple countries, robust demand management strategies (demand management strategies mentioned in Table III), robust product management strategies (postponement strategy) and robust information management strategies (information sharing, vendor managed inventory, collaborative forecasting and replenishment planning to increase SC visibility) [21].

Article in [5], has framed epidemic outbreaks as a unique type of SC disruption risk and used the example of coronavirus (COVID-19), anyLogistix simulation and optimization software to examine and predict the impacts of epidemic outbreaks on the SC performance. Reference [5] [22] have recognized lead-time, risk mitigation inventory and backup suppliers as crucial elements affecting the SC reactions to disruptions. Moreover, geographic location data, lead-time data, and demand data are primarily needed to run the simulation models [5] [23]. A guided framework is needed to develop pandemic plans for a company's SC because epidemic outbreaks create a lot of uncertainty.

TABLE III. STRATEGIC AND TACTICAL PLANS TO MANAGE SUPPLY CHAIN RISKS [21]

	Supply Management	Demand Management	Product Management	Information Management
Strategic Plans	Supply Network Design (Network configuration, Product assignment, Customer assignment, Production planning, Transportation planning)	Product Rollovers Product Pricing	Product Variety	Supply Chain Visibility
Tactical Plans	Supplier relationship Supplier selection process (Criteria, approval/selection) Supplier order allocation (Uncertain demands, supply yields, supply lead times, supply costs) Supply Contract (Uncertain demand-Wholesale price contracts, buy-back contracts, revenue sharing contracts, quantity-based contracts: quality flexibility and minimum order; and Uncertain price)	Shift Demand Across Time Shift Demand Across Markets Shift Demand Across Products (Product substitution and product bundling)	Postponement (Make-To-Order systems without forecast updating, Make-To-Stock systems without forecast updating, Make-To-Stock systems with forecast updating) Process Sequencing.	Information Sharing Vendor Managed Inventory Collaborative Planning, Forecasting & Replenishment

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Article in [24] have identified and analysed the SC risks using a vulnerability matrix. Similarly, article in [25] [26] have used vulnerability matrix and correlation analysis to identify and analyse the SC risks during an epidemic outbreak.

III. METHODOLOGY

Prioritization of risk is essential as the risk factors may act as drivers to other risk factors. Therefore, managers should initially focus on the few (major) risks which act as drivers to other risks. The main purpose of this paper is to identify risk and vulnerability to analyse the costs and time associated with the SC risks and identify the mitigation strategies. It is important to control these risks since it might lead companies to go through a temporary shutdown during an epidemic outbreak. The steps of the research methodology could be explained in the following flow diagram.

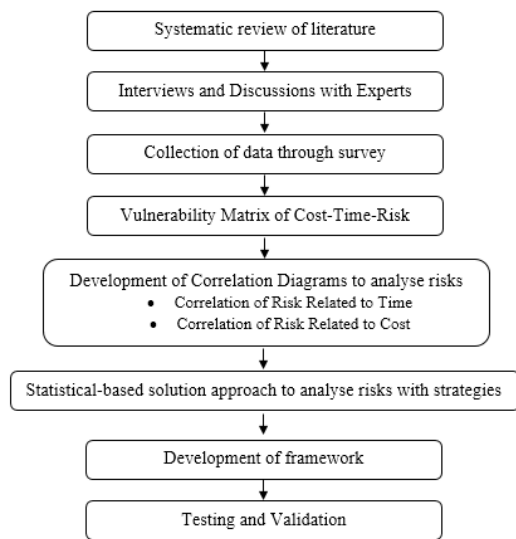


Fig 3. Flow diagram of the methodology

According to [16] [17] [18] [19] SC risks were identified through the literature. Moreover, to further identify the related SC risks, SC managers who have more than five years of experience in the apparel industry were interviewed. A five scale Likert scale was used to collect data (1 - strongly disagree, 2 - disagree, 3 - neither agree nor disagree, 4 - agree, 5 - strongly agree). The experts were drawn from companies whose clients were international and suppliers were both local and international.

There are 300-350 apparel manufacturing plants in Sri Lanka [13]. However, there are less than 20 companies which are competing internationally. Information was collected from 8 leading apparel manufacturing companies which cover almost 75% market share of the apparel industry in Sri Lanka. Five participants from each of the companies were selected. They were of executive grade or higher, with more than 5 years' experience and were selected using random sampling.

As of risk definitions and characteristics stated by [16], the study selected "risk is an attitude towards future event", "disadvantage to the company" as the characteristics to categorize the risks because most of the risk related matrixes, models, frameworks were developed using likelihood of the risk / disruption / threat and its consequences [16] [17] [20]. However, the study focus is to prioritize these risks in order to identify which risks should be addressed first and mitigate them. Therefore, risks were categorized using time and economical loss factors. Time factor is taken as the time taken to address the risk and, economical loss factor as the cost occurred to the company when the risks were not handled. The more time it takes to address or control the disruption, it is categorized into high risk category. Similarly, the higher the economic loss or the cost to bear the risk, also falls into the higher risk category. The identified SC risks through the literature review and experts' opinion were,

- (R1) - Loss of local key supplier [16] [18] [19] [24] [25] [26]
- (R2) - Loss of international key supplier [16] [18] [19] [24] [25] [26]

- (R3) - Local port closure [16] [24] [25] [26]
- (R4) - International port closure [16] [24] [25] [26]
- (R5) - Transportation link disruption- other than ports [16] [18] [19] [24] [25] [26]
- (R6) - Raw materials delays and shortages [18] [19] [24] [25] [26]
- (R7) - Human Resource shortages [18] [24] [25] [26]
- (R8) - Product demand variations [18] [19] [24] [25] [26]
- (R9) - Order cancellations ([18]; [19]; [24]; [25] ; [26])
- (R10) - Lead time variations [5] [18] [24] [25] [26]

The identified mitigation strategies were,

- (S1) - Backward Integration [14] [19]
- (S2) - Outsourcing [14] [19] [20] [21]
- (S3) - Local Sourcing [14] [19] [20] [21]
- (S4) - International Sourcing [14] [19] [20] [21]
- (S5) -Strategic Stock [14] [19] [20]
- (S6) - Sharing Information [14] [19] [21]
- (S7) - Supply Chain Visibility [14] [19] [21]
- (S8) - Alternative Transportation [14] [19] [21]
- (S9) - Customer Incentives [19] [20]
- (S10) - Product Differentiation [21]
- (S11) - Health Safety [14]

A risk assessment was conducted and identified the positions of each risk under time and cost category. Based on the experts' opinion Cost-Time-Risk (CTR) matrix was developed. Next, a correlation analysis was conducted to identify the association between each risk and the mitigation strategies. This enable the decision makers to identify the best mitigation strategies that is applicable or could be applied to control or mitigate the risks. Based on the evidence an empirical model was developed. The study used 80% of the data to develop the model and 20% of the data for testing and validation. Moreover, experts' opinions were taken regarding the output of this study.

IV. RESULTS AND DISCUSSION

A. Vulnerability matrix of cost-time-risk

The main two questions which were asked to identify the position of the risk in the vulnerability matrix were the time taken to mitigate the risk and the cost incurred when the risks were not handled.

The scores shown under time and cost in Table IV, are the average score taken from the survey. Higher the time taken to mitigate the SC risk, higher the risk. Likewise, higher the cost occurred to the company when the SC risks are not handled, higher the risk.

According to the data collected from the experts through the survey, the SC risks were mapped in a vulnerability matrix and shown in Fig. 4. Fig. 4 was drawn from time and cost scores which were collected from the survey and shown in Table IV.

TABLE IV. RESULTS OF COLLECTED DATA FROM THE SURVEY

Supply Chain Risks	Time	Cost
(R1)- Loss of local key supplier	3.5	3
(R2)- Loss of international key supplier	4.5	4
(R3)- Local port closure	5	2
(R4)- International port closure	4.5	2
(R5)- Transportation link disruption- other than ports	3	2
(R6)- Raw materials delays and shortages	3.5	3
(R7)- Human Resource shortages	2	2
(R8)- Product demand variations	3.5	3.5
(R9)- Order cancellations	4.5	4
(R10)- Lead time variations	3.5	2.5

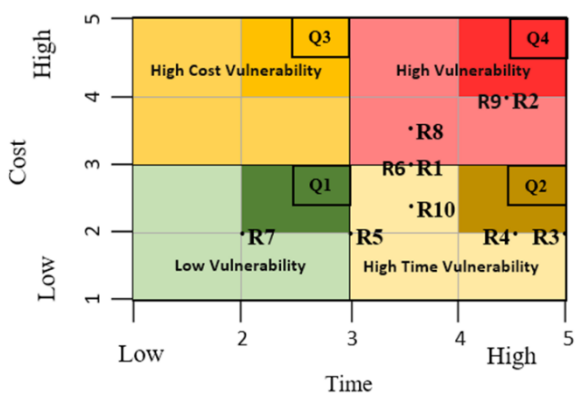


Fig 4. Risk assessment matrix on Cost and Time (CTR Vulnerability Matrix)

If the cost is high, then the risk is high, as the risk incur a cost to the company which might lead the company to go through a temporary shutdown if it's not handled or mitigated properly. If the time is high, it means that the risk is taking more time to handle or mitigate, therefore, the risk is also high which falls to Quadrant 2 (Q2). It is beneficial to focus on high vulnerability risks where the cost and time are both high, which means that the risk is very high compared to the other quadrants as shown in Quadrant 4 (Q4). A generalized vulnerability model is developed in this study considering cost and time factors, however, it can be customized using different factors and risks depending on the experience and needs of the company.

The weight for cost and time is measured on the same scale of Likert scale 1 to 5. According to the vulnerability matrix shown in Figure 4, loss of international key supplier (R2) and order cancellations (R9) are towards the right side in the matrix which means that the risk is high. However, human resource shortages (R7) is towards the left side in the matrix which means the risk related to it is low compared to the other SC risks [25] [26]. It is because human resource shortage can be solved internally, quickly compared to the other risks, whereas, in the loss of international key suppliers, order cancellations are decided by external parties and cannot be handled internally as it takes time and resources to solve the issue.

Loss of international key supplier can be mitigated by having several suppliers from different regions. It may be

costly, however, in order to mitigate the risk, you should at least have a minimum order from these suppliers. Order cancellation can be mitigated by having several customers and a variety of products. Moreover, during the epidemic outbreak, manufacturers should switch to products such as personal protective equipment, face masks, and similar alternate products which can be manufactured with the same resources.

As the vulnerability matrix only indicates the time and cost but doesn't indicate the association of each risks, a statistical approach of correlation analysis was used to analyse the data.

B. Development of correlation diagram to analyse risks

Using the data gathered from the survey, the identified risks were analysed using bivariate correlation to measure the strength of the relationship between each pair. Only 35% of the data follows a normal distribution, therefore, spearman's rho was used to calculate the correlation for each category. The study considered value which is greater than or equal to 0.7 as highly correlated. The results of the survey analysis under time category is shown in Table V.

C. Correlation of risk related to time

TABLE V. CORRELATION RESULTS UNDER TIME CATEGORY

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1	1									
R2	0.839	1								
R3	0.648	0.797	1							
R4	0.723	0.813	0.97	1						
R5	0.686	0.847	0.725	0.719	1					
R6	0.487	0.786	0.684	0.635	0.821	1				
R7	0.555	0.775	0.614	0.579	0.873	0.974	1			
R8	0.547	0.832	0.923	0.888	0.849	0.861	0.798	1		
R9	0.638	0.845	0.974	0.965	0.817	0.738	0.668	0.961	1	
R10	0.612	0.856	0.852	0.877	0.809	0.889	0.831	0.944	0.905	1

Correlation values which are greater than or equal to 0.7 are highlighted in light grey and considered as highly correlated risks, ignoring the correlation between the same risk. Using the relationship shown in Table V, a hierarchical diagram was developed to understand the relationship between each risks and it's shown in Fig. 5. The hierarchical diagram was developed considering the number of highly correlated risks.

The dotted box represents correlated risks. Hence, any relation between another and the dotted box represents an inclusive relationship of all risks within the dotted box. According to Fig. 5, R2 (Loss of international key supplier) is highly correlated to all the other risks which means that there is a high probability of occurrence of other risks due to R2 [25].

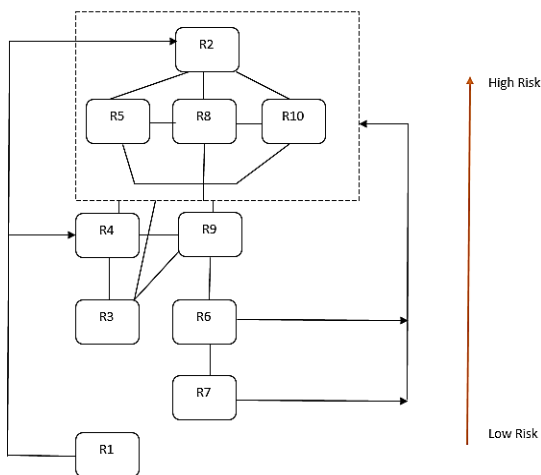


Fig 5. Hierarchical diagram under time category

Therefore, companies should focus primarily to mitigate on losing international key suppliers. Further, companies should focus on R5 (Transportation link disruption), R8 (Product demand variations) and R10 (Lead time variations) as these risks are secondly highly correlated to the rest of the risks [25].

1) Correlation of risk related to cost

The results of the survey analysis under cost category is shown in Table VI.

TABLE VI. CORRELATION RESULTS UNDER COST CATEGORY

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1	1									
R2	0.71 5	1								
R3	0.93 1	0.64 5	1							
R4	0.6	0.47 6	0.79 3	1						
R5	0.79 7	0.66 1	0.78 1	0.74 7	1					
R6	0.82 8	0.40 6	0.82 1	0.73 6	0.81 1	1				
R7	0.63	0.77 2	0.67 9	0.53 1	0.62 2	0.45 8	1			
R8	0.55 8	0.53 8	0.40 9	0.06	0.13 5	0.24	0.31 3	1		
R9	0.62 5	0.61	0.66 8	0.57 4	0.31 9	0.55	0.61 3	0.62 8	1	
R10	0.58 6	0.83 9	0.53 7	0.39 8	0.32 4	0.32 5	0.52	0.71 2	0.81 6	1

Correlation values which are greater than or equal to 0.7 are shaded in light grey and considered as highly correlated risks. Using the relationship shown in Table VI, a diagram was developed to understand the co-relationship between each risks and shown in Figure 6. The hierarchical diagram was developed considering the number of highly correlated risks.

According to Figure 6, R1 (Loss of local key supplier), R3 (Local port closure), R5 (Transportation link disruption) and R6 (Raw materials delays and shortages) are highly correlated to other risks, which means that there is a high probability of occurrence of other risks due to R1, R3, R5 and R6 [25]. Therefore, companies should focus primarily to mitigate on losing local key suppliers, local port closure,

transportation link disruption and raw materials delays and shortages when considering cost.

It can be seen that R5 (Transportation link disruption) is highly correlated to rest of the risks when you consider both categories. Therefore, it is better to mitigate transportation link disruption first and then the rest of the risks under each category.

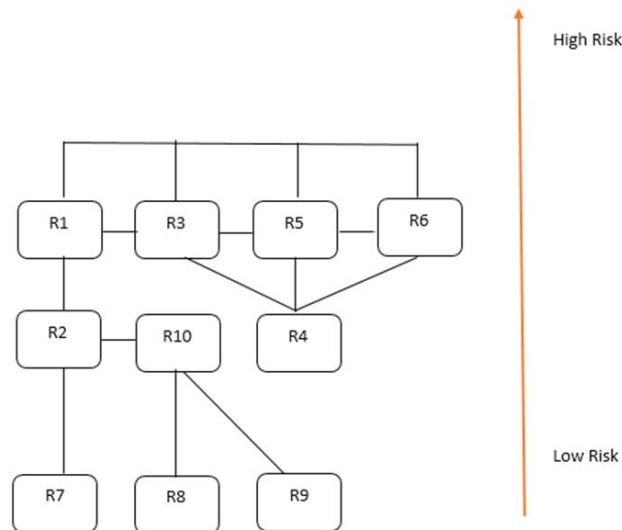


Fig 6. Hierarchical diagram under cost category

Based on the discussion with experts, the study identified that it takes more time to mitigate loss of international key supplier (R2) and it is highly correlated to the rest of risks because international key suppliers are the main source of income to the company. Therefore, losing them will cause a chain reaction. Customers may not like the alternative supplier, quality issues, and it takes time to find alternative suppliers. Therefore, lead time will increase, raw materials to produce the product will be insufficient which will lead to order cancellations or delay in fulfilling orders.

Considering loss of local key supplier (R1) under cost category, it was identified that it is costly because losing local key supplier will lead to find alternative suppliers and there will be shipping cost, lead time to deliver the raw materials will be high which is costly to the company. Moreover, local port closure (R3) will lead to sourcing other means of transportation for raw materials into the country and products out of the country. This will be costly because you may be currently using the optimum method of transportation resulting in, shortage and delay of raw materials which will lead to delayed orders.

At the end of every production we should deliver the products on time to gain the benefit from it. Therefore, transportation link disruption is a crucial risk to be mitigated.

D. Statistical-based solution approach to analyse risks with strategies

Using the data from the survey, a correlation analysis was conducted to identify the association between each risks with strategies in order to mitigate the risks. Only 35% of the data follows a normal distribution. Therefore, spearman's rho was used to calculate the correlation. Value which is greater than or equal to 0.4 and less than 0.7 was considered as moderately correlated and highlighted in yellow. In this

research, only positive correlated values are considered as experts assumed that they can mitigate the risks by each highly or moderately positive correlated strategies.

The results of the analysis under time category is shown in Table VII.

TABLE VII. CORRELATION RESULTS FOR RISK AND STRATEGY UNDER TIME CATEGORY

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
R1	0.12	0.44	0.40	0.12	0.08	0.10	0.09	0.02	0.07	0.08	0.17
R2	0.31	0.02	0.22	0.47	0.21	0.22	0.15	0.28	0.21	0.12	0.20
R3	0.16	0.03	0.01	0.47	0.60	0.29	0.07	0.32	0.00	0.17	0.41
R4	0.28	0.23	0.45	0.40	0.02	0.07	0.04	0.03	0.11	0.03	0.36
R5	0.07	0.59	0.23	0.02	0.02	0.14	0.13	0.02	0.10	0.04	0.31
R6	0.14	0.55	0.18	0.26	0.11	0.34	0.14	0.05	0.13	0.27	0.09
R7	0.24	0.58	0.64	0.52	0.32	0.32	0.47	0.66	0.67	0.68	0.56
R8	0.22	0.08	0.45	0.45	0.25	0.03	0.12	0.26	0.06	0.26	0.27
R9	0.21	0.19	0.17	0.17	0.17	0.60	0.54	0.06	0.59	0.47	0.00
R10	0.21	0.30	0.06	0.06	0.06	0.23	0.28	0.17	0.16	0.15	0.09

It can be seen that human resource shortages (R7) can be mitigated using many strategies. Whereas, loss of local key supplier (R1), loss of international key supplier (R2) and international port closure (R4) can be mitigated by only implementing one strategy from the considered strategies. Moreover, local port closure (R3), product demand variation (R8) and lead time variations (R10) cannot be mitigated by

Risk/ Strategies	(S1)- Backward Integration	(S2)- Outsourcing	(S3)- Local Sourcing	(S4)- International Sourcing	(S5)- Strategic Stock	(S6)- Sharing Information	(S7)- Supply Chain Viability	(S8)- Alternative Transportation	(S9)- Customer Incentives	(S10)- Product Differentiation	(S11)- Health Safety
(R1)- Loss of local key supplier			✓								
(R2)- Loss of international key supplier				✓							
(R3)- Local port closure											
(R4)- International port closure			✓								
(R5)- Transportation link disruption- other than ports		✓									
(R6)- Raw materials delays and shortages		✓									
(R7)- Human Resource shortages		✓	✓	✓		✓	✓	✓	✓	✓	✓
(R8)- Product demand variations						✓	✓		✓	✓	
(R9)- Order cancellations								✓	✓		
(R10)- Lead time variations										✓	

implementing any strategies under time category. Using the correlation analysis for risk and strategies a framework was developed.

TABLE VIII. FRAMEWORK TO MITIGATE SUPY CHAIN DISRUPTIONS - TIME

The results of the analysis under cost category is shown in Table IX. It can be seen that transportation link disruption (R5) and human resource shortages (R7) can be mitigated using many strategies. Whereas, international port closure (R4), product demand variation (R8) and lead time variations (R10) can be mitigated by only implementing one strategy we considered. Moreover, local port closure (R3) and order

cancellations (R9) cannot be mitigated by implementing any strategies under cost category.

TABLE IX. CORRELATION RESULTS FOR RISK AND STRATEGY UNDER COST CATEGORY

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
R1	0.39	0.50	0.39	0.12	0.28	0.41	0.47	0.29	0.30	0.11	0.35
R2	0.57	0.02	0.16	0.41	0.09	0.09	0.06	0.12	0.14	0.13	0.25
R3	0.32	0.35	0.07	0.21	0.30	0.12	0.25	0.31	0.12	0.37	0.00
R4	0.22	0.09	0.62	0.21	0.28	0.21	0.18	0.23	0.23	0.40	0.20
R5	0.31	0.23	0.27	0.35	0.31	0.47	0.45	0.27	0.47	0.29	0.53
R6	0.22	0.00	0.41	0.54	0.39	0.32	0.20	0.19	0.14	0.21	0.15
R7	0.33	0.49	0.46	0.51	0.47	0.18	0.26	0.44	0.42	0.46	0.65
R8	0.10	0.27	0.08	0.00	0.03	0.37	0.33	0.10	0.41	0.01	0.04
R9	0.29	0.27	0.24	0.24	0.24	0.22	0.32	0.35	0.23	0.38	0.28
R10	0.08	0.27	0.16	0.19	0.20	0.09	0.01	0.11	0.51	0.16	0.02

It can be observed that international port closure (R4) can be mitigated using the same strategy without considering the category. According to the framework, it can be seen that most of the risks can be mitigated by local sourcing (S3) and giving incentives to customer (S9). Therefore, by implementing these strategies company can save time and cost.

TABLE X. FRAMEWORK TO MITIGATE SUPPLY CHIAN DISRUPTIONS - COST

Risk/ Strategies	(S1)- Backward Integration	(S2)- Outsourcing	(S3)- Local Sourcing	(S4)- International Sourcing	(S5)- Strategic Stock	(S6)- Sharing Information	(S7)- Supply Chain Viability	(S8)- Alternative Transportation	(S9)- Customer Incentives	(S10)- Product Differentiation	(S11)- Health Safety
(R1)- Loss of local key supplier						✓	✓				
(R2)- Loss of international key supplier	✓			✓							
(R3)- Local port closure											
(R4)- International port closure			✓								
(R5)- Transportation link disruption- other than ports		✓					✓		✓		✓
(R6)- Raw materials delays and shortages			✓	✓							
(R7)- Human Resource shortages		✓	✓	✓	✓				✓	✓	✓
(R8)- Product demand variations									✓		
(R9)- Order cancellations											
(R10)- Lead time variations									✓		

Developed framework and resulting diagrams were validated through data collected from survey resulting in anticipated actual results. Hence, proving the accuracy of the model developed.

V. CONCLUSION

It is difficult to anticipate the arrival of an extreme disruption to the SC, like an epidemic outbreak. However, companies can identify SC risks and be prepared for it now rather than reacting to it, when it occurs. In this paper, an empirical investigation was conducted to assess SC risks, under time and cost categorization. The results provide several insights for theory and practice. It is recommended to focus on the high vulnerability quadrant in the vulnerability matrix (Figure 4) as its risk is high compared to other quadrants. If it's not mitigated the business might have to temporarily shut down due to the disruption caused.

The study contributes to identify SC risks during major disruptions to SC. The research also contributes to organizational theory by building a matrix to prioritize the SC risks they face during an epidemic outbreak in order to focus and mitigate them. Loss of international key supplier (R2) and order cancellations (R9) are considered as high risk based on the vulnerability matrix. However, human resource shortages (R7) is considered as low risk, based on the vulnerability matrix.

The vulnerability matrix doesn't indicate the association of each risks but it shows the time and cost for each risks. Therefore, considering the correlation analysis, it is recommended to focus on the highly correlated risks under time and cost category as its risk is high compared to others. If the risk is not mitigated, the business might even have to temporarily shut down due to the disruption caused. Considering the time category, the study identified that the loss of international key supplier is highly correlated to all the other risks which means that there is a high probability of occurrence of other risks and companies should focus primarily to mitigate it. Further, companies should focus on transportation link disruption, product demand variations and lead time variations as these risks are also highly correlated to the rest of the risks.

Moreover, considering the cost category, the study identified that loss of local key suppliers, local port closure, transportation link disruption and raw materials delays and shortages are highly correlated to other risks which means that there is a high probability of occurrence of other risks and companies should focus primarily to mitigate them.

When considering association of risks with strategies, it can be seen that international port closure (R4) can be mitigated using the same strategy without considering the category. According to the framework, it can be seen that most of the risks can be mitigated by local sourcing (S3) and giving incentives to customer (S9). Therefore, by implementing these strategies company can save time and cost. The summary findings of the study in Table XI.

It could be observed that some of the past implemented strategies for identified risks were same as [19] [21] and [20] studies and some were not. According to [19], loss of local key supplier (R1), loss of international key supplier (R2), raw materials delays and shortages (R6) has got more strategies than the strategies found in this study. It is because [19] have considered the risks in a combined and wide range, whereas this study considered the risks separately. Moreover, [19] have considered a day-to-day SC risk, whereas, the study considered a special case, of an epidemic outbreak. Therefore, it can be concluded that Sharing Information (S6), SC Visibility (S7) strategies are vital when considering an epidemic outbreak.

Strategies in [20] and strategies in the conducted study in this article are almost different because [20] has only considered

nine strategies for their study and the risks and disruption as a combined and wide range where this study considered them separately.

[21] has also considered the risks in a combined and wide range and the strategies were limited. Considering Product demand variations (R8), it can be seen that in a normal SC disruption, Product differentiation (S10) could be taken as a mitigation strategy. However, considering a special case such as epidemic outbreak Customer incentives (S9) are crucial to mitigate the risk.

TABLE XI. FINDINGS OF THE STUDY

Risk	Strategies found in this study		Strategies found in past literature		
	Under Time Category	Under Cost Category	[19]	[20]	[21]
(R1)- Loss of local key supplier	S3	S6, S7	S1, S2, S3, S4, S5, S8		S2, S3, S4
(R2)- Loss of international key supplier	S4	S1, S4	S1, S2, S3, S4, S5, S8		S2, S3, S4
(R3)- Local port closure				S8	
(R4)- International port closure	S3	S3		S8	
(R5)- Transportation link disruption- other than ports	S2	S6, S7, S9, S11		S8	
(R6)- Raw materials delays and shortages	S2	S3, S4	S1, S2, S3, S4, S5, S8		
(R7)- Human Resource shortages	S2, S3, S4, S7, S8, S9, S10, S11	S2, S3, S4, S5, S8, S9, S10, S11			
(R8)- Product demand variations		S9	S5, S9	S9	S10
(R9)- Order cancellations	S6, S7, S9, S10		S5, S9	S9	
(R10)- Lead time variations		S9			

In conclusion, considering time and cost only Loss of international key supplier (R2) and order cancellations (R9) are crucial to mitigate. However, considering the risk association to each other, under time category, Loss of international key supplier is crucial to mitigate. Moreover, under cost category, Loss of local key supplier, Local port closure, Transportation link disruption and Raw materials delays and shortages are crucial to mitigate. Further, considering the association of risks with strategies, it can be said that most of the risks can be mitigated by local sourcing and giving incentives to the customer.

The limitation of this study was that an assumption was made that the clients were international and suppliers were both local and international. This would somewhat restrict external validity.

As for future work, the study can be extended to identify the root causes of these risks which should be taken in order to mitigate the SC disruptions. These outcomes of the research allow managers to evaluate the course of action that

they should take concerning the SC disruption that they experience during an epidemic outbreak.

REFERENCES

- [1] Meyer, S., 7 “Steps For Minimizing Supply Chain Disruptions + Prevention Tips”. (online) The BigCommerce Blog. Available at: <https://www.bigcommerce.com/blog/supply-chain-disruptions/#what-is-a-supply-chain-disruption>, 2020
- [2] Escaith, H., Teh, R., Keck, A., & Nee, C. “Japan’s earthquake and tsunami: Global supply chain impacts”, | VOX, CEPR Policy Portal. Retrieved 26 July 2020, from <https://voxeu.org/article/japans-earthquake-and-tsunami-global-supply-chain-impacts>, 2011
- [3] Ziaul, H., Muhammad, A., & Barbara, D. “Impact of Man-Made Disasters on Commercial Logistics”. International Journal Of Economics, Commerce and Management, United Kingdom, III(6), 2015
- [4] Nishiguchi, T., & Beaudet, A., “Self-Organization and Clustered Control in the Toyota Group: Lessons from the Asian Fire”, Massachusetts Institute of Technology International Motor Vehicle Program, 2002
- [5] Ivanov, D., “Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case”, Transportation Research Part E, pp. 136, 2020
- [6] Seric, A., Görg, H., Möslé, S., & Windisch, M. Managing COVID-19: “How the pandemic disrupts global value chains Industrial Analytics Platform”, <https://iap.unido.org/articles/managing-covid-19-how-pandemic-disrupts-global-value-chains>, 2020
- [7] Leonard, M., “44% of supply chain pros have no plan for China supply disruption”. Available: <https://www.supplychaindive.com/news/44-of-supply-chain-pros-have-no-plan-for-china-supply-disruption/573899/>, March 11, 2020
- [8] Hobbs, B., “How to Prepare for Major Supply Chain Disruption”. Available: <https://www.entrepreneur.com/article/348081>, March 31, 2020
- [9] Hui, P. and Choi, T., “Using artificial neural networks to improve decision making in apparel supply chain systems. Information Systems for the Fashion and Apparel Industry”, pp.97-107, 2016
- [10] McIntosh, S., “Coronavirus: Why The Fashion Industry Faces An Existential Crisis”. (online) BBC News. Available at <https://www.bbc.com/news/entertainment-arts-52394504>, 2020.
- [11] Businesswire, “Global \$1,182.9 Billion Clothing And Apparel Market Analysis, Opportunities And Strategies To 2022”, Researchandmarkets.Com. (online) Available at: <https://www.businesswire.com/news/home/20191025005178/en/Global-1182.9-Billion-Clothing-Apparel-Market-Analysis>, 2020
- [12] BOI, Apparel – BOI Sri Lanka. Available: <http://investsri Lanka.com/sectors/apparel-2/>, 2020
- [13] Export Development Board (EDB), Sri Lanka, Industry Capability Report Sri Lankan Apparel Sector, 2020
- [14] Kilpatrick, J. and Barter, L., COVID-19: Managing Supply Chain Risk and Disruption. Canada: Deloitte, 2020
- [15] Hippold, S., Coronavirus: How To Secure Your Supply Chain. (online) Gartner. Available at: <https://www.gartner.com/smarterwithgartner/coronavirus-how-to-secure-your-supply-chain/>, 2020
- [16] Xu, J., “Managing the Risk of Supply Chain Disruption: Towards a Resilient Approach of Supply Chain Management”. ISECS International Colloquium on Computing, Communication, Control, and Management, 2008
- [17] Sheffi, Y., Rice Jr. J. B., “A Supply Chain View of the Resilient Enterprise”, MIT Sloan Management Review, pp.41-48, 2005
- [18] Venkatesh, V.G., Rath, S., and Patwa, S., “Analysis on supply chain risks in Indian apparel retail chains and proposal of risk prioritization model using Interpretive structural modeling”, Journal of Retailing and Consumer Services 26, pp. 153–167, 2005
- [19] Tukamuhabwa Benjamin, Stevenson Mark, Busby Jerry, “Supply chain resilience in a developing country context: a case study on the interconnectedness of threats, strategies and outcomes”, Supply Chain Management: An International Journal, Vol. 22, No. 6, pp. 486–505, 2017
- [20] Kumar Sameer, Himes Katie J. and Kritze Collin P., “Risk assessment and operational approaches to managing risk in global supply chains”, Journal of Manufacturing Technology Management, Vol. 25, No. 6, pp. 873-890, 2014
- [21] Tang Christopher S., “Perspectives in Supply Chain Risk Management: A Review”, 2005
- [22] Ivanov, D., Dolgui, A., “Low-Certainty-Need (LCN) supply chains: A new perspective in managing disruption risks and resilience”. Int. J. Prod. Res. 57 (15–16), pp. 5119–5136, 2019
- [23] Dolgui, A., Ivanov, D., Rozhkov, M., “Does the ripple effect influence the bullwhip effect? An integrated analysis of structural and operational dynamics in the supply chain. Int. J. Prod. Res. 58 (5), pp. 1285–1301, 2020
- [24] Perera, M. A. S. M., Wijeyanayake, A., Peter, S., “Classifying risk and vulnerability in the supply chain during an epidemic outbreak”, International Conference on Applied and Pure Sciences, 2020 Faculty of Science, University of Kelaniya, Sri Lanka, pp 111, 2020
- [25] Perera, M. A. S. M., Wijeyanayake, A., Peter, S., “Analysis of Correlation of Risks in the Supply Chain Disruption in Apparel Industry during epidemic Outbreak, COVID 19: Impact, Mitigation, Opportunities and Building Resilience “From Adversity to Serendipity”, Perspectives of global relevance based on research, experience and successes in combating COVID-19 in Sri Lanka, Vol. 1, National Science Foundation, Sri Lanka: ISBN 978-624-5896-00-4, pp 672-677, 2021
- [26] Perera, S., Wijeyanayake, A., Peter, S., “Analysing the risk in the supply chain of apparel industry during an epidemic outbreak”, Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management Singapore, pp 864-874, 2021.