LUND UNIVERSITY

Master's Thesis SMMM40

Supply Chain Strategies for Trade War Conditions:

A Scenario Analysis of Strategies and Tariffs Using a Linear Programming Model.

By:

Panu Kärnä

Botond Szász

Department of Service Studies

Campus Helsingborg

Supervisor:

Dr. Daniel Hellström, Lund University

Thesis for the fulfilment of the Master of Science in Service Management, Supply Chain Management

Date of Submission: 14th of May 2024

ACKNOWLEDGEMENTS

The completion of this thesis has been a profound journey of academic and personal growth. We would like to express our gratitude to a number of people and organizations whose contributions were indispensable to complete this thesis. First of all, we would like to thank Nexus, the company whose generous provision of crucial data greatly benefited our research. Their support not only was fundamental to our work, but also demonstrated the practical application of industry-academic partnerships.

Secondly, we would like to express our gratitude to our supervisors who have supported us and provided us with valuable feedback. Initially, we would like to thank Dr. Daniel Hellström, our supervisor, who has guided us through the research process and helped us craft a coherent text. Furthermore, we would like to dedicate an acknowledgement to Dr. Henrik Sternberg, whose accurate feedback and experience in the industry has contributed to elevating the quality of this study.

We would like to also thank our peers who we could bounce our ideas off and get further feedback from.

Finally, we are immensely grateful for the unwavering support of our loved ones.

Panu Kärnä

Botond Szász

ABSTRACT

Study purpose: The primary aim of this study is to explore the performance of different supply chain configurations made in response to various U.S. tariff rate conditions, particularly those impacting imports from China. Previous research has predominantly addressed this topic at the macro level, whereas this study employs a single-case firm, Nexus, to provide a more comprehensive analysis of the performance of tariff mitigation strategies at the micro level.

Methodology: The methodology employed in this study uses linear programming models and scenario analysis within a case study framework. We utilized the linear programming tool, Cosmic Frog by Optilogic, recognized for its capability to simulate real-world supply chain networks and various scenario outcomes including changes in tariff rates and different sourcing strategies. The tool enabled the creation of a model of the firm's supply chain, the implementation of alterations to sourcing and assembly configurations, and the assessment of their performance under a range of tariff rate scenarios.

Findings: The analysis revealed that, from the tested strategies, reallocating supply capacity to Mexico emerged as the most cost-effective one, significantly improving cost metrics compared to the Default. However, the study also revealed that strategies designed solely to avoid tariffs could lead to increased costs in other operational areas, thereby necessitating careful integration into the firm's existing supply chain framework. Geographical factors also emerged as crucial, with configurations in lower-cost regions like Vietnam showing distinct advantages in operational expenditures compared to areas such as South Korea.

Research implications: The implications of this research extend to both theoretical and practical realms of supply chain and operations management. Theoretically, the study enriches the existing literature by providing empirical evidence on the impacts of strategic supply chain reconfigurations in response to international trade policies. Practically, it offers an example to firms that it is possible to evaluate tariff mitigation strategies with relatively low risk and investment. Furthermore, it provides insight that firms can use to better evaluate their strategical options.

Keywords: tariff impact analysis, linear programming, scenario analysis, sourcing and assembly strategies, trade policy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

1.1 Background

In 2018, then US President Donald Trump, initiated a series of trade restrictions against China and US allies in Europe and North America, now known as the trade war. Among these policy changes were quotas, which limit the amount of certain goods that can be imported in a given time period, and steep increases in import tariffs on many goods (Bown & Kolb, 2023). These were initially intended to protect domestic firms and markets (Chen et al., 2022), reduce dependence on China and balance trade, but ended up wreaking havoc, causing damage estimated in the tens of billions of U.S. dollars, slowed U.S. economic growth, and diverted trade away from both China and the U.S. (Hass & Denmark, 2020). Considering the domestic and global impacts, the trade war is one of the most severe trade conflicts in recent history (Zeng, 2023). Since the beginning of the trade war, imports from China to the U.S. have fallen sharply, which was exacerbated by the global pandemic in 2020 (Bown, 2022). At the same time, Chinese exporters reduced their exports to the U.S. due to lower profit margins, partially replacing U.S. exports with exports to the European Union (Jiao et al., 2022).

Recent statistics show that more than 8,600 U.S. companies have operations in China (Lindner, 2023). Therefore, a shock to the trade balance, such as tariff escalation, will affect a significant number of firms, especially those headquartered in the U.S. (Feng et al., 2022). A survey conducted in 2018 by the American Chamber of Commerce in South China confirms that more than 70 percent of U.S. firms in South China are considering scaling back investments and reallocating their operations to other countries following the trade war (Wong, 2018). Major global firms, such as Apple, diversified their source of supply for the latest iPhone to India. The move, which saw the iPhone being manufactured outside of China for the first time in decades. This is believed to be driven by the need to ensure that it continues to serve its global customer base and reduce dependence on China amid rising trade tensions (Benedicto, 2023). Furthermore, the automotive and agricultural are amongst the most affected industries (Reiff, 2019). In the automotive industry, major global brands such as Ford, Honda, and BMW reported trade war-related downsides as early as 2018, such as Ford's layoffs to cut costs, as the company estimated that new steel and aluminum tariffs would cost it $1 billion between 2018 and 2019 (Bryan, 2018). Similarly, China's tariffs on U.S. soybeans have resulted in millions of dollars in losses for U.S. farmers (Reiff, 2019).

The impact of the trade war went beyond the U.S. and China. The impact on the European Union (EU) is considered to be twofold. On the one hand, EU trade with China is believed to have benefited from the decline in U.S.-China trade. At the same time, the EU was under constant threat from the Trump administration, with EU car manufacturing and wine production threatened with tariff sanctions (Goulard, 2020). In addition, Europe experienced its own trade disruptions with Brexit. The UK's exit from the EU significantly increased uncertainty about future trading conditions for UK imports, leading to significant changes in supply chains and manufacturing (Graziano et al., 2023). The UK economy still hasn't fully recovered from Brexit, with trade issues such as food supplies with delayed safety checks to avoid shortages and trade relations that haven't fully recovered (Ziady, 2023). A similar conclusion can be drawn from the trade war. While the trade war has cooled down and some of the introduced tariffs have been lifted, stabilizing trade, many of the tariffs introduced in 2018 are still in place (Bown & Kolb, 2023). This comes to show how these trade disruptions can lead to long-term consequences affecting both firms and world economies.

In recent years, there has been a surge of scholarly interest in tariffs, with prominent literature attempting to capture the nuanced impacts of tariffs on firms and the broader population. In addition, a stream of research that examines how to mitigate tariffs has seemingly received less attention, often left in the sidebars of studies. When considering tariffs, the focus shifts to sourcing and manufacturing at the beginning of the chain (Dong & Kouvelis, 2020) and how changes at these stages could help mitigate the impact of tariffs. One such action in the supplier base is diversification. Diversification to reduce the risk of disruption has been studied for decades in the supply chain risk management literature (Anupindi & Akella, 1993). While the strategic importance benefits and drawbacks of diversification have been extensively documented (Burke et al., 2007; Chaturvedi & Martínez-de-Albéniz, 2011; Craighead et al., 2007; Lampel & Giachetti, 2013), there has been limited research on the positive and negative correlations between performance and diversified sourcing strategies against tariff escalation.

1.2 Research problem

In recent years, there has been an increasing scholarly interest in tariffs, with prominent literature attempting to capture the nuanced impacts of tariffs on firms and the broader population. For example, Nagurney et al. (2019) examined the impact of tariffs on product quality and notions of welfare in the tariff-imposing country, and Johnson and Haug (2021), who worked with firms to examine how the trade war affected their supply chains. Less attention has seemingly been paid to another stream of tariff research that explores ways to mitigate tariffs. Some of the key articles involved in the discourse are those investigating optimal allocation and diversifying under tariff uncertainty and tax considerations (Dong & Kouvelis, 2020; Prataviera et al., 2022).

While the existing literature points to reallocation as a solution to mitigate tariffs, there is a lack of studies that delve deeper into these strategies by investigating outcomes, advantages, and disadvantages. Thus, limited evidence has been collected from the perspective of a firm on how reallocation due to tariffs would affect MNFs global operations and whether the reallocation is beneficial. The majority of the literature that examines tariffs takes a macro-level approach to identify causal relationships between phenomena, such as the study by Rogers et al. (2024), who identified a decline in the number facilities among firms after the onset of a trade war, indicating a reduction in spatial complexity as a response to import tariffs. Furthermore, prominent studies identify what firms are doing to reduce their dependence on China and identify the actions taken by the firm (Darby et al., 2020).

1.3 Research question and aim

Motivated by the strategic decisions identified from the literature and the industry, this study examines how different supplier and manufacturing strategies affect the operations of MNFs. Using real company data in a case study setting, a linear programming model was constructed utilizing Cosmic Frog modelling tool (Optilogic, 2024), representing the company a Default Model, or in other terms Default strategy, was constructed, and later modified with multiple scenarios, based on identified strategic decisions. Inspired by the studies of Fan et al. (2022) who did a macro-level investigation of causality of trade war and firm's competitive performance and Namdar et al. (2018) investigations to resilient disruption planning and mitigation. The goal was to analyze the created strategic scenarios to determine which of the strategies is most optimal in terms of tariff reduction and performance.

This study, contrary to Fan et al. (2022), takes a micro firm-level approach by investigating concepts such as responsiveness, resilience, and economic metrics. These concepts and metrics help determine the optimality of strategic scenarios developed for the firm throughout tariff fluctuations. We define responsiveness similarly to the Cohen and Kouvelis (2021) article about best performing supply chains, as we measure responsiveness and robustness, for example how the scenario changes the situation against the Default Model in terms of delivery time. As for resilience, the definition adopted is the one introduced by Namdar et al. (2018), consisting of the strategy's ability to recover or shift to a new, more desirable state compared to the default model. Finally, the economic metrics used represent the total cost of the strategic scenario. We used these metrics to answer following research questions:

How do different supplier and manufacturing strategies affect the operational performance of global supply chains under different tariff scenarios?

This study contributes to two branches of Supply Chain/Operations Management (SC/OM) literature, first is tariff literature where this study contributes to mitigative investigations against fluctuating tariff impact on MNFs. Second is the sourcing literature where this study contributes on diversification and reallocation under disruption risk. In addition, this study provides a unique framework for SC/OM modeling by introducing Optilogic (2024) software, in an industry settings commonly used supply chain management tool that hasn't seen traction in SC/OM research yet. Therefore, this study is the first to utilize its unique attributes in exploratory rate research.

1.4 Thesis outline

This research is divided into the following sections: theoretical background, methodology, scenario/simulation results, discussion, and conclusion. Theoretical background looks at recent relevant literature in tariff research in the field of SC/OM to represent previous discoveries as well as commonly used methodology and theory in tariff research. Furthermore, this chapter also evaluates literature of disruption in sourcing and manufacturing, followed by a final section that represents previous literature combining these sections to evaluate how changes in sourcing and manufacturing could provide a basis for reducing the impact of tariffs in global supply chain networks (SCNs). The methodology section presents the research overview, settings, design, model, and tool. It provides a detailed overview of the research conducted, followed by scenario development and analysis. In the simulation results chapter, the results of the scenario analysis are interpreted with appropriate figures and tables to give the reader an overview as well as a presentation of the most optimal strategic scenarios. Discussion will focus on deeper analysis interpreting the scenario/simulation results with the purpose of critically evaluating the pros and cons of the scenarios. The discussion is followed by a final concluding chapter that summarizes the overall findings of the study.

2. THEORETICAL BACKGROUND

This section will build on the theoretical background from two branches of the SC/OM literature. First focusing on the impact of fluctuating tariffs on MNFs, followed by the literature on sourcing strategies and procurement risk management. Finally, in the third section, the focus is at how sourcing strategies can be linked to sustaining performance under tariff escalation, drawing on strategies from the existing literature to be adopted into this research.

2.1 Theories in tariff research

For decades, the trade tariffs and their effects were a topic of discourser exclusively for economists, sensitizing the impact on global trade and nations (Dent, 2020). However, trade restrictions introduced by former U.S. President Donald Trump inspired the study of tariffs as a topic in the SC/OM discipline (Rogers et al., 2024). Introduction of restrictions included trade quotas, which limits the amount of imports in certain time frames, and increases of tariffs for several products (Hezarkhani et al., 2023) hitting especially on steel and aluminum products (Dong & Kouvelis, 2020). In recent years, the threat and challenge of tariffs to global manufacturing and sourcing has been explored in prominent publications, and today tariffs are widely understood to cause significant challenges for MNFs. One major challenge, according to Darby et al. (2020), is that tariffs bring uncertainty, and firms can't reliably predict when and how governments will decide to implement new policy. This brings real challenges to both researchers and firms.

A variety of methodological approaches, such as in-depth interviews and modeling, have been used to gain understanding of the impact of tariffs. One of the most prominent methodologies to study this phenomenon is modeling, with several publications that have utilized the method when approaching the impact of tariff escalations on MNFs and the broader economy. For instance, Nagurney et al. (2019) introduced a differentiated product network equilibrium model to determine the impact of tariffs and other trade policies on product quality, with major founding that consumer welfare is reduced in countries that impose tariffs. Moreover, they expanded that in order to remain competitive and profitable, firms should seek to relocate to non-tariffed countries. Using the newsvendor network model, Dong and Kouvelis (2020) examined the impact of trade policies on the design of the firm's global facility network. They emphasized the importance of identifying weaknesses in the SCN to maintain optimal performance. Chen et al. (2022) constructed a game-theoretic model to analyze a global manufacturer's sourcing decisions for foreign and domestic manufacturing and sales in a competitive environment. They found that price premiums are drivers for domestic sourcing. Which indicates that a higher selling price for domestically produced goods drives firms to source domestically, while tariffs have the opposite effect as rate increases may induce MNFs to seek better prices from foreign suppliers, thereby encouraging foreign sourcing. Furthermore, Zhang et al. (2023) conducted a Cournot model to assess the role of tariffs in MNFs' international competition and found that increasing tariffs in both exporting and importing countries affect the extent to which MNFs adjust their influence in foreign markets. Like Covid-19, the disruptive nature of escalating tariffs requires careful consideration of supply chain adjustments by firms' decision makers.

Given the multifaceted impact of tariffs on industries, prominent studies have sought to capture industry perspectives, which is often achieved through qualitative studies engaging with firms and experts. Often focusing on investigating how firms perceive trade disruptions such as tariffs, and how they have affected decision making. These studies provide valuable insights on how firms have navigated through trade disruptions. For example, Handfield et al. (2020) interviewed executives of two MNFs to identify actions taken to protect supply chain in an exploratory study combining constructive law and two case studies. The authors found that tariff increases in recent years have had an impact on the trading environment together with increases in transportation costs and sustainability issues. They discovered that tariffs drive reallocation of operations, while transportation cost and sustainability accelerated nearshoring, therefore reallocating operations closer to domestic markets. These findings are closely aligned with those of Johnson and Haug (2021) who conducted in-depth interviews with six industry experts determining that the current wave of disruption began as early as 2016 with the rise of protectionist movements and populism. They found that companies were not prepared for a prolonged trade war only expecting a short-term shock. As a result, interviewees made both short-term adjustments, such as rushing orders before tariffs took effect, and long-term strategic changes, such as shifting operations from China to unaffected countries.

Evaluating literature, the phenomenon of tariffs has been investigated throughout different theories. One such used to theorize tariffs is Resource Dependency Theory (RDT). RDT focuses on the relationship between an organization and a set of actors (Chi & Mei-Chen, 2024), such as suppliers, and assumes that the firm’s choices are constrained by external pressure (Sutton et al., 2021). Focusing on the need to access resources from external actors, and when resources become scarce it drives firms to innovate and discover new alternatives. Thus, RDT focuses on the firms’ ability to establish relationships and maintain competitiveness

(Hessels & Terjesen, 2010). This motivates them to shape their relationships and dynamics, in order to reduce dependency through management strategies (Jiang et al., 2023).

Darby et al. (2020) used RDT to assess the conditions at the macro and industry level, and evaluated how trade policy uncertainties cause firms to build up excess stock as a defensive measure to buffer against potential changes in trade environment. They took a critical stance on inventory hedging, seeing it as a temporary solution to the increasing trade tension, instead highlighting reallocation as a mean to reduce dependency and form new relationships with suppliers. Rogers et al. (2024) used RDT in a similar way in their study on the impact of tariffs on protected industries and partners in supply chains with increasing tariff uncertainty. They found that tariffs impose significant costs on U.S. consumers and protected producers with conclusion that the negative aspects of tariffs outweigh the positive aspects. As such, aspects of RDT can be extended to analyze the impact of tariffs and the mitigation of MNFs against disruption. According to Sutton et al. (2021) as a firm grows, so does the number of resources needed, while the alternative sources available are becoming increasingly scarce. Thus, uncertainty and dependency increase alongside, leading to vulnerability to external factors, as suppliers and changes in the environment are beyond MNFs control.

Besides RDT, tariffs have been approached with other theories as well. One such is variational inequality theory (VIT). Feng et al. (2022) for example, studied the impact of the trade policy on the global SC equilibrium through the use of Cournot-Nash competition in an optimization model, which provides equilibrium conditions utilizing variational inequality theory. They found that, depending on where in the supply chain the tariffs are imposed, will determine which party is harmed. For instance, if the tariff is imposed on the supply side, the domestic supplier will benefit. On the other hand, if the tariff is imposed on the demand side, the domestic producer of the final product will benefit from the trade policy.

Existing literature manages to highlight how tariff escalation challenges firms and the global supply chain networks (SCNs), forcing firms to rethink strategies during decision making process. As such, when firms face uncertainty in the trade environment they operate in, it is found that the uncertainty will reduce investments (Zhang et al., 2021). Instead, firms direct the investments towards operations expenses and assume a wait-and-see stance until the situation is solved or the trade environment is stabile again. In highly competitive markets this wait-and-see strategy often means the decline of competitive capabilities (Chen et al., 2023). Similarly, uncertainty reduces sticky expenditures in the cost of goods manufactured (COGM) and administrative expenses, which affects operational performance (Zhang et al., 2021). In addition to affecting operational performance negatively, Fan et al. (2022), using COGM and inventory replenishment days in macro-level analysis, found that there is a positive correlation between tariff escalation and increase in the metrics utilized. Thus, their findings indicate that escalating tariffs affect the competitive capabilities of MNFs who source their supplies from China, when MNF enters in domestic competition with firms sourcing domestically.

The review of existing studies shows the complex nature of phenomenon and the nuanced ways escalating tariffs impact both firms and economies, and trade escalation shook the global trade equilibrium. Forcing firms to reconsider major changes and both short-term and long-term strategical decisions (Johnson & Haug, 2021), which this study also aims to investigate. Consequences of sudden escalation of tariffs may lead firms to seek drastic measures that will end up in long-term changes (Hughes et al., 2022). One such measure, that arises from recent investigations is reallocation of sourcing and manufacturing.

2.2 Importance of sourcing against tariff disruption

Supply chains are dependent on the supplier base. Therefore, sourcing strategies are one of the most important strategic decisions that determine a company's competitiveness and, to a large extent, its survival (Cohen & Lee, 2020). The entire operation can be crippled or even stopped by disruptive effects on the supplier base. Reconfiguration of sourcing strategy towards resilience helps firms to absorb more impacts and ensure their operational functioning under disruptions (Namdar et al., 2018). Craighead et al. (2007) argues that the following three factors; complexity, density, and node criticality, contribute to the perceived severity of disruptions in supply chains, resulting from external factors such as natural and man-made disasters. Expanding on why these three factors contribute to the severity of disruptions, complexity means the level of SCN diversification; density means closeness of suppliers in a geographic location; and node criticality correlates with the number of suppliers in the network.

Thus, a high level of diversity makes it difficult to mitigate disruptive effects, as an impact on one location can negatively impact the entire supply base, and in the case of only having a few sources, disasters can stop the flow of supply entirely (Craighead et al., 2007). Furthermore, Chakkol et al. (2023) utilizing data from the 30 largest U.S. manufacturers from Bloomberg Supply Chain Function over a seven-year period, found a declining trend in numbers of firms' locations during the trade restrictions. Interestingly, they found that this trend extended to those sourcing domestically in the U.S. as well. Suggesting that MNFs need to reduce the spatial complexity of their networks to reduce their vulnerability to restrictions and changes in trade policies.

The significance of minimizing vulnerabilities resulting from political risks, such as detrimental decisions pertaining to trade, was already the subject of strategic deliberations decades ago. Suggestions such as reallocating inventory, rerouting shipments, and rearranging sourcing being detrimental part of discourse (Kleindorfer & Saad, 2005). This discourse of solutions to political risk aligns well with the more recent notion of destructive policies such as tariffs. As it is established that tariffs and other trade policies increase the uncertainty of the firm's operating environment (Chen et al., 2023) and affect negative on costs hindering profitability (Chen et al., 2022; Fan et al., 2022; Rogers et al., 2024).

These strategical concepts introduced by Kleindorfer and Saad (2005) remain still a potential attributes for modern day policy risks. Chaturvedi and Martínez-de-Albéniz (2011) delved further into sourcing under presence of supply risk, they discovered that the sourcing from single supplier is beneficial when appropriate information of supplier capabilities and cost are known. Burke et al. (2007) add to these conditions by noting the importance of the supplier's production capacity. They argue that if the capacity is greater than the buyer's demand, the optimal choice would be to proceed with the cheapest single sourcing option. However, as noted by Craighead et al. (2007) reliance on a single source will increase the criticality of the node, which means a disruptive outcome if the said source fails.

A possible alternative to single sourcing is often considered to be the diversification of the supplier base where the buyers' demand is sourced from multiple suppliers (Sting & Huchzermeier, 2014). The decision between them is often subjective due to each firm's specificities, with optimal setting for single sourcing often relying on the information gathered from suppliers and their capabilities to meet demand (Chaturvedi & Martínez-de-Albéniz, 2011). Under systemic risk, including the possibility of supplier failure, or in the case of escalating tariffs, a multiple supplier configuration setting may be more beneficial. As Birge et al. (2023) demonstrates this using resilience and fragility as metrics. They found that when the financial capitalization of the firm is high, more diversifications would increase fragility. On the other hand, they noted that when the risk of failure on the supplier side is high, a more diversified network is optimal. According to Birge et al. (2023) concludes that, when a buyer is hit with an economic downturn and the risk of supplier failure is high, an optimal solution would be a more diversified network. Thus, when firms face increased tariffs, while not directly contributing to supplier failure, it will add cost pressure. In order to reduce this, opting for a more diversified network is suggested as a solution. Chaturvedi and Martínez-de-Albéniz (2016) additionally contributes to diversification, by noting that diversification could be beneficial in the situations where firm faces supplier capacity uncertainty.

Increased uncertainty caused by tariffs (Chen et al., 2023), necessitates considerations in strategical decision making, as uncertainty is a potential source of bias, as Bendoly et al. (2022) explores in their controlled laboratory experiment that attempts to understand uncertainty bias in sourcing conditions. They found that demand uncertainty potentially contributes to unnecessary diversification in sourcing, while supplier uncertainty leads to higher orders. The latter response is consistent with what Darby et al. (2020) found about inventory hedging in the face of trade policy uncertainty. Furthermore, Bendoly et al. (2022) found that both uncertainties together have a greater impact on decision making than either one has alone, highlighting the importance of consideration in the decision-making process. Jadidi et al. (2022) come to a similar conclusion in their study of optimal supplier selection under uncertain demand, using the newsvendor model to calculate optimal order quantities for each supplier.

2.3 Optimizing global supply chain networks against tariff impact

Recent literature has established that an effective way to mitigate the impact of tariff escalation is to focus on sourcing (Darby et al., 2020; Handfield et al., 2020; Johnson & Haug, 2021) and manufacturing (Lampel & Giachetti, 2013). But this is only part of the picture. Several questions remain unanswered: Where to allocate, what to allocate, what approach to adopt, among others. Nagurney et al. (2019) suggested reallocating to countries not sanctioned by tariffs or trade quotas. However, this answer is still imprecise, leaving several countries as options. In addition, for the choice of approach, several metrics or key performance indicators (KPIs) can be used to benchmark results (Terrada et al., 2023)

As Johnson and Haug (2021) discovered in their research that a proportion of the subject companies were considering the relocation of manufacturing and sourcing from China as a result of trade disruptions. In their interviews they found Mexico and Vietnam as a viable alternatives to China, as both countries have shown potential in terms of manufacturing and sourcing capabilities with lower labor cost and improved infrastructure. Handfield et al. (2020) also concluded that nearshoring as a way of being closer to the markets, in particular to destinations such as Mexico, has started to occur due to disruptions in trade. In their view, the advantage consists of maximizing the market with favorable trade agreements, while potentially maintaining sourcing from East Asia.

In addition to nearshoring, a closely related strategy, reshoring, with the key difference of shifting sourcing and production directly to the domestic market, has gained interest recently as a result of trade disruptions (Yang et al., 2021). The idea of reshoring stems from problems associated with outsourcing that trade disruptions have brought to light, such as hidden costs due to lack of information asymmetry, production disruptions, and lower production quality. Reshoring and increased control over processes could address these issues (Wang et al., 2023). Despite the above, there is a reluctance among firms to shift to reshoring, mainly due to the capacity and cost advantages offered by China and developing countries (Xie et al., 2023). However, the trade environment is constantly changing the perceived advantages; decades ago, when a significant number of U.S. firms globalized their operations, it was due to opportunities to increase profitability while reducing operating costs. Events in the last decade have rapidly reduced the cost advantages for example, rising wages, transportation costs, industrial prices, and tariffs have all contributed to the decline in the perceived benefits of outsourcing (Wang et al., 2023). Cohen et al. (2018) noted similar attributes a couple years earlier, discovering that firms are restructuring their footprint globally. However, their data collection between 2014 and 2015 did not see the trend of reshoring, indicating that the recent trade restrictions are driving this change in attitudes, as Wang et al. (2023) mentioned.

A recent study by Moradlou et al. (2021) examining the reshoring decision-making process of UK manufacturers shows similar perceptions across Europe, suggesting that these issues are more typical all across the Western World than just being country specific. Firstly, the findings are consistent with other similar studies conducted with U.S. companies. In addition, there are some interesting notions. Firms are not only looking for cost reduction, but also performance when offshoring, such as material and labor, but also flexibility. Interestingly, one of the reasons for reshoring comes from the potentially higher price that UK customers are willing to pay for domestic products. A similar conclusion is reached by Chen et al. (2022), who found that price premiums, a higher price of domestically manufactured products, in the U.S. could be seen as a motivating factor for bringing sourcing and production back to the U.S. domestic market.

While these examinations of nearshoring and reshoring offer a range of benefits to firms that could potentially offset the problems of highly outsourced SCNs, there are other solutions that could outweigh the problems without the need to offshore or nearshore all or significant portions of SCN operations (Ray & Jenamani, 2014). These include configurations such as multi-sourcing and backup supplier arrangements, which have the potential to reduce the significance of the impact of trade escalations. One solution is to consider resilience, which could be defined as the ability of the supply chain to return to its pre-disruption state, or the ability to emerge in a new, more desirable state in the aftermath. One simple strategy would be to invest in improving visibility between buyer and supplier, which works well against contemporary disruptions such as accidents and environmental disasters. Another is back-up supplier, which would require a contract with an alternative supplier and payment in exchange for a promise to receive an agreed-upon number of supplies on demand. This can improve short-term resilience when disruptions occur (Namdar et al., 2018). The potential of diversification for resiliency comes from the idea of not depending on one source, similar to the idea in finance of not putting all eggs in one basket (Sting & Huchzermeier, 2014).

Many of the Western companies have established their base in China due to the sheer capabilities and historically low and skilled labor costs, this has led China to enjoy significant status on the global manufacturing stage (Xu et al., 2017). However, recent trade disruptions that have caused companies to consider locating closer to domestic markets have often hindered the consideration of other opportunities that Asia has to offer. For example, Vietnam has increased its potential as an alternative for sourcing and manufacturing with advantages such as location, trade agreements, and cheaper costs compared to the West (Basu & Ray, 2022). This is often referred to as a China plus one strategy, where operations are shifted to surrounding Asian countries. However, shifting to lower cost countries such as Vietnam often comes with trade-offs such as potential length, fragmentation, and lower quality of supply compared to potential cost savings (Zhang & Huang, 2012). When considering medium and low-cost sourcing options, a split procurement strategy can be employed where both sources are used simultaneously. This approach leverages the lower production costs of the low-cost source while ensuring supply chain stability by integrating a medium-cost alternative as a contingency against disruptions. As a result, this strategy does not fully capitalize on the cost benefits of the low-cost source alone but mitigates risks related to quality issues and supply interruptions (Wang et al., 2011).

Trends in supply chain optimization against tariffs can be identified from recent literature. Determining the optimal SCN configuration is challenging, as it depends on the longevity of the disruption (Kleindorfer & Saad, 2005), the level of significance (Craighead et al., 2007), and actions chosen that are subjective to the company (Terrada et al., 2023). In addition, such a drastic measure, as alternating the global presence of companies, requires the assessment of metrics as a key performance indicator (KPI) to be used in benchmarking the effectiveness. In their study, Cohen and Kouvelis (2021) revised the Triple A approach which is used to determine the attributes of the best performing SCNs of today. Originally, Triple A consisted of agility, adaptability, and alignment. After revisiting the concept to fit into new frameworks used since 2020 and beyond by introducing triple A & R, with robustness, responsiveness, and realignment. The authors argue that alignment becomes useless without the ability to realign processes and adapt models to the changing operating environment, similarly robustness and responsiveness connects to each other, as responsiveness of action taken gains the value from robustness or quality of response. Moreover, these are closely aligned with the resilience described in Namdar et al. (2018) study. Given the range of potential strategic approaches to global SCN optimization presented in the tariff and sourcing literature, in the present study we will utilize metrics inspired by aforementioned attributes from Cohen and Kouvelis (2021) refined Triple A approach and resilience, as defined by Namdar et al. (2018), when analyzing strategic changes.

3. METHODOLOGY

In this chapter, we outline the methodology employed to investigate the impact of tariffs on a multinational firm's sourcing and assembly configurations. Utilizing simulation modeling, we explore various scenarios within a controlled virtual environment, which allows for a precise examination of strategic adjustments in response to changing tariff regimes. The chapter details the use of linear programming tools to create realistic models of supply chain networks, the development and validation of these models, and the scenario analysis conducted to evaluate the effectiveness of different strategies under fluctuating tariff conditions.

3.1 Motivation

Given the uncertain and inherently political nature of tariffs and a problem as complex as determining the optimal sourcing and assembly configurations in a multinational context, simulation modeling offers a robust choice that allows to explore different sourcing and tariff scenarios in a controlled virtual environment, while mitigating the inherent uncertainties and risks associated with real experimentation and maintaining relative accuracy (Campuzano & Mula, 2011). The use of a linear programming tool (Optilogic, 2024) provides the ability to create a real-world counterpart of the SCN and different scenarios, such as increasing tariff levels and alternative sourcing and assembly configurations. Motivated by the study done by Pålsson and Sternberg (2018), we perform a Scenario Analysis based on the scenarios generated from the model.

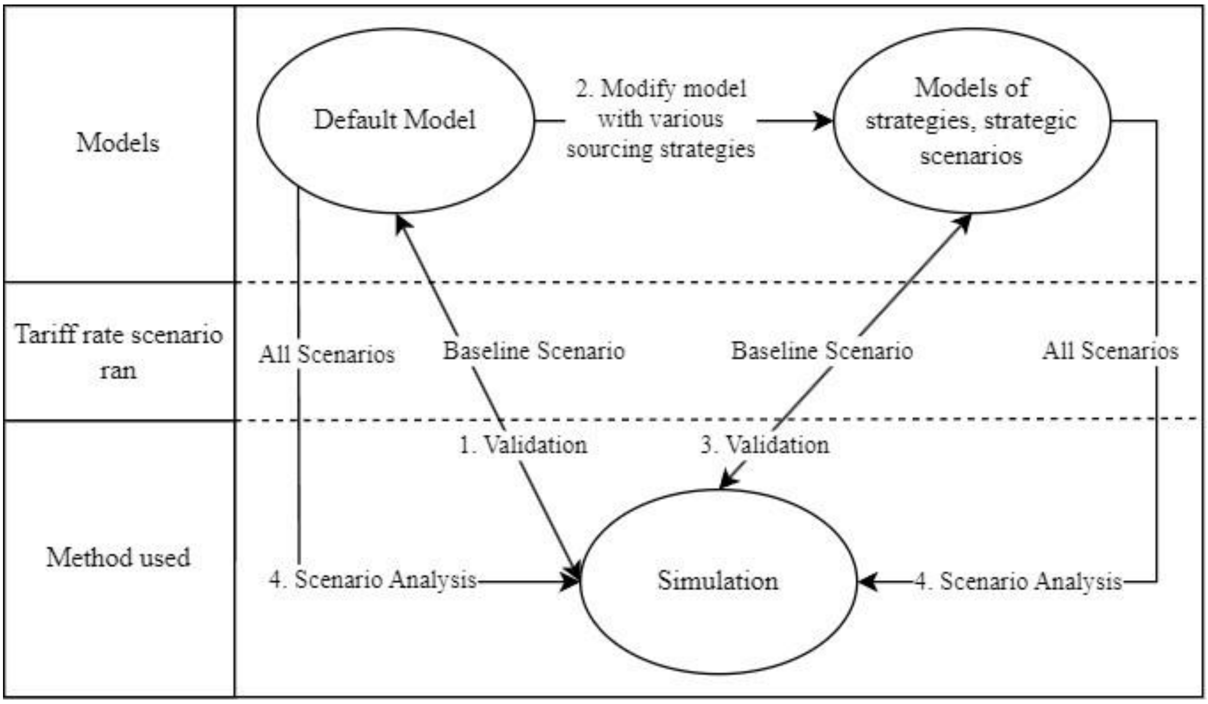
The software used to develop the model is a widely used tool across industries for operational management, decision making, and optimization of existing and new SCN alternatives of firms. However, we argue that the attributes of the modeling tool Cosmic Frog by Optilogic are highly applicable to the contemporary quantitative modeling in the SC/OM research. Thus, this study will be one of the pioneering efforts to systematically explore and substantiate the application of Cosmic Frog in this academic field. The rationale for using the tool can be derived from several of the features it offers in end-to-end supply chain modeling, such as easy implementation customer, supplier, inventory, handling cost, transportation cost, and tariff information, in addition, it is highly modifiable to fit both academic and industry purposes (Optilogic, 2024). Due to the complex nature of business operations and the potential risks associated with the implementation of untested strategies, traditional trial and error methods may not be the most adequate. In addition, the complexity of analytically testing different sourcing and assembly strategies across a spectrum of scenarios would be a significant challenge, as it would require an excessive number of mathematical calculations (Campuzano & Mula, 2011). With the use of software, these otherwise excessive calculations can be streamlined into a manageable volume.

3.2 Research design

The methodology used in this research combines a linear programming model and a scenario analysis in a case study. In complex problems, linear programming, also known as linear optimization, excels in analyzing the decision-making processes. It is a method used to identify the optimal solutions with multiple constraints (Rafei et al., 2023). Thus, when the purpose is to identify optimal configurations throughout fluctuating tariffs, within the context of a realistic supply chain it offers the advantage that most dimensions and constraints of a supply chain are possible to grasp within its framework. We ground our model in the real world and attempt to represent the nuances of global supply chain operations accurately using data from an assembly and sourcing service provider based in the U.S. The model provides the basis for evaluating the effectiveness of different sourcing and assembly configurations under varying tariff conditions.

The construction of the model, which we refer to as the Default Model, was a fundamental step of the study. Since simulation is done using linear programming when the model is constructed, we needed to ensure that the collected data provides constraints based on which the Default Model represents an optimal supply chain configuration. Following the modeling of the Default Model we validated (Figure 1- step 1) it using simulation observing the reliability of the results modifying the model accordingly if needed. After the stability and reliability of the Default Model was ensured two scenario dimensions, sourcing/assembly strategic scenarios (Figure 1- step 2) and tariff rate scenarios were designed. These several scenarios together will form the basis for simulating different supply chain configurations and conditions resembling varying levels of tariff escalations. The foundation of the strategic scenarios was identified from relevant tariff and offshoring risk mitigation literature presented in previous chapter (Chapter 2).

Figure 1. Simplified figure of our research design, with steps taken numbered in order.



We proceeded with validating (Figure 1- step 3) the reliability and stability of the scenarios and modifying them if necessary to ensure that they produce realistic results. After finalizing our scenarios, we conducted a scenario analysis (Figure 1- step 4) to evaluate how optimal these sourcing and assembly strategies are under different tariff regimes. Scenario analysis is utilized to evaluate the feasibility of outcomes (Vipond, 2023) based on selected metrics, specifically responsiveness, robustness, resiliency and economic metrics (Cohen & Kouvelis, 2021; Namdar et al., 2018). Each tariff rate scenario provides a comprehensive view of how these changes affect supply chain dynamics, representing different potential tariff environments ranging from minor adjustments to significant increases. Strategic adjustments, consisting of supplier allocations and new assembly facilities, represent the second scenario dimension.

3.3 Sample and data

This research adopted the convenience sampling method, a technique commonly used in organizational studies (Bryman, 2016). This approach is subject to criticism, due to its non-probabilistic nature and significant challenges in generalizing the findings to a broader context. However, convenience sampling has its uses, such as in exploratory studies and for testing research instruments and frameworks. It also provides use cases where the opportunity of analyzing an interesting set of data is too good to be missed (Bryman, 2016). This applies to the present study considering that the opportunity to obtain data at the scale required to conduct a micro-level analysis and thus validate the research with a real-world industry connection is rare. This is specifically true in a domain that is highly volatile in the current competitive environment, where firms are highly protective of data that could potentially expose their operations. Despite the criticisms, these serve as a rationale for adopting this sampling method.

3.3.1 Case description and data collection

The case company is a U.S.-based MNF, which provides a range of supply chain services, including assembly and contract manufacturing, that link customers and suppliers. We refer to the company as "Nexus" to protect its identity. Nexus serves customers of varying sizes, providing end-to-end solutions for those without manufacturing capabilities, but also serves as a partner of original equipment manufacturers (OEMs). It aids OEMs by operating supply chains to import and assemble parent products from child products, in other words components, which are manufactured by Nexus' suppliers and shipped to one of Nexus' facilities for assembly of the parent product, meaning the larger products compromising of child products. While largely based in the U.S., Nexus operates complex SCN facilities in Europe and has a large supplier base located in major manufacturing centers in Asia, Europe, and North and Central America.

The data was gathered from Nexus' supply chain with one U.S.-based original equipment manufacturer (OEM) as a customer and two Nexus assembly plants in the U.S. Midwest. In order to identify the independent and dependent variables, including the data required to construct the model, two separate test models were constructed using available generic data. The objective was twofold: to gain insight into the intricacies of the software and to identify the optimal data and methodology for model construction. The testing phase proved to be beneficial as it permitted the formulation of more detailed and refined data collection, which in turn facilitated the streamlining of primary data processing. In this case, our attention was focused on the initial nodes of the SCN: suppliers, transportation, and the flow of products between suppliers and assembly plants. The data collection process resulted in a significant amount of data. This consisted of order data from the sample company's two U.S. facilities, such as products, product descriptions, unit quantity, price, and sourcing location. The data represented a single customer. Therefore, we used the data in a single customer environment. In total, the raw data received consisted of more than 8500 records. After aggregation and anonymization, a primary dataset (Table 1) was created to be implemented in a Default model.

In total, we collected data on 109 products, 12 suppliers, demand (Table 1), and related costs, including unit costs, to run our linear programming model. The data collection period spanned one month, commencing in March 2024.

Table 1. Summary of collected data.

Parent Products	Child Products	Suppliers	Facilities	Customer orders	Units of Demand
81	109	12	2	847	335004

3.4 Model description

The Default Model is critical for the comparison and analysis of the value and impact of strategic changes along the selected metrics of economic nature, responsiveness, and resilience. The baseline model was built from collected and anonymized primary data to resemble a realistic import network. The Default Model (Figure 1) consists of 12 suppliers located in Europe, Asia, and North and Central America. It also includes two assembly plants and one customer located in Central U.S. From the suppliers to the assembly plants, a total of 109 different parts with individual requirements are transported. The parent product is shipped to the customer's facility after a simple assembly process of combining one or more supplied child parts.

Figure 2. Map of the Default Model.

While the focus in the later parts of the study is mostly on the upstream meaning supplier base and sourcing, it's necessary to observe the downstream, namely the assembly and customer, to understand the impact of the strategic changes made in order to mitigate tariff costs. The manufacturing costs which were implemented into the model were based on multiple factors. Firstly, we based it on the unit cost and product information given by Nexus. Furthermore, to ensure that they remain proportional to the rest of the costs, we used the data from the NBER-CES Manufacturing Industry Database, including industry specific information on manufacturing costs (Becker et al., 2021). Inventory carrying costs, including handling costs, were developed based on the information provided by the company and were also ensured to be proportional to the rest of the costs, keeping them at roughly 10% of total cost. While some costs such as capital cost and service cost were held constant throughout the strategies as they were assumed to be less impacted by the changes in the supply chain. Other costs such as storage cost, which includes handling and warehouse costs associated with the storage of the product were insured to change proportionally during the strategies (Rushton et al., 2022).

Furthermore, the purpose of the model is to approximate the most cost and time optimized configuration based on the constraints of the given data, the primary data collected from Nexus. To develop the model to be able to produce outputs that enable measuring those metrics assumptions were made in order to develop transportation time and cost within the context of the model. Based on information from Nexus we implemented the use of ocean freight with 40ft containers for routes in Europe and China and overland transportation from the suppliers to ports and ports to assembly, and routes from suppliers in Canada and Mexico to assembly. For ocean freight, the estimated transportation time and distance was based on publicly available shipping schedules and records. While for overland transportation, Google Maps was used to acquire the same information. To determine transportation costs, we used previous shipment records of the case company and generalized it for all products. In order to ensure the proportionality of transportation cost, we relied on the work of Rodrigue (2024). The choice of optimal routes was determined by the simulation model which used mixed-integer programming to do so (Optilogic, 2024).

3.5 Scenario development and analysis

In order to increase the validity and to ground the strategic and tariff scenarios we opted to identify assumptions (Table 2) and trends from the literature and the industry.

Table 2. From assumptions to scenario construction.

Assumption	***Description***	***Author***
Mexico the rising star of manufacturing.	Identified as a potential manufacturing hub amongst experts and as a lucrative nearshoring destination for U.S. markets.	Handfield et al. (2020); Johnson and Haug (2021)
Vietnam threatening Chinese dominance in manufacturing.	Steadily growing manufacturing and sourcing potential. Gradually acquiring many similar benefits to the ones of manufacturing in China three decades ago.	Basu and Ray (2022); Zhang and Huang (2012)
South Korea's attributes could potentially balance drawbacks.	South Korea's benefits stem from skilled labor force, high quality manufacturing facilities, and already established supplier of Nexus. However, in tradeoff is approx. 25% higher costs compared to China.	KPMG International (2021)
Possibilities of split procurement to mitigate tariffs.	Combining both low-cost sourcing/assembly with medium to high-cost alternatives could potentially lead cost reduction, while optimizing SCN against tariffs.	Wang et al. (2011)

To conduct comprehensive testing, several scenarios were created. Those adopted to the final testing phase can be divided into two category dimensions – strategic scenarios and tariff rate scenarios. Strategic scenarios are a set of configurations that each change how the SCN works based on the Default Model, for example reallocating supplier capacity or changing production policies depending on which strategic scenario is in question. The second dimension is tariff scenarios, which are pivotal for controlling the tariff levels impacting the Default Model and the strategic scenarios. Thus, these two category dimensions connect to each other by enabling the possibility to observe and measure how different tariff changes affect the strategic scenarios observed.

3.5.1 Strategic scenarios

Several strategic approaches were considered, with 9 eventually selected. Our choices of strategies to analyze were made using two criteria: firstly, the approach must have realistic attributes; secondly it can be constructed utilizing the dedicated software and replicated. The final selection to be constructed (Table 3) can be divided into three subcategories. The first one is scenarios, where only one new supplier is constructed with all capabilities of the Chinese suppliers reallocated to new vendor. In this context, capability refers to the ability to supply a set of products. The second subcategory encompasses scenarios where a new assembly is established, and some of the supply flows are redirected to the new assembly to accommodate the established production policy for a set of parent products. This entails the assembly of a parent products consisting of one or more supplied parts and shipping them to the U.S. and transporting them to the already established facilities to be distributed to the customer. The third subcategory includes both a new assembly and supplier, which are now established in the same country. Essentially, these scenarios combine the first and third subcategories.

Table 3. Overview of the constructed strategic scenarios.

Scenario name	*New Supplier*	*New Assembly*	*Assembly and Supplier*
MEX Strategy	X		
KOR1 Strategy	X		
KOR2 Strategy		X	
KOR3 Strategy		X	
KOR4 Strategy			X
VN1 Strategy	X		
VN2 Strategy		X	
VN3 Strategy		X	
VN4 Strategy			X

3.5.2 Construction of strategic scenarios

The **MEX** strategy is designed to allocate all of the Chinese supply from the default model to a new Mexican supplier. This strategy is expected to have two major benefits. First, it will reduce transportation time and costs. Second, it will eliminate the tariffs associated with the Chinese suppliers. The purchase price of products is assumed to be the same as in China, based on KPMG's report on manufacturing locations (KPMG International, 2021).

The **KOR1** strategy is analogous to the Mexico Scenario in that it follows the same principle: all Chinese capacity is reallocated, but, in this case, into South Korea. South Korea has added advantages that make it an attractive option. For starters, a highly skilled and capable workforce will decrease potential underlying issues with quality. Additionally, skilled labor manufacturing facilities are considered to be of high quality (KPMG International, 2021). Furthermore, Nexus has already established a foothold in South Korea, which is beneficial as it reduced some of the costs and difficulties associated with establishing new supply routes. In the KOR1 strategy, as South Korea is a developed nation, the costs of purchasing the child products are assumed to be higher than in China by 25% (KPMG International, 2021). Nevertheless, it is assumed that the elimination of tariffs could balance the cost and profitability disadvantages.

Figure 3. Map including new nodes introduced in the strategies.

One advantage of the **VN1** strategy is that Vietnam has one of the lowest operating costs in Asia (Nguyen, 2022). Additionally, it offers significant potential for offshoring, particularly in terms of labor costs and infrastructure (Basu & Ray, 2022). However, there are also trade-offs to consider. For instance, managing and scaling operations in Vietnam may be more challenging than in other countries. Furthermore, there may be issues with information sharing and communication. As an example, the scaling of manufacturing or the receival of information from suppliers may be more challenging in Vietnam than in China. However, Vietnam is also developing its capabilities outside of textile products (Kennemer, 2023). The assumption is that by taking advantage of Vietnam's purchase price which we assume to be the same as China's (KPMG

International, 2021), production capacities, and the lack of tariffs, the potential of replacing South Korean and Chinese suppliers, and streamlining Asian sourcing with lower cost while maintaining similar performance can be increased.

The **KOR2 & VN2** strategies are the first assembly strategies. In both strategies a new assembly plant is established. The new assembly assumes the production of parent products which are assembled from both Chinese and non-Chinese parts. This means that the parent parts that only have Chinese components are not assembled at the new facility. This is due to the fact that tariff laws on the country of origin are quite strict about what counts as a big enough contribution from the country that assembles the product for it to be considered to be from there (Moon, 2023). Which is important as that is partly the reason why this strategy helps avoid tariffs. In order to reduce this risk, these strategies only move the production of products that are guaranteed to get the new favorable country of origin. However, there are differences between the KOR2 and VN2 strategies. Firstly, the manufacturing and inventory carrying costs are assumed to be 88% of the U.S. in the case of South Korea and 70% in Vietnam. Secondly, while in South Korea we already have an established port in Vietnam a new port had to be added to the model.

The **KOR3 & VN3** are strategies where the newly established assembly has the capability to assemble all the parent products that have Chinese child parts. In these strategies, contrary to the KOR2 and VN2 strategies, we assume that all parent parts that have Chinese components even the ones with only Chinese components would qualify to the new country of origin. While this is a riskier strategy it might give more insight into the potential savings if a company had the power to properly optimize their operation in order to save on tariffs.

KOR4 & VN4 are the strategies with the most changes. In both these strategies a new supplier and a new assembly are established depending on which strategy, either in South Korea or in Vietnam. The new supplier will obtain the whole capacity of Chinese suppliers similarly to KOR3 and VN3 strategies, which will positively affect transportation time between supplier and assembly and simplify transportation routes from Asia. This will also eliminate concerns regarding the rule of the country of origin.

These modifications are designed to reflect on changes such as the adjusting of the geographic location of suppliers, and assemblies. The transportation routing of these strategies is then optimized using mixed-integer programming, which allows us to find the best combination of decision variables that minimizes costs while maximizing supply chain efficiency and resilience. Optimization is central to the treatment of our data, as it allows the model to suggest the most effective sourcing strategy under predefined constraints and objectives.

3.5.3 Tariff rate scenarios

The second scenario dimension consisted of multiple tariff rate scenarios. As a crucial aspect of the testing process, these scenarios served to ascertain the resilience of each strategy through the simulation of tariff increases in Europe and China. A total of 27 tariff scenarios were considered. The tariffs in the **Baseline** tariff rate scenario were developed based on the information Nexus provided us of the ordered products. Using the tariffs we determined the appropriate HS (Harmonized System) codes which in turn we used to determine the appropriate tariff rate for each product using the Harmonized Tariff Schedule (HTS) (*Harmonized Tariff Schedule*, n.d.). The exact tariff rates are shown in Appendix 1 as a percentage of the unit price, which we have determined based on the HS codes for the products if they are coming from countries in the General Tariff Category. Most of the countries in Nexus' supply chain belong to the general tariff category which means that the normal tariff rates apply to them while Canada, Mexico and South Korea are exempt thanks to the FDA's signed. The rest of the scenarios were all modifications of the Baseline tariff rate scenario.

Most of the tariff scenarios were developed to impact the Chinese suppliers and in turn the products imported from China. First, a series of scenarios were created, each representing a different percentage of tariff rate implemented by the U.S. towards imported products of Chinese origin, ranging from 0% to 25%. These were all run against all strategies to help determine the level of tariff increase required to reach the point from where the strategies are more cost efficient than the Default Model. Furthermore, a **China+25%** tariff rate scenario was run where a +25% tariff was introduced on top of the general tariff rate category in case of Chinese imports. This scenario is also an exact recreation of the tariff sanctions wagered by Donald Trump during his presidency (Fan et al., 2022). The tariff scenario **Europe+10** represents a scenario in which all European suppliers are subject to a +10% tariff rate in addition to the tariffs on countries in the general tariff category upon arrival to the United States.

Furthermore, this scenario also includes the same conditions as the China+25% scenario, meaning overall this scenario causes the largest rise in duty costs.

3.6 Validity and reliability

To validate the simulation models before testing them under different scenarios, multiple test simulations were conducted. Through observing KPIs and further metrics produced during the simulations it was ensured that the models results align with the expectations and are realistic. Additionally, the results of the models at different stages were continuously compared to ensure reliability and consistency. Furthermore, it was insured that all measurements align in the model though a dimensional consistency test (Campuzano & Mula, 2011).

3.7 Ethical considerations

Although this study does not involve respondents and is not in conflict with GDPR regulations, several measures have been taken in order to initiate good ethical practices in the conduct of the research. First, a non-disclosure agreement (NDA) was constructed and signed between us and the company in accordance with Lund University guidelines to guarantee the integrity and protection of data. This includes the appropriate and secure handling of the collected material during the research project and the permanent deletion of the material once the project is completed. Active measures to protect the integrity of the company during the research project included careful anonymization of exact locations (streets and cities), customer name, company name, detailed part and product descriptions, product costs and other attributes that could potentially cause harm to the participants' operations in the U.S. and globally. To ensure confidential handling and storage of the original data, anonymization was performed in password protected Excel spreadsheets. In addition, to ensure that the results and other information discussed in this research are in compliance with NDA agreements, we used only anonymized data in modeling software.

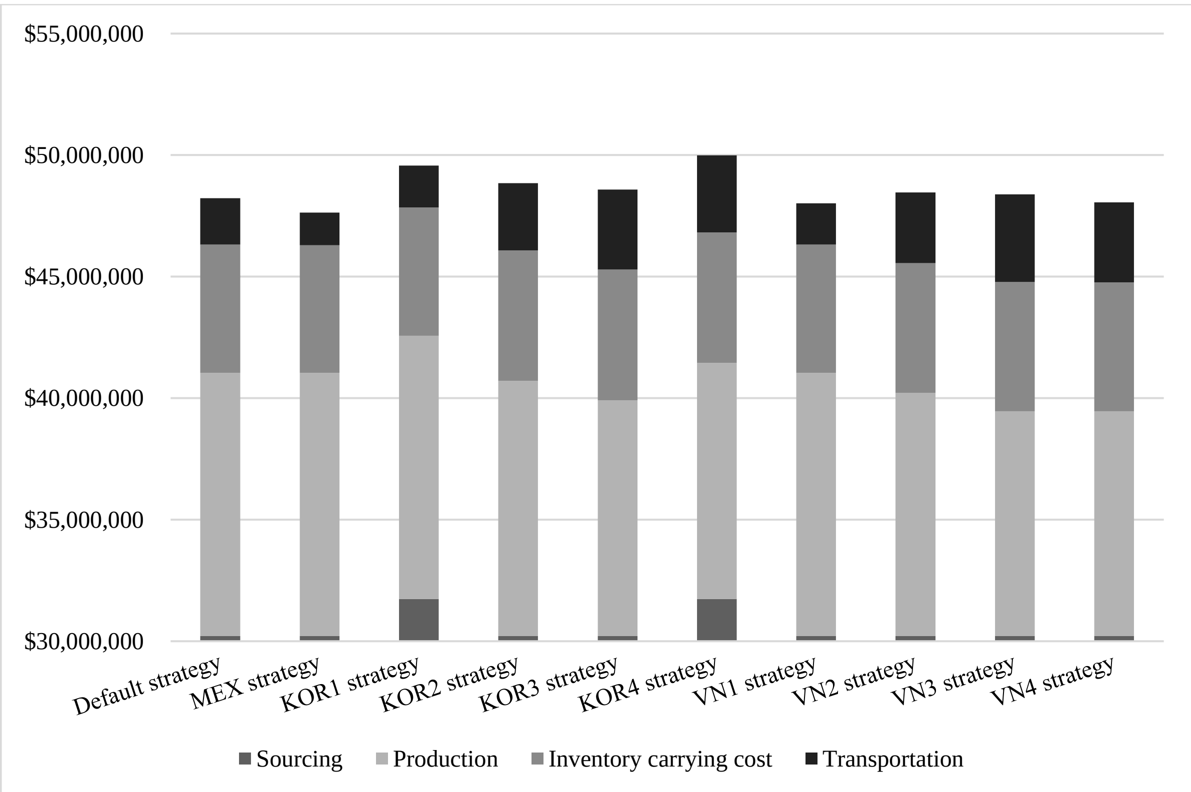
4. SIMULATION RESULTS

In the following section, we present the results of the models under different tariff rate scenarios. Our outputs include key cost data for nine strategies and the Default strategy (Default Model) under four tariff scenarios and the baseline tariff scenario. The tariff scenarios affect only the tariff cost outputs. Thus, the remaining outputs for each strategy are constant across the tariff scenarios. The exact values that are displayed in the Figures can be found in the Appendix. Figure 4 shows all of the costs associated with each strategy together, excluding the tariff costs. The tariff cost of each strategy, also referred to as duty cost, is presented in Figure 5. The percentage change in total cost compared to the Default strategy can be found in Figure 6. In Figure 7 the average transportation time spent overall throughout the supply chain per parent product can be found, which we use to measure changes in lead times. In Table 4 displays the tariff rates on Chinese products where each strategy becomes more cost efficient than the Default strategy.

4.1 Total costs

Figure 4 illustrates variations in total costs excluding tariff costs across different strategies and scenarios. A notable reduction in transportation and production costs is observed in strategies that realign supply chains closer to the market or use more cost-effective manufacturing locat-

Figure 4. Total costs excluding tariff costs.

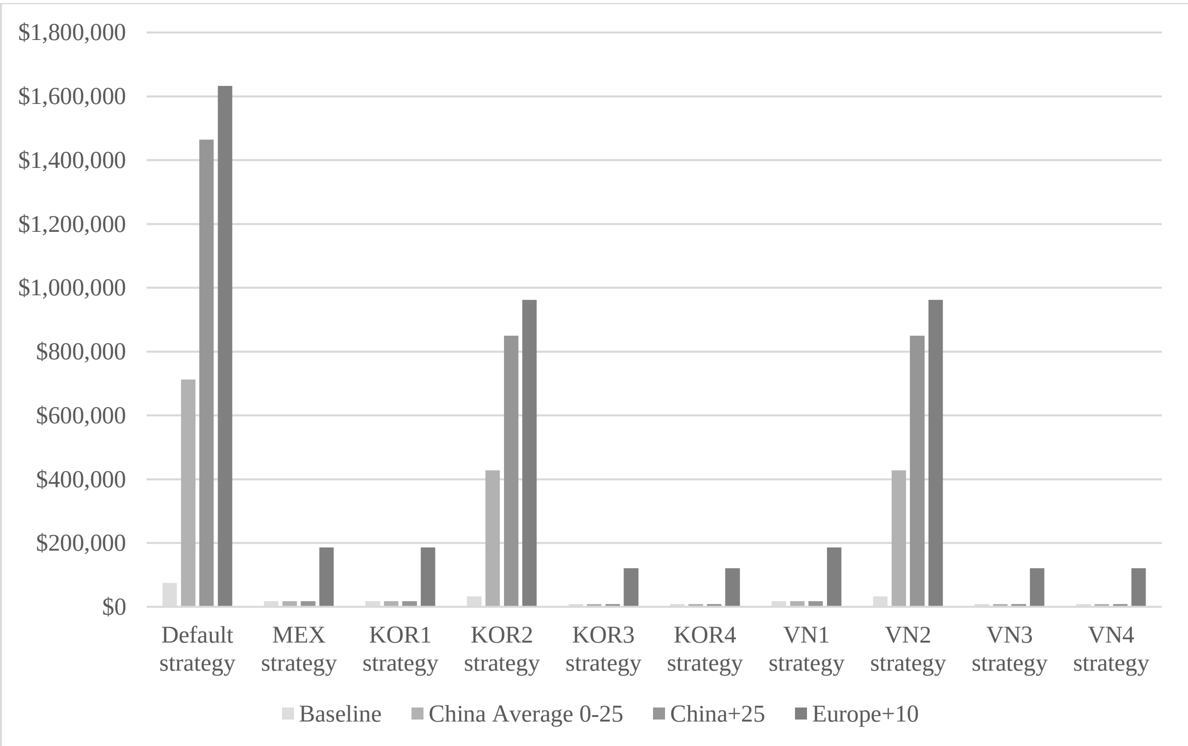


ions. For example, the Mexico (MEX) strategy shows a significant drop in transportation costs, reducing them by 30% from the Default strategy. In contrast, strategies involving South Korea (KOR2 and KOR3) and Vietnam (VN2 and VN3) highlight a blend of increased transportation costs due to longer routes but decreased production costs because of cheaper manufacturing processes. These cost dynamics underscore the complex trade-offs between different elements of supply chain costs that companies must navigate.

4.2 Tariff costs

Tariff costs, as depicted in Figure 5, vary significantly across the strategic scenarios, particularly influenced by changes in sourcing regions and tariff regimes. For instance, shifting sourcing from China to Mexico or Vietnam leads to substantial reductions in duty costs in scenarios with high tariffs on Chinese imports. The most drastic reductions are seen in the Vietnamese (VN3 and VN4) and South Korean (KOR3 and KOR4) strategies, where duty costs are almost nullified across most scenarios compared to the baseline. These reductions Compared to the Default strategy tariff costs reflect the strategic benefit of relocating production to regions with more favorable tariff conditions.

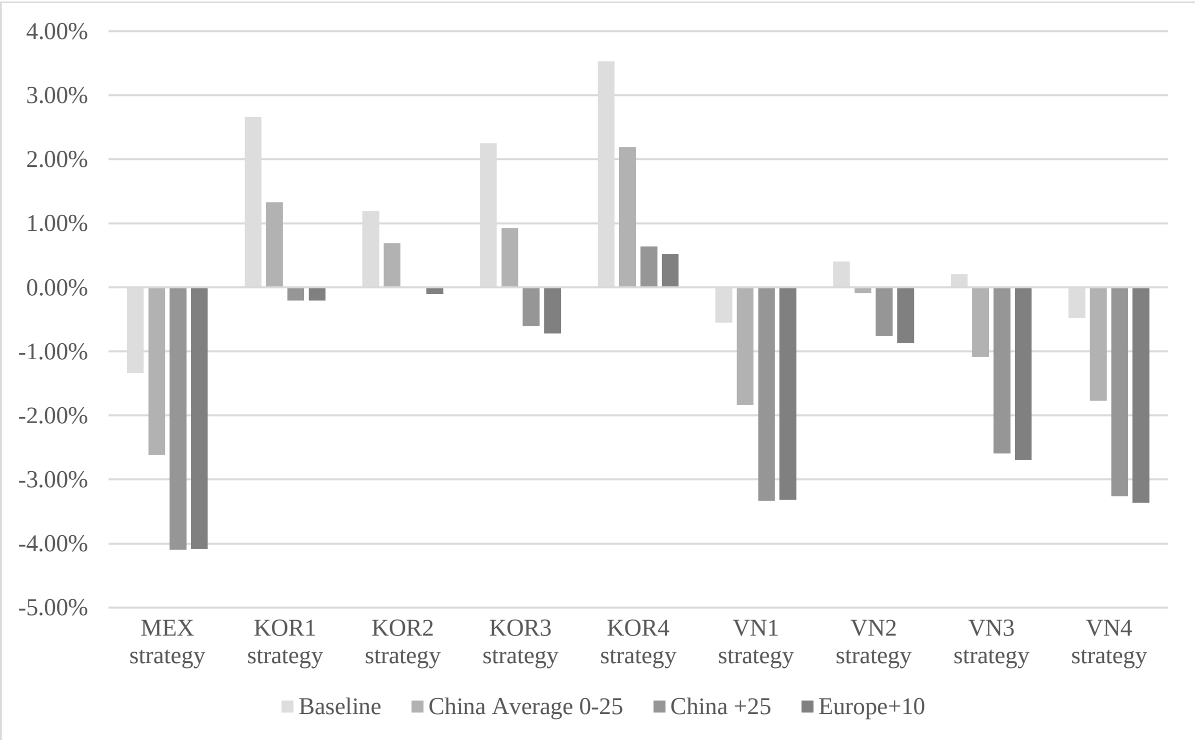
Figure 5. Tariff costs.



4.3 Change in total cost throughout scenario

Changes in total costs compared to the Default strategy are detailed in Figure 6. Each strategy offers different levels of cost efficiency, influenced by tariff rates and operational changes. The Mexican strategy yields the most significant cost savings across all tariff scenarios, highlighting its effectiveness even with lower tariffs. In contrast, more aggressive strategies like the Vietnamese VN3 and the Korean KOR3 show higher cost savings only under specific higher tariff conditions on China. These scenarios illustrate how strategic adjustments in supply chain management can leverage tariff dynamics to achieve cost savings.

Figure 6. Change in total cost compared to the Default strategy.



4.4 The turning point

Table 4. The U.S. tariff percentage on China at which the total cost of the strategy is less than the Default Model.

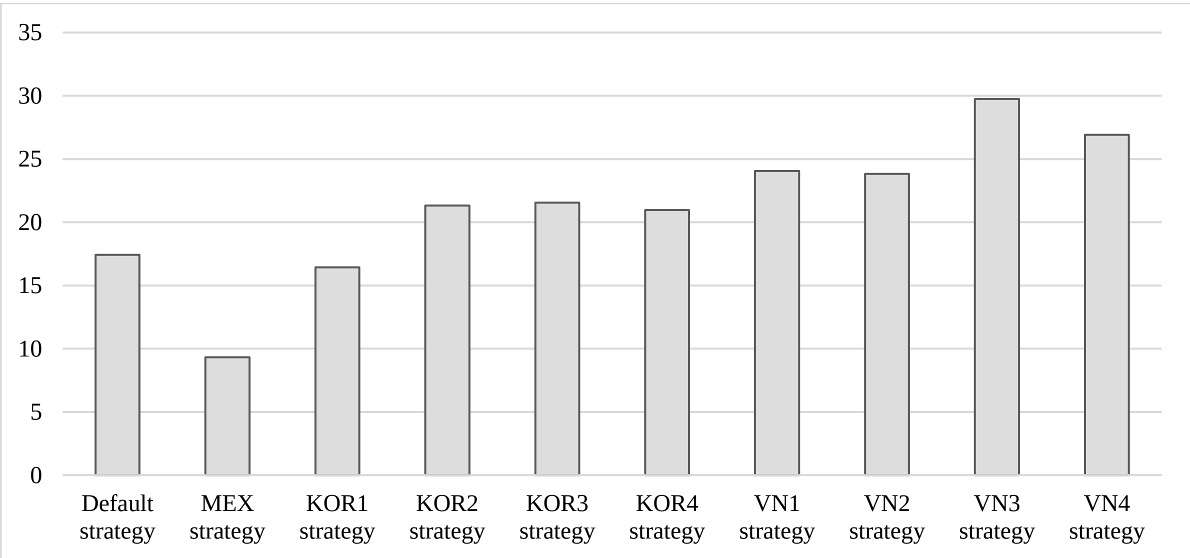
MEX strategy	KOR1 strategy	KOR2 strategy	KOR3 strategy	KOR4 strategy	VN1 strategy	VN2 strategy	VN3 strategy	VN4 strategy
0%	25%	Above 25%	21%	Above 25%	0%	11%	3%	0%

Table 4 provides a crucial financial analysis, pinpointing the tariff thresholds where alternative strategies become more cost-effective than the Default strategy. Strategies like the South

Korean KOR2 become more advantageous as U.S. tariffs on Chinese products exceed 25%, emphasizing the role of tariff rates in strategic decision-making. While, the Vietnamese strategies and the Mexican one offers a competitive edge at relatively lower tariff rates, demonstrating their potential for cost savings in various tariff scenarios. This analysis assists in understanding the strategic financial thresholds crucial for making informed sourcing decisions.

4.5 Transportation time

Figure 7. Average transportation time (in days) per parent product.



Average transportation times are critically reviewed in Figure 7, showcasing the impact of supply chain restructuring on logistics efficiency. Notably, the Mexican strategy cuts transportation time almost by half, enhancing speed to market and reducing inventory carrying costs. On the other hand, strategies involving distant sourcing locations like Vietnam (VN1 and VN3) result in significantly longer transportation times, which could affect overall supply chain agility and responsiveness. These results highlight the logistical challenges and considerations that must be balanced when designing global supply chains.

4.6 Results from the Default strategy and the strategic scenarios

The results from the Default strategy (Default model) and all the strategic scenarios.

4.6.1 Default strategy

The various cost components of the Default strategy are displayed in Figure 4, with the exception of duty costs. Figure 5 presents the variations in duty cost across different tariff scenarios during the Default strategy. Notably, in the China+25% tariff scenario, the duty constitutes 2.95% of total costs, despite only a third of the products being sourced from China. Figure 4 illustrates that the average transit time for final products and their components from supplier to customer is approximately 17 days (Figure 7).

4.6.2 MEX strategy

In the Mexico strategy, the local supplier assumes the role of sourcing products previously imported from China in order to mitigate the impact of tariffs. As illustrated in Figure 6, this transition results in a reduction of total costs, compared to the Default strategy of 4% in the China+25 and the Europe+10 scenarios. While in the case of the Baseline and China Average scenarios, a 1.34% and 2.62% fall in total cost can be seen respectively. Total cost is also reduced compared to the default model if the U.S. would have 0% tariffs on China (Table 4). Figure 4 illustrates a significant reduction in transportation costs, which decreased from the baseline's $1,905,820 to $1,335,226, representing a 30% reduction. The average transportation time is reduced to nine days per product, representing a 47% reduction (Figure 7). Additionally, inventory carrying costs are reduced by approximately $20,000, which is linked to a reduction in reliance on ports. With the exception of the European scenario, duty costs remain constant at $17,862 (Figure 5).

4.6.3 KOR1 strategy

This approach allows an existing South Korean supplier to handle the sourcing of Chinese products. As the purchase price of products in South Korea is 25% higher than in China, the overall sourcing cost is naturally higher than the Default strategy (Figure 4), while inventory carrying costs are equal. However, it reduces transportation costs by 10% to $1,717,276 (Figure 4). Duty costs are significantly reduced in all scenarios compared to the baseline (Figure 5). Even so, the overall cost is higher in the baseline and China average scenarios, with a marginal reduction of 0.21% in the other scenarios. This strategy becomes more cost efficient than the default, when the U.S. imposes a tariff rate of 25% or more on China (Table 4). Transportation times are reduced by 6% (Figure 7).

4.6.4 KOR2 strategy

In the second South Korean strategy, we tested the performance of the supply chain with a newly established assembly in South Korea. The new assembly had the capability to manufacture the parent products, which were composed of both Chinese and non-Chinese components. The most obvious difference from the baseline is the 45% increase in transportation costs ($2,756,960). Because manufacturing is 12% cheaper than in the U.S., total production costs are 3% lower (Figure 4). Duty costs are about 50% lower in each scenario (Figure 5). Total costs are only marginally cheaper in one scenario, namely the Europe+10 tariff scenario. The Strategy is 1.2% and 0.7% more expensive in the baseline and China average scenarios, respectively (Figure 6). The Chinese tariff rate, where this strategy becomes more cost efficient than the Default strategy, is above 25% outside the scope of our tested scenarios (Table 4). Transportation time (21 days) is also 22% longer than in the baseline (Figure 7).

4.6.5 KOR3 strategy

This strategy differs from the previous one by giving the capability to the South Korean assembly to also produce the parent products that are only made up of Chinese components, meaning that in this strategy all parent parts that have Chinese child parts are being assembled in South Korea, avoiding all tariffs on China. Transportation costs ($3,285,406) are 72% higher, whereas inventory carrying costs are 2% higher than the Default strategy (Figure 4). Production costs are lower than the Default strategy at $9,709,897 (Figure 4). Duty costs are also significantly lower than the Default strategy in all scenarios (Figure 5). The difference between the total cost increase in the baseline and the China average scenario and the total cost decrease in the other scenarios is high, with an over 2% increase during the baseline and the minimum of 0.6% decrease in the other scenarios (Figure 6). This Strategy promises a total cost reduction compared to the baseline if the tariffs on China reach 21% or more (Table 4). The average transportation time is 22 days using this strategy (Figure 7).

4.6.6 KOR4 strategy

The combination of strategies 1 and 3 aims to reduce transportation costs, resulting in a slightly milder increase which results in a cost of $3,178,239 (Figure 4). The average transportation time is projected to be 21 days (Figure 7). Duty and production costs follow similar trends to the other South Korean strategies. Sourcing cost ($31,736,859) is higher as the South Korean supplier is more expensive than the Chinese was. This strategy within our scope never reached a tariff rate where it would be cheaper than the Default strategy (Table 4).

4.6.7 VN1 strategy

This strategy is analogous to the Korean and Mexican strategies, wherein a supplier assumes the responsibilities typically bore by Chinese suppliers. However, as there was no prior supplier in Vietnam, a new supplier is established, and a new port is incorporated into the model. The transportation costs ($1,697,086) are 11% lower in comparison to the Default strategy. The remaining costs are identical to those of the Default strategy, with the exception of duty costs, which have been significantly reduced (Figure 5). The transportation time (44 days) is increased by 38% in comparison to the Default strategy (Figure 7). In all tariff rate scenarios, total costs are reduced in comparison to the Default strategy. In the baseline scenario, the reduction was 0.6%. In the case of the China average scenario, the reduction is 1.8%. In the remaining scenarios, the reduction in costs is 3.3% (Figure 6). Furthermore, the strategy is also lower in total costs, irrespective of what are the U.S. tariff rates on China meaning that, even at 0% tariff rate, it promises cost benefits (Table 4).

4.6.8 VN2 strategy

This strategy, similar to KOR2 strategy, establishes a new assembly, but this time in Vietnam. In a similar manner, the new assembly is responsible for the production of parent products comprising of both Chinese and non-Chinese components. Additionally, a new port is established. Transportation costs are increased by 53% compared to the Default strategy, amounting to $2,906,362. As manufacturing is 30% cheaper than in the United States, the overall production costs are 8% lower (Figure 4). In every scenario, duty costs are reduced by approximately 50% (Figure 5). In comparison to the Default strategy, total costs are reduced by less than 1% in every scenario, with the exception of the baseline scenario where they exhibited a sub 0.5% increase (Figure 6). At 11% or more tariff rate on China, the strategy becomes more cost efficient than the Default strategy (Table 4). The transportation time (24 days) exhibited an increase compared to the Default strategy by 37% (Figure 7).

4.6.9 VN3 strategy

This strategy, which builds upon the same fundamental concept as the South Korea strategy 3, allows the newly established assembly to manufacture all parent products that contain a Chinese component. Transportation costs ($3,604,700) are increased by 89% in comparison to the Default strategy. As manufacturing is 30% cheaper than in the United States, the overall production costs are 15% lower (Figure 4). In comparison to the baseline scenario, the duty costs were found to have decreased significantly in all scenarios (Figure 5). In every scenario, total costs are reduced in comparison to the Default strategy, with the exception of the baseline scenario (Figure 6). The increase in total cost in the baseline scenario is 0.21%, while the decrease in total cost in the China Average scenario is 1.09% and in the remaining scenarios it is above 2.5% (Figure 6). The flat tariff rate of 3% or more on Chinese products would provide this strategy with a cost benefit compared to the Default one (Table 4). The transportation time (30 days) exhibited a 71% increase in comparison to the Default (Figure 7).

4.6.10 VN4 strategy

This strategy combines Vietnamese strategy 1 and 3 in order to attempt to reduce the transportation costs associated with strategy 3. The transportation costs, which were previously estimated at $2,293,001, have increased by 54% compared to the Default strategy. As manufacturing is 30% cheaper than in the United States, the overall production costs are 15% lower (Figure 4). In comparison to the Default strategy, the duty costs were found to have decreased significantly in all scenarios (Figure 5). In every scenario, total costs are reduced in comparison to the Default strategy (Figure 6, Table 4). The reduction in total cost in the baseline scenario is 0.48%, while the reduction in total cost in the China average scenario is 1.77% and in the remaining scenarios it is above 3.3% (Figure 6). This strategy also provides a cost benefit if there are 0% tariffs on Chinese products. The transportation time (27 days) exhibited a 54% increase compared to the baseline (Figure 7).

5. DISCUSSION

This research serves as a framework for identifying the attributes of optimal supply chains in the contemporary era. In accordance with the insights provided by Cohen and Kouvelis (2021), we adopted the concepts of robustness, and responsiveness, which is an attribute of agility, and resiliency in accordance of Namdar et al. (2018). As operational costs are of significance when measuring tariffs and mitigation (Fan et al., 2022; Rogers et al., 2024), we included the total cost of the configurations among the used metrics. With the scenarios and appropriate metrics in mind, firstly, it is crucial to examine how configurations respond to changes in tariff levels in comparison to the default scenario. Secondly, the ability of configurations to maintain or improve default performance in the context of tariff level scenarios is to be evaluated.

A clear overarching trend in the results is that, while significant savings on tariffs can be achieved with the different strategies, it is important that the strategies do not cause a drastic increase in any of the other costs. If they do so, they must be offset by further savings in other cost categories. Increased sourcing costs are especially difficult to offset by savings on tariffs. Moreover, in the case of strategies involving a new offshore assembly, significantly increased transportation costs cannot simply be avoided due to two main factors. Firstly, the already established suppliers are often located at a greater distance. Secondly, the supplies must travel an additional distance as they not only have to reach the new assembly point, but also a facility in the United States, before being distributed to the customer. This also implies an augmented handling cost, as the products must pass through an additional number of ports and facilities before reaching the customer. Furthermore, all strategies involving a new assembly entail markedly elevated average transportation times for products, resulting in increased lead times and diminished responsiveness.

5.1 Evaluating strategies

The strategies may be classified into two categories: one based on the configuration type and the other based on the country. By examining the results, it is possible to identify which configurations are the most optimal in the supplier, assembly, and both supplier and assembly category. Nevertheless, when attempting to determine which country would be most optimal for outsourcing, it is crucial to recognize that this is a highly subjective topic that varies considerably between firms. To illustrate this, a Swedish manufacturer may not realize the same benefits by sourcing from Finland the same way a U.S. based manufacturer would by sourcing from Mexico. Similarly, a firm's global influence and size can increase its leverage over a supplier during tariff fluctuations due to the increased cost, which may result in the firm negotiating a better wholesale price. This implies that the supplier bears a portion of the tariff value (Chen et al., 2022).

5.2 Optimal configuration choices

Upon examining the supplier configurations, the MEX, KOR1, and VN1 strategies, it becomes clear that the most optimal choice is to reallocate the entire Chinese capacity to a new supplier in Mexico. This is evidenced by the assessment of supplier configurations against the Default Model and other strategic scenarios. While all three supplier configurations provide the same level of adaptation in various tariff scenarios, largely due to the fact that all configurations eliminate the use of China as a sourcing hub. As the rest of the network remains intact, the impact is identical across each strategy in each scenario where European tariffs are increased. Thus, each of the supplier configurations improved economic metrics by reducing total costs when compared to the Default model. However, due to the reduced lead times, Mexico configuration would yield improvements in responsiveness and robustness over the Default Model. As the reduced distance the supply has to travel to the assembly reduces the risks of disruption and also improves response time to fluctuating demand. Furthermore, the total cost with and without tariffs would be lower than in the other new supplier strategies. The Mexican strategy is also aligned with Handfield et al. (2020) idea that companies should strive to reduce their overly extended supply chains.

When examining the strategies employed with new assemblies and the original Chinese suppliers, namely KOR2 and 3 and VN2 and 3, it is necessary to consider the location of the assembly. Depending on the scenario, this may be carried out in South Korea or Vietnam. In the initial assembly category (KOR2 and VN2), all parent products that combine parts from both Chinese and non-Chinese suppliers are identified, and the flows are directed to the newly established Asian assembly facility. In the second assembly subcategory (KOR3 and VN3), the newly established assembly facility has been granted the authority to assemble all parent products from Chinese suppliers. A comparison of South Korea's configurations 2 and 3 with Vietnam's alternatives reveals that South Korea's costs are significantly higher. This can be attributed to the fact that Vietnam has one of the lowest operating costs in Asia (Nguyen, 2022). However, a significant drawback of the South Korea and Vietnam 3 configuration is the possibility that the rules of origin are not favorable, which may result in the parent product failing to meet the guidelines determining whether the product has undergone sufficient changes to be exempted from tariffs or, alternatively, if it will be moved to another tariff category (Moon, 2023).

The risk of failing to meet the criteria is significantly smaller in assembly configuration 2 (KOR2 and VN2), as the parent product is built only partially from parts under tariff sanctions. All strategies numbered 2, 3 and 4 promise a higher level of robustness and resilience compared the supplier strategies and the Default setup as the new assembly provides more redundancy in case of disruptions, especially tariff and trade disruptions. However, all aforementioned strategic scenarios also have the disadvantage of greatly increasing lead times, leading to reduced responsiveness. Furthermore, this aligns the notion of complexity increasing when level of diversification is increased (Craighead et al., 2007), and how this negatively affect profitability (Fan et al., 2022; Rogers et al., 2024)

A more risk-free choice in terms of the products' origin would be a final category of strategic scenarios, specifically the KOR4 and VN4. As previously mentioned, these combine the supplier and assembly strategies. Having Chinese supply capacity completely reallocated to a new supplier within the same country as the assembly has some added benefits, such as a faster flow between the supplier and the assembly. However, when the overall results are considered, it becomes evident that the KOR4 scenario is the least optimal compared to the VN4 and the default model. While it has a shorter transportation time, it cannot match the cost benefits provided by Vietnam. While a new assembly provides potential in reducing manufacturing costs and increasing robustness, our scenarios compared to the Default strategy indicate that the strategies with new suppliers are generally the cheapest and simplest ways of negating the tariffs on China, provided that the purchase price does not exceed the Chinese purchase price significantly. Among these strategies, the Mexican one stands out as the most cost-effective. However, it should be noted that not all products may be available from Mexico, which could make the assembly strategies a more universal solution for avoiding tariffs.

5.3 New location for sourcing

China has emerged as the optimal country for manufacturing and sourcing over the past several decades. Its status as the world manufacturing hub has been reinforced by a seemingly unbeatable combination of manufacturing capacity, vendors, quality, and low costs (Basu & Ray, 2022). The economic boom that China has experienced over the past decades has gradually shifted its status from a supplier for other nations to a lucrative market for domestic firms (Xu et al., 2017). This has prompted some to consider other nations, such as Vietnam, as a potential new base for sourcing and manufacturing (Zhang & Huang, 2012). While China offers a combination of potential and quality for manufacturing, U.S. firms have begun to express concern due to their reliance on Chinese suppliers (Johnson & Haug, 2021). This is largely due to the introduction of trade barriers, most notably the increase of tariffs by the United States (Dong & Kouvelis, 2020), which has resulted in a range of negative outcomes for firms, including a decline in competitive capabilities (Fan et al., 2022) and the emergence of new costs (Rogers et al., 2024). Consequently, the significance of these scenarios is to examine the potential for reducing China-related dependency while maintaining the integrity of performance.

When developing the scenarios, we expected to see prominent results with the MEX and VN1 strategies. This was largely based on previous literature where Mexico and Vietnam are considered as alternatives to Chinese sourcing (Basu & Ray, 2022; Handfield et al., 2020; Johnson & Haug, 2021) and the literature discussing reallocation due to increased costs in China (Zhang & Huang, 2012). What was not expected were the results from the VN2 scenario, where sourcing is split between China and non-Chinese suppliers and assembly is to take place in Vietnam. This was mainly due to the high transportation costs calculated. However, our initial results from VN2 shows what Wang et al. (2011) noted about the benefits of split procurement between low-cost and medium cost countries. Overall, the simulation results of the scenarios indicated that there are additional benefits to nearshoring compared to the Default Model, which is supported by past literature (Moradlou et al., 2021; Wang et al., 2023).

5.3.1 New opportunity in North America

The results of scenario simulations indicate that the benefits of nearshoring can be found within the strategy in Mexico (MEX). This corroborates the findings of Handfield et al. (2020), which identified Mexico as a promising location for nearshoring. Similarly, industry experts such as Boston Consulting Group's experts Van Wyck et al. (2023) have noted the undisputed potential of Mexico, citing its large workforce, appealing costs, and close proximity to domestic markets. Our results contribute to these findings, providing indications of how nearshoring to Mexico could benefit U.S. manufacturers by comparing scenario results to the default model. While financial and operational metrics are subject to the features of individual firms, our results provide evidence of benefits that can be achieved by a wider audience.

5.4 Alternative options

The strategies with new assemblies outside of the U.S. are constrained by elevated transportation costs, which is in part a consequence of adding a new facility to a company operation that is solely engaged in delivering to domestic customers and is otherwise ill-prepared for a new assembly outside of the U.S. Nevertheless, the potential for reduced total cost in all tariff scenarios, except for the sub-0.5% increase in the baseline tariff scenario, suggests that, if the company was structured to facilitate an offshore assembly, there could be significant benefits with no fiscal downsides. This restructuring would require suppliers to be more optimally located, for example by having more suppliers from Southeast Asia, to supply the assembly in Vietnam. A change like this could reduce transportation costs and transportation time and, in turn, lead times. Moreover, if the case company had non-domestic suppliers, unlike the current model we analyzed solely involving domestic sources, the savings could be even more substantial compared to the Default strategy, as transportation costs would not likely increase by such a high margin. A setup like this could both negate most tariff-induced costs and have a lower overall total cost, even in conditions similar to the baseline tariff scenario due to the lower manufacturing costs (KPMG International, 2021).

The potential viability of these strategies suggests that imposing tariffs might inadvertently produce effects contrary to lawmakers' intentions, which are aimed at protecting domestic manufacturers. Offshoring assembly operations could not only offer the benefit of avoiding tariffs on products from China, but it could also lower production costs through reduced labor, rental, and other manufacturing-related expenses. Additionally, the improving quality of products from emerging markets could be a further disadvantage to domestic manufacturers in the Us, offering little competitive advantage in maintaining production domestically. These conclusions are also supported by previous studies on tariffs effects on domestic manufacturers (Chen et al., 2022; Nagurney et al., 2019).

Being reflexive about our choices, it is crucial to acknowledge that our analysis omitted certain elements that could significantly impact the economic viability of implementing the discussed strategies. First, the establishment of new facilities and assembly lines entails substantial costs and investments. Therefore, if a company opts to pursue any offshoring strategy, it is essential to ensure that such choice is likely to yield long-term savings that would offset the considerable initial expenses. Second, although Vietnam offers the allure of low-cost manufacturing, it also presents additional risks and potential unforeseen expenses that are less prevalent in the U.S.

These challenges are primarily related to the quality of infrastructure and labor, as well as everyday business operations (KPMG International, 2021).

5.5 Practical implications

Our analysis, while insightful, comes with certain limitations, primarily due to restricted access to detailed and comprehensive data about the company's operations. In an ideal scenario, companies themselves could adopt a similar analytical approach, leveraging their internal data to produce a more precise and detailed model to help identify the optimal way to manage tariff risks. With unrestricted access to their operational metrics, these companies can incorporate highly specific data points that are not available to external analysts. This would enable them to refine their strategies with a higher degree of accuracy. By integrating a broader range of metrics, such as quality, sustainability, reliability, and agility, into their strategic models, companies can gain a more holistic view of their operations. Quality metrics can improve product reliability and enhance brand reputation, while sustainability measures align with environmental goals and regulations, boosting consumer appeal and compliance (Delipinar & Kocaoglu, 2016).

Reliability metrics enhance the consistency of operations, reducing disruptions, and agility metrics allow for rapid adaptation to market changes or supply chain issues. Incorporating these diverse dimensions enables companies to not only optimize costs but also to build a more resilient and adaptable business framework, ultimately supporting long-term success. Additionally, given their deep understanding of internal processes and long-term objectives, companies are well-positioned to develop more sophisticated and targeted strategies. This capability allows them to align operational changes with their broader corporate goals effectively, ensuring that each strategic adjustment not only addresses immediate challenges like tariff risks but also supports their overarching business ambitions. By integrating these insights into their strategic planning, companies can craft nuanced approaches that are finely tuned to their unique operational contexts and future aspirations.

6. CONCLUSION

6.1 Findings

This study examined several supplier and assembly strategies that deviated from the default model. The objective was to test how global supply chain operational performance is affected by tariff rate fluctuations. To test this hypothesis, we created nine strategic scenarios based on relevant literature to alter the default configuration. Additionally, we created 27 tariff rate scenarios to simulate tariff escalations, which allowed us to observe how operational performance was affected in both the default model and the strategic scenarios. While the results indicate that significant tariff savings are achievable with the strategies, it is found that the other costs can outweigh the assumed benefits of tariff avoidance. This requires companies to look at other cost elements to optimize their cost. We found that increased sourcing expenses are particularly difficult to offset by the savings from avoided tariffs.

Testing the strategic scenarios with different tariff rates yielded several key findings. We found that three strategic scenarios, including supplier and supplier/assembly strategies, out of nine tested, were cheaper than the default model even at 0% tariffs. These were the Mexican strategy (MEX) and the Vietnamese strategies with a Vietnamese supplier (VN1 and VN4). Further analysis shows that, of the strategies tested, Mexico stands out as the most optimal, due to the 30 % reduction in transportation costs and almost 50% reduction in transportation time. This is consistent with the findings of Johnson and Haug (2021), who noted the potential of Mexico, and Handfield et al. (2020), who also discussed the benefits of nearshoring. Similar benefits can be seen with the VN1 supplier strategy, as transportation costs are 11% lower compared to the standard model. VN1 would increase transportation time by almost 40%, but similar to Mexico, supplier cost benefits are already seen at 0% level. The supplier and assembly strategy VN4 are interesting, as transportation cost is found to be increased 54% compared to default model. However, as manufacturing cost was found to be 30% lower compared to the U.S. (KPMG International, 2021), it reduces overall production costs by 15%.

While MEX strategy provides the most optimal alternative to default model, it is largely due to the attributes of case firm's SC, with downstream chain directed towards U.S. Thus, the geographical location of Mexico provides benefit with its close proximity to assembly and customer. This finding indicates that when downstream SC is directed to U.S., it would be beneficial for firm to obtain supplies from Mexico. However, the benefits provided by Vietnam should not be underestimated. Against the Default Model, VN1 and VN4 didn't provide as strong benefits as the Mexican strategy, but results indicate that this is largely due the long distances between U.S. and Vietnam. Thus, in cases where the firm has a global customer base, extending to markets outside of North America to places such as Europe and Asia, the VN1 and VN4 strategies would hold higher profitability.

6.2 Contributions

This study provides several contributions to both SC/OM domain as well as the industry.

6.2.1 Contributions to existing literature

As reiterated at the beginning, this study contributes to two ever-growing branches of literature in the SC/OM discipline. First, the tariff research, which has gained popularity after the recent trade war that shook the trade balance (Feng et al., 2022). Another branch is the sourcing and manufacturing literature, which focuses on the mitigation of disruption risk in sourcing. Tariff research has recently focused on assessing the US-China trade war, with constant contributions to understanding its impact on firms, and just this year Rogers et al. (2024) shared their insights on how the trade war affected the operations of US firms. However, while the SC/OM community is beginning to understand how tariffs affect firms, this study takes an exploratory approach and contributes by evaluating the many strategic trends to mitigate tariffs. Thus, the contribution to tariff research stems from the framework that considers preparing for future tariff escalations by identifying the optimal strategies. At last, this study introduces a new modeling framework as a tool to study diversification and reallocation against disruption risk, as well as a new way to study past disasters to potentially make new discoveries for future risk management, contributing to the literature on sourcing and manufacturing risk management.

6.2.2 Practical contributions

Our analysis suggests that firms need to cautiously evaluate the decision to reconfigure supply chains for the primary purpose of circumventing tariff costs. The potential savings gathered from reduced tariff expenditures can be negated by supplementary costs incurred if the reconfiguration does not seamlessly integrate with the firm's existing supply chain operations. Moreover, if the supply chain lacks the necessary flexibility to adapt to new configurations, the costs can escalate, diminishing the financial benefits intended by such strategic shifts. Additionally, our findings underline the relative simplicity of calculating tariff costs for firms under various scenarios. This straightforward simulation process with modern modelling software allows firms to readily assess potential increases in costs across numerous tariff situations. Consequently, with access to reliable forecasts concerning the likelihood of future tariff alterations, firms are equipped to evaluate the risk associated with additional costs in both their current supply chain setup and any proposed strategic changes.

6.3 Limitations

Our study provides insights into tariff mitigation strategies based on the data and specific circumstances of a single firm, Nexus. The findings, while revealing much about the viability of possible strategies to mitigate tariff costs, are not universally applicable across the industry. This limitation is primarily due to the singular case study approach, which does not encompass the diverse operational, financial, and market contexts present in other firms within the industry. Therefore, while the results provide valuable perspectives on the effectiveness of tariff cost mitigation strategies within this particular organizational context, extrapolating these findings to other firms should be approached with caution. In addition, the need to make certain assumptions to fill gaps in the available data means that while our results are informative about the overall trends and relationships between various costs and metrics within the strategies. The assumptions, while based on reasonable estimates, introduce an element of uncertainty that potentially reduces the precision of our analytical results. The results should therefore be interpreted with an understanding of this underlying imprecision.

Additionally, our investigation was constrained to the production activities at only two of the firms' facilities. This limited scope restricts our study's conclusions to these specific segments of the company's operations and does not reflect the broader operational dynamics that may prevail across the entire organization. This partial view further limits the generalizability of our results, emphasizing the need for a more comprehensive analysis to fully understand the implications of tariff mitigation strategies across all facets of the firm. These limitations emphasize the importance of extending research to multiple firms and incorporating a more comprehensive dataset to enhance the robustness and applicability of the findings. Future studies should aim to simulate the full spectrum of company operations and integrate broader industry data to overcome these constraints and provide more definitive insights into the effectiveness of tariff mitigation strategies.

6.4 Future research

Being an explorative study and one of the first to use Cosmic Frog (Optilogic, 2024), we consider several future research directions for which this study serves as a basis. First, extending a similar study with European companies, constructing a comparative study to observe how the presented strategic scenarios would play out when the downstream is towards Europe. In particular, a comparative study between European and U.S. companies using our framework of modelling would be interesting and provide more insights how tariffs and mitigation shape different companies following similar strategies. Currently, the majority of literature, including our own work, focuses on trade disruptions between the U.S. and China. Consequently, questions such as how European firms can mitigate trade policy disruptions and how European firms could potentially benefit if trade tensions between the U.S. and China escalate again are particularly interesting. Furthermore, the European Union and the benefits it offers to firms located within, provides an interesting perspective on the study of trade to and from the EU.

Second, our framework for modeling complex challenges using a linear programming software can be extended to several other studies in SC/OM research. We see the benefits of Optilogic in various studies of decision making, inventory, and transportation optimization. A particularly interesting approach would be to study complex decision making in operations management using mixed methods such as interviews and modeling. Quantifying decision processes under different scenarios using Optilogic would provide an insightful and interesting take to conventional research methods. As there are several other interpretations that can be made from Optilogic in the field of SC/OM research, we hope that our research and framework will inspire future researchers to use Optilogic and other unconventional methods in their expeditions into future challenges and problems of supply chain operations.

6.5 Final remarks

This research makes an important contribution by considering both operational costs and performance when mitigating the impact of escalated tariffs. Grounding the research by basing it on a real company strengthened the contribution by providing the opportunity to build a default model from actual operational data. This brought a practical aspect in advancing knowledge in the field by contributing to the strategic discourse of tariffs and optimal mitigation. Making this contribution has been both challenging and rewarding. The initial challenge came from entering the field of supply chain management modeling, a field that we as graduate students were just beginning to grasp. Due to the scarcity of relevant literature surrounding the supply chain modeling tool, a great deal of trial-and-error testing of software with generic data was required before a breakthrough could be made. However, the experience and study of modeling was rewarding as it allowed us to delve into this new methodology, a prominent and interesting approach to studying phenomenon in the field.

LIST OF REFERENCES

Anupindi, R., & Akella, R. (1993). Diversification under Supply Uncertainty. *Management Science*, *39*(8), 944-963. https://doi.org/10.1007/978-1-84628-607-0_15

Basu, P., & Ray, P. (2022). China-plus-one: expanding global value chains. *Journal of Business Strategy*, *43*(6), 350-356. https://doi.org/10.1108/JBS-04-2021-0066

Becker, R. A., Wayne B. Gray, & Marvakov, J. (2021). *NBER-CES Manufacturing Industry Database (1958-2018, version 2021a).* https://www.nber.org/research/data/nber-ces-manufacturing-industry-database

Bendoly, E., Boyer, K., Craig, N., & Paul, S. (2022). Pulled in opposite directions: A joint consideration of supply and demand uncertainty in supply chain decision-making. *Journal of Business Logistics*, *43*(4), 448-471. https://doi.org/10.1111/jbl.12315

Benedicto, I. (2023). Why Apple Is Manufacturing The iPhone 15 In India. *Forbes*. https://www.forbes.com/sites/katyasoldak/2024/03/22/friday-march-22-russias-war-on-ukraine-news-and-information-from-ukraine/?sh=700dd57d5c82

Birge, J. R., Capponi, A., & Chen, P.-C. (2023). Disruption and Rerouting in Supply Chain Networks. *Operations Research*, *71*(2), 750-767. https://doi.org/10.1287/opre.2022.2409

Bown, C. P. (2022). *US imports of some Chinese products have tanked. Others are higher than ever. Trump's selective trade war continues to matter.* Peterson Institute For International Economics. https://www.piie.com/blogs/realtime-economics/four-years-trade-war-are-us-and-china-decoupling

Bown, C. P., & Kolb, M. (2023). Trump´s Trade War Timeline: An Up-to-Date Guide. https://www.piie.com/blogs/trade-and-investment-policy-watch/2018/trumps-trade-war-timeline-date-guide

Bryan, B. (2018). Trump's trade war is starting to whack car companies like Ford, Honda, and BMW. *Business Insider*. https://www.businessinsider.com/trump-tariff-china-trade-war-ford-bmw-automakers-pain-2018-9

Bryman, A. (2016). Social research methods (Fifth edition). Oxford University Press.

Burke, G. J., Carrillo, J. E., & Vakharia, A. J. (2007). Single versus multiple supplier sourcing strategies. *European Journal of Operational Research*, *182*(1), 95-112. https://doi.org/10.1016/j.ejor.2006.07.007

Campuzano, F., & Mula, J. (2011). *Supply chain simulation: A system dynamics Approach for Improving Performance*. Springer Science & Business Media.

Chakkol, M., Johnson, M., Karatzas, A., Papadopoulos, G., & Korfiatis, N. (2023). Making supply chains great again: examining structural changes to US manufacturing supply chains. *International Journal of Operations & Production Management*. https://doi.org/10.1108/IJOPM-12-2022-0783

Chaturvedi, A., & Martínez-de-Albéniz, V. (2011). Optimal Procurement Design in the Presence of Supply Risk. *Manufacturing & Service Operations Management*, *13*(2), 227-243. https://doi.org/10.1287/msom.1100.0319

Chaturvedi, A., & Martínez-de-Albéniz, V. (2016). Safety Stock, Excess Capacity or Diversification: Trade-Offs under Supply and Demand Uncertainty. *Production & Operations Management*, *25*(1), 77-95. https://doi.org/10.1111/poms.12406

Chen, D., Hu, N., Liang, P., & Swink, M. (2023). Understanding the impact of trade policy effect uncertainty on firm-level innovation investment. *Journal of Operations Management*. https://doi.org/10.1002/joom.1285

Chen, K., Wang, X., Niu, B., & Chen, Y. J. (2022). The impact of tariffs and price premiums of locally manufactured products on global manufacturers' sourcing strategies. *Production and Operations Management*, *31*(9), 3474-3490. https://doi.org/10.1111/poms.13774

Chi, C., & Mei-Chen, C. (2024). Effect of Sustainable Supply Chain Management on Procurement Environmental Performance: A Perspective on Resource Dependence Theory [article]. *Sustainability*, *16*(2), 586-586. https://doi.org/10.3390/su16020586

Cohen, M. A., & Kouvelis, P. (2021). Revisit of AAA excellence of global value chains: robustness, resilience, and realignment. *Production and Operations Management*, *30*(3), 633-643. https://doi.org/10.1111/poms.13305

Cohen, M. A., & Lee, H. L. (2020). Designing the Right Global Supply Chain Network. *Manufacturing & Service Operations Management*, *22*(1), 15-24. https://doi.org/10.1287/msom.2019.0839

Cohen, M. A., Shiliang, C., Ernst, R., Huchzermeier, A., Kouvelis, P., Lee, H. L., Hirofumi, M., Steuber, M., & Tsay, A. A. (2018). Benchmarking Global Production Sourcing Decisions: Where and Why Firms Offshore and Reshore. *Manufacturing & Service Operations Management*, *20*(3), 389-402. https://doi.org/10.1287/msom.2017.0666

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., & Handfield, R. B. (2007). The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities. *Decision Sciences*, *38*(1), 131-156. https://doi.org/https://doi.org/10.1111/j.1540-5915.2007.00151.x

Darby, J. L., Ketchen, D. J., Williams, B. D., & Tokar, T. (2020). The Implications of Firm-Specific Policy Risk, Policy Uncertainty, and Industry Factors for Inventory: A Resource Dependence Perspective. *Journal of Supply Chain Management*, *56*(4), 3-24. https://doi.org/10.1111/jscm.12229

Delipinar, G. E., & Kocaoglu, B. (2016). Using SCOR Model to Gain Competitive Advantage: A Literature Review. *Procedia - Social and Behavioral Sciences*, *229*, 398-406. https://doi.org/10.1016/j.sbspro.2016.07.150

Dent, C. M. (2020). Brexit, Trump and Trade: Back to a Late 19th Century Future? *Competition and Change*, *24*(3-4), 338-357. https://doi.org/10.1177/1024529420921481

Dong, L., & Kouvelis, P. (2020). Impact of Tariffs on Global Supply Chain Network Configuration: Models, Predictions, and Future Research. *Manufacturing & Service Operations Management*, *22*(1), 25-35. https://doi.org/10.1287/msom.2019.0802

Fan, D., Zhou, Y., Yeung, A. C. L., Lo, C. K. Y., & Tang, C. (2022). Impact of the U.S.–China trade war on the operating performance of U.S. firms: The role of outsourcing and supply base complexity. *Journal of Operations Management*, *68*(8), 928-962. https://doi.org/10.1002/joom.1225

Feng, P., Zhou, X., Zhang, D., Chen, Z., & Wang, S. (2022). The impact of trade policy on global supply chain network equilibrium: A new perspective of product-market chain competition. *Omega*, *109*. https://doi.org/10.1016/j.omega.2022.102612

Goulard, S. (2020). The Impact of the US-China Trade War on the European Union. *Global Journal of Emerging Market Economies*, *12*(1), 56-68. https://doi.org/10.1177/0974910119896642

Graziano, A., Handley, K., & Limão, N. (2023). Brexit inflation: The role of trade policy uncertainty in increasing UK import prices. *Vox EU*. https://cepr.org/voxeu/columns/brexit-inflation-role-trade-policy-uncertainty-increasing-uk-import-prices

Handfield, R. B., Graham, G., & Burns, L. (2020). Corona virus, tariffs, trade wars and supply chain evolutionary design. *International Journal of Operations & Production Management*, *40*(10), 1649-1660. https://doi.org/10.1108/ijopm-03-2020-0171

Harmonized tariff schedule. (n.d.). Harmonized Tariff Schedule. https://hts.usitc.gov/

Hass, R., & Denmark, A. (2020). *More pain than gain: How the US-China trade war hurt America*. https://www.brookings.edu/articles/more-pain-than-gain-how-the-us-china-trade-war-hurt-america/

Hessels, J., & Terjesen, S. (2010). Resource Dependency and Institutional Theory Perspectives on Direct and Indirect Export Choices. *Small Business Economics*, *34*(2), 203-220. https://doi.org/10.1007/s11187-008-9156-4

Hezarkhani, B., Arisian, S., & Mansouri, A. (2023). Global agricultural supply chains under tariff-rate quotas. *Production and Operations Management*, *32*(11), 3634-3649. https://doi.org/10.1111/poms.14054

Hughes, M. M., Zhou, Z., Zinn, W., & Knemeyer, A. M. (2022). Plastic response to disruptions: Significant redesign of supply chains. *Journal of Business Logistics*, *44*(1), 80-108. https://doi.org/10.1111/jbl.12321

Jadidi, O., Firouzi, F., Loucks, J. S., & Park, Y. S. (2022). Multi-criteria Supplier Selection Problem with Fuzzy Demand: A Newsvendor Model. *Computational Management Science*, *19*(3), 375-394. https://doi.org/10.1007/s10287-021-00420-w

Jiang, H., Luo, Y., Xia, J., Hitt, M., & Shen, J. (2023). Resource dependence theory in international business: Progress and prospects. *Global Strategy Journal*, *13*(1), 3-57. https://doi.org/10.1002/gsj.1467

Jiao, Y., Liu, Z., Tian, Z., & Wang, X. (2022). The Impacts of the U.S. Trade War on Chinese Exporters. *The Review of Economics and Statistics*, 1-34. https://doi.org/10.1162/rest_a_01229

Johnson, J., & Haug, P. (2021). Modifications to global supply chain management strategies resulting from recent trade disruptions: an exploratory study. *Journal of Global Operations and Strategic Sourcing*, *14*, 701-722. https://doi.org/10.1108/JGOSS-12-2020-0074

Kennemer, J. (2023). Vietnam Vs. China For Product Sourcing // Complete Guide. https://www.cosmosourcing.com/blog/challenges-sourcing-from-vietnam

Kleindorfer, P. R., & Saad, G. H. (2005). Managing Disruption Risks in Supply Chains. *Production and Operations Management*, *14*(1), 53-68. https://doi.org/https://doi.org/10.1111/j.1937-5956.2005.tb00009.x

KPMG International. (2021). *Where to manufacture? Global analysis of the cost of doing business*. KPMG International. https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2021/06/where-to-manufacture.pdf

Lampel, J., & Giachetti, C. (2013). International diversification of manufacturing operations: Performance implications and moderating forces. *Journal of Operations Management*, *31*(4), 213-227. https://doi.org/10.1016/j.jom.2013.04.001

Lindner, J. (2023). *US Companies In China Statistics [Fresh Research]*. Business Statistics, Issue. https://gitnux.org/us-companies-in-china-statistics/

Moon, B. E. (2023). *rules of origin*. Britannica Money. https://www.britannica.com/money/rules-of-origin

Moradlou, H., Fratocchi, L., Skipworth, H., & Ghadge, D. A. (2021). Post-Brexit back-shoring strategies: What UK manufacturing companies could learn from the past? *Production Planning and Control*, *33*. https://doi.org/10.1080/09537287.2020.1863500

Nagurney, A., Besik, D., & Li, D. (2019). Strict quotas or tariffs? Implications for product quality and consumer welfare in differentiated product supply chains. *Transportation Research Part E: Logistics and Transportation Review*, *129*, 136-161. https://doi.org/10.1016/j.tre.2019.07.008

Namdar, J., Li, X., Sawhney, R., & Pradhan, N. (2018). Supply chain resilience for single and multiple sourcing in the presence of disruption risks. *International Journal of Production Research*, *56*(6), 2339-2360. https://doi.org/10.1080/00207543.2017.1370149

Nguyen, D. (2022). Vietnam operating costs among Asia's lowest: report. *VNExpress*. https://e.vnexpress.net/news/business/data-speaks/vietnam-operating-costs-among-asia-s-lowest-report-4414957.html

Optilogic. (2024). *A Better Way to Design Your Supply Chain*. Optilogic.com. https://www.optilogic.com/

Pålsson, H., & Sternberg, H. (2018). LRN 2016 SPECIAL – high capacity vehicles and modal shift from rail to road: combining macro and micro analyses. *International Journal of Logistics Research and Applications*, *21*(2), 115-132. https://doi.org/10.1080/13675567.2018.1430232

Prataviera, L. B., Norrman, A., & Melacini, M. (2022). Global distribution network design: exploration of facility location driven by tax considerations and related cross-country implications. *International Journal of Logistics Research and Applications*, *25*(7), 1067-1090. https://doi.org/10.1080/13675567.2020.1869192

Rafei, A., Danehkar, A., & Goodarzi, M. S. (2023). Linear programming the Ramsar convention's criterion IV (case study: Shadegan Wetland, West Asia). *Environmental Monitoring and Assessment: An International Journal Devoted to Progress in the Use of Monitoring Data in Assessing Environmental Risks to Humans and the Environment*, *195*(10). https://doi.org/10.1007/s10661-023-11809-2

Ray, P., & Jenamani, M. (2014). Sourcing decision with correlated supplier disruption: An MV framework. In *2014 IEEE International Conference on Industrial Engineering and Engineering Management, Industrial Engineering and Engineering Management (IEEM), 2014 IEEE International Conference on* (pp. 868-871): IEEE.

Reiff, N. (2019). *The Top 3 Industries Affected by the Trade War With China*. Investopedia. https://www.investopedia.com/industries-most-likely-to-be-impacted-by-trade-disputes-with-china-in-2019-4580508

Rodrigue, J.-P. (2024). *The geography of transport systems* ([Sixth edition]. ed.). Routledge. https://doi.org/10.4324/9781003343196

Rogers, Z. S., Golara, S., Abdulsalam, Y., & Rogers, D. S. (2024). Protect me not: The effect of tariffs on U.S. supply networks. *Journal of Purchasing and Supply Management*. https://doi.org/10.1016/j.pursup.2024.100897

Rushton, A., Croucher, P., & Baker, P. (2022). *The handbook of logistics and distribution management : understanding the supply chain* (Seventh edition. ed.). Kogan Page.

Sting, F. J., & Huchzermeier, A. (2014). Operational Hedging and Diversification under Correlated Supply and Demand Uncertainty. *Production & Operations Management*, *23*(7), 1212-1226. https://doi.org/10.1111/poms.12196

Sutton, T., Devine, R. A., Lamont, B. T., & Holmes, R. M. (2021). Resource Dependence, Uncertainty, and the Allocation of Corporate Political Activity across Multiple Jurisdictions. *Academy of Management Journal*, *64*(1), 38-62. https://doi.org/10.5465/amj.2017.1258

Terrada, L., El Khaili, M., Elasri, B., Ouajji, H., & Zamma, A. (2023). Conceptualization and Configuration of a Generic SCM 4.0 Business Process Model Using BPMN Based on SCOR. In *2023 3rd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET), Innovative Research in Applied Science, Engineering and Technology (IRASET), 2023 3rd International Conference on* (pp. 1-7): IEEE.

Van Wyck, J., Phillips, K., Gilbert, M., McAdoo, M., Xue, H., Srivastava, R., Kuhlmann, K., & Xu, G. (2023). Harnessing the Tectonic Shifts in Global Manufacturing. https://www.bcg.com/publications/2023/harnessing-tectonic-global-shift-in-manufacturing

Vipond, T. (2023). *Scenario analysis*. https://corporatefinanceinstitute.com/resources/financial-modeling/scenario-analysis/

Wang, Y., Gilland, W., & Tomlin, B. (2011). Regulatory Trade Risk and Supply Chain Strategy. *Production and Operations Management*, *20*(4), 522-540. https://doi.org/10.1111/j.1937-5956.2010.01167.x

Wang, Z., Cheng, F., Chen, J., & Yao, D.-Q. (2023). Offshoring or reshoring: the impact of tax regulations on operations strategies. *Annals of Operations Research*, 1-23. https://doi.org/10.1007/s10479-023-05346-x

Wong, S.-L. (2018). Many U.S. firms in China eyeing relocation as trade war bites: survey. *Reuters*. https://www.reuters.com/article/idUSKCN1N30ZA/

Xie, L., Liu, Y., Han, H., & Qiu, C. (2023). Outsourcing or reshoring? A manufacturer's sourcing strategy in the presence of government subsidy. *European Journal of Operational Research*, *308*(1), 131-149. https://doi.org/10.1016/j.ejor.2022.11.003

Xu, J., Hsu, V. N., & Niu, B. (2017). The Impacts of Markets and Tax on a Multinational Firm's Procurement Strategy in China. *Production and Operations Management*, *27*(2), 251-264. https://doi.org/10.1111/poms.12798

Yang, H., Ou, J., & Chen, X. (2021). Impact of tariffs and production cost on a multinational firm's incentive for backshoring under competition. *Omega*, *105*. https://doi.org/10.1016/j.omega.2021.102500

Zeng, K. (2023). Gauging the Impact of the China-US Trade War: Did the tit-for-tat tariffs move China and the U.S. toward economic decoupling? *The Diplomat*. https://thediplomat.com/2023/02/gauging-the-impact-of-the-china-us-trade-war/

Zhang, A., & Huang, G. Q. (2012). Impacts of business environment changes on global manufacturing outsourcing in China [Article]. *Supply Chain Management*, *17*(2), 138-151. https://doi.org/10.1108/13598541211212889

Zhang, R., Hora, M., John, S., & Wier, H. A. (2021). Competition and slack: The role of tariffs on cost stickiness. *Journal of Operations Management*, *68*(8), 855-880. https://doi.org/10.1002/joom.1162

Zhang, T., Wang, Y., Shen, B., & Prak, D. (2023). Welfare-maximizing tariff versus trade-surplus-maximizing tariff: Impacts on multinational firm competition. *International Journal of Production Economics*, *264*. https://doi.org/10.1016/j.ijpe.2023.108972

Ziady, H. (2023). The UK economy still can't cope with the consequences of Brexit. *CNN*. https://edition.cnn.com/2023/08/29/economy/uk-food-imports-safety-brexit/index.html

APPENDICES

Appendix 1. Tariff rates.

ProductName	General tariff rate	ProductName	General tariff rate	ProductName	General tariff rate
Product_1	Free	Product_38	Free	Product_74	Free
Product_2	Free	Product_39	Free	Product_75	Free
Product_3	Free	Product_40	Free	Product_76	Free
Product_4	Free	Product_41	Free	Product_77	Free
Product_5	Free	Product_42	Free	Product_78	Free
Product_6	5%	Product_43	Free	Product_79	Free
Product_7	Free	Product_44	Free	Product_80	Free
Product_8	Free	Product_45	Free	Product_81	Free
Product_9	Free	Product_46	Free	Product_82	2.50%
Product_10	Free	Product_47	2.50%	Product_83	2.50%
Product_11	Free	Product_48	Free	Product_84	2.50%
Product_12	Free	Product_49	Free	Product_85	2.50%
Product_13	Free	Product_50	Free	Product_86	Free
Product_14	Free	Product_51	Free	Product_87	Free
Product_15	Free	Product_52	2.50%	Product_88	Free
Product_16	Free	Product_53	Free	Product_89	Free
Product_17	2.80%	Product_54	Free	Product_90	2%
Product_18	2.50%	Product_55	Free	Product_91	Free
Product_19	5%	Product_56	Free	Product_92	Free
Product_20	5%	Product_57	Free	Product_93	Free
Product_21	Free	Product_58	Free	Product_94	Free
Product_22	Free	Product_59	Free	Product_95	2.40%
Product_23	Free	Product_60	Free	Product_96	2.50%
Product_24	Free	Product_61	Free	Product_97	2.50%
Product_25	Free	Product_62	Free	Product_98	4.90%
Product_26	Free	Product_63	Free	Product_99	1.80%
Product_27	Free	Product_64	Free	Product_100	2.50%
Product_28	Free	Product_65	Free	Product_101	5%
Product_29	Free	Product_66	Free	Product_102	Free
Product_30	Free	Product_67	Free	Product_103	Free
Product_31	Free	Product_68	2.70%	Product_104	Free
Product_32	Free	Product_69	Free	Product_105	Free
Product_33	Free	Product_70	Free	Product_106	2.50%
Product_34	Free	Product_71	Free	Product_107	2.50%
Product_35	Free	Product_72	Free	Product_108	2.50%
Product_36	2.80%	Product_73	Free	Product_109	1.40%
Product_37	Free				

Appendix 3. Costs. Data used in Figure 3.

	Default strategy (Model)	MEX strategy	KOR1 strategy	KOR2 strategy	KOR3 strategy	KOR4 strategy	VN1 strategy	VN2 strategy	VN3 strategy	VN4 strategy
Transportation	$1,905,820	$1,335,226	$1,717,276	$2,756,960	$3,285,406	$3,178,239	$1,697,086	$2,906,362	$3,604,700	$3,293,001
Production	$10,835,830	$10,835,830	$10,835,830	$10,507,098	9,709,897	9,709,897	$10,835,830	$10,014,000	9,254,211	9,254,211
Sourcing	$30,205,503	$30,205,503	$31,736,859	$30,205,503	$30,205,503	$31,736,859	$30,205,503	$30,205,503	$30,205,503	$30,205,503
Inventory carrying cost	$5,275,258	$5,255,625	$5,275,258	$5,371,619	$5,377,854	$5,369,256	$5,275,258	$5,333,450	$5,323,915	$5,304,283
Total	**$48,222,411**	**$47,632,184**	**$49,565,222**	**$48,841,180**	**$48,578,660**	**$49,994,250**	**$48,013,677**	**$48,459,315**	**$48,388,330**	**$48,056,998**

Appendix 2. Duty costs. Data used in Figure 4.

	Default strategy (Model)	MEX strategy	KOR1 strategy	KOR2 strategy	KOR3 strategy	KOR4 strategy	VN1 strategy	VN2 strategy	VN3 strategy	VN4 strategy
Baseline	$74,880	$17,862	$17,862	$32,389	$8,635	$8,635	$17,862	$32,389	$8,635	$8,635
China Average 0-25	$712,354	$17,862	$17,862	$427,662	$8,635	$8,635	$17,862	$427,662	$8,635	$8,635
China+25	$1,463,865	$17,862	$17,862	$850,133	$8,635	$8,635	$17,862	$850,133	$8,635	$8,635
Europe+10	$1,632,411	$186,407	$186,407	$962,436	$120,938	$120,938	$186,407	$962,436	$120,938	$120,938

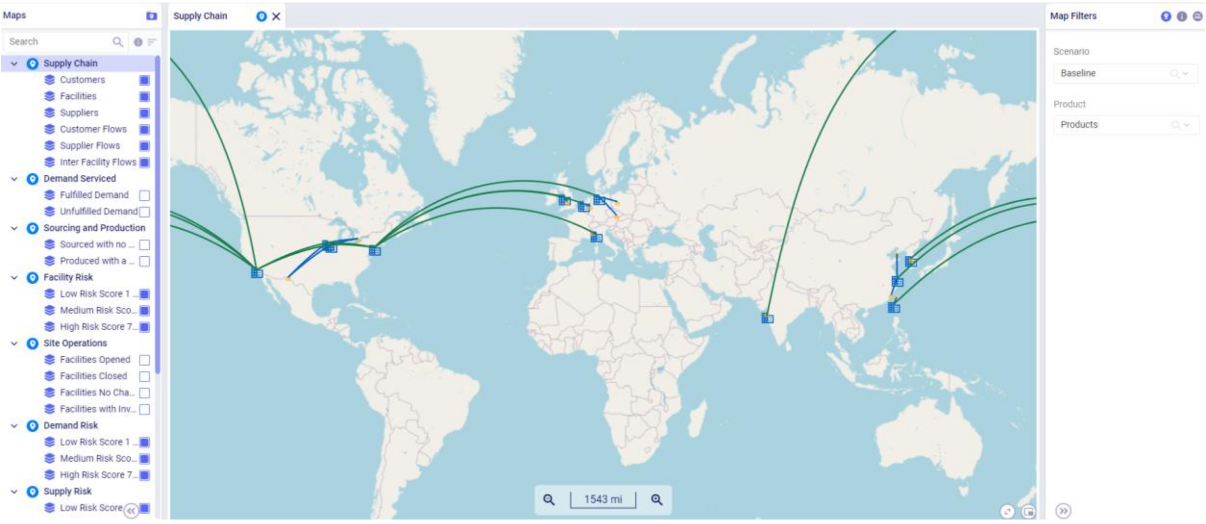
Appendix 4. Total costs. Data used in Figure 5 and Table 4.

	Default Model	**MEX strategy**	**KOR1 strategy**	**KOR2 strategy**	**KOR3 strategy**	**KOR4 strategy**	**VN1 strategy**	**VN2 strategy**	**VN3 strategy**	**VN4 strategy**
Baseline	$48,297,291	$47,650,046	$49,583,084	$48,873,568	$49,384,497	$50,002,886	$48,031,538	$48,491,704	$48,396,966	$48,065,634
0	$48,240,272	$47,650,046	$49,583,084	$48,849,815	$49,384,497	$50,002,886	$48,031,538	$48,467,951	$48,396,966	$48,065,634
1	$48,295,832	$47,650,046	$49,583,084	$48,883,337	$49,384,497	$50,002,886	$48,031,538	$48,501,473	$48,396,966	$48,065,634
2	$48,351,391	$47,650,046	$49,583,084	$48,916,859	$49,384,497	$50,002,886	$48,031,538	$48,534,995	$48,396,966	$48,065,634
3	$48,406,950	$47,650,046	$49,583,084	$48,950,381	$49,384,497	$50,002,886	$48,031,538	$48,568,517	$48,396,966	$48,065,634
4	$48,462,510	$47,650,046	$49,583,084	$48,983,904	$49,384,497	$50,002,886	$48,031,538	$48,602,039	$48,396,966	$48,065,634
5	$48,518,069	$47,650,046	$49,583,084	$49,017,426	$49,384,497	$50,002,886	$48,031,538	$48,635,561	$48,396,966	$48,065,634
6	$48,573,629	$47,650,046	$49,583,084	$49,050,948	$49,384,497	$50,002,886	$48,031,538	$48,669,084	$48,396,966	$48,065,634
7	$48,629,188	$47,650,046	$49,583,084	$49,084,470	$49,384,497	$50,002,886	$48,031,538	$48,702,606	$48,396,966	$48,065,634
8	$48,684,747	$47,650,046	$49,583,084	$49,117,992	$49,384,497	$50,002,886	$48,031,538	$48,736,128	$48,396,966	$48,065,634
9	$48,740,307	$47,650,046	$49,583,084	$49,151,514	$49,384,497	$50,002,886	$48,031,538	$48,769,650	$48,396,966	$48,065,634
10	$48,795,866	$47,650,046	$49,583,084	$49,185,037	$49,384,497	$50,002,886	$48,031,538	$48,803,172	$48,396,966	$48,065,634
11	$48,851,425	$47,650,046	$49,583,084	$49,218,559	$49,384,497	$50,002,886	$48,031,538	$48,836,694	$48,396,966	$48,065,634
12	$48,906,985	$47,650,046	$49,583,084	$49,252,081	$49,384,497	$50,002,886	$48,031,538	$48,870,216	$48,396,966	$48,065,634
13	$48,962,544	$47,650,046	$49,583,084	$49,285,603	$49,384,497	$50,002,886	$48,031,538	$48,903,739	$48,396,966	$48,065,634
14	$49,018,104	$47,650,046	$49,583,084	$49,319,125	$49,384,497	$50,002,886	$48,031,538	$48,937,261	$48,396,966	$48,065,634
15	$49,073,663	$47,650,046	$49,583,084	$49,352,647	$49,384,497	$50,002,886	$48,031,538	$48,970,783	$48,396,966	$48,065,634
16	$49,129,222	$47,650,046	$49,583,084	$49,386,169	$49,384,497	$50,002,886	$48,031,538	$49,004,305	$48,396,966	$48,065,634
17	$49,184,782	$47,650,046	$49,583,084	$49,419,692	$49,384,497	$50,002,886	$48,031,538	$49,037,827	$48,396,966	$48,065,634
18	$49,240,341	$47,650,046	$49,583,084	$49,453,214	$49,384,497	$50,002,886	$48,031,538	$49,071,349	$48,396,966	$48,065,634
19	$49,295,901	$47,650,046	$49,583,084	$49,486,736	$49,384,497	$50,002,886	$48,031,538	$49,104,871	$48,396,966	$48,065,634
20	$49,351,460	$47,650,046	$49,583,084	$49,520,258	$49,384,497	$50,002,886	$48,031,538	$49,138,394	$48,396,966	$48,065,634
21	$49,407,019	$47,650,046	$49,583,084	$49,553,780	$49,384,497	$50,002,886	$48,031,538	$49,171,916	$48,396,966	$48,065,634
22	$49,462,579	$47,650,046	$49,583,084	$49,587,302	$49,384,497	$50,002,886	$48,031,538	$49,205,438	$48,396,966	$48,065,634
23	$49,518,138	$47,650,046	$49,583,084	$49,620,824	$49,384,497	$50,002,886	$48,031,538	$49,238,960	$48,396,966	$48,065,634
24	$49,573,697	$47,650,046	$49,583,084	$49,654,347	$49,384,497	$50,002,886	$48,031,538	$49,272,482	$48,396,966	$48,065,634
25	$49,629,257	$47,650,046	$49,583,084	$49,687,869	$49,384,497	$50,002,886	$48,031,538	$49,306,004	$48,396,966	$48,065,634
China+25	$49,686,276	$47,650,046	$49,583,084	$49,691,313	$49,384,497	$50,002,886	$48,031,538	$49,309,448	$48,396,966	$48,065,634
Europe+10	$49,854,821	$47,818,592	$49,751,630	$49,803,616	$49,496,800	$50,115,189	$48,200,084	$49,421,752	$48,509,269	$48,177,937

Appendix 5. Average Transportation time per parent product (Days). Data used in Figure 6.

Column1	Average Transportation time per parent product (Days)
Default Model	17.43
MEX strategy	9.32
KOR1 strategy	16.44
KOR2 strategy	21.31
KOR3 strategy	21.55
KOR4 strategy	20.96
VN1 strategy	24.06
VN2 strategy	23.82
VN3 strategy	29.75
VN4 strategy	26.91

Appendix 6. Screenshot of the map of the Default Model in Cosmic Frog.



Appendix 7. Tables filled in the Cosmic Frog modeling software.