M.Tech. Thesis

Minimizing Ripple Effect and Complexities in a supply chain

Aniket Modi

June 2024

MINIMIZING RIPPLE EFFECT AND COMPLEXITIES IN A SUPPLY CHAIN

A Thesis Submitted
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY

in

INDUSTRIAL ENGINEERING AND MANAGEMENT

by

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CANDIDATE'S DECLARATION

I, Aniket Modi (Enrollment no. 2K22/IEM/03) student of M.Tech in Industrial Engineering and Management, Final Year, Department of Mechanical Engineering, hereby certify that the work which is being presented in the thesis entitled "Minimizing Ripple Effect and complexities in a supply chain" in partial fulfillment of the requirements for the award of the Degree of Master of Technology, submitted in the Department of Mechanical Engineering, Delhi Technological University is an authentic record of my own work carried out during the period from 1/01/2024 to 19/05/2024 under the supervision of Dr. N. Yuvraj and Dr. Mohd. Shuaib.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Candidate's Signature

CERTIFICATE BY THE SUPERVISORS

Certified that Aniket Modi (Enrollment no. 2K22/IEM/03) has carried out their research work presented in this thesis entitled "Minimizing ripple effect and complexities in a supply chain" for the award of Master of Technology from Department of Mechanical Engineering, Delhi Technological University, Delhi, under our supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ACKNOWLEDGEMENTS

I would like to express the deepest gratitude to my mentors, **Dr. N. Yuvraj and Dr. Mohd. Shuaib, Department of Mechanical Engineering, Delhi Technological University, Delhi**, for giving us invaluable feedback and guidance throughout this research work.

I would also like to extend special thanks to the **Hon'ble Vice-Chancellor, Delhi Technological University, Delhi,** for providing us this platform to explore new avenues in life and carry out research. My sincere thanks go to all the people, and researchers whose research papers have helped me.

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MINIMIZING RIPPLE EFFECT AND COMPLEXITIES IN A SUPPLY CHAIN

Aniket Modi

ABSTRACT

The purpose of this project dissertation is to maximize the profits in a supply chain by using risk analysis tools to fulfill the customer demand within the constraints of *ripple effect*. The research approach used in this project dissertation is a combination of quantitative and qualitative methods. In quantitative analysis, the proposition is to use supply chain analytics tools like Risk analysis with the help of anyLogistix software. For qualitative analysis, we conducted a survey to rate the risk factors on the basis of their ability to create an exceptional impact on a supply chain in case of a rare occurrence of them. The risk analysis confirms the hypothesis that "supply chain analytics when applied to an organization can reduce the impact of *the ripple effect*". The findings in the experiments conducted show a negative correlation of the duration of maximum disruption with the worst service level. Beside the service level by products, we have recorded the worst service level, and the worst fulfillment received (on-time) for each trial taken in an experiment, which has provided us with insights in the variation in these values depending on the experiment undertaken. It is difficult to objectively evaluate the effectiveness of the proposed methodology due to the lack of verification of statistical significance of the experimental results. There are very few empirical studies on simulation - based modeling of the ripple effect in a supply chain. The empirical results provide an insight into risk analysis and management in logistics and supply chain. This insight offers practical guidance for developing and deploying risk analysis tools to support efforts in preventing *the ripple effect*.

Keywords

Ripple Effect, Supply Chain Analytics, Risk Analysis

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List of Abbreviations

Abbreviation	Full Form
SC	Supply Chain
SCA	Supply Chain Analytics
RO	Research Objective
NB	Nota bene (latin for special attention)
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
BDA	Big Data Analytics
DC	Distribution Centre
ELT	Expected Lead Time

Chapter 1: Introduction

1.1 The Ripple Effect

Ripple effect is often referred to as the negative consequence of a disruption in a supply chain stage which has a cascading effect on the entire supply chain (SC). Such disruptions are exceptional-impact non-periodic events in the supply chain that change the SCs structural design (Ivanov 2019). In order to analyze these ripple effects, data collection and analysis throughout the supply chain are essential (Ivanov 2014) This research article aims to propose a framework to minimize the ripple effect by utilizing supply chain analytics techniques. On the other hand, disruptive innovations such as digitalisation and Industry 4.0 influence the development of new paradigms, concepts and models in supply chain management (SCM) which minimize ripple effect (Liao et al. 2017) like Big Data Analytics (BDA), Autonomous Robots, Digital Twin, IoT, π-containers (Tran-Dang et al. 2017), Augmented Reality, Cyber-security and smart manufacturing have a potential to upend traditional SCs with faster operations and efficient production. In the past, data analysis was mainly done at the individual company level. However, analyzing ripple effects requires data integration and analysis across the entire supply chain. Disruptions are hard to predict and their associated SC risks have to be proactively captured in the design stages of a supply chain (Bakshi et al. 2009).

1.2 The complexities of a Supply Chain: Risk

Ripple Effect emanates from Supply Chain Risks, and may have a significant impact on supply chain operations. Companies nowadays can manage and mitigate these risks which otherwise would have translated to *the ripple effect*. Supplier risk management is the core of supply chain risk management (Blackhurst 2008). Organizations must closely monitor their suppliers` financial health, operational capabilities, and quality control. *Supplier risk* can be managed through using many suppliers, periodic review of supplier contracts, and improving supplier evaluation. *Complexity of demand patterns*, fast product life cycles, and multiple sales channels can lead to difficulties in inventory management, production planning, and transportation. Organizations leverage AI and data analytics technologies to increase demand forecast accuracy and optimize supply chain operation to minimize these difficulties. Similarly, *Global Labor Shortage* around the world due to the COVID-19 pandemic, aging population, and changes in immigration policies may cause disruption throughout the supply chain, including (but not limited to) production, services and logistics. Organizations can anticipate labor shortages by investing in automation, outsourcing, and flexible work hours. Economic indicators like *Inflation* can lead to increased costs and cause problems such as worsening profitability and pressure to increase prices. Inflation risk can be handled by collaborating with suppliers and understanding their needs, inventory optimization, and pricing strategy. Recently, organizations are also paying attention to sustainability risks in terms of *environmental, social, and governance (ESG)*. We must also discuss that risks are different from uncertainties in a supply chain. Risks are factors associated with positive and negative potential for a supply chain`s performance. Uncertainties can be defined in stochastic terms and do not bear a negative potential for a supply chain. *Disruptions* can occur due to a variety of factors, including natural disasters, political unrest, labor disputes, and technological changes. This can directly contribute to the chances of *ripple effect* where otherwise harmless events can last for unforeseen periods of time (Stecke 2009). *Lack of flexibility in supply* source makes it difficult to respond quickly to changes in demand. This can lead to disruptions due to high-capacity utilization of the resources at the supplier, excess inventory levels, and lags in delivery, etc. Organizations have a mandate to use a variety of supply sources and strengthen existing suppliers to increase supply flexibility (Tang 2008). *Failure of information systems* such as data loss, process disruption, and cyber-attacks can undermine reliability throughout the supply chain. Companies must manage information infrastructure risks through information security, regular awareness programs among the employees, and backup and recovery plans.

Figure 1. Risks in SC (Chopra 2004)

Intellectual property rights such as technology, know-how, and data may be infringed within the supply chain. This can reduce competitiveness of the company, create legal disputes, and may lead to loss of customers; however, it can be negotiated using contract management, security monitoring, and customer management. One of the emerging trends in the supply chains from the viewpoint of *ripple effect* is the influence of *exchange rates* on how they can affect purchasing costs, profitability, cash flow, and more. Companies must manage exchange rate risk through strategies such as foreign exchange hedging and settlement in various currencies. *Fluctuations in customer numbers* is a rather common phenomenon as one can`t expect a static market for a made to use products (Chopra 2004). Uncertainty amplification effect is the phenomenon of amplified information distortion or mis-information in the SC (also called the Bull-whip effect). This often leads to de-coupling of inventory with demand fulfilment, & production planning overall. *Bull-whip effect* is a well-established phenomenon in traditional SCs and can be mitigated using real-time data collection at the retail point, called Point of sale data and also by using periodic checks in the warehouse to keep track of the inventory (Yuan 2008) Overall, A multi-faceted approach will be needed, including supplier management, demand planning, labour acquisition, inflation response, and sustainability.

1.3 Supply Chain Analytics and Ripple Effect

The ripple effect can have a negative impact on supply chain performance indicators such as sales, average lead times, and product quality. Supply Chain Analytics has emerged as a key tool for understanding and managing *the ripple effect*. Predicting future demand, supply issues, and risk using past data and external factors can be understood in visual terms at shop floor level by the employees, pushing the boundaries of efficiencies in the supply chain. Supply chain analysis, and simulation have been used in our study in section 4.1 to analyze ripple effects for various scenarios. Analysis tools are not only easy to develop and understand nowadays but rather have become accessible making those who keep it closed off from common knowledge obsolete. Real-time monitoring technologies such as big data analytics are advancing to collect and monitor real-time data across the supply chain using technologies such as sensors, IoT, and cloud computing which can contribute to *inferential analytics* to make conclusions from the data sources. Collaboration and decision-making support foster information sharing among supply chain agents and units. This allows for a joint response to ripple effects. In this way, supply chain analysis technology is developing to increase understanding and make faster responses to *the ripple effect*. Moving away from simple data analysis of the past, prediction, real-time monitoring, and simulation.

1.4 Analyzing Ripple Effect using anyLogistix software

The ripple effect can be analyzed and its impact measured on the various stakeholders in the supply chain by its thorough use. Specifically, *the ripple effect* can be studied in real-life scenarios to find its impact on the supply chain in terms of business-critical metrics such as total cost, profit, revenue, service level of the products, demand placed by the customer, fulfillment received by the customer, fulfillment received on time, Lead time etc. From these parameters, we can see how a disruption materializes its impact on the supply chain from the end point to the starting point i.e from lead times to the demand received in times of unavailability of resources. This provides the critical points which can be resolved before the supply chain is set up. *The ripple effect* in the context of our supply chains such as that for Knit- clothing products or toasters which may be local or global is an event in which there is a breakdown of critical systems. Now a breakdown can be fixed by introducing redundancy in the SC by using alternative factories and distribution centers to provide fulfillment. The problem statement is thus "maximize the profits in the SC by using multiple DCs and factories to fulfill the customer demand within the constraints of *ripple effect*". We will be using the anyLogistix software as our supply chain analytic tool to solve this problem.

1.5 Objectives of this study

Specifically, this major project will (RO1) redefine, by research on previous scientific work, what SCA means in the context of Ripple Effect, and how it differs and has evolved from previous analytics technologies; (RO2) identify and classify the different sources and types of data arising in modern supply chains; (RO3) identify the complexities in SCA implementation; (RO4) Capture the perceived importance of SCA in improving Ripple Effect mitigation; and (RO5) Explore the perceived impact of SCA on Ripple Effect. *(N.B. RO stands for Research Objective)*. We also need to form a null and alternate hypothesis to test our work in a real-world scenario (Table 1).

Table 1: Hypothesis framing

# Hypothesis	Hypothesis
H(null)	Application of supply chain analytics in a supply chain can reduce *the ripple effect*.
H(alternate)	Application of supply chain analytics in a supply chain has no effect on *the ripple effect*.

Chapter 2: Literature Review

A seven-stage process was conducted (illustrated in Fig. 2) which involved careful formulation of research questions, identification of relevant keywords, removal of duplicates, assessment of article quality and relevance, capturing other relevant articles, full-text analysis, and reporting.

Stage 1: Question Formulation: The first stage involved formulating research questions. These questions guide the entire literature review process. For instance, the questions were "What is the current state-of-the-art in SCA research on minimizing Ripple Effect?" or "What is the level of research in the Ripple Effect?"

Stage 2: Keyword Search in Identified Databases: In the second stage, the identified keywords were searched in international peer-reviewed journals. The keywords were "Supply Chain Analytics" and/or "Ripple Effect". The time range for the search was from January 2001 to December 2022. In this case, 435 articles from google scholar and 878 papers from another database were selected, resulting in a total of 1313 papers.

Stage 3: Removal of Duplicates: The third stage involved removing duplicate entries. The search keywords were used in a way to prevent any duplication. In this case, no duplicates were found, so the number of papers selected remained the same at 1313.

Stage 4: Article Quality and Relevance Assessment: In the fourth stage, irrelevant articles were removed after a title and abstract analysis. Less relevant articles were removed after full-text scanning. Articles that are not listed in the ABS Academic Journal Quality Guide were also eliminated.

Stage 5: Capturing Other Relevant Articles: The fifth stage involved adding some articles to the database through the citation checking process and finding articles through Google Scholar.

Stage 6: Full-Text Analysis: In the sixth stage, a thorough analysis of the full texts of the remaining articles was conducted. This involved reading each article carefully and taking detailed notes on the main arguments, evidence, and conclusions.

Stage 7: Reporting: The final stage involved reporting. This involved a thematic analysis on the four types of SCA processes and the types of Ripple Effect. The aim is to synthesize the information gathered from the literature and present it in a coherent and structured manner.

2.1 Summary of literature review

- Mishra et al. (2019) constructs network analysis and identified five emerging research clusters: fundamental aspects of supply chain, different perspectives on supply chain risk management, managing and mitigating disruption risks in the supply chain, building resilient supply chains to deal with catastrophic events and developing various contracts, such as, revenue-sharing, option, and quantity-flexibility contracts
- Hosseini (2020) studies the application of Bayesian networks (BNs) to supply chain risk and resilience which introduces a research methodology and data visualization. Then they review the literature on BN applications to SC risk and resilience. In particular, they discuss the use of BNs for modeling, measuring, and assessing SC risk and resilience problems. The authors also compare BNs with other popular SC risk management approaches and discuss potential research opportunities.
- Ali et al. (2023) discusses the gaps in Supply Chain Risk Management (SCRM), including the definition, process, and methodology. It suggests that developing a clear definition of SCRM and conducting more empirically oriented research on SCRM could involve the use of data management and analytics.
- Shivam et al. (2022) categorizes supply chain risks and explores factors affecting these risks. It suggests that using data analytics could help understand and manage these risks.

- Ou (2011) provides a clear definition of risk within SCRM and reviews quantitative approaches to SCRM based on the definition of supply chain risk and risk measures. It suggests that using data analytics could help define and measure these risks.

Table 2. Summary of the literature review

References	Research Objective	Prominent work
Xu et al. (2014)	Fabricating a mathematical approach for assessing supply chain resilience against random disruptions	Structural evolutionary process for repairing the supply network following an interruption
Ivanov (2017)	Ripple effect modelling using simulation tools in anyLogistix software	Simulation modelling of SC to reduce financial effect of disruptions
Kinra, A et al. (2020)	Evaluate the risk exposure model to quantify the ripple effect using actual company data	Ripple Effect exposure of a supply chain
Wang, M et al. (2020)	Logistic innovation to establish link between supply chain risk and Industry 4.0 tech	Logistics innovation capability and its negative correlation to systematic risks

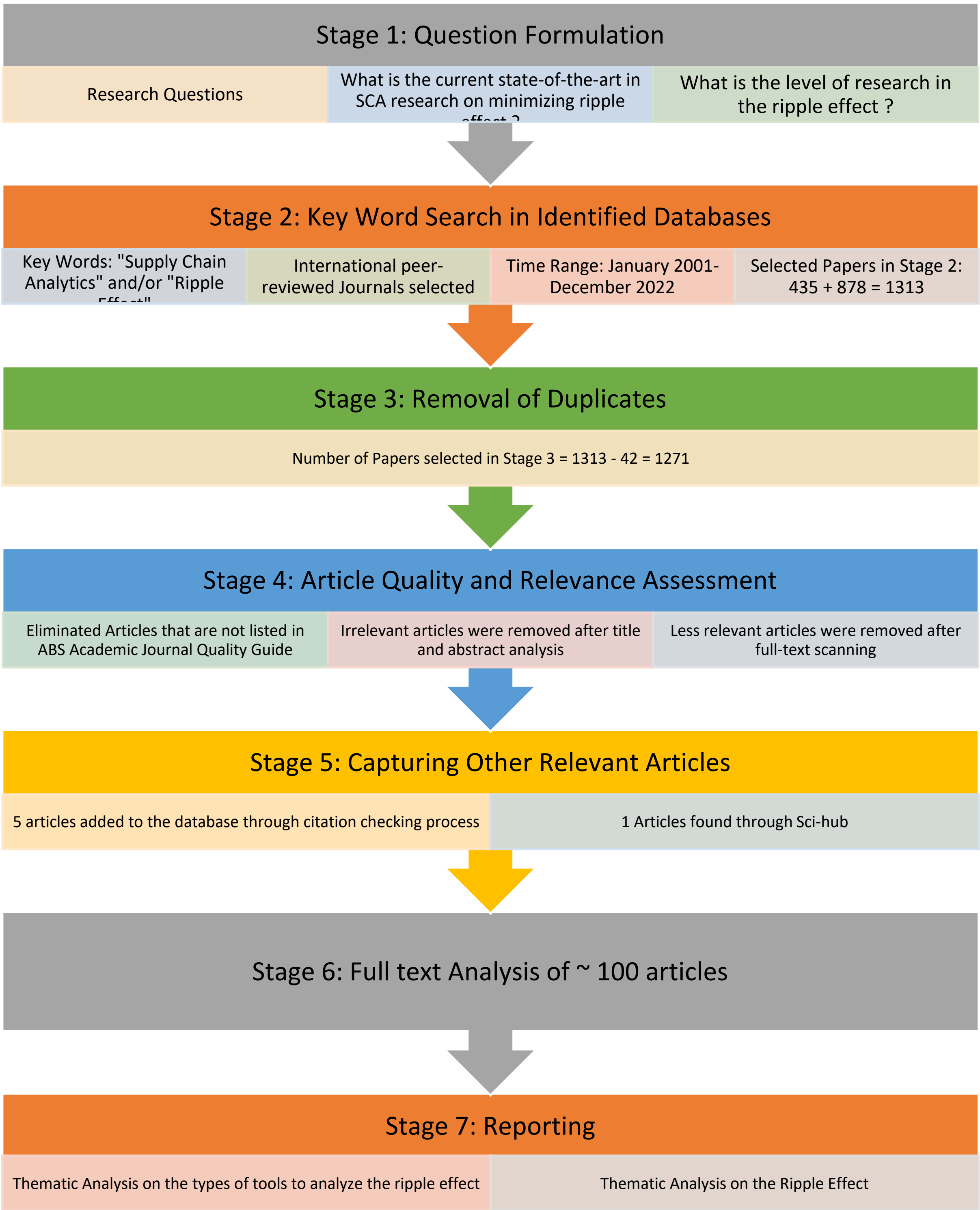

Fig. 2 Stages of Literature Review

Chapter 3: Methodology

The research methodology used in this major project is a combination of quantitative and qualitative methods. For qualitative analysis, we have taken a survey of experts in the field of Industrial Engineering and Management. The survey contained a questionnaire rating the severity of the risk factors (mentioned in section 1.2) in a supply chain. The title of the survey was “Survey for ranking factors affecting exceptional impact-low frequency events". In quantitative analysis, the proposition is to use supply chain analytics tools like Risk analysis methods with the help of anyLogistix software (personal learning edition available here) serving as a catalyst to minimize the ripple effect in the supply chain.

3.1 Research Gaps

After reviewing the provided references, we can identify the following research gaps in supply chain ripple effects-related research:

1. Various data analysis techniques such as risk analysis and simulation have been used, but sensitivity analysis have not applied to test the robustness of test results (Ivanov 2017). There is a need to more precisely model various factors in the supply chain (inventory, demand fulfillment, production etc.).
2. Complexity of ripple effect and lack of reflection of reality: While noting the impact of digitalization and Industry 4.0 on ripple effect, the contribution of digital technologies on the supply chain disruptions is not comprehensively evaluated (Ivanov 2018).
3. Lack of ways to utilize supply chain digital twin and AI technology: The reference literature did not suggest a plan to manage ripple effects using supply chain digital twin or artificial intelligence technology. There is a need to develop decision support methods to predict and minimize ripple effects by utilizing these latest technologies.

3.2 Modelling Approach

Quantitative Techniques as described earlier will be used to create a tuning fork approach to create resonance with the problem statement i.e. “maximize the profits in the SC by using multiple DCs and factories to fulfil the customer demand within the constraints of probabilistic *ripple effect*”. The two prongs of the fork being “risk analysis” and “What-if scenario analysis”.

3.2.1 Risk analysis in a supply chain under the constraint of ripple effect

1. Data usage: We have used both primary and secondary data sources to create and run our experiments. The customer data is sourced from anyLogistix website by the software and is thus a secondary data source.

2. Parameters: For each experiment the input parameters are mentioned in Table 3.1.

Table 3.1 Parameters for risk analysis experiment

Parameter Name	Values	Description
Experiment Start / End	Any datetime values	Time interval in which the supply chain is operational in a year
Replications per result	Positive integer values (typically 10)	No. of times an experiment is conducted (replicated) with the same parameter values
Target service level	Service Level by products, Service Level by revenue, Service Level by orders, ETL Service Level by products, ETL Service Level by revenue,	Target parameter which decides the formula for failure and recovery service level

	ETL Service Level by orders.	
Failure Service Level	0-100% (typically 95% or more)	No. of orders delivered on time / Total no. of orders delivered
Recovery Service Level	0-100% (typically 97% or more)	Revenue from orders delivered on time / Total revenue from orders delivered

4. Experiments conducted:

Table 3.2 Details of experiments conducted

Experiment #	Experiment Type	Trials conducted	Disruptive Events	No. of customers
A	1 Factory, 2 DCs	5	Rainy season	50
B	1 Factory, 2 Delivery Ports, 2 DCs	5	Trade sanctions	50
C	1 Factory, 4 DCs, 3 countries	5	Rainy season, Demand Fluctuation	70

3.3 Exploratory Data Analytics

Minimizing ripple effect requires consideration of inexplicable connections of risks and uncertainties with the supply chain. To capture risks, we have taken 3 types of events which cause deviations in the SC if triggered. The events are mentioned in table 3.3. In this section, we perform Supply Chain Analysis Experiments to evaluate *the ripple effect* of events by implementing predicted disruptions.

The SC we have taken in the example has:

- Knit clothing and accessories factory
- Port located at a distance from the factory, through which the products are shipped
- Ports in the countries where customers are located
- Country sites or Distribution centers (DCs) located in Indonesia, Philippines and Japan
- 50 customers in cities exceeding 15000 population in Japan
- 20 customers in cities exceeding 15000 population in Indonesia and Philippines.

Table 3.3 Disruptions planned in the supply chain

Disruption	Change in	Value of	Event type	Period	Trigger (if any)	Probability
Raining season	Path state	Path Factory Qui Nhon to Vung Tau	Random	1/7/23 - 30/8/23		0.5
End of raining season	Path state	Path Factory Qui Nhon to Vung Tau	Date	1/9/23 12:00 AM	Raining Season	1
Increase in demand	Demand coefficient	Coefficient: 1.1	Random	1/4/23 - 30/6/23		0.8
Decrease in demand	Demand coefficient	Coefficient: 0.7	Random	1/8/23 - 30/09/23		0.9
Factory failure	Facility state	Factory Qui Nhon	Random	1/1/23 - 31/12/23		0.5
Factory recovery	Facility state	Factory Qui Nhon	Delay (days)	7	Factory Failure	1

Start of the rainy season, factory failure, increase and decrease in demand are independent events. Whilst the end of the rainy season and factory recovery are dependent events as they can only happen if pre-conditions of the rainy season and the factory failure are met. Increase in demand event occurs at a random time between 4.01.2023 to 30.06.2023 with a probability of 0.8 and this leads to demand be 1.1x. Decrease in demand occurs at a probability of 0.9 and decreases the demand to 0.7x. Factory failure occurs at 0.5 probability at any random moment in the basic period which compromises the ability of the factory to send products. Factory failure can occur due to many reasons such as infrastructure upgradation, labour shortages, machine downtime etc. Factory recovery occurs at a 7-day delay of the factory failure irrespective of the reasons of the factory failure. In table 3.4, we find the service level by products for each replication. Here we can accept or reject the service level parameters of a replication depending on whether the service level is above or below a threshold service level. In this multi-replication experiment, due to probabilistic scenario parameters each replication results in a different outcome. This allows us to design a network that minimizes *the ripple effect*. We have assigned Failure service level at 95%.

Table 3.4 Service level by the products in different replications of an experiment

#	Statistics	Replication	Value	Unit
	filter	filter	filter	filter
1	Service Level by Products	Replication 1	1	Ratio
2	Service Level by Products	Replication 3	1	Ratio
3	Service Level by Products	Replication 5	1	Ratio
4	Service Level by Products	Replication 6	1	Ratio
5	Service Level by Products	Replication 2	1	Ratio
6	Service Level by Products	Replication 9	0.998	Ratio
7	Service Level by Products	Replication 4	0.958	Ratio
8	Service Level by Products	Replication 8	0.935	Ratio
9	Service Level by Products	Replication 10	0.81	Ratio
10	Service Level by Products	Replication 7	0.763	Ratio

The service level is an indicator of the amount of time that services are working and determines its availability. Similarly, we have taken the Recovery service level at 97%.

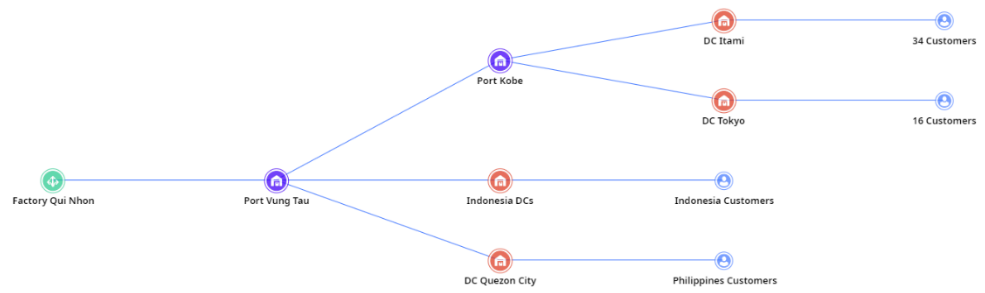

Figure 3.1 Supply Chain considered in the exploratory data analysis

The supply chain considered in the figure above (Fig 3.1) shows the Factory Qui Nhon connected to the port Vung Tau via trucks. This route is affected by the rainy season and all the transportation ceases on it. The Port Vung Tau ships items to Port Kobe and the Indonesia DC (DC Jakarta) and DC Quezon City via containers. The type of shipping used is LTL i.e. less than truck-load or less than ship-load in this case. The priority to the items being transferred from land to water or from land to land in a port or DC is done on FIFO basis. The sourcing scheme used by DCs and the customers can be Uniform Split, Split by ratio, Most Inventory, Fixed Source (fastest or first), Most Inventory (dynamically sourced), Fastest (dynamic sourcing), Cheapest sourcing or Closest (Fixed or dynamic Source). We have considered Most Inventory (dynamic sourced) as our sourcing policy. Now in one of the replications we have observed the service level of 0.792 (Table 3.5) which was *the ripple effect* of a prolonged rainy season.

Table 3.5 Effect on service level

	Disruption	Time of event	Day of event
Replication 6	Raining season	1/7/23 1:25 AM	182
Replication 6	End of raining season	1/9/23 12:00 AM	243
		Service level	
Service Level by product	Replication 6	0.792	

We have also observed that the initial state parameters such as minimum, maximum and safety stock in a warehouse/DC can impact that magnitude of *ripple effect* on the supply chain. One of the observations from table 3.5 is that the raining season disrupted the arterial road from the factory from 1/7/23 to 1/9/23. However, the service level at the customers was fulfilled by safety stocks in DCs to some extent which reduced the recovery time to 35 days. This however hit the bottom-line of the organization as can be seen in the following graph (Figure 3.2) where the total cost, profit and revenues for the organization tapers off in the replication 6.

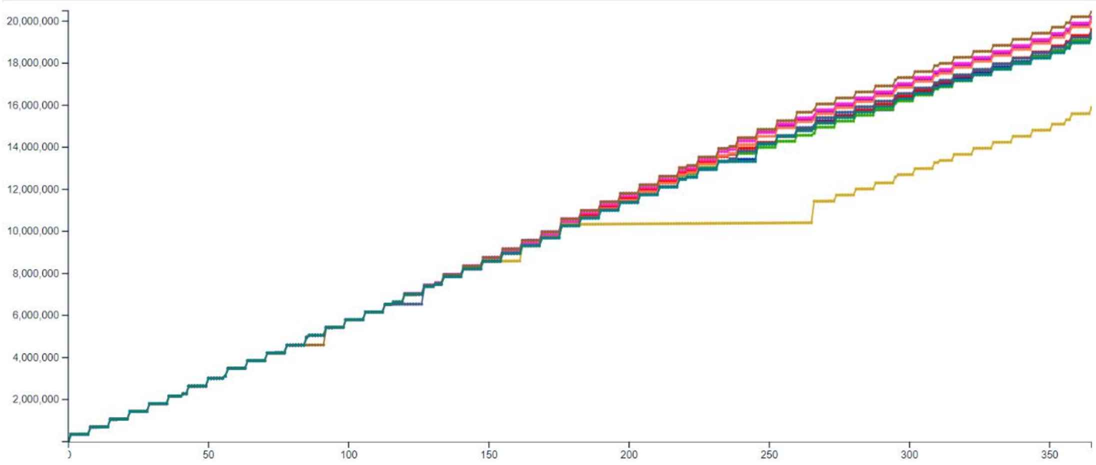

Figure 3.2 Comparison chart for total costs incurred in executing different replications in the experiment

The total cost (in yellow, replication 6) for the organization is significantly lower than those replications which had minimal delays in customer delivery and fulfillment. In fact, all other parameters corroborate the same story of *the ripple effect* of the event that occurred in replication 6. To overcome this predicament, we create a new supply chain for the same customers and run an experiment to test our hypothesis of alleviating *the ripple effect* from the supply chain and identifying the complicated patterns which emerge from it. After having taken an overview of the outcomes of our first experiment we delve deeper in the second experiment to unearth the details which can improve the supply chain from the perspective of minimizing *the ripple effect*. To get a better understanding of the service level of customers let us take a look at a best-mean-worse value graph (Figure 3.3). In this graph we see the daily service level for each of the best replication, the mean replication and the worst replication in terms of the service level.

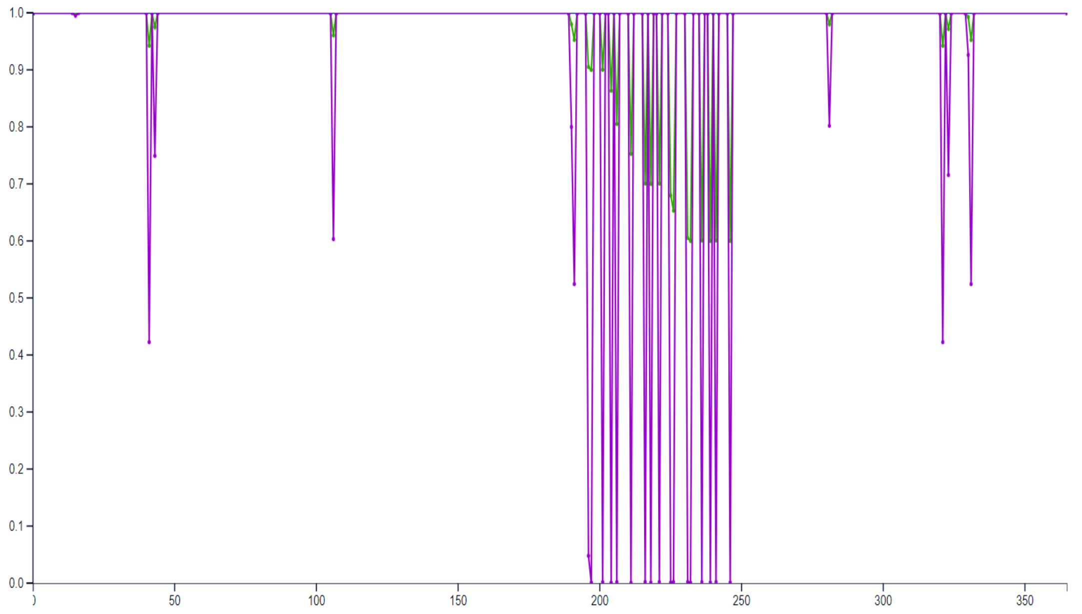

Figure 3.3 Best-Mean-Worst Graph for service level of a product

The graph which has the value reaching 0 the greatest number of times is the one with lowest service level over the year. We also observe this is the worst possible scenario among the 10 replications executed in this experiment and the mean scenario is much better than this one. The service level in the mean scenario dropped linearly from 1.00 to 0.60 whereas in the worst scenario the service level was 0 for nearly 50 days. The total time to recover for the supply chain is mostly in acceptable regions for the replications in this experiment (Figure 3.4).

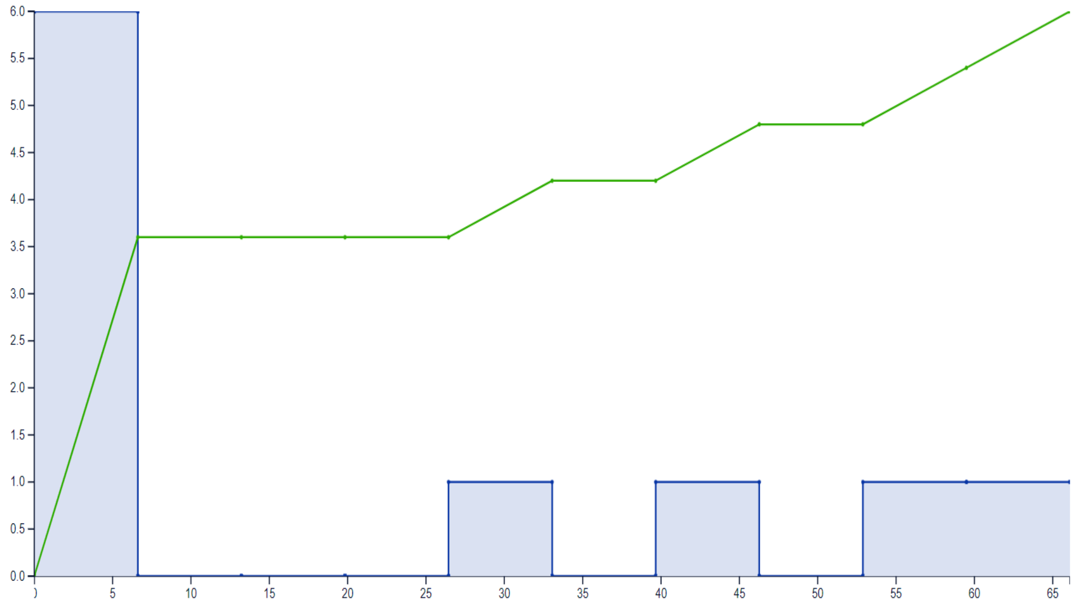

Fig. 3.4 Total time to recover for a supply chain (no. of replications on vertical axis and no. of days to recover on horizontal axis)

The graph elucidates the fact that most of the supply chains had a factory disruption in a year lasting 7 days but some of them endured a prolonged period of rainy season which occurs randomly. The goal of our experiments is to suggest a strategy to systematically overcome the constraints posed by the unpredictability of the rainy season on demand fulfillment of customers.

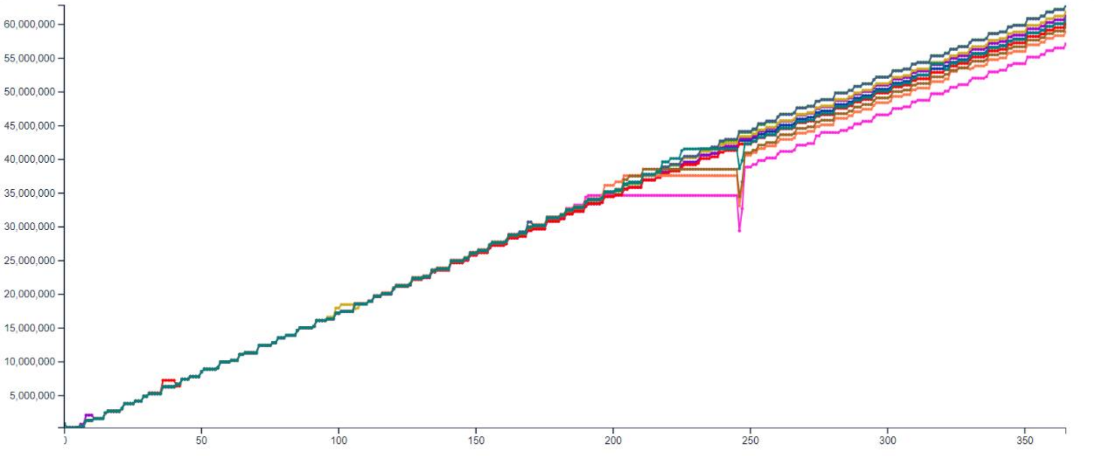

Fig. 3.5(a) Profits in the supply chain in differing replications;

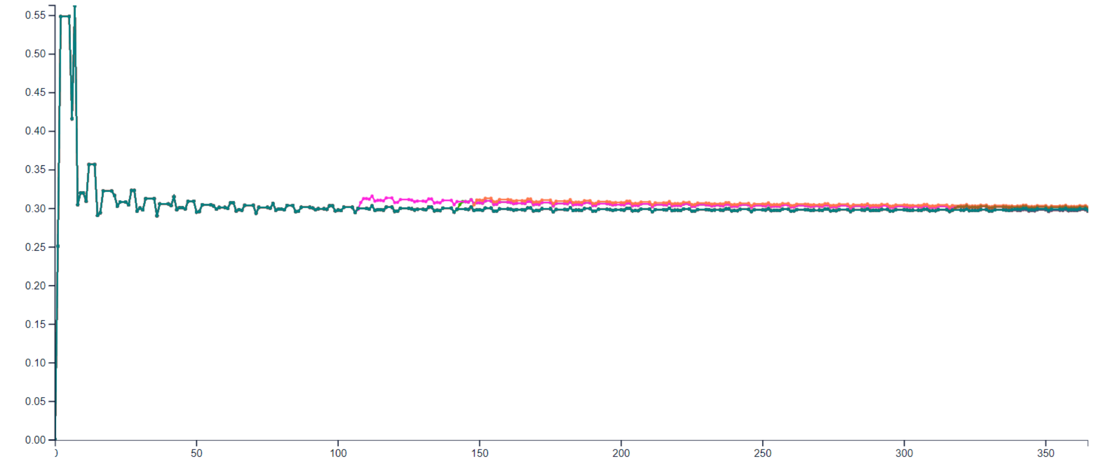

Fig. 3.5(b) Mean Lead time for customer (with vehicle type train included)

The ripple effect of the rainy season becomes more evident across multiple replications as all the replications follow more or less the same regression of profit line. They are however translated parallelly to the best-case scenarios by the number of days of the rainy season disrupting the delivery of goods. Now let us hypothesize an experiment where we include an elevated train route operating between the factory at Qui Nhon and port Vung Tau. This train route made on an elevated track would be less affected by the seasonal rains and would help the customers in receiving the desired orders on time (Figure 3.5 (b)).

3.4 Strength and Weakness Analysis

Strength	Weakness
An approach that seeks to solve problems by systematically modeling and analyzing ripple effects in the supply chain is appropriate.	It is difficult to judge the validity of the model because the variables and assumptions considered in the ripple effect modeling process are not sufficiently explained.
It suggests an efficient way to predict and minimize ripple effects by utilizing various data analysis techniques.	In the method employed in this major project, the parameter setting to set the customer demand for each customer is not necessarily proportional to the cities in which they are located.
Verifying the effectiveness of the proposed methodology using actual supply chain data is positive in terms of practicality.	It is difficult to objectively evaluate the effectiveness of the proposed methodology due to the lack of verification of statistical significance of the experimental results.

3.5 Heuristics for modelling Ripple Effect in a supply chain

Substantial improvements in supply chain management, such as inventory and asset optimization, are being made through big data analytics (BDA). In Agent-based modeling, we analyze the failure propagation process by simulating the interaction rules between enterprises. In Network Analysis by modeling the supply chain as a network, we analyze vulnerabilities between nodes. In Risk analysis the ripple effect can be understood by analyzing the disruptions of various risk factors in the supply ichain. Improved supply chain visibility can enhance information sharing, whereas collaboration within the supply chain can increase visibility to mitigate the ripple effect.

Chapter 4: Results and Discussion

The risk analysis conducted in section 3.2 gave a new perspective on the goal posed at the start of this major project i.e. "maximize the profits in the SC by using multiple DCs and factories to fulfill the customer demand within the constraints of *ripple effect"*. Let us evaluate the findings of experiment 'A' in the risk analysis section (Table 4.1).

Table 4.1 Findings of Experiment 'A' in Table 3.2

Trial	Best Total Costs	Best Profits	Worst Fulfillment received	Worst Service Level	Duration of max disruption
1	18742534.42	27330469.58	510	0.56	61
2	20538764.14	30186035.86	507	0.595	59
3	20385834.28	29781385.72	573	0.655	34
4	20158482.12	29637627.88	512	0.570	58
5	18395305.86	26976216.14	507	0.518	60

This table at first shows correlation between the values of 'Best Total Costs' and 'Best Profits' in the supply chain suggesting that greater expenses usually mean higher profits but it's just that profits and total costs form a fixed ratio of the revenues generated. The best total costs and best profits are selected from the set of 10 replications in the experiment 'A'. The Fulfillment received metric in the table shows the products received (on-time) by the consumer in the SC. The worst fulfillment shows the products received by customers in the case of worse ripple effect. Similarly, the worst service level is the ratio of the no. of products received by the customer (on-time) / no. of products received by the customer, in the worst case replication. Duration of max. disruption shows how long (in days) the respective disruption event which rainy season in this case lasted. Duration of maximum disruption shows a slight negative correlation with the service level.

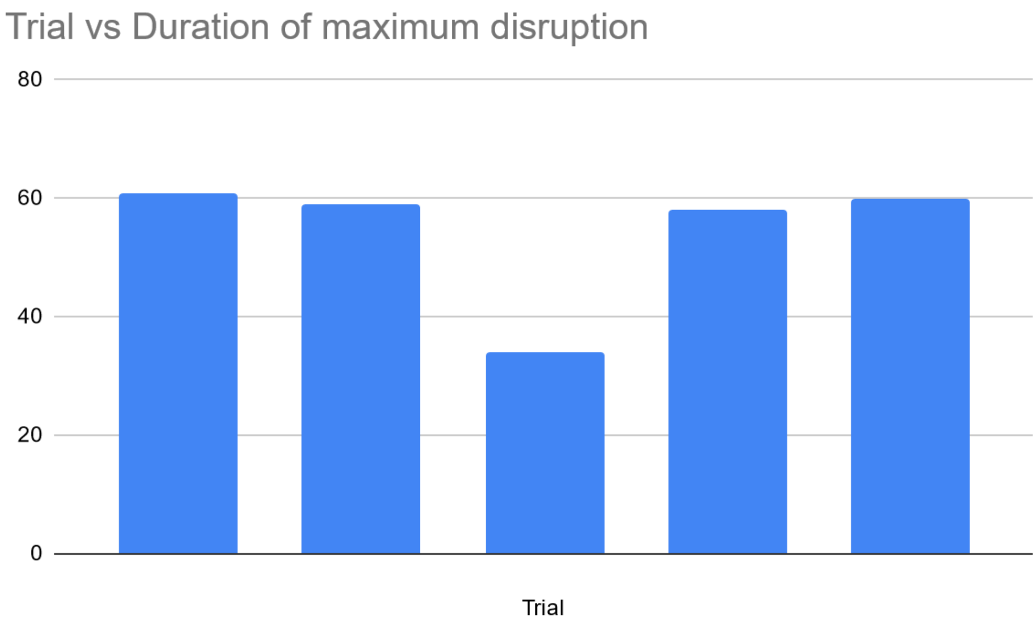

Figure 4.1 (a) Showing the maximum duration of disruption in days (in vertical axis) and the trials (on horizontal axis);

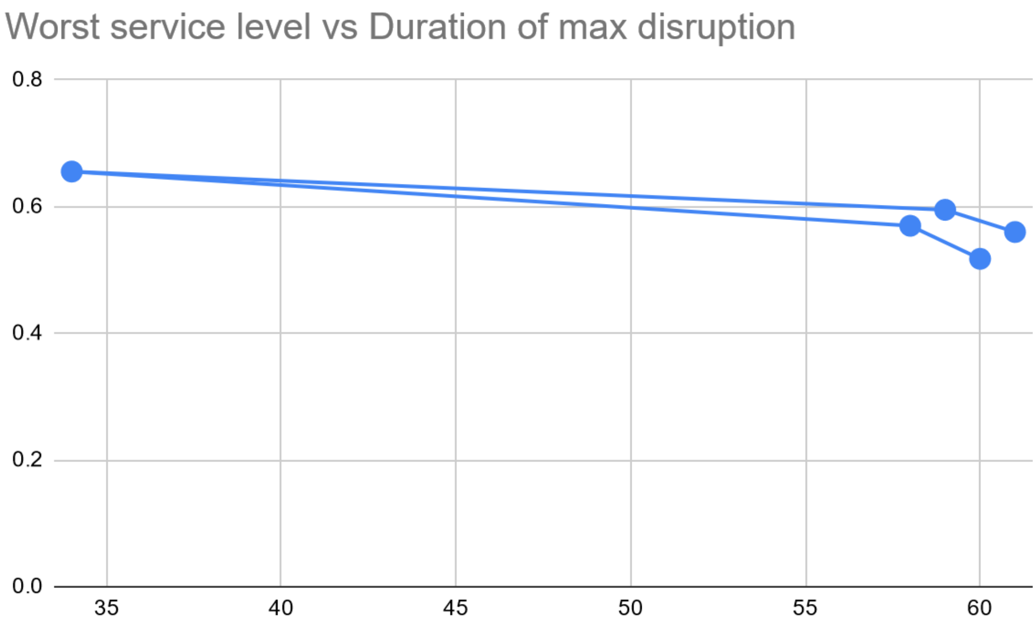

Figure 4.1(b) Worst service level vs Duration of max disruption

4.1 Results of the risk analysis experiments

In the experiment 'B' (in section 3.2.1), we consider the supply chain with two ports to supply the customers. This supply chain design is able to overcome the restrictions imposed by *the ripple effect* of the disruptions in the experiment. Similar to the disruptions in experiment 'A', we have imposed trade sanctions on the country of Vietnam which prohibits it from supplying the products to Japan. Now the trade sanctions are a potential risk which may or may not happen in the supply chain.

Table 4.2 Findings of Experiment 'B' in Table 3.2

Trial	Best Total Costs	Best Profits	Worst Fulfilment received	Worst Service Level	Duration of max disruption
1	37039512.94	53902807.06	1145.845	0.767	56
2	40373567.38	58810626.82	1193.187	0.759	54
3	32592838.29	47283685.43	1127.964	0.760	54
4	36919247.95	53724158.05	1271.648	0.819	32
5	40548615.59	59064927.81	1075.234	0.550	32

We have taken a dynamic scenario in which the supply chain structure is changed to avoid this sanction on the sea route connecting Vietnam and Japan. For the first year of operation (Basic Period), the trade route operates between Port Vung Tau (Vietnam) and Port Kobe (Japan) under the risk of trade sanctions which can happen in the months of July and August at a likelihood of 0.5. For the second year of operations (Basic Period 2) with anticipation of the outcome if the trade routes are not modified, the second port in Hong Kong (China) is made operational to supply the products to the customer. This is enabled by using a road route between the factory at Qui Nhon and the port of Hong Kong. Here are the parameters which are set for sourcing of the products (Table 4.3).

Table 4.3 Sourcing of products in Experiment 'B' in section 3.2.1

Delivery Destination	Sources	Product	Type	Time Period
Port Vung Tau	Factory Qui Nhon	Shoes	Most Inventory (Dynamic sources)	Basic Period
Port Hong Kong	Factory Qui Nhon	Shoes	Most Inventory (Dynamic sources)	Basic Period 2
Port Kobe	Port Vung Tau	Shoes	Most Inventory (Dynamic sources)	Basic Period
Port Kobe	Port Hong Kong	Shoes	Most Inventory (Dynamic sources)	Basic Period 2

Perhaps Experiment 'B' is the clearest case of *the ripple effect* of the trade sanctions where the SC structure changed. Moving forward let us study the findings in the operation of this SC. In table 4.3, we get the total costs and profits (best case scenario among all the replications in a trial) of the SC in each trial conducted.

Figure 4.2 (a) Total costs and profits vs trials in Experiment 'B' for the combined period of two periods;

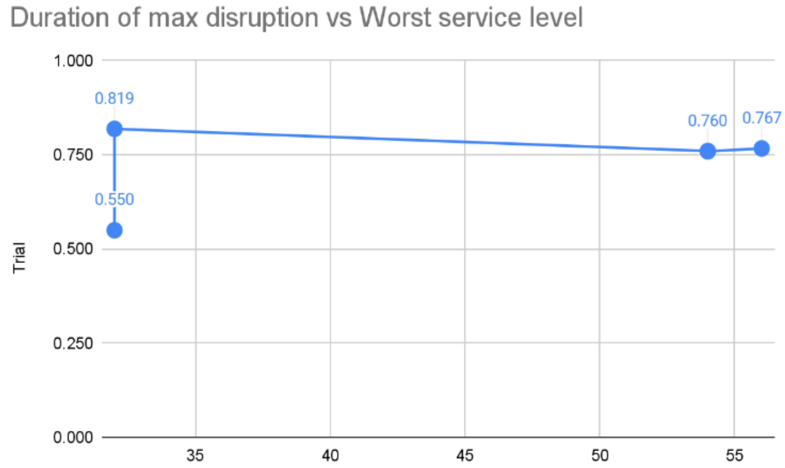

Figure 4.2 (b) Worst service level vs Duration of max disruption

Higher duration of max. Disruption usually corresponds to both worst service level and worst fulfilment received being lower (Figure 4.3).

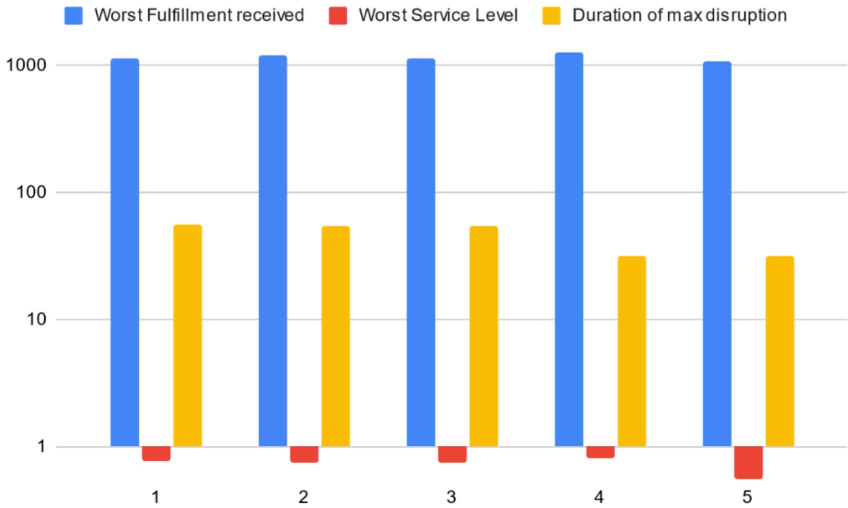

Figure 4.3 Fulfilment received, Service Level, and Duration of max disruption in various trials of experiment 'B' on logarithmic scale

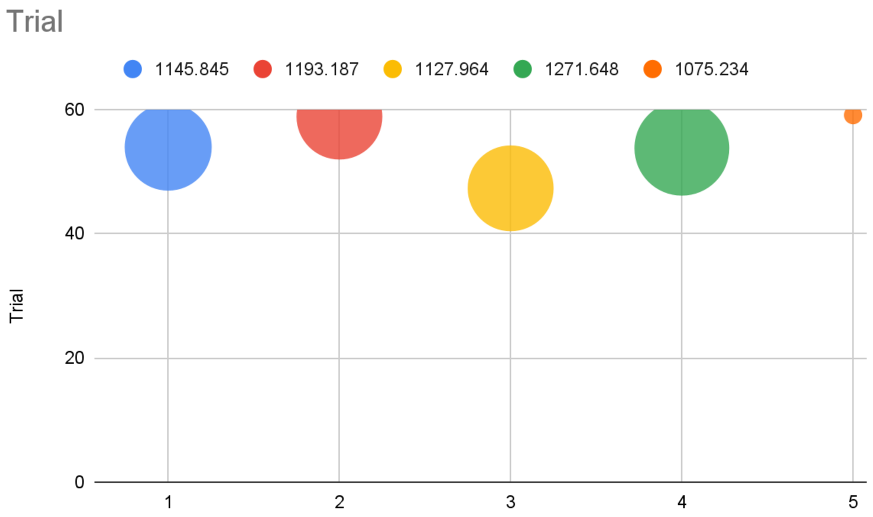

Figure 4.4 Bubble Chart - Vertical axis (Profits, in million), horizontal axis (trials), series (worst fulfilment received, indicated at top), size (worst service level) for experiment 'B'

In experiment 'C', we have taken 70 customers based in 3 countries namely Japan, Indonesia, and Philippines with the original SC configuration of the Port in Vung Tau. Refer to section 3.3 to get delve deeper in the workings of this SC. We are now concerned with the performance of this experiment under duress of multiple disruptions such as the rainy season and demand fluctuations.

Table 4.4 Findings of Experiment 'C' in Table 3.2

Trial	Best Total Costs	Best Profits	Worst Fulfillment received	Worst service level	Duration of max disruption
1	45150650.12	65208689.88	913478.34	0.852	55
2	45430296.47	65758363.53	916856.92	0.872	51
3	45072035.57	65006774.43	930199.2	0.892	45
4	45451812.71	65704198.06	896739.54	0.835	61
5	45211809.28	65433370.72	994302	0.938	27

The unit of Worst fulfillment received in this experiment is different than the previous ones as we have chosen the product to be 'Knit clothing and accessories'.

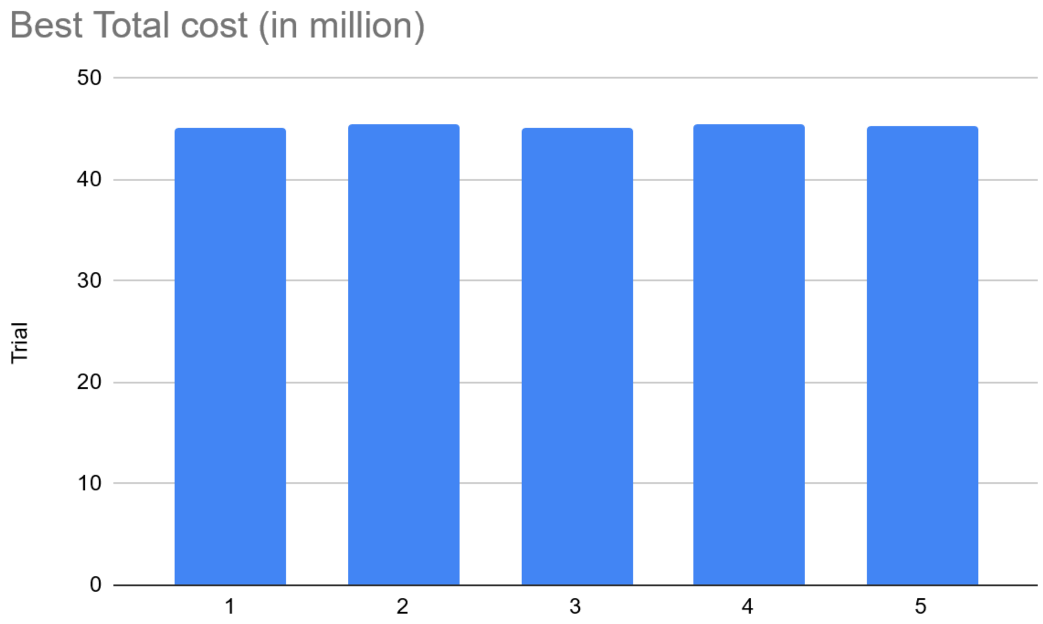

Figure 4.5(a) Total cost vs trials in Experiment 'C';

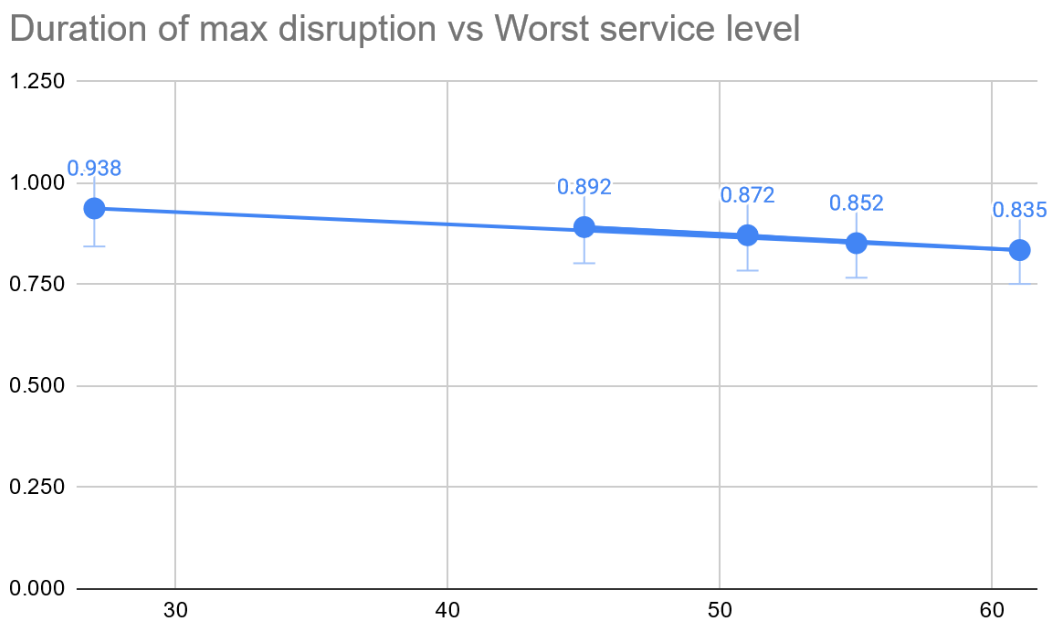

Figure 4.5(b) Worst service level vs Duration of max disruption

In the Fig. 4.5 we can clearly see the negative correlation of the duration of mx. Disruption with the worst service level. This implies it is imperative in a supply chain to combat *the ripple effect* to improve the experience for the customer. The main theme of the experiment 'C' is to explore the diversity of the customer in different countries. Using this experiment, we can make a case for diversifying the market for an organization to sell their products to, in the case of sudden increase or decrease of customers in a particular region. This will prove to be an effective strategy to overcome *the ripple effect* in a supply chain.

4.2 Analyzing supplier risk in supply chains to avert the ripple effect

In the experiments conducted in this subsection we are aiming to identify the ripple effects in supply chains due to supplier risk. We have considered two SCs, the first of which has the following configuration:

- Toaster parts manufacturer and assembly factory in China
- Port of Hong Kong located at a distance from the factory, through which the products are shipped
- Port in France where customers are located
- DCs in France, Austria and Deutschland

The supply chain which we are broadly considering is mentioned below in Fig. 4.6.

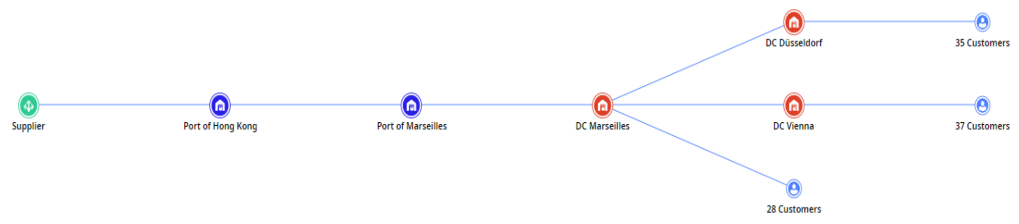

Figure 4.6 Supply Chain in the baseline scenario (production based in China)

Overall, the supply chain has to serve 100 customers located in France (Marseilles), Dusseldorf (Germany), Vienna (Austria) and other countries in Europe. The demand for each customer is such that the order is placed every 5 to 7 days, periodically. The magnitude of the order is proportional to the population of the city the customer resides in. The product in this supply chain is a toaster which is made by assembling a heating element, polypropylene made parts and steel. Now we have identified the long route connecting the port of Hong Kong to the port of Marseilles to be a critical link. Disruption of this path can lead to higher lead times and potential loss for the organization due to lack of fulfillment of customer orders. We plan a second supply chain to mitigate this potential risk due to disruption (Figure 4.7).

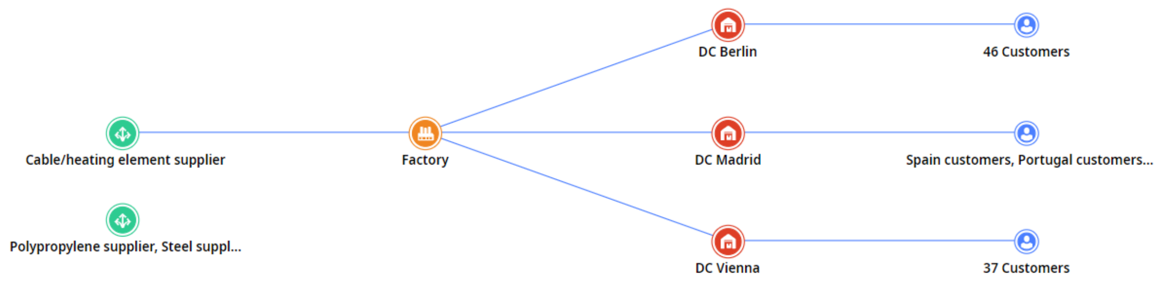

Fig. 4.7 Supply Chain with production based in Europe

In this supply chain we avert *the ripple effect* of a disruption in the critical path connecting the port of Hong Kong to the port of Marseilles by sourcing the raw materials from suppliers in Europe, assembling them in a factory at Krakow, Poland. Here we compare the max lead times for our product delivery to customers where the European-based supply chain is the what-if comparison scenario and the baseline scenario is the China-based supply chain.

Table 4.5 Maximum Lead Time in the delivery of products for baseline and comparison scenarios

Max Lead Time	Replication 6	What-if Baseline scenario	1.498	day
Max Lead Time	Replication 7	What-if Baseline scenario	1.498	day
Max Lead Time	Replication 8	What-if Baseline scenario	1.499	day
Max Lead Time	Replication 9	What-if Baseline scenario	1.498	day
Max Lead Time	Replication 11	What-if Comparison scenario	1.42	day
Max Lead Time	Replication 12	What-if Comparison scenario	1.42	day
Max Lead Time	Replication 13	What-if Comparison scenario	1.421	day
Max Lead Time	Replication 14	What-if Comparison scenario	1.42	day
Max Lead Time	Replication 15	What-if Comparison scenario	1.421	day
Max Lead Time	Replication 16	What-if Comparison scenario	1.42	day

We can clearly observe that bringing the supplier closer to the customers decreases the likelihood of the ripple effect of any major disruptions in the routes or factories but also decreases the overall lead time to the customer, increasing the customer satisfaction. In the profit-revenue-total cost analysis for both the scenarios that is the baseline scenario and the comparison scenario the cost of setting up the factories in Europe is higher than in Hong Kong. This leads to the decision to not allocate resources to set-up the supply chain entirely in Europe. In the graph below the upper set of replications belong to the baseline scenario indicating higher profits and the lower set of replications represent the comparison scenario.

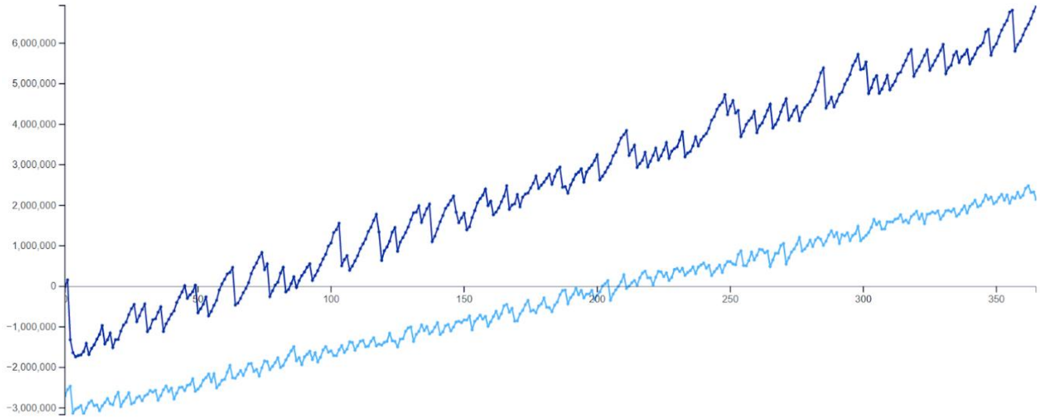

Figure 4.8 Profits with time interval in the baseline and comparison scenario

4.3 Qualitative Analysis of factors affecting exceptional impact-low frequency events

As per the goals set at onset of this project i.e. to (RO3) identify the complexities in SCA implementation; and to (RO4) Capture the perceived importance of SCA in improving Ripple Effect mitigation; we conducted a survey conducted to "rate the risk factors on the basis of their ability to create an exceptional impact on a supply chain in case of a rare occurrence of them", we have found that the majority of experts agree that Natural Disasters, Labor shortages etc. can change the structure of the SC (Figure 4.9).

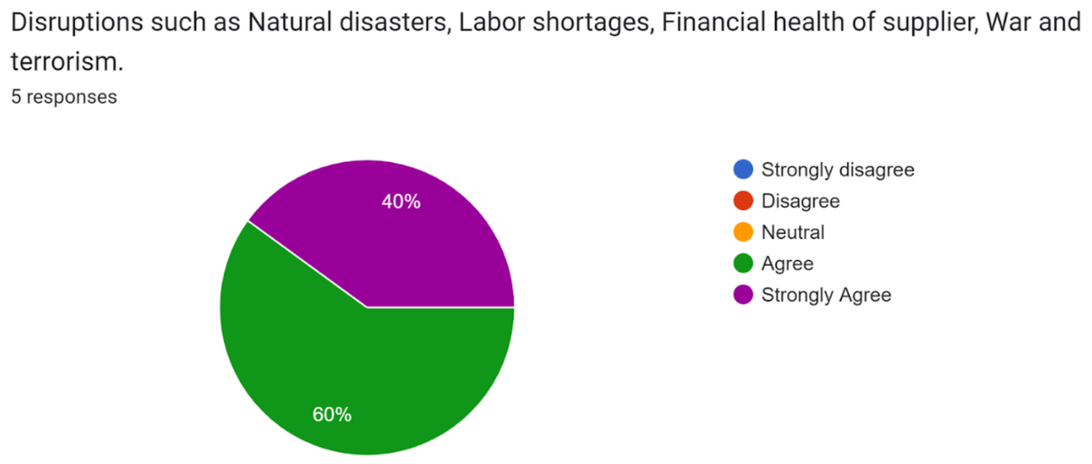

Figure 4.9 Disruptions such as Natural disasters, Labor shortages, financial health of suppliers, War and terrorism.

Disruptions caused by delay due to the source itself utilizing the most of the factory output, or its inflexibility also contribute to *the ripple effect* in a supply chain (Figure 4.10, Appendix 'B'). The example which supports this claim could be that of Steel Industry where the steel plants themselves in times of war may divert most of the steel production towards building of rail lines and defense machines rather than other uses. Survey experts mostly agree that systematic issues may lead to complete breakdown of a supply chain contributing to structural changes (Figure 4.11, Appendix 'B'). On the topic of forecast issues most of the experts answered with neutrality that they have any effect on the supply chain (Figure 4.12, Appendix 'B'). Intellectual Property issues found most of the experts agreeing that they can indeed *have a ripple effect* in a supply chain. For e.g. Coca-Cola was about to introduce a new drink in the market which would fundamentally change the taste of their coca-cola drink but the experts in the organization realized that this would cause a massive *ripple effect* in the supply chain which could have led the customers to the rival drinks (Figure 4.13, Appendix 'B'). The survey showed favorability to the issues of procurement and capacity in terms of their impact on the SC leading to the *ripple effect* (Figure 4.15, Appendix 'B'). Whereas the experts surveyed showed neutral opinion on the issues of variability of customers in a supply chain can create the *ripple effect* (Figure 4.16, Appendix 'B').

4.4 Data sources and classification within Ripple Effect

As per (RO2), considering the supply chain mentioned in section 4.2 we want to classify the sources and types of data arising in it. The data sources in this supply chain can be classified on the basis of which stage or level of supply chain we are in. At the supplier level, demand forecast itself can be treated as structured data which is generated at quarterly intervals. More data at supplier stage in relation to the product which we are producing (toaster) will be daily production targets, the inventory of each of the parts which are to be assembled to get the final product, the time at which the batch of product is to be shipped, and the demand received for the products to be manufactured on the next day. Moving to the production level we have the visibility of the highest volume of data being generated at the shop floor. In the case of producing a toaster, we would require a prior inspection of the heating element to check its functioning, where the functioning of the element itself matters less from the viewpoint of *the ripple effect*. The no. of elements being inspected or repaired would serve as a good indicator in *predictive analytics* to mark future propensity of the ripple effect happening in a supply chain. We can reflect on this view from three dimensions first, if the no. of heating elements being inspected is more than usual then it could be an indicator of increasing demand of the product which happens in our supply chain with a probability of 0.8. The ripple effect of this phenomenon could be more strain on the same amount of labour, and more strain on the infrastructure of the factory producing the element. The second dimension could be an increase in usage of our product in the market as more of its defects and limitations are passed upstream in the supply chain because of its comparison with its competitors, this could cause a structural change in the supply chain as a different heating element could be used to make the toaster. The third dimension would be to create a larger sample size to process the batch of heating elements produced, which reduces the chance of Type II errors (false-negative) in hypothesis testing. Where the null hypothesis is that the batch of heating elements produced have less than ‘x’ defective elements.

Chapter 5: Conclusion and Future Scope

During the research conducted to explore the deficiencies of current methods and techniques applied in Industry to anticipate *the ripple effect* due to various disruptions in a supply chain, we have concluded that supply chain analytics is an important tool to overcome the hurdles and challenges posed by various risk factors in a supply chain. Specifically, we have used the risk analysis experiments to find out the service level by products for a supply chain and financial metrics such as total cost, profits, and revenue. Beside the service level by products we have recorded the worst service level, and the worst fulfilment received (on-time) for each trial taken in an experiment, which has provided us with insights in the variation in these values depending on the experiment undertaken. In experiment ‘C’ (section 3.2.1) despite no measures taken to mitigate the ripple effect of the disruptions we observed better values of service level and fulfillment received than experiment ‘B’ (section 3.2.1). The experiment ‘B’ confirmed with the null hypothesis mentioned in Table 1 that supply chain analytics when applied to an organization can reduce the impact of *the ripple effect*. Further studies can delve deeper on three important questions regarding this topic:

- What would be the impact of *the ripple effect* in case of a supply chain of perishable products?
- What would be the results of sensitivity analysis of the supply chain in terms of change in safety stock at various DCs?
- Disruptions based risk analysis uses SC resilience principles like redundancy used in experiment ‘B’. What agent-based modelling can be applied to broaden the scope of SC resilience principles?

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Annexure 'B' – Pie Charts

Delays such as high capacity utilization at supply source, inflexibility of supply source, or poor quality, excess handling.

5 responses

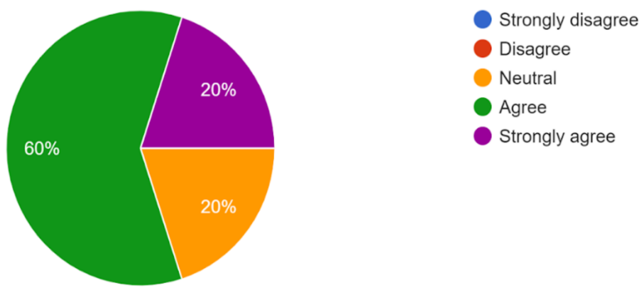

Figure 4.10 Delays such as high-capacity utilization at supply source, inflexibility of supply source, or poor quality, excess handling.

Systematic issues such as Information Infra Breakdown, E-commerce issues

5 responses

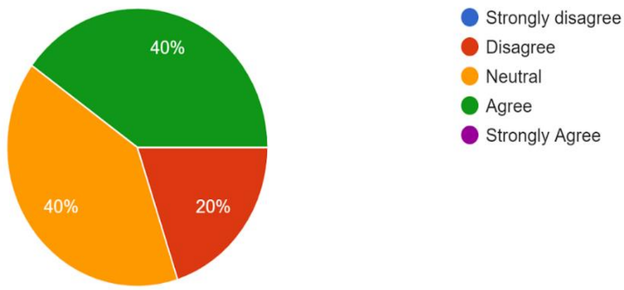

Figure 4.11 Systematic issues such as Information Infra Breakdown, E-commerce issues

Forecast issues such as inaccurate forecasts due to long lead times, product variety, or information distortion due to sales promotions, incentives.

5 responses

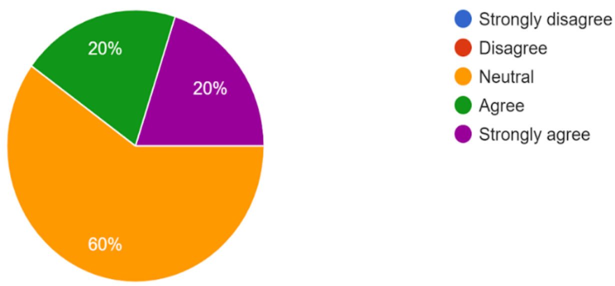

Figure 4.12 Forecast issues such as inaccurate forecasts due to long lead times, product variety, or information distortion due to sales promotions, incentives

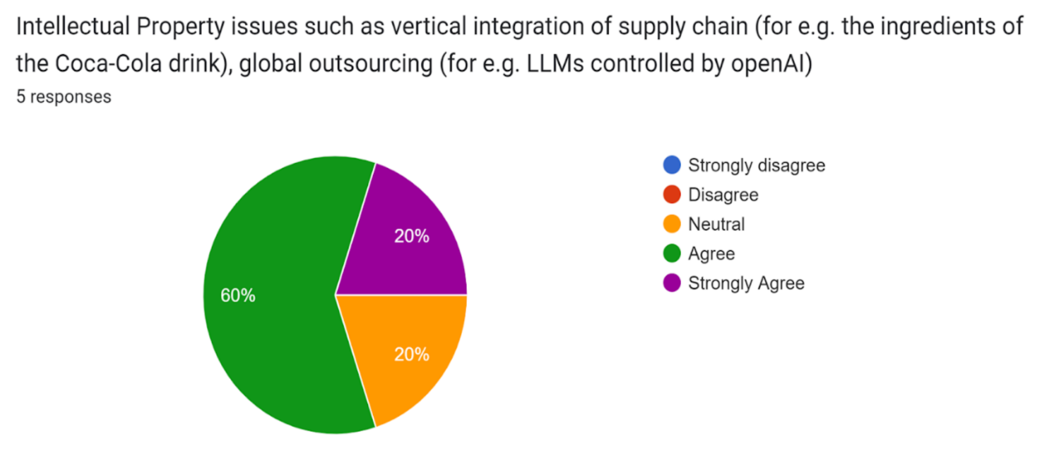

Figure 4.13 Intellectual Property issues such as vertical integration of supply chain (for e.g. the ingredients of the Coca-Cola drink), global outsourcing (for e.g. LLMs controlled by openAI)

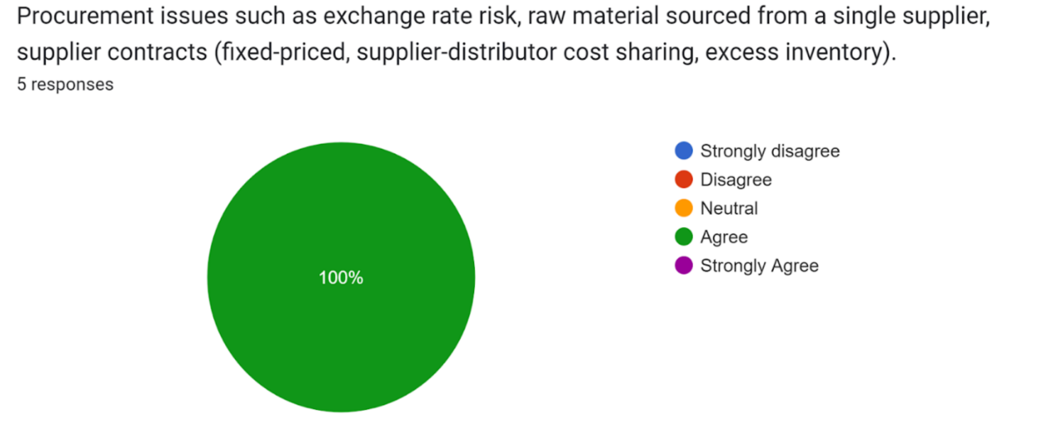

Figure 4.14 Procurement issues such as exchange rate risk, raw material sourced from a single supplier, supplier contracts (fixed-priced, supplier-distributor cost sharing, excess inventory).

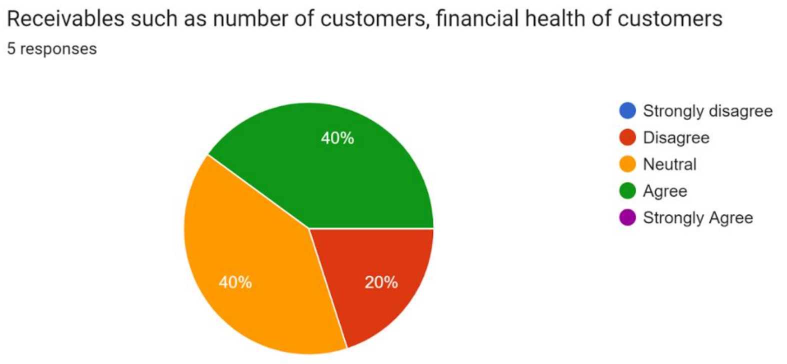

Figure 4.15 Receivables such as number of customers, financial health of customers

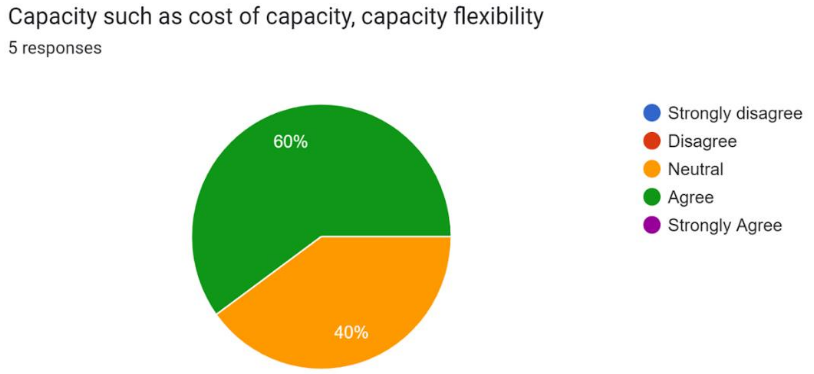

Figure 4.16 Capacity such as cost of capacity, capacity flexibility

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Annexure 'D' – SIMILARITY REPORT

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IEM5407 : Product Design & Development

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		Credits	4	4	2	3	4			
1	ADITYA SAXENA	2K22/IEM/01	B	F	A	B	B	13	4.82	IEM503,
2	AMAN MAAN	2K22/IEM/02	A	P	A+	A	A+	17	7.41	
3	ANIKET MODI	2K22/IEM/03	A	B	A	A	A+	17	7.76	
4	ASHISH MALHOTRA	2K22/IEM/04	B	C	B+	C	A	17	6.18	
5	HAMISH ALI	2K22/IEM/05	B	P	B+	B	A	17	6.12	
6	KAMALDEEP SAHU	2K22/IEM/06	A	C	O	A+	A+	17	7.94	
7	KUMAR AMIT	2K22/IEM/07	O	A+	O	O	O	17	9.76	
8	LAKSHYA SAINI	2K22/IEM/08	O	A	A+	A+	A+	17	9.00	
9	SAMIR KUMAR	2K22/IEM/09	B+	B+	A+	A+	A+	17	8.06	
10	SHEETAL SHARMA	2K22/IEM/10	A+	B	A	B	A+	17	7.65	
11	SHUBHAM SAURABH	2K22/IEM/11	A+	B	A	A	A	17	7.76	
12	SUBADEEP DAS	2K22/IEM/12	A	B+	A+	A	O	17	8.35	
13	VATAN SINGH	2K22/IEM/13	O	A	A+	O	O	17	9.41	

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IEM502 : OPERATIONS RESEARCH   IEM504 : SUPPLY CHAIN MANAGEMENT   IEM5404 : INDUSTRY 4.0 & SMART MANUFACTURING   IEM5304 : International Logistics and Warehouse Managment
IEM5210 : Contemporary Issues in Industrial Engineering and Managment

Sr.No	Name	Roll No.	IEM502	IEM504	IEM5404	IEM5304	IEM5210	TC	SGPA	Papers Failed
		Credits	4	4	4	3	2			
1	ADITYA SAXENA	2K22/IEM/01	F	F	F	F	F	0	0.00	IEM502IEM504, IEM5404, IEM5304, IEM5210,
2	AMAN MAAN	2K22/IEM/02	O	B+	A+	A	O	17	8.71	
3	ANIKET MODI	2K22/IEM/03	O	B+	A	A	A	17	8.24	
4	ASHISH MALHOTRA	2K22/IEM/04	B+	B	B	B	B	17	6.24	
5	HAMISH ALI	2K22/IEM/05	A	C	A	B+	A+	17	7.24	
6	KAMALDEEP SAHU	2K22/IEM/06	A+	B+	O	A+	A+	17	8.76	
7	KUMAR AMIT	2K22/IEM/07	O	O	O	O	O	17	10.00	
8	LAKSHYA SAINI	2K22/IEM/08	A+	A	A	A+	A+	17	8.53	
9	SAMIR KUMAR	2K22/IEM/09	A+	A	O	O	A+	17	9.18	
10	SHEETAL SHARMA	2K22/IEM/10	A	A	O	A+	A	17	8.65	
11	SHUBHAM SAURABH	2K22/IEM/11	A+	B+	A	A	A	17	8.00	
12	SUBADEEP DAS	2K22/IEM/12	O	B+	A+	A+	A	17	8.65	
13	VATAN SINGH	2K22/IEM/13	A+	A+	A+	A+	A+	17	9.00	

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Sr.No	Roll No.	Name of Student	IEM601	IEM6201	IEM6303	IEM6405	SGPA	TC	Failed Courses
			3.00	2.00	3.00	4.00			
1	2K22/IEM/02	AMAN MAAN	B+	O	A	A+	8.42	12	
2	2K22/IEM/03	ANIKET MODI	B+	A	B+	A	7.5	12	
3	2K22/IEM/04	ASHISH MALHOTRA	B+	A	C	B	6.33	12	
4	2K22/IEM/05	HAMISH ALI	B+	A+	B	B+	7.08	12	
5	2K22/IEM/06	KAMALDEEP SAHU	B+	A+	B	A+	7.75	12	
6	2K22/IEM/07	KUMAR AMIT	A+	O	O	O	9.75	12	
7	2K22/IEM/08	LAKSHYA SAINI	A+	A+	B+	A+	8.5	12	
8	2K22/IEM/09	SAMIR KUMAR	B+	A+	A	A	7.92	12	
9	2K22/IEM/10	SHEETAL SHARMA	B+	A+	B	A	7.42	12	
10	2K22/IEM/11	SHUBHAM SAURABH	B+	A	B	A	7.25	12	
11	2K22/IEM/12	SUBADEEP DAS	A	A+	B	A	7.67	12	
12	2K22/IEM/13	VATAN SINGH	A	O	A	A+	8.67	12	

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CANDIDATE`S PROFILE

I'm Aniket Modi, a driven professional with a background in Production and Industrial Engineering, holding B.Tech. degree and pursuing M.Tech. degree. My journey in data analytics includes projects like Cricket Player Auction Price analysis (github link) and Health Insurance Lead Classification, showcasing my proficiency in Python programming. Additionally, I have been involved in Industry 4.0 initiatives like Forest Fire Detection using IoT reflecting my commitment to innovative solutions addressing real-world challenges.

Research Paper acceptance letter

SOCIETY FOR EDUCATION

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15th-June-2024 | Delhi, India

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Paper ID: SFE_67981

Paper Title: Minimizing ripple effect and complexities in a supply chain

Authors Name: Aniket Modi

Dear Author,

With heartiest congratulations I am pleased to inform you that based on the recommendations of the reviewers and the Technical Program Committees, your paper identified above has been accepted for publication and oral presentation by **International Conference On Science Technology And Management (ICSTM-24)**

This conference received number of submissions from different countries and regions, reviewed by international experts and your paper cleared all the criteria, got accepted for the conference. Your paper will be published in the conference proceeding after the registration.

For registration: https://www.sfe.net.in/conf/registration.php?id=2479537

Herewith, the conference committee sincerely invites you to come to present your paper at our conference.

Sincerely,

Dr. James Crusoe
President
Society for Education (SFE)

+91 9677007228 info@sfe.net.in www.sfe.net.in

Google Scholar

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OF PRESENTATION

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15th June 2024 | Delhi, India

This is to certify that **Aniket Modi** affiliated with Delhi Technological University, Delhi, India has presented a paper titled "Minimizing Ripple Effect And Complexities In A Supply Chain"

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