Supply Chain Network design models for a circular economy: A Review and a case study assessment

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Abstract

Global supply chains are getting increasingly dispersed, and hence, more complex. This has also made them more vulnerable to disruptions and risks. As a result, there is a constant need to reconfigure/redesign them to ensure competitiveness. However, the relevant aspects/facets for doing so are fragmented and scattered across the literature. This study reviews the literature to develop a holistic understanding of the key considerations (environment, cost, efficiency, and risks) in designing/redesigning global supply chains. This understanding is then applied to assess the global supply chain network of a leading multinational tire manufacturing firm; also to provide recommendations on redesigning it. The study has significant practical and research implications for global supply chain management.

Keywords: Supply chain design, environment, supply chain modeling, global supply chains, tire industry

1. Introduction

Globalization provides international firms' with a host of benefits such as access to new markets and reduced costs of production and taxes (through manufacturing across borders) (Varzandeh et al., 2016). However, this requires management/leveraging of global supply chain networks (Garcia and You, 2015) that are facing pressure from competitors and customers. These networks are, therefore, constantly being reconfigured so that they continue to be competitive. However, this is making them increasingly complex to manage (Hammami et al., 2008; Mokhtar et al., 2019; Jaehne et al., 2009) and also increasing the risks of disruptions (for multinational firms). For example, the current COVID-19 pandemic has caused large scale travel and trade restrictions with associated disruptions and consequences for global supply chains across most sectors. Similar is the case for international political instability related (negative) implications for global supply chains. For example, Brexit has caused disruptions in the global supply chains of many firms (Lockett et al., 2019), and Apple Inc. is considering moving its manufacturing from China to India due to the US-China Trade war (Vaitheesvaran, 2019). Resilient supply chains with the ability to handle such disruptions have a significant strategic advantage over the others that don't.

The other critical aspect is environmental sustainability. Managers are under increasing pressure to reduce their supply chain's adverse environmental impacts. This is not surprising given that environmental pollution and global climate change have emerged as one of the significant challenges of the twenty-first century. Thus, industries around the world are looking at options to meet the market demand in a more environmentally responsible way (Habib et al., 2020).

The rubber sector is one of the key ones from an environmental impact perspective. Rubber-based industries have witnessed significant worldwide growth in recent times (Chanchaichujit et al., 2020), and that is also expected to continue into the future; annual growth rate of around 5% is projected for the next ten years to reach a market size of USD 45 billion globally by 2027 (Kenneth Research, 2019). This is largely due to the growing demand from the tire industry. Rubber production is considered to be energy-intensive and environmentally polluting (Jawjit et al., 2015), though there have been few efforts to tackle its negative environmental impacts (Chanchaichujit et al., 2020).

Therefore, a great deal of emphasis is now placed on the design/redesign of global supply chains (dispersed geographical elements that are highly coordinated with each other) that takes into account environmental sustainability, cost, responsiveness, and supply chain risk considerations, together with the short term and long term organisational objectives. Figure 1 shows the different supply chain network design/redesign aspects that need to be simultaneously considered.

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                Supply Chain Network Design/Redesign
                            Considerations

    Environmental       Economic        Agility         Uncertainty

                                                     Risk Mitigation in SC
                        Cost-
        Green SC      effective SC    Efficient &
                                    Responsive SC
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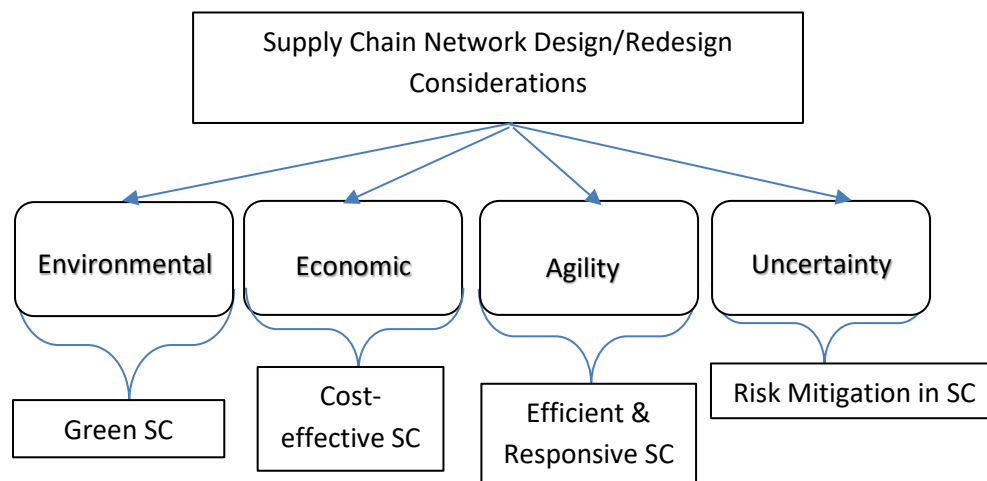
Figure 1 - Supply Chain Network Design Considerations

This increased relevance given to supply chain design/redesign is reflected in the growing academic interest in this area, especially in the use of mathematical models for supply chain design/redesign. Yet, different studies have used different approaches, tools, and techniques for supply chain design/redesign, and that too with very specific objectives, resulting in the knowledge being fragmented and scattered across the literature. A holistic understanding of global chain modeling strategies is therefore lacking, and which requires a comprehensive review to understand the current state of knowledge on this subject. This forms the focus of this study whose objectives are:

- To conduct a review and synthesis of different mathematical modeling approaches used in supply chain management in order to comprehend the various considerations (environmental, cost, efficiency, and risks) in supply chain network design/redesign

- To apply this understanding on supply chain network design/redesign to a real-world case study of a multinational tire manufacturing firm
- To provide implications for research and practice

The rest of the study is structured as follows. The research methodology is discussed in section 2. Section 3 presents a review of the literature on different mathematical models used in supply chain management. Its application for the supply chain redesign of the case company (a leading global tire manufacturer) is discussed in section 4. The study concludes in section 5 where the implications for research and practice are discussed.

2. Research Methodology

In line with the research objectives, the methodology adopted in this chapter consists of two parts, the literature review and the case study. Figure 2 shows the research methodology adopted in this study.
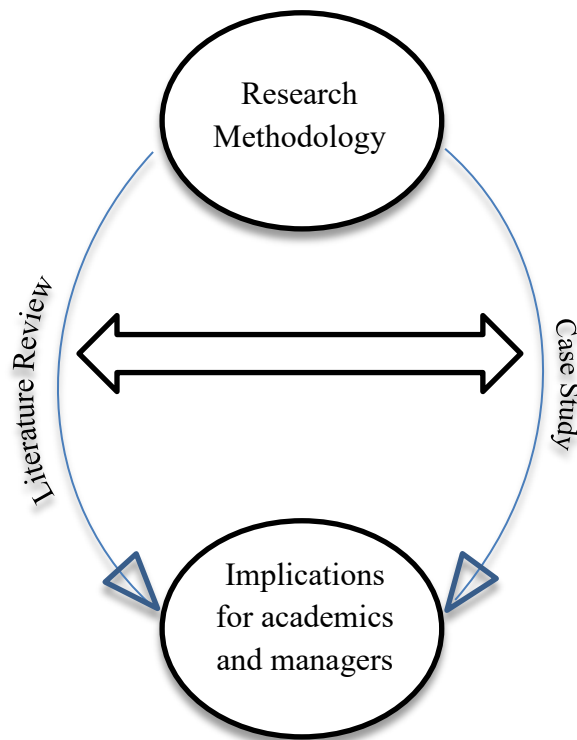

Figure 2 - Research Methodology used in study

2.1 Literature Review

The review of the literature was undertaken using the Web of Science database. The keywords used for the search included "Global Supply Chain Network Design" and "Global Supply Chain Network Redesign". While this returned more than 1000 studies, these were narrowed down by abstract based screening; only studies that had used mathematical modeling and had a primary focus on one of the research objectives were retained, while the others were excluded.

2.2. Case Study Methodology

The case study considered is the regional headquarters of a global tire manufacturing firm. It is located in Dubai, UAE, and is responsible for meeting the demands of 52 countries in the Middle East and North Africa (MENA) region.

An initial two-hour meeting with the CEO and senior supply chain managers was conducted to understand the significant issues in their supply chain network. This was followed by meetings with other senior executives where internal company data was also obtained. Additionally, four semi-structured interviews with mid-level executives from the different departments were conducted to comprehend their operational supply chain issues. Further clarifications were obtained via emails and phone calls.

3. Literature Review Findings

3.1. Considerations for Supply Chain Network Design/Redesign

3.1.1. Environmental/Green Supply Chain Models

Governments, organizations, and business managers are facing increasing pressure to minimize the environmental impacts of supply chains. This is because the related issues of environmental pollution, climate change, and resource depletion have become one of the greatest challenges of the 21st century (IPCC, 2007). The total global greenhouse gas (GHG) emissions, the main driver of climate change, amounted to approximately 52.7 gigatonnes of carbon dioxide equivalent (GtCO2e) in 2014, the highest level reported since the pre-industrial levels (UNEP-

EGR, 2014). Also, the increase in the annual rate of GHG emissions during the period 2000-2010 was faster (2.2%) than during the period 1970-2000 (1.3%) (UNEP-EGR, 2016). The effects of these emissions, mainly in the form of global warming and rising sea levels, are clearly evident: 2015 was the hottest year ever recorded and ten of the warmest years on record have occurred since 2000 (UNEP-EGR, 2016); the rate of rising sea levels has accelerated in recent years (EPA, 2017). The significant push for economic development and industrialization is also accelerating the depletion of natural resources. At current rates of use, the world will soon run out of many vital resources, including renewable resources. For example, assessment by the US Energy Information Administration (EIA) shows that fossil fuels could be entirely depleted in the next 25 years (EIA-IEO, 2013). From a rubber industry perspective, too, there is increasing pressure on the industry from global buyers, especially in developed countries, to reduce the negative environmental impacts (Krungsri Report, 2019). However, this needs to be done while still meeting the increasing global demand for rubber products and sustaining its economic contribution.

Because of this, incorporating environmental concerns into supply chain management, or green supply chain management (GSCM), has seen significant interest among academics and practitioners. GSCM addresses environmental issues dispersed across the different stages of the supply chain, i.e., from design through to end-of-life leading to a circular economy. Trade-offs are usually involved, and generally among incompatible objectives; optimization models for GSCM related decision making are therefore common (Ansari & Kant, 2017). These models are based on mathematical procedures that strive to find optimum solutions under a given set of assumptions, constraints, and data (Coyle et al., 2004). While different mathematical programming procedures/techniques such as linear programming, mixed-integer programming, and non-linear programming (Ansari & Kant, 2017; Srivastava, 2007) are used, single and multi-objective linear programming techniques are the most popular (Ansari & Kant, 2017).

Chanchaichujit et al. (2016), for example, used the single objective linear programming model to find the association between the quantity of rubber product flow between supply chain entities

and the transportation mode and route, to minimize total greenhouse gas (GHG) emissions. The authors considered GHG emissions and costs as two single objective functions and found the relationship between GHG emissions and costs to be in conflict with each other. Multi-objective optimization has also been considered by different researchers; this involves minimizing total costs or maximizing total profits while simultaneously minimizing environmental impacts (Kim et al., 2010; Wang et al., 2011). In these studies, the total costs are usually tire summation of supply chain activity costs such as production, inventory, and transportation (You & Wang, 2011), while total profits are generally the net profits (Hugo & Pistikopoulos, 2005). For environmental objectives, different measures are used including CO_2 emissions (Kim et al., 2010; Wang et al., 2011), GHG emissions (You & Wang, 2011), energy consumption (Winebrake et al., 2008) and Global Warming Potential (Buddadee et al., 2008).

3.1.2. Closed-loop Supply Chain Models

A related aspect to environmental supply chains is the closed-loop supply chains. Closed-loop supply chain design refers to the integration of the forward and reverse supply chain designs (Amin et al., 2017; Pedram et al. 2017). Reverse supply chains involve activities that return used goods to the manufacturers, for resuse/refurbishing/remanufacturing. In the case of the tire industry, this involves the tire being returned, retreaded and made available in the market again (Amin et al., 2017). However, evidence from the literature shows that while the practice of tire retreading is good from an environmental standpoint, it is not preferred by manufacturers as it may reduce new product sales. Table 1 shows select studies in supply chain network design using closed-loop models and that have focussed on the tire industry. All three studies have used multi-objective and integrated models.

Table 1: Supply Chain Network Design using Closed-loop Models in the Tire industry

Author	Decision Levels		Optimization	Model	Objective
	Operational	Strategic			

				Mixed Integer Linear	Optimize profit
Amin et al. (2017)	✓		✓	Programming & Scenario Analysis	of returns
Pedram et al. (2017)	✓		✓	Mixed Integer Linear Programming & Scenario Analysis	Optimize transportation Cost
Subulan et al. (2015)		✓	✓	Mixed Integer Linear Programming	Optimize profit with less environmental impact

Amin et al.'s article provide excellent insight into the tire remanufacturing process in Canada. Figure 3 shows the closed-loop model proposed by Amin et al. (2017), and which uses mixed-integer linear programming for optimization. Additionally, their framework uses scenario analysis tree to analyze sources of uncertainty (such as demand) over the multi-period decision making and considers discounted cash flow for assessment. The strategic model selects facility locations as well as those of retailers and drop-off depots; however, it does not take waste management and CO_2 emission factors into account. Furthermore, the model has been applied to a case study context that operates predominantly in one state of Canada.
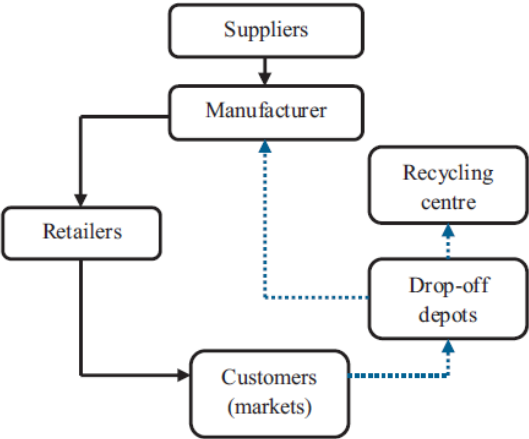

Figure 3 - Closed-loop Supply Chain Network (Amin et al., 2017)

The closed-loop design model of Pedram et al. (2017), unlike Amin et al.'s, considers the uncertainty of demand and introduces a formulation that solves for facility locations, including drop-off depots locations as well as product flows between subsidiaries to minimize the overall cost of transportation. The paper discusses product recovery for a tire manufacturer in Iran, and first uses mixed-integer linear programming with a fixed cost, capacity, and distance between facilities. This is followed by a scenario analysis that considers three scenario expectations for demand. Nevertheless, Pedram et al. (2017)'s model does not account for global supply chain variables, such as duty and tax charges.

Subulan et al. (2015)'s study discusses the various options of used tire recovery and disposal; it then integrates measures of environmental impact into a closed-loop supply chain logistics network design model. The framework, similar to other studies discussed in this section, uses mixed-integer linear programming to maximize profit, but in addition, it seeks to reduce the total ecological bearing of the supply chain. The model uses parameters for demand, cost (inventory, inventory hold, distribution, and new facility) and capacity, then proceeds to conduct sensitivity analysis using the Taguchi Method (Robust Design). Taguchi design is a productivity method that reduces production cost, environmental impact, and seeks to meet customer demand. In this case, Subulan et al. (2015) used the Taguchi method to analyze the profitability of the model. The proposed framework, in addition to disregarding global factors of a supply chain, also uses many constraints, which reduces its utility for real world applications.

3.1.3 Cost-Efficiency optimization Models

Cost optimization can be achieved in various ways in the supply chain; however, in most studies, this is realized by monitoring the activities of warehousing, inventory management, and order management (Croxton and Zinn, 2005). Among different frameworks, a useful one for strategic cost optimization modeling is the strategic safety stock supply chain concept developed by Graves and Willems (2000). It focuses on minimizing inventory costs and providing a high level of service for the customers in the supply chain, that is subject to demand and forecast uncertainty. The emphasis is on designing a supply chain network where each stage of the network operates

with a periodic-review base-stock policy, and where demand is bounded, and service for customers, guaranteed (as shown in Figure 4).

Graves and Willems's model used an optimization algorithm for inventory modeling. Based on calculated assumptions, the model detects problems within the supply chain and capture the source of the problem and formulate that into deterministic optimization. The optimization algorithm minimizes the inventory cost level, meaning that the holding cost for safety stock in the supply chain decreases.
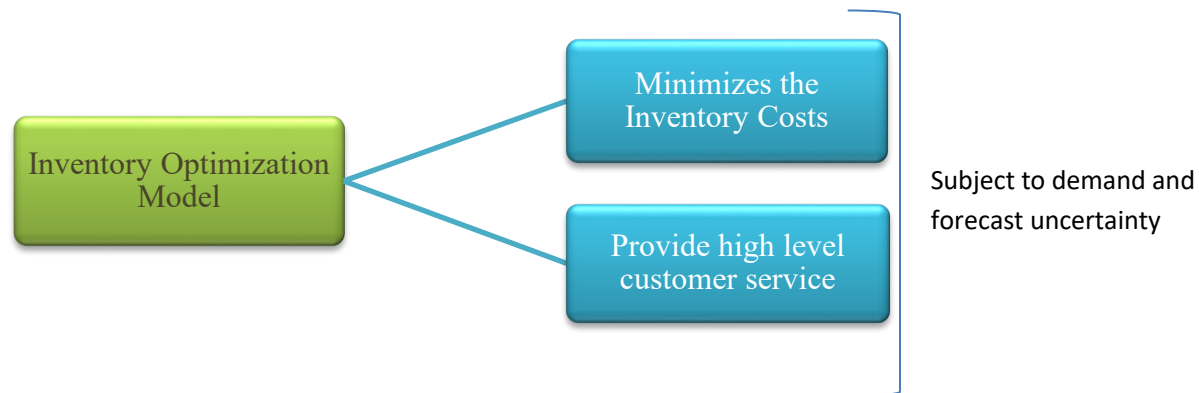

Figure 4 - Inventory Optimization Model outcomes subject to demand and forecast uncertainty

Margolis et al. (2018) managerial decision support supply chain network design model considers both costs, which are associated with supply chain network design decisions, such as increasing number of facilities or closing down facilities, and cost of operations such as assigning the production capacity and flow of products for each node through the network; its goal is to suggest optimum location and production quantity plans as well as the routing network. The authors consider weighted demand parameters to make the model less susceptible to disruptions. They also show (through examples) that their model can withstand production disruptions; nevertheless, the resultant computations are quite complex and take a long time (approximately 24 hours as per the authors for the context they considered).

Hammami and Frein (2014) analyze the previous literature on both supply chain network design and redesign; they recognize that most of it focuses on facility allocations, but which does not consider taxation, exchange rate and transfer pricing related apects that are important in a global context. The authors acknowledge that tax rewards by some countries are the reason why many supply chain networks are redesigned by firms. Their model therefore takes a profit-maximizing approach that considers facility relocation and productions capacities, as also transfer pricing aspects. Two frameworks for transfer pricing are considered; in the first, finished products are considered where a range of prices (maximum and minimum) for the product are assumed based on similar products in the market; in the second, the focus is on semi-finished products where a Profit-Split method is assumed, where the profit is divided between the parties involved in production based on their respective contributions. Factors that impact redesign, such as facility closing cost and capacity relocation are also considered in the study.

Finally, Creazza et al. (2012) propose a supply chain network redesign optimization framework based on Pirelli Tires in Europe. Their framework uses a standard Mixed Integer Linear Programming approach to reduce cost and to reconfigure the network to realise optimum cost efficiency at the lowest cost. However, it has limitations; for example, aspects such as exchange rates and tariffs were not considered; additionally (and which is also recognized by the authors), accurate implementation of the model requires precise data, such as on transportation cost, which may not be possible to get.

Besides the individual limitations considered in each of the above models/studies, all of them have an additional limitation; they may not perform well under uncertainty, such as non-stationary demand (in place of the stationary one that is generally assumed), use of different review periods for stocks (vis-à-vis the fixed/standard one assumed), and capacity constraints that are usually ignored in models. To address these issues, a few studies have proposed cost-optimization models under uncertainty. For example, Fattahi et al. (2018) model proposes a multi-stage stochastic model that addresses the uncertainty of demand by considering different customer segments. Such a model is useful for making supply chain decisions both at strategic as well as tactical levels.

3.1.4 Supply Chain Risk Management Models

Global supply chains are susceptible to risks and uncertainties; this section of the paper reviews supply chain network design and redesign models that address risks and uncertainties. Goh et al. (2007) classified risks into two categories, as shown in Figure 5, strategic risks, and operational risks. Strategic risks refer to threats of political instability (change in policies), natural disasters, and climate effects that could cease production. In contrast, operational risks involve factors that could impact the operation of the supply chain, for instance, demand fluctuations, price, and cost volatility. There are many approaches to solving the issue of supply chain risks; the following frameworks consider diverse categories of risks and uncertainties in their supply chain network design and redesign models.
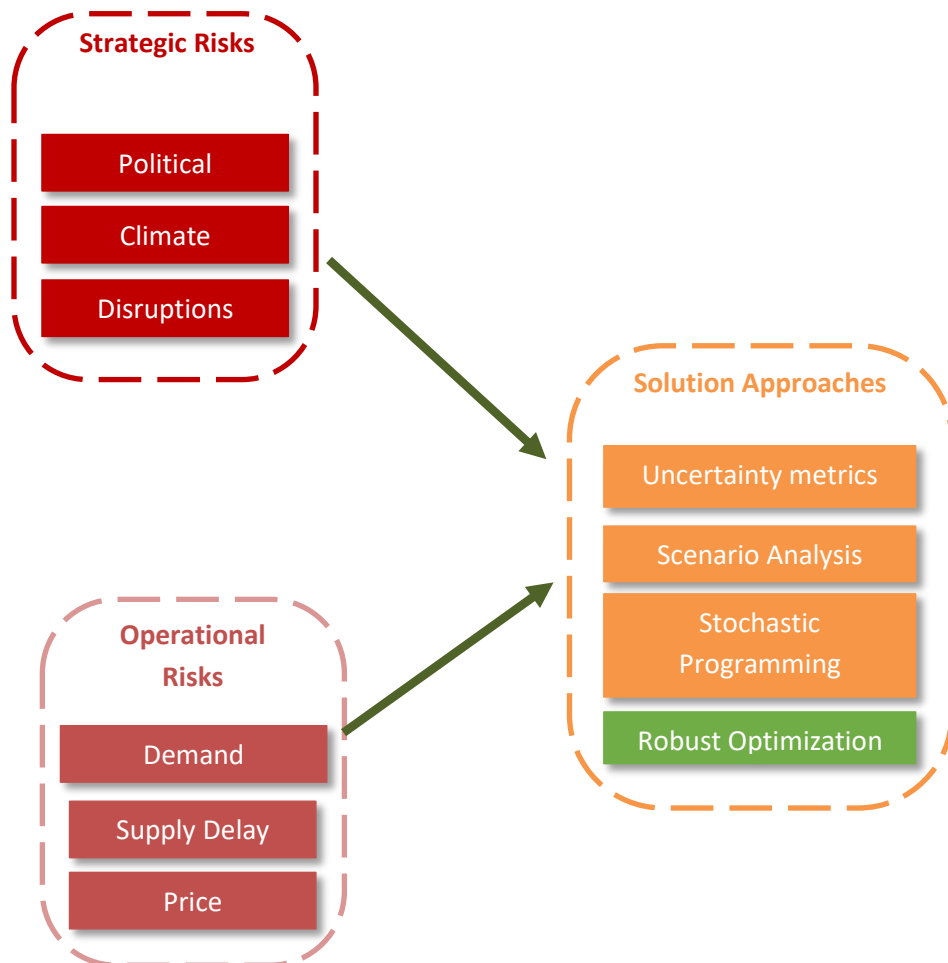
Figure 5- Levels of Risks and Solution Approaches

Rahimi et al.'s (2019) study addressed demand uncertainty and used a two-stage stochastic programming framework to handle the fluctuation of demand and strategic risks. Stochastic programming (two or multi-stage) enables long-term scenario analysis, which helps organizations develop strategies to manage uncertainties for the long term. Here stages of design or redesign are divided into various scenarios; first, the primary decisions are made, and subsequently assessed with the dimension of uncertainty and then updated in the following stage; however, the greater the number of stages, the more is the computation time required (Garcia and You, 2015). Table 2 below provides a summary of supply chain network design or redesign models that consider uncertainty and risks in modeling.

Table 2- Supply Chain Network Design Risk Models

Author	Operational Risks		Strategic Risks	Model	Objective
	Demand	Price			
Rahimi et al. (2019)	✓		✓	Two-Stage Stochastic Model	Risk Aversion Parameters
Jahani et al. (2018)	✓	✓		Multi-tier Stochastic Model	Risks due to price and demand uncertainty
Carvalho et al. (2012)			✓	Simulation Model for Resilience	Risk Minimization
Nickel et al. (2012)	✓		✓	Multi-Stage Stochastic Model	Risk Minimization
Goh et al. (2007)	✓		✓	Multi-Stage Stochastic Model	Risk Minimization

Rahimi et al.'s (2019) study considers uncertainty and risk in supply chain network design while simultaneously factoring in sustainability elements. They use a mixed-integer non-linear program that considers the carbon footprint impact of opening a new manufacturing plant or distribution center, as well as the effect of transportation-related emissions. The model conducts a scenario analysis and assumes the worst-case scenario (total loss) in each computational stage one by one to solve the multi-objective problem. Although this study's contribution to supply chain network design is significant, the suggested model has not been applied/tested on a real-life supply chain context.

Jahani et al. (2018) propose a stochastic model that addresses risks due to price and demand uncertainty. The multi-tiered, multi-period stochastic model considers geometric Brownian motion, an exponential time-continuous model. The study then successfully uses the model to redesign the supply chain network of the Australian cement industry as a case study. However, the model falls short, as most network redesign models do; it only considers the risk and uncertainty of two dimensions, price and demand.

The objective of the framework proposed by Carvalho et al. (2012) is to incorporate a simulation-based model into the supply chain design decision-making process, and use it as a tool to boost supply chain resilience against possible disruptions caused by changes in external supply chain policies. Resilience refers to a supply chain's ability to foresee and evade disruptions or an ability to recuperate swiftly from failures. Carvalho et al.'s simulation model analyses possible disturbances across supply chains that could cause failures, and helps managers design risk mitigation strategies to overcome them. The model uses total cost (material, production, inventory holding and transportation) and lead time to assess the scenarios.

Nickel et al. (2012)'s multi-stochastic programming based supply chain network design framework solves the facility location problem while highlighting the risks associated with the investments in facilities. The model considers factors of return of investment and uncertainty, such as on interest rates that affect financial decisions on network design including on opening/closing a facility also, demand uncertainty, which affects extent of customer service provision. The framework uses a scenario tree to find the risk of forecasted revenue.

The framework proposed by Goh et al. (2007) considers all relevant risk and uncertainty aspects for a global company, and provides a solution to simultaneously minimize all of them. The multi-stage stochastic framework seeks to optimize after-tax profit by considering uncertainty factors of demand, fluctuating import tariffs, and tax charges, as well as the continually shifting exchange rates. It accordingly helps managers make decisions regarding closing/opening a facility, capacity planning, and development of the distribution network.

Now that we have reviewed different supply chain design/redesign models for environmental, closed-loops, cost-efficiency, and risk/uncertainty aspects, in the next phase, we will apply the combined learning from the review to understand the supply chain network issues of the case company and provide recommendations.

4. Case Study of the Global Tire Manufacturing Firm

The case firm manufactures various sizes and types of tires catering to multiple industries (mining, aircraft) as well as trucks and passenger cars. Even though the firm has been expanding geographically and opening new production facilities, the current supply chain network design configuration of the firm has remained the same for the most part in the last 20 years. The focus of this case study, though, is on redesigning the supply chain network of the regional subsidiary that only handles the sales of passenger and truck tires in the Middle East and Africa (MEA) region. In the initial meeting with CEO and top management, the company's proposed strategic plan for the next five years was understood. One of the key aspects in the strategic plan was that regional customer demand must be satisfied from production within each region, as the firm will not operate any manufacturing plants in MEA; instead, this region will be integrated with Europe (EMEA), and European plants will be expected to fulfill the MEA demand in the future. In the meeting, the CEO also highlighted: i) the need to improve customer service level (as they have long waiting times); ii) reduce the distance between the manufacturing plants and demand points; iii) reduce supply chain costs to remain competitive in the global environment; iv) reduce logistics and production delays; and v) be prepared for various supply chain risks.

4.1 Current Supply Chain Network Analysis of the Case Firm

In this section, the knowledge developed from the literature review was applied to thoroughly understand the supply chain network of the case company and delineate the supply chain issues facing the firm.

The case study's regional supply chain network contains 82 demand points located in 52 different countries in MEA with 30 corresponding manufacturing plants that are geographically dispersed and located in 12 countries. Figure 6 shows the supply chain network of the case company and how they satisfy demand.
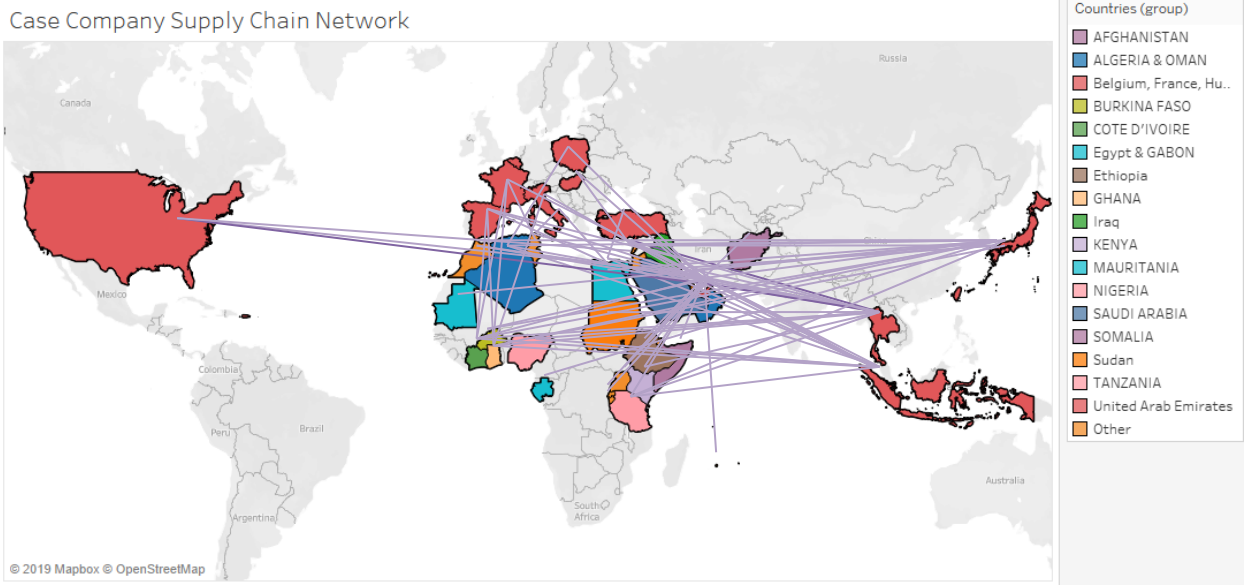

Figure 6: Case Company Supply Chain Network

It is to be noted that only 10 of these manufacturing plants lie under the umbrella of Europe and MEA (EMEA) subsidiaries (Europe and Turkey); therefore, the other 20 plants are supporting the region from outside of their appointed district (Japan, Thailand, Taiwan, Indonesia, and the US). Similarly, 74 percent of demand in the region is met from plants outside of the region, and only 26 percent of the orders are fulfilled from production in Europe and Turkey. Of the 74 percent, 40 percent of the total orders are fulfilled by manufacturing plants in Japan (Headquarters), while plants in Thailand, Taiwan, and Indonesia fulfill more than 30 percent of the orders from the MEA region.

Of the total orders placed from the 52 countries in the region, 71.5 percent (on average) are directly shipped from manufacturing plants to demand points. The remaining 28.5 percent are directly shipped to Dubai (UAE), for local consolidation, and subsequently shipped to end customers in various countries, including those countries that have: (i) very low demand; (ii) political instability; and (iii) payment issues. To get deeper insights and to account for seasonality, the demand per month coming from the regional 52 countries is provided in Figure 7. The blue highlighted bars represent the orders that are directly shipped from the manufacturing plants, while the red shows the orders that are consolidated in the Dubai (UAE) warehouse for transshipment. As can be seen, the demand is seasonal; therefore, the firm is challenged with operational uncertainty in many countries.
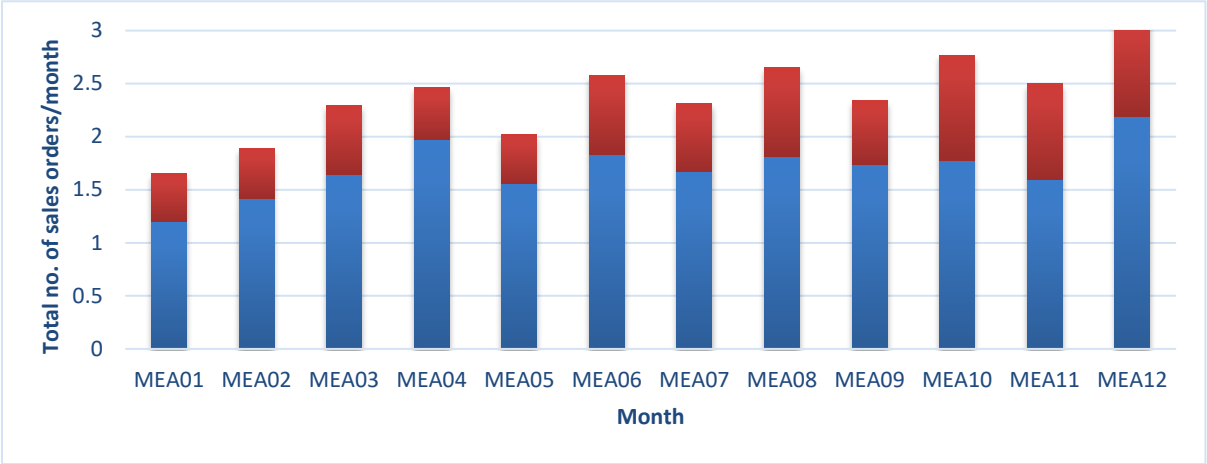

Figure 7: Monthly Regional Stochastic Demand

It is clear from the current network configuration, the demand of the MEA region has imposed pressure on manufacturing plants outside of the EMEA region (to operate over capacity), while the plants within the EMEA region are underutilized. Consequently, the lead time from production to delivery for plants in Japan, Thailand, Taiwan, and Indonesia is high, as these facilities are operating over capacity with associated large waiting times.

Moreover, the geographical distance from these plants to the demand points further adds to the lead time. When we analyzed the company's internal data, we identified that the average order-delivery lead times of 52 countries in the region are 30 days. However, when we analyzed at an

individual country level, we found some countries with significantly higher order-delivery lead times compared to average. These countries with the highest lead times are provided in Table 3.

Countries	Order-Delivery Lead Time Days
MAURITANIA	163
SUDAN	146
ALGERIA	126
COTE D'IVOIRE	96
MALTA	91
QATAR	84
KUWAIT	81
TUNISIA	77
IRAQ	72
GABON	71
NIGERIA	70

Table 3: Lead Time per Days

The company's goal is to reverse these numbers, which means Europe will fulfill most of the demands of the MEA region within the next five years. The capacity of the production facilities is to be assumed fixed, and that the manufacturing facilities in Europe can meet the demand of the MEA region. As mentioned earlier, in the current competitive global business environment, customers expect fast deliveries. Therefore, higher lead times mean lower quality of service, which is one of the challenges the case the company is facing, and that is similar to those discussed in the literature (Fattahi et al., 2018; Monostori, 2016; Stevens and Johnson, 2016). One of the critical drivers of supply chain network design is improvement of customer service levels that in turn enhances competitive advantage.

Additionally, analysis of internal data shows that some of the orders shipped directly to demand points involve small quantities. As displayed in Tables 4 and 5, countries such as Ghana and Tunisia have low demand throughout the year and orders directly shipped to them are below the company's threshold for efficient delivery, which is 1.5. The yellow highlighted data in the Tables also show countries and periods with low demand and high demand variability/uncertainty; the need to consider such uncertainty in supply chain network redesign is therefore also highlighted. It was also highghted during the interviews that profit margins for passenger car tires are low; therefore, any inefficiency in the design of the logistics network has a significant bearing on business profitability.

Month	Countries	Japan	Indonesia	Thailand
Mar	GHANA		0.38	
May	GHANA		0.75	
Jun	GHANA	0.87		
Jul	GHANA	0.44		
Aug	GHANA	0.68		0.59
Dec	GHANA			0.89

Table 4- Shipment below the efficiency level (highlighted in yellow)

The manufacturing locations are also not optimally allocated to demand points; the lower demand locations are allocated to over capacitated plants that provide slower deliveries (refer to Tunisia in the Table 5 below).

Month	Countries	Japan	Thailand	Europe
Jan	TUNISIA	0.59		
Apr	TUNISIA	0.19		
May	TUNISIA		0.17	
Jun	TUNISIA			0.71

| Sep | TUNISIA | 0.32 |
| Nov | TUNISIA | 0.59 |

Table 5- Evidence of non-optimal ordering (highlighted in yellow)

The low quantity and (still) regular/frequent shipments have raised the question of whether increasing the capacity of the consolidation point in UAE by extending the facility and consolidating smaller orders is the optimal solution. For example, in that case, orders for Ghana for June, July, and August can be shipped from Japan to Dubai, and consolidated and shipped to Ghana all at once in one shipment. Facility location problems, closure, and opening have been addressed in many of the network design models discussed in the literature. Inventory Optimization Model found in the literature could be the most appropriate model for handling inventory operations since the model works by considering lead-time subject to demand and forecasting uncertainty.

Another critical challenge that needs to be factored in is the political and financial instability in the region, which results in fluctuating exchange rates, as well as a change in customs regulations. As was seen in the literature, strategic uncertainty is another driver of supply chain network design. As per internal documents and discussions with executives, for countries such as Ethiopia and Algeria, the organization is facing significant challenges in terms of credit payments as a result of unbalanced exchange rates.

The other important issue facing the company is the lack of consideration for environmental issues while meeting the demand for the 52 countries in the region. This is concerning given that the case company global headquarters insists considerations for environmental aspects in the supply chain, including a reduction in CO_2 emissions, specifically, reduction of at least 50% GHG emissions worldwide by 2050. Further, there is no recycling program for the development of closed-loop supply chains in the case company. Again, the global headquarters insists that for every new tire the company sells, one company tire or any one tire needs to be recovered and put to reuse or recycle. There is pressure on the case company to implement this.

Overall, the analysis of the case company demonstrated that the firm is facing many of the same challenges that were discussed in the literature, such as inefficiencies in the supply chain network along with strategic and operational uncertainty due to political and demand uncertainty. Furthermore, longer lead times, reduce the company's competitive advantage and customer service level, which were another two reasons highlighted for network design; lastly, frequent low order quantity shipments are not cost-effective. Therefore, it can be stated that the company will benefit from implementing supply chain network design configuration, which will optimize the network and potentially reduce their associated logistics network cost. Moreover, redesigning the supply chain network with strategies that can withstand any levels of uncertainty, will increase the case company's supply chain network resilience.

4.2 Recommendations for the Case Firm

In this section, the understanding from the literature is used to propose recommendations that address the issues identified for the case study. As discussed in the literature, configuring a supply chain network for any company is an intricate process; it is even more so for the case company as its network is very complex. Its supply chain network design should involve an integrated strategic and tactical level decision of network design models, as the supply chain network design decisions that involve facility location and capacity allocation are part of the long-term strategic decisions. In comparison, reconfiguration of the distribution network is a tactical level issue, which requires mid-term planning.

Furthermore, the case firm's supply chain network design problem is far more complex than any of the models we have come across in the literature, since the case firm's network redesign has multiple objectives which include optimal facility location for each demand point, and uncertainty of demand and political instability, therefore a decomposition method is recommended. Decomposition approaches allow managers to make realistic and detailed decisions at each of the levels of the supply chain network (Dullaert et al., 2007). The company should segregate the countries based on the challenges they face in each.

It is recommended that the case company consider implementing optimization network design models for countries that have minimum levels of uncertainty. Optimization supply chain network design models with certain demand quantity of Margolis et al., (2018) and Hammami and Frein (2014) that provide solutions for facility location problems, and the design of the distribution network can be adopted. These models also address facility opening problems. The network optimization design models of Zheng et al. (2019) that address lead time constraints with certain demand could be used to optimize lead time for those countries that are facing longer order-delivery time but have certain demand. On the other hand, those locations which have issues with demand uncertainty should be redesigned with models that address uncertainty (Jahani et al., 2018; Rahimi et al., 2019).

The supply chain network of the countries that are faced with stochastic demand and strategic level of uncertainty could be configured with the frameworks that address uncertainty such as the model proposed Fattahi et al. (2018). These models could be implemented to mitigate the uncertainty of demand while redesigning the supply chain network; most of these models use stochastic programming and scenario analysis to mitigate the risk while solving the production-distribution problem. Supply chain network design models such as Rahimi et al. (2019) and Goh et al. (2007) could be implemented for countries that have both demand and political uncertainty. These models address the optimal selection of distribution links and facility locations (including inventory and warehouse) with consideration of risks.

For integrating environmental issues, a multi-objective linear programming model similar to the one proposed by Chanchaichujit et al. (2020) for the tire industry could be used to optimize total costs and total GHG emissions simultaneously. The total costs can include all supply chain costs, such as production, inventory, and transportation.

Furthermore, for the circular economy, the supply chain network design of the retreading plants and collection points for old tires could be executed with the use of the models of Amin et al. (2017) and Pedram et al. (2017).

5. Conclusion and lessons learned

In this paper, the objectives have been met, as many supply chain network design models were reviewed to provide managerial support for the case firm's network design planning. This includes a review of the models and approaches that optimize supply chain networks by reducing the cost of operation or maximizing profit while focusing on improving customer service level (lead time). Similarly, levels of uncertainty were first identified, followed by the introduction of models that configure supply chain networks with solution approaches to multiple levels of uncertainty. Environmental and closed-loop models were analyzed to support the supply chain network design of the case firm. Importantly, the understanding garnered from the review was helpful in first understanding the network issues of the case firm and then provide valuable recommendations.

Given the valuable insights synthesized from the review and case study, the literature and case study be understand the network issues to any firm in any industry. The studies discoursed in this paper could provide implications for practitioners that are considering supply chain network design by guiding them to the right network design models based on their supply chain network design objectives. Similarly, through the analysis and review of the recent works of literature, this paper has added to the body of the supply chain network design models by highlighting the gaps that exist in literature. Therefore, supply chain network academics may find this paper helpful to recognize the gaps in the models and consequently build on the knowledge.

The study has some limitations. While the literature review for this paper was extensive, it is not exhaustive or systematic. In future research, additional aspects can be considered in the supply chain network design/redesign such as customs, duties, and the clearance time at ports. Despite the limitations, we think that the findings of this study can significantly contribute towards the advancement of supply chain network design/redesign models and encourage more research in this field.

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