QATAR UNIVERSITY

COLLEGE OF ENGINEERING

OPTIMIZING THE DISTRIBUTION CENTRE LOCATIONS FOR AGRICO FOOD COMPANY USING ANYLOGISTIX SIMULATION

BY

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ABSTRACT

ALNABET AISHA JARALLA, Masters: January 2023, Masters of Science in Engineering Management: Robustness and Resilience of Supply Chain at Agrico Food Company

Supervisor of Thesis: Mohamed Kharbeche, Khalifa Al-Khalifa.

A supply chain is an integral part of any organization. Every company needs effective, robust, resilient supply chain processes to remain profitable and competitive. Resilience can be defined as the ability of a supply chain process to go back to its original functional state or improve to a better state after interruptions. On the other hand, robustness is the ability of a firm to sustain operations during periods of crisis (Miroudot, 2020).

This Thesis evaluated the robustness and resilience of the supply chain in Agrico food company amid many challenges that disrupt supply chain processes. The study used a descriptive nature and a quantitative approach to analyze data and make conclusions and recommendations. The study used secondary data obtained from Agrico food company. Additionally, the study used AnyLogistix software to conduct several simulations and modeling to optimize supply chain operations. GFA analysis was done to establish the best scenario for adoption by Agrico Company. The nonlinear mathematical model was also used to locate a distribution center that serves many customers to minimize the distance between the distribution center and customers. From the analysis, scenario 1 was the best since it takes one day to deliver the products to the customers. On the other hand, scenarios 3 and 4 take more than a day to make deliveries.

DEDICATION

This work is dedicated to my family, parents, and friends for supporting me throughout my studies.

ACKNOWLEDGMENTS

"First, I want to acknowledge my supervisors' continuous guidance and coaching throughout this Thesis. I could not have made it were it not for the frequent follow-up meetings and guidance on methodology.

I want to acknowledge Chaima Ben Rabeh for her unswerving support regarding technology resources, including AnyLogistix software. Your contribution went a long way in making this project a success.

My acknowledgment goes to the entire university staff, particularly the teaching fraternity, for the support they accorded to me during the period of this Thesis.

Lastly, I acknowledge my fellow students with whom we have traveled the journey of education together, always supporting one another for the success of everyone.

To all of you who helped me in one way or another, I thank you very much”.

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ACRONYMS

AFSCN	Agro-Food Supply Chain Networks
CMS	Complex Manufacturing Systems
COVID-19	Corona Virus Disease
DC	Distribution Center
FIFA World Cup	Fédération Internationale de Football Association World Cup
GFA	Green Fields Analysis
QAR	Qatari Riyal
SME	Small and Medium-sized Enterprise

CHAPTER 1: INTRODUCTION

1.0 Background Information

A supply chain is an integral part of any organization. Every company needs effective, robust, resilient supply chain processes to remain profitable and compete effectively. A food company's supply chain focuses on the movement of food from the farm and its distribution to the household or in food retail shops and enterprises (Dani S., 2015). Food supply chain processes comprise production at the farm, processing for value addition, distribution to different locations, and consumption and disposal of food wastes. The agricultural food supply chain involves the supply and deliveries of firm inputs such as fertilizers, pesticides, and manures useful for the production of farm produce. Several organizations use resilience and robustness to measure the optimization of their supply chains.

Supply chain resilience is the ability of a process to go back to its original functional state or improve to a better state post-interruption (Christopher & Peck, 2004). Ponomarov & Holcomb (2009) defined resilience as the system's capability to be ready for unplanned events, prompt response to any disruption, and its ability to regain its original operations at the needed proper management level. Tukamuhabwa et al. (2015) defined resilience as the adaptive nature and capability of a process supply chain to prepare adequately. Its subsequent ability to effectively respond to various disruptions, make a cost-effective recovery promptly, and after that, move to an after-disruption condition of its operations in an ideal way which should be better than the condition before the disruption. The authors add that operationalization should be done systematically, involving preparing for an event of a disruption; secondly, responding to the disruptive event; thirdly, recovering from such an event; and lastly, its ability to grow and gain competitive advantage post the disruptive event. Additionally, the adaptive capability entails its latency and ability to have various responses that match the varying nature of threats it is likely to face. The disruptions could be coevolving, inherent, and unforeseeable (Tukamuhabwa et al., 2015).

Resilience is typically adapting to difficult situations involving resistance and recovery. While resistance focuses on avoidance and containment, recovery entails stabilization of recovery of the supply chain processes and networks. Resistance means the supply chain networks have a capability for mitigating disruptive events and, at the same time, minimizing the impacts of such events through avoidance of the occurrence of such problems, after that containing the impact by mitigating it and restoring it to control. On the other hand, recovery makes the supply chain stable and returns to its original state. Supply chain robustness is defined as its ability to avoid or resist change. It is characterized by its optimization, low cost, consistency, and timeliness (Durach et al., 2015). These supply chain elements are important to an organization's overall performance because they reduce potential disruptive events, which cost resources and time and may lead to inefficiencies.

For an organization to achieve robustness, several factors must be considered, including functionality, effective communication, diversification, relevant data, resilience, flexibility, cost, and stakeholder management. Supply chain robustness leads to effective control of quality; collaborative nature of suppliers; optimized overhead costs and inventory; optimization of shipping; business agility; improvement in risk management; increased cash flow and revenue; and data-driven decision-making (Monostori, 2018).

A domino effect characterizes the food supply chain, whereby disruption of one point of the process leads to similar disruption in the entire supply chain. This manifests itself through changes in food availability and respective prices. For example, the onset of COVID-19 led to health safety issues which called for strict working conditions required of all workers while carrying out farming activities. Subsequently, the pandemic increased food demand due to panic buying by consumers. This forced many restaurants to close, leading to distributors and suppliers having excessive stock levels (Hassen et al., 2020). Figure 1 below shows cycle of movements of food and money in a simple food supply chain.

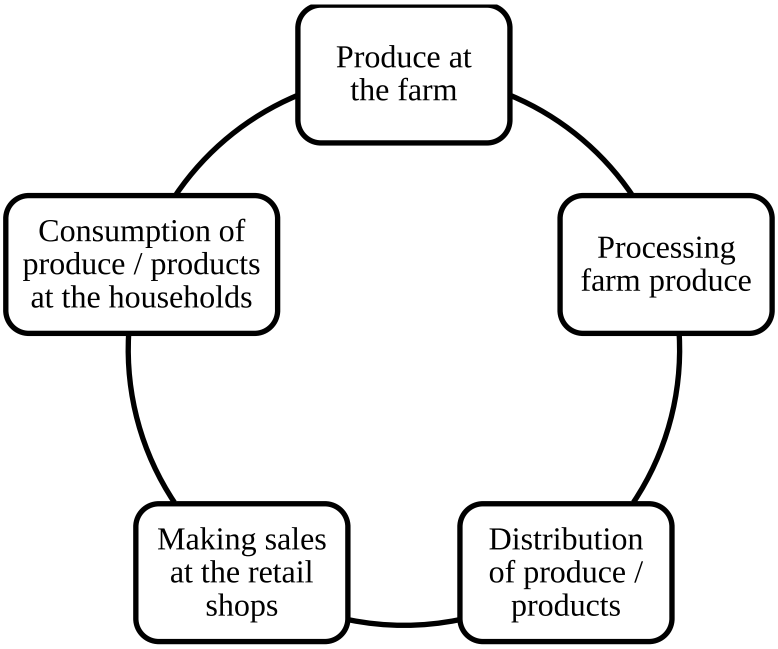

Figure 1. Cycle of movements of food and money in a simple food supply chain.

Food produce is transported from the farm to the consumer, whose money is used by the respective customers to pay for the food item. The food is supplied to individuals at various phases of the distribution channels. The supply chain process involves the coordination of deliveries and the computation of food costs. According to van der Vorst and J. G. (2000), it requires good collaboration, knowledge-sharing, adequate resources, and, most importantly, effective communication across all levels. Because one stage of the chain affects another stage, it becomes necessary to streamline the process to reduce costs resulting from inefficiencies. Globalization of the supply chain means that a disruption in one part of the world would be felt in another (Tasnim & Zerin (2020). Therefore, nations need to be responsible for optimizing and streamlining food supply chains to maintain safety and affordable costs for retailers and final consumers of the products (Vlajic, 2012).

Challenges faced in the distribution channels include food loss and waste, which can lead to decreased availability (Gustavsson et al., 2011). As a result, it negatively affects food prices and the unavailability of items to low-income consumers. Deterioration of the quality of food, which is most common to perishable food items, negatively impacts the livelihood and well-being of producers, especially if these items are sold at throwaway prices. This means that the food supply chain is quickly evolving, and governments and consumers continue to satisfy the demand and provide safe and fresh foodstuffs.

1.1 Overview of Agrico Company

Agrico is a food company located 58 kilometers from Doha, Qatar. The company has existed for about 70 years, established in 1955. The company contributes significantly to national food security through an extensive distribution of its farm products beyond Doha (Hassen et al., 2020). It is dedicated to helping Qatar's government break the ever-increasing cycle of imported foods (Kaitibie et al., 2017), conserve resources, manage climate variability, and improve the nutrition and well-being of the people of Qatar (Seed, 2015).

Agrico started its production of excellent fresh foods in 2011 to supply mainly farm fruits, vegetables, and seafood and has been credited for its significant contribution to the food supply in Qatar. The Agrico market segment includes Qatari families, neighboring markets, and about 1,400 supermarkets, cafes, hotels, restaurants, and caterers. Some of Agrico's distributors and customers include Spar, Almeria, Carrefour, Geant, lulu, mega mart, makar hypermarkets, smart, Saudia hypermarkets, Ansar gallery, and family food center. Agrico's key products include eggs, vegetables, mushrooms, leafy –greens, honey, and fruits (Seed, 2015).

The company has taken advantage of the advancement in global agricultural technology, available local knowledge, expertise, and experience to set a new trend for future farming. For example, Agrico was the first food company in Qatar to install air conditioning, which enabled it to produce and import fruits and meat from Lebanon. This facility allowed the company also to export frozen fish to Lebanon when establishing the first road transport service (Seed, 2015).

Advanced research and agricultural technologies have enabled the company to consume less water and electricity, thereby contributing to environmental sustainability (Ismail, 2015). The use of greenhouse farming technology led to its production capability in all seasons. Therefore, the farm can carry out continuous farming that makes all products available in all seasons. Furthermore, Agrico supports upcoming farmers in Qatar by offering a solution to farming issues through its customized farming systems. It achieves this by providing knowledge and required farming information, planning, and setup of farms, harvesting and distribution, farm growth management, and maintenance of the farms (Messerlin, 2003).

1.2 Problem Statement

There are many shortcomings in the supply chain of foodstuffs, including the ability of food handlers to carry out food traceability when needed as per consumers' demand, fragmentation of the supply chain, increased government regulations, lack of honesty, and food fraud (Turi et al., 2014). These factors negatively affect the robustness, resilience, and effectiveness of the food supply chain, whose management requires a robust involvement in oversight of every activity of its supply networks to ensure the taste, safety, and quality of all items distributed along the chain. All stages of the food supply chain are bound to be disrupted if proper management activities and processes are not properly followed.

Food security is an important issue throughout the world, as it reflects on a country's self-sufficiency and the welfare of citizens. Several factors affect food security in the Middle East region (Babar & Kamrava, 2014). For instance, Qatar is hosting the 2022 FIFA World Cup, where more than 2 million people will be accommodated; hence food consumption will increase significantly (Henderson, 2014). Therefore, the supply network is expected to quickly respond to this increase in the constantly changing market needs and to any other disruption or risks that threaten its efficiency.

It is worth noting that the vision, mission, and objectives of Agrico Farm align with Qatar National Food Security Strategy 2018 – 2023. To build a robust food security strategy, Qatar focuses on key pillars, one of them being the supply chain. The supply chain pillar focuses on food supply chain efficiency, Reduced waste in the supply chain, and Better food quality for end-consumers.

Several studies have been conducted on the resilience and robustness of supply networks. However, these past studies remained the same on the agricultural food supply chain, particularly in Qatar and Arabian Gulf, which have unconducive climatic conditions for successful agricultural production. Moreover, this may be because of a few agricultural fresh farm food production/farming companies in Qatar. Few farming activities may be attributed to unfavorable weather and climate, which make farming prospects unaffordable (Karanisa et al., 2021). Therefore, this research sought to bridge the gaps by measuring and evaluating the performance of Agrico Food concerning the changing industry standards.

1.3 Aims of the Research

This Thesis aimed to determine and recommend an optimal network design based on the location of the distribution center for Agrico Food Company.

1.4 Objectives of the Research

1. To evaluate the level of performance of supply chain processes at Agrico Food company by use of AnyLogistix GFA analysis.
2. To determine optimal network design based on the location of the distribution center for Agrico Food Company.

1.5 Research Questions

In this Thesis, the researcher sought to answer the below questions:

1. What were the best simulation scenario and optimal networks for optimizing supply chain processes at Agrico Food company?
2. What was the level of performance of the supply chain processes of Agrico Food Company?

1.6 Significance of Research

This research was important as it established key factors that affected the robustness and resilience of the supply chain processes of Agrico Company and generated measures and solutions to be put in place to reduce the risks. Likewise, the findings were useful to similar farms producing and supplying various products in Qatar and the Middle East. The report would be useful to potential investors in food and agribusiness firms in Qatar and the neighborhood. When the food supply chains of most companies improve, the national food supply chain improves, thereby improving distribution and availability to all populations. Finally, the recommendation of this study is useful to future researchers to further studies on similar and related research topics.

1.7 Scope of Study

The research is limited to evaluating the robustness and resilience of the supply chain of Agrico Food Company. The study was conducted at Agrico food Company in Doha, Qatar.

1.8 Structure of the Report

This report has five chapters. In the beginning, the introduction is covered, including background information, an overview of Agrico Food Company, a description of the problem under investigation, aims, objectives, questions, significance, and the scope of this research. Chapter two covers the literature review with a summary of past similar literary works done by other researchers. Chapter three describes the research methodology, including the design used, statement of hypothesis, research location, procedures of collecting and analyzing data, results from discussion and interpretation, measures and operationalization of research, ethical issues, and research limitations. Chapter four mainly covers simulation and modeling using AnyLogistix program. This is where green field analysis (GFA) is conducted for various scenarios, and outcomes are analyzed and evaluated for implementation and possible risk analysis. In the end, the conclusion and the recommendation for future works are covered in chapter 5. Finally, the report lists references and appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to the Chapter

In chapter two, the study explores disruptions and disturbances in the general supply chain, the design model of a robust supply chain, supply chain performance, and the food supply chain.

2.2 Disruptions and Disturbances in Supply Chain

Bevilacqua et al. (2018) studied the structure and components of supply chain resilience to assess how the supply chain performs during business threats and disruptions. Resilience is understood through accuracy in studying various factors that affect the overall performance of supply processes.

The supply process disruption consists of two divisions, namely the dampening time and the recovery time. The two periods consist of eight stages: the preparation phase, where the firm puts together activities to prevent an anomaly, thereby reducing chances plus the outcome of a risk when possible. The disruptive event stage is the second phase when the actual disruption occurs. The initial reaction is when the organization establishes the first response to the disruption regarding a workable solution to contain and avoid more damage. In this phase, the effect of disturbance on results and performance is felt for the first time (Bevilacqua et al., 2018). The preparation for recovery aims to restore tasks and activities to normalcy and involves creating and listing all items required to normalize the situation. In their conclusion, Bevilacqua et al. (2018) find a direct contribution of various performance factors in periods of disruptions.

Disruptive circumstances in complex manufacturing systems (CMS) with high labor characteristics and routine tasks increase the system's vulnerability; therefore, the processes need to be optimized (Latsou et al., 2021). The authors note that the ever-increasing interest raises the need to understand and handle systems' complexities, making them prone to vulnerability whenever there is a disruption (Latsou et al., 2021).

The culmination of effects resulting from disruptive occurrences can become rapid and of considerable magnitude, leading to delays in production or losses. Therefore, the research by Latsou et al. (2021) aimed to optimize the varying resilience in CMSs subject to various concurrent disruptions by changes made to the system's design by establishing the combination of allocating resources with the most incredible efficiency. The study results found that reallocating operators at various workstations significantly improves the resilience of the multi-dimensional system.

Supply chain management involves internal risks aggravated by the ever-piling pressure to make processes efficient. There is uncertainty and subjectivity in an attempt to deal with these complex risks in the supply chain, creating difficult analytical evaluations of circumstances, particularly with the adequacy of analysis (Garcia & You, 2015). Therefore, there is a need to assess and quantify supply chain risks by utilizing an effective and acceptable risk index and applying appropriate tools. The proposed risk evaluation and quantification methodology involve creating a risk hierarchy for a specific environment; determining risk weight at each level; determining risk score at the lowest level; and finally consolidating scores and weights indicating the overall risk index (Samvedi et al., 2013).

The COVID-19 pandemic led to unforeseen effects on the availability of labor, movement of services and products in value chains, and, consequently, in the markets. There was a need to document the short-term impacts of the pandemic, plus its relevant mitigation measures on agricultural setups for future planning and resource allocation. Additionally, there was a need to assess and quantify the impacts and opportunities to guarantee resilience, particularly for farming systems and farms, as noted by Snow et al. (2021). The research found relatively low impacts of the pandemic on New Zealand and Australian agricultural farms in the respective case studies. Resilience improves with increased technology, enhanced connections and supply networks, learning from previous experiences of shocks of similar magnitudes, and government support through subsidies (Snow et al., 2021).

Artsiomchyk & Zhivitskaya (2013) note that many supply chain events are attributed to disturbances in the processes. These include failures of suppliers as a result of unplanned events like fires burning down the warehouses, delays of deliveries due to problems during transportation, and product recalls when their safety and quality standards are not adequately met as per customers' requirements. On the other hand, an adequate integral methodology to guide organizations in managing disruptions to achieve robustness in the supply chain. Additionally, the authors suggest e need to reduce supply chain vulnerabilities to enhance robustness. To mitigate the impacts of the disturbances and improve efficiencies, organizations have tried to identify and eliminate nonvalue add activities in the processes (Artsiomchyk & Zhivitskaya, 2013). Figure 2 below shows a research model for establishing a supply chain with robustness.

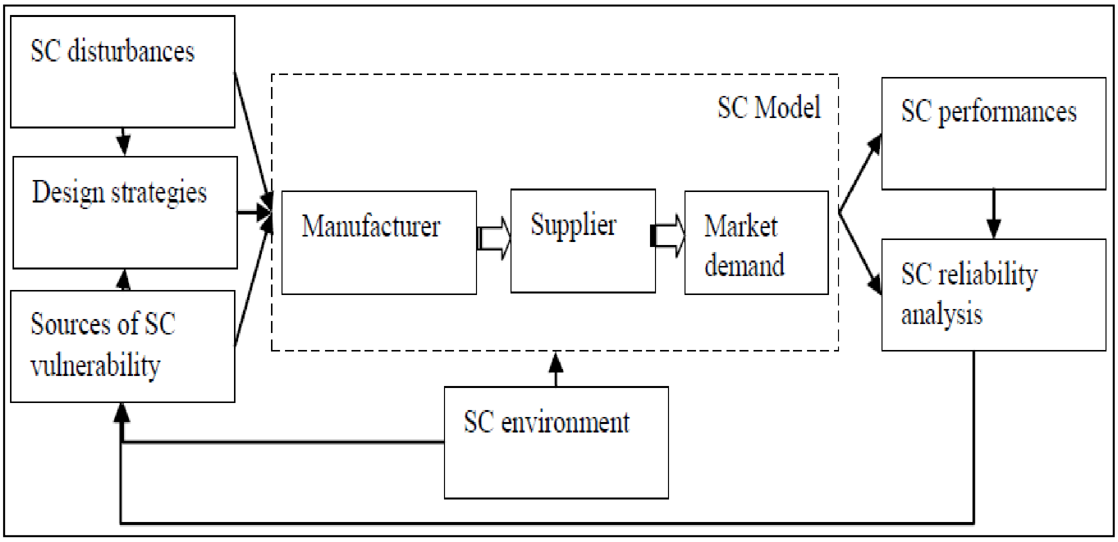

Figure 2. Design model for a robust supply chain. Source: Artsiomchyk & Zhivitskaya (2013)

According to Viswanadham & Gaonkar (2008), the initial preparation step for preventing supply chain disturbance means being aware of their existence. The authors added that the design strategies' determination depends on the disorders and their respective sources of vulnerabilities. These include strategic plans and the cascaded operational actions linked to the results of supply chain robustness. In implementing the redesign strategy, at least one of the elements is altered to give the desired scenarios. The outcome involves the removal of the source of vulnerability leading to a reduction of the disturbances and respective frequencies.

2.3 Supply Chain Performance

Robust and resilient supply processes are essential for any business to remain competitive. According to Artsiomchyk & Zhivitskaya (2015), the supply chain has leveraged technological advancement through innovations that are necessary for the performance and improvement of the processes. The authors assessed the sustainability of the supply chain regarding organizational innovation management. They also note that success depends on using innovations as a critical and intangible resource in supply chain control. Innovations in the supply chain put together technology developments around information and communication advancements. These technologies possess new logistics and procedures for marketing, which are essential in improving efficiencies in operations and promoting the effectiveness of the services offered.

Innovations in the supply chain comprise automated orders through scanning, on-time response to customers, and consistent and adequate replenishment among the rest of the processes utilizing technology in outbound supply chain activities. Besides improving operational efficiencies, technology-oriented supply chain activities save money for organizations through significant cost reductions, thereby increasing profits and revenue. In their study, Artsiomchyk & Zhivitskaya (2015) conclude that adequate evidence supports the notion that network structures and corresponding relationships form supply networks. These are vital elements used to identify essential components in supply chain management, as is also argued by Borgatti & Li (2009). In their findings, Artsiomchyk & Zhivitskaya also note that enhanced knowledge and information flow due to the accessibility of the supply network influences the output of a firm. Therefore, a firm's overall performance is improved by the impact of innovation on the supply chain components. The Internet of Things (IoT) has improved supply chain networks by allowing enhanced connectedness (Al-Talib et al., 2020). IoT is a valuable tool for effective communication, on-time risk management, and restoring processes to normalcy in the event of a disruption.

Sustaining global performance requires resilient supply networks built on trust to counteract the ripple effects of propagating disruptions, as Giannoccaro & Iftikhar (2022) argue in their study to investigate the key drivers to supply networks resilience. Trust positively affects supply networks, even though varied, based on different topologies. On the other hand, it also depends on the frequency of disruption. In this case, trust reduces with the increased number of disruptions, thereby reducing the level of resilience of supply networks.

2.4 Food Supply Chain

The supply chain of modern agriculture has significantly evolved into a globally interconnected platform consisting of millions of stakeholders connected through the Internet of Things. The incorporation of technology in farming has influenced the production, manufacturing, transportation, and delivery of produce to markets and households. One of the critical concerns faced by agricultural stakeholders is the frequent fraud due to inadequate transparency in farming supply chains, leading to losses in finances, customer mistrust, and brand values. To address these gaps, there is a need to develop a trading environment with high efficiency and reliability, such as the use of blockchain (Mirabelli & Solina, 2020).

There are many risks in the agricultural supply chain. The number and magnitude of risks increase with the number of actors at different levels (Bavarsad et al., 1999). Additionally, Nyamah et al. (2017) argue that the agricultural food supply chain is complex due to the production of seasonal products, production lead times that take more extended, non-uniform quality standards, and restrictions due to trade and buffer stocks. Moreover, in their review of the literature with attempts to identify the different obstacles faced in agro-food supply chain networks (AFSCN) and to investigate measurements of performance in AFSCN, Yadav et al. (2022) note escalating issues to do with inadequate regulations by the government, food security, traceability, and sustainability gaps. In conclusion, Yadav et al. (2022) recommend adopting appropriate tools and techniques to address these common hurdles.

Measuring the supply chain's performance is key because it enables tracking and follow-up of efficiency parameters vital in designing supply chain processes and networks. The many inputs and outputs in the system make the supply chain complicated. In their study, Aramyan et al., 2007, recommend the evaluation of the applicability of a conceptual model for effective performance reviews in the agricultural food supply chain (McCullough et al., 2010). Enhancing openness in the food supply chain through technologies requires efforts from relevant stakeholders to work as a team and tackle the challenges. The specific challenges include technical connectivity issues, requirements for data storage, security of devices, and regulations by the government (Astill et al., 2019).

In a study that sought to develop a quality application to improve the supply chain's resilience in small and medium-sized enterprises (SME) for agricultural food systems and to understand the risks involved and customer needs better, Wicaksono & Illés (2022) found that the critical customer requirements include colors that are bright and attractive, firm textures, and fresh produce. Additionally, the researchers note that high-priority risks include improper storage facilities and methods, human skills risks, and harvest failure. Furthermore, they add that improving resilience means engaging in preventive maintenance, forecasting, and continuous training of farmers and employees.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Methodology of the Study

This study focused on the food supply chain to evaluate the robustness and resilience of the supply chain at Agrico Company in Qatar. Qatar's economic food supply chain has been modeled by its different components, such as farms, distribution centers, and retailers (Namany et al., 2022). The study design used in this Thesis took a descriptive nature by evaluating the resilience and robustness of the food supply chain in the study company. Moreover, the study applied a quantitative approach as it used the readily available secondary data at Agrico farm.

Information about the locally produced fruits and vegetables in Qatar, their demand, and the corresponding retailers were collected from Agrico food company. Data analysis was done using Microsoft Excel to determine the demand variations in 2019 and 2020. The data was analyzed to establish the demand level for each product, including capsicum, cherry, cucumber, eggplant, tomato, and zucchini (Disman et al., 2017).

Data analysis included the computation of each product's totals and averages of each product which were compared against the subsequent years. The quantities were used to determine the demand generated by the company. Both products with the highest and lowest demands were determined, and the factors and reasons behind these were evaluated. On the other hand, a detailed analysis of the customers and distribution channels was done to determine the highest purchasers, their frequency of purchases, and the type of products mostly bought (Albers, 2017).

As Mishra et al. 92018) note, the analysis results were used to answer the research questions about the statement of the research problem. Results were presented in graphical formats, figures, and tables for clear interpretation and to generate conclusions and recommendations. Particularly, time series trends were applied to compare the demand for the years 2019 and 2020. The study's final report was presented and shared with all relevant stakeholders.

Secondly, AnyLogistix software was also used to develop a multi-agent simulation model for the Agrico supply chain. The simulations aimed to reflect the overall performance during different disruption events (Utomo et al., 2018). Key performance indicators such as inventory level, service level, lead time, expected lead time service level, fulfillment rates, and financial metrics were evaluated, and comparisons were made (Chae, 2009). Several scenarios were simulated to determine their impacts on costs and delivery times. For example, the first scenario involved analysis of the original condition, which was disruption free; scenario one simulation involved GFA analysis using one distribution center (DC); scenario two involved GFA analysis using 2 DCs; demand was increased and impacts evaluated in scenario 3; and finally in scenario 4, key road networks were closed in 3 occasions and their respective impacts on Agrico supply chain performance evaluated. For each scenario outcome, a risk evaluation was conducted to develop mitigation measures in the likely event that such disruptions happen in the Agrico supply chain (Utomo et al., 2018).

Furthermore, a nonlinear mathematical model was used to establish a central location of a distribution center capable of serving a pool of customers while reducing the distance between the customers and the distribution center. An appropriate nonlinear process was followed in establishing the model. The steps included the definition and simplification of the Agrico problem; the creation of the mathematical model; transforming and solving the model; interpretation and validation, and application of the model.

3.1.1 Ethical Research

The research was conducted ethically. All research processes, including gathering data, were done according to the rules and regulations of doing ethical research. Consent was obtained that allowed the use of the company data and involved the company's participation in the study. Data acquired were utilized only for this research and would not be accessible to any third party. The data were safely stored in computers and password protected. These data were permanently deleted from the computers, and hard-copy files were destroyed upon completion of the study. Furthermore, no personal information and details were gathered during the study. All data were treated with the utmost confidentiality (Zyphur & Pierides, 2017).

The study used the readily available secondary data obtained from Agrico databases for 2019 and 2020. The authenticity and reliability of data were ensured, as risks were minimized. Agrico Company's inventory consists of its key products cherry, capsicum, eggplant, cucumber, zucchini, and tomatoes. The company had a pool of customers and distribution channels that purchased the products from the company's distribution center (DC) (Johnston, 2017).

3.1.2 Parameters for Supply Chain Optimization

a) The delivery time for the products is not more than one day

One of the key parameters monitored in the research was the products' delivery time in Agrico Food Company. In this aspect, the lead time of the delivery was regarded as the time taken between order placement and its actual delivery time.

b) Profits from Various Scenarios

Supply chain profit is determined by subtracting the overall costs from the total sales of products. It considers revenue allocation, costs incurred in supply chain operations, and risks. A profitable supply-chain efficient and effective management of resources, people, resources, technology, and supply chain activities. It is expected that an optimized supply chain would create and maintain a competitive advantage leading to cost reduction as well as improvement of revenue. These efficiencies can increase revenue while decreasing costs.

3.2 Secondary Data Analysis

Tomato had the highest demand, followed by cucumber, while capsicum had the lowest demand within the two years. Generally, the demand for 2020 was higher than in 2019 for cherry, cucumber, eggplant, and tomato. However, the demand dropped for a few products, including capsicum and zucchini. Figure 3 below shows the total generated demand for 2019 and 2020 for Agrico Food Company.

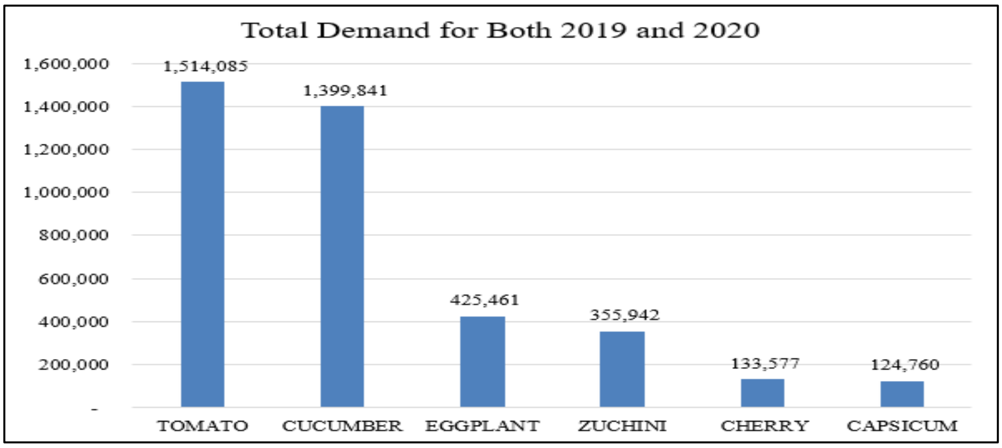

Figure 3. Total demand for both 2019 and 2020

The demand for tomatoes and cucumbers made up more than 50% of the total quantities for all products in 2019 and 2020. The comparison of demand for different products is made for 2019 versus 2020. Figure 4 below shows the comparison of generated demands of different products between 2019 and 2020 for Agrico Food Company.

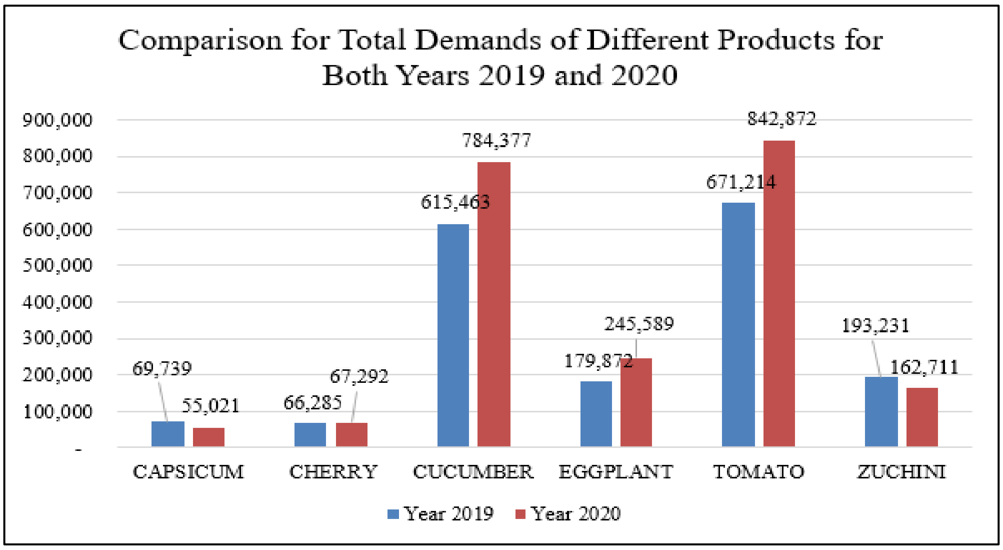

Figure 4. Comparison of demands of different products between 2019 and 2020

There was a significant variation in the demand generation by various customers for all the products combined in 2019. Some customers purchase higher quantities of some specific products than other customers. This was also the same case for the year 2020, where there was a significant variation in the demand generation by various customers for all the products combined. Figure 5 below compares the top 10 companies based on total generated demand quantities for all products in 2019.

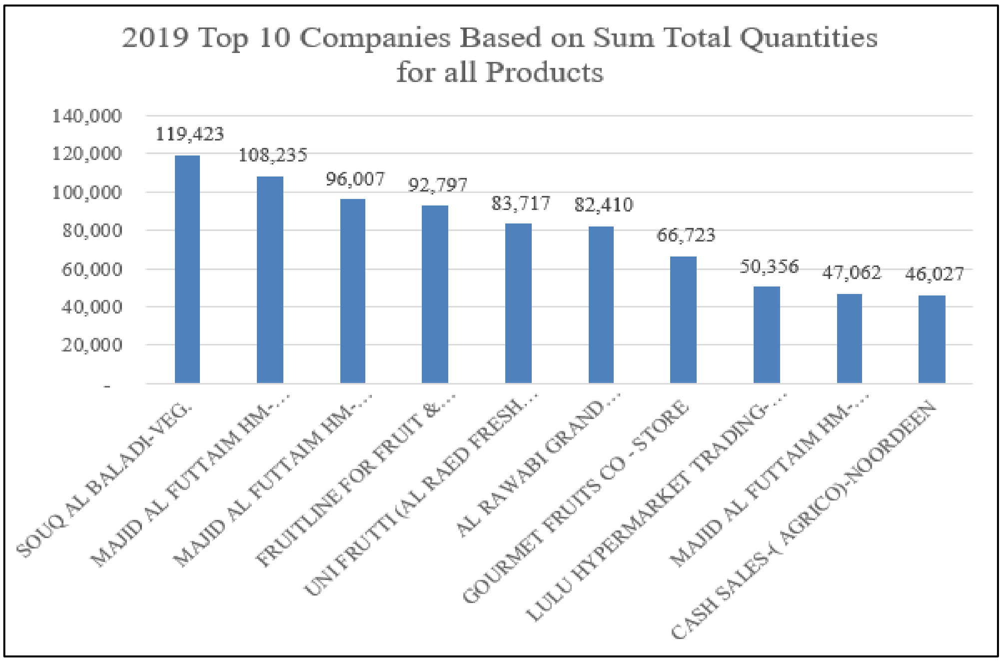

Figure 5. Top 10 customers based on overall total quantities for all products

The average demand for cucumber and tomato was higher than the average for all the products. For both years combined, tomatoes had the highest average quantities demanded in the two years, followed by the average demand for cucumber, which was the second highest within the two years. Additionally, the average demands in 2020 for most products were higher than those for 2019. Products with higher average demands included cherry, cucumber, eggplant, and tomato. However, the average demand dropped for a few products, including capsicum and zucchini. The average demands for cucumber and tomato were way higher than the average for all the products in both years. Figure 6 below compares the average total generated demand by-products for 2019 and 2020.

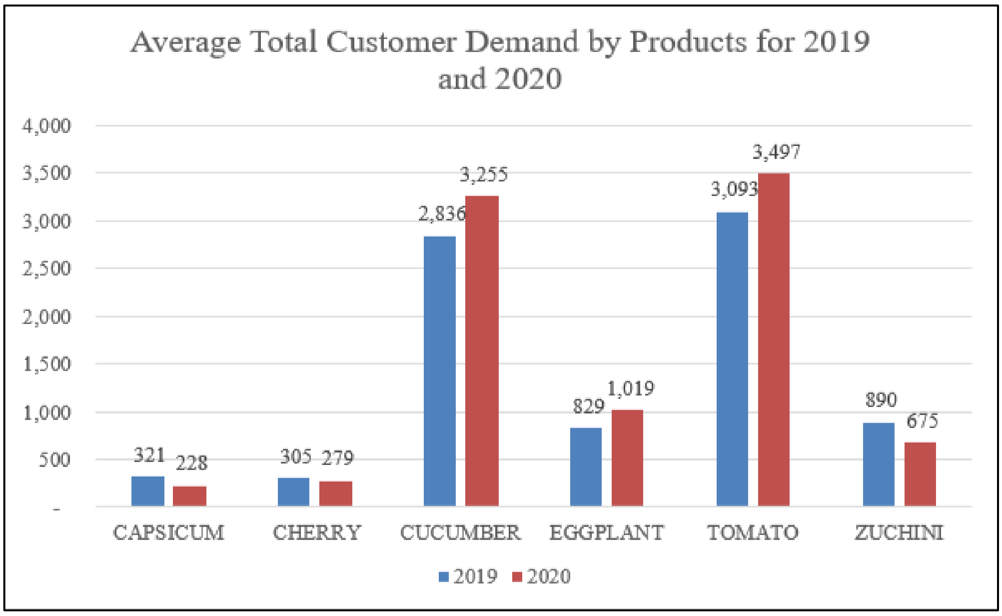

Figure 6. Average total demand by-products for 2019 and 2020

CHAPTER FOUR: SIMULATION AND MATHEMATICAL MODELING

4.0 A. OPTIMIZATION USING ANYLOGISTIX SOFTWARE

4.1 Introduction

AnyLogistix software is a supply chain and logistics simulator that is globally recognized. It is currently the only single multimethod software for analysis, network design, and supply chain optimization. The tool effectively combines innovative simulation technologies with traditional analytical optimization techniques. For the part of the analytical optimization, traditionally, the supply chain involves a series of equations and formulas whose outcome does not give the whole picture yet produces quick results (AnyLogistix, 2022). Several products have been compared to it that works the same as AnyLogistix, such as NetSuite, Tada, and supplier management software, all with specific capabilities in running the supply chain.

Linear equations are used to define operations in an analytical supply chain model. The consequences of applying this kind of approach comprise an increase in the complexity of modeling in an attempt to simplify the supply chain networks (Kleijnen, 2005). AnyLogistix assists management by giving a command center perspective. AnyLogistix optimization and simulation features allow, for example, the design of plans using network optimization and evaluation using simulation modeling. Supply chain analytics may be improved by combining optimization and simulation using AnyLogistix (AnyLogistix, 2022).

Tiwari et al. (2018) note that today's supply chains create a large amount of data and are, exposed to many risks. This further complicates the analysis even though it makes dynamic simulation modeling more appealing. In complex supply chains, the simulation may be used to determine safety stock values, evaluate inventory levels, and identify bottleneck areas and cost service levels. It can also be used to simulate worst-case scenarios by applying what-if questions, for example, new production facilities or transportation facilities.

Analytical optimization and dynamic simulation work together because they complement each other through useful features (Sarimveis et al., 2008). Companies may simulate the whole supply chain by using AnyLogistix software as a robust supply chain simulation tool and make profits from the advantages of both approaches at the same time.

In the application of AnyLogistix, supply chain managers and experts can create simulations to optimize their processes and conduct analysis before actual implementation. It helps optimize distribution center capacity, location, planning, and the frequent reviews of inventory control policies and ordering rules. AnyLogistix software may assist businesses in better answering the following questions: What is the optimal number of facilities, and where to locate them?; where and how much do they need to produce, store, and deliver?; what happens when they alter their inventory management strategy?; what are the possible outcomes of boosting the efficiency of a distribution center?; what happens when there is a shift in the order?; what is the impact of the additional products?; and what is the cost of having an out-of-stock event? (Ayanangshu, 2021).

4.2 Stepwise Optimization of AnyLogistix

AnyLogistix has become an ideal tool for organizations expanding to new markets or locations where they must begin and adapt the supply chain processes. Using AnyLogistix, managers, and supply chain process experts can discover new positions and ideal locations where warehouses can be established. This can be achieved by using the data to develop a simulation model (AnyLogistixs, 2022). Having such details in hand allows an organization to discover the effectiveness of the internal and external processes and take appropriate actions (Rachmawati et al., 2022).

4.3 Advantages of Using AnyLogistix

During the simulation, the software allows the user to consider every detail and specific mechanism of the supply chain elements. The results allow the user to visualize all the network operations while tracing all the inside processes (AnyLogistixs, 2022); AnyLogistix is an ideal tool for supply chain management because it does not require knowledge of programming. It offers a user-friendly experience with features and functions that are easy to use and understand (AnyLogistixs, 2022); Random network behavior can be captured using the tool, ensuring risk evaluation and reduction. The model is programmed to visualize, enabling the user to obtain credible results. On the other hand, it enables the user to alter the design of the network to execute the ordering and transportation of goods remotely, thereby avoiding the hustle of 'what-if' scenarios (Ayanangshu, 2021).

4.4 Challenges of Application of AnyLogistix

At times, it was hard to do a follow-up on the roadmap because of the confusion and the general use of the software; the tool may have waste routing and optimization habits in the major cities, and when the software is zoomed out, some of the links and features are cut off and disappear hence preventing the user from showing the whole network of the supply chain (Capterra, 2022).

4.5 Application of AnyLogistix in Green Fields Analysis

Using Green Fields Analysis (GFA), solving a facility's location problem was easier by employing the AnyLogistix system. GFA is a design for the supply chain that is sometimes referred to as the center of gravity analysis. The design is mainly used in the early stages of supply chain analysis. The procedure is vital since it permits the idea of effectively solving a facility's location problems, which involves determining the optimal number of distribution centers.

The procedure works for the production facilities and the best location for their placements. Usually, for any user in the supply chain, GFA is the first step in the design of the supply chain. Many options have to be in place for the location of the facilities, which GFA readily offers from the word go. Assumptions of the GFA thoughts are that there should be a high abstraction level where there should be fewer detail numbers needed, including; products, the customer location, individual customer products, demand, and distances to customers and distribution centers (AnyLogistixs, 2022).

Leaders use GFA to establish the best locations based on the proximity to customers in order to minimize transportation costs; figure out which customers need to be served from a specific facility; establish the optimum number of required facilities for the supply chain; minimize costs by optimizing the geographic location of facilities; determine the number of facilities required for a specific demand, and finally to carry out various simulations for demand and supply changes (Adhitya et al., 2022). Normally, analysts do not automatically have a list of "candidate" facilities; hence they use the tool to search for the best location in a target area.

Therefore, GFA simplifies the facility location problem because it only requires the locations of the customers and each customer's demand (weight) for each product.

The point of GFA is that it finds the approximate optimal location for a producing warehouse or a facility where there is a depreciation of the outbound and the inbound transportation making the optimal point the gravity center. The procedure, however, involves something other than geographical areas, roads, and cities, making it an ideal process for the basic supply chain (Zheng et al., 2022).

Supply chain GFA’s goal is to locate one or more facilities for distribution. The locations for these facilities are selected from a set of options and candidate locations. In normal circumstances, there is always an alternative set of existing facilities for evaluating new locations. Facility location, also called location-allocation analysis, is used to determine optimal locations for a certain number of facilities from a pool of alternative locations while concurrently assigning customers' demands to the distribution centers. By doing this, the provision of a high level of service is guaranteed, which minimizes costs and optimizes profits.

Each of the facilities usually serves several clients at the same time. For instance, in some cases, the clients are households or individuals; in other cases, clients can be manufacturing facilities or stores than a single facility. Additionally, a client may need more deliveries of a particular product different from another client located some distance from the distribution center (DC).

In other circumstances, one may put consideration to close existing warehouses as part of a warehouse location problem. In this scenario, the facility that might be closed is treated as one of the candidate facilities rather than the existing facilities. A maptitude is then used to determine whether these facilities should be closed or continue to operate.

AnyLogistix gives an exact picture of getting the optimal solution to the location of a facility and the general supply chain optimization and simulation. Since the GFA experiment does not use the analytical approach, the AnyLogistix tool comes in handy. Using the GFA experiment, AnyLogistix is fully employed to establish a product's stock volume, configure policies for inventory and do away with the orders lost and act on the ‘what if’ scenarios (Ayanangshu, 2021).

4.6 Simulation Metrics

The simulation results were evaluated through financial metrics, expected lead times, fulfillment (late orders), and average daily available inventory for different scenarios.

4.6.1 Financial Metrics

Financial metrics provide details about income and expenditures derived from different simulation scenarios. The supply chain's costs, revenues, and profits are all included in these metrics.

4.6.2 Expected Lead Time

This is the expected duration when a supply order is placed to Agrico Farm by the customer to the actual time when that order is delivered to the respective customer, usually measured in days. It tracks the estimated delivery time for the ordered product.

4.6.3 Average Daily Available Inventory

This is the amount of stock available at the stores for each of the Agrico products, counted and tracked daily. It shows the average volume of products in stock available to meet customers’ demands. It is important to keep inventory at safe levels to avoid stockouts and overstocking of the products.

4.6.4 Expected Lead Time (ELT) Service Level

This is a measure of value and satisfaction that customers derive from product deliveries. It is calculated by dividing the number of on-time orders by the total number of outgoing orders. High ELT service level generates high demand, while low levels lower the demand and may lead to customer complaints.

4.6.5 Fulfillment (Late Orders)

This is the average proportion of orders that a company can ship out of the existing stock while avoiding loss of backorders, stockouts, and sales. It measures the ability of Agrico Company to meet and satisfy customer demands and the supply chain's performance level. Additionally, it gives statistics on orders that still need to arrive as per the agreed-upon ELT.

4.7 The Green Field Analysis and Simulation Scenarios

4.7.1 Original Model (Status Before Simulations)

GFA was conducted for the original DC of Mahaseel at the location of latitude 25.20447 and longitude 51.3657, as shown in figure 7 below. The Mahaseel DC receives products from various farms, including SAIC, Agrico, and Safwa. Mahaseel DC serves various retailers, as outlined in appendixes 3 and 4 at the end of the report. The following are the assumptions used for simulation experiments:

- 50 customers.
- Three farms.
- Cucumber was selected for the simulation to represent other products. Other

products would still be selected, as they would still give similar outcomes.

- The cucumber selling price was taken from the Ministry of Commerce and Industry website.

By analyzing the original model, we found out that:

A - ELT service level is one during the full period.

B - Inventory for all farms and DC is stable.

C - Maximum lead time to deliver products to customers to be less than one day.

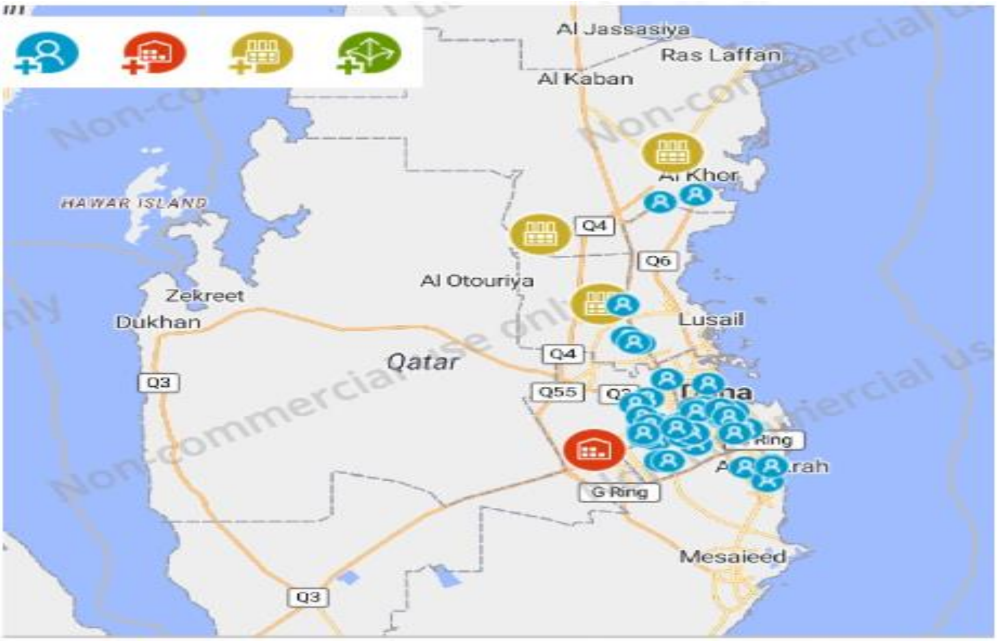

Figure 7. Original location of DC

Figure 8 below shows the financial performance metrics for the original (disruption-free) model. Various metrics were evaluated to be used as baselines to compare with other scenarios. The key metrics included inventory carrying cost, other costs, amount of profits generated, revenues generated, total costs, and transportation costs.

Supply chain cost centers		Value in QAR
1	Inventory carrying cost	218,439
2	Other cost	5,117,000
3	Profit	9,287,044
4	Revenue	16,365,427
5	Total cost	7,078,382
6	Transportation cost	1,742,944

Figure 8. Financial metrics for the original scenario

It was evident from the results in figure 9 below that there was enough stock available (more than 6,000kgs), allowing a high degree of flexibility to demand satisfaction. Additionally, inventory levels were stable throughout the period, as no fluctuations were observed.

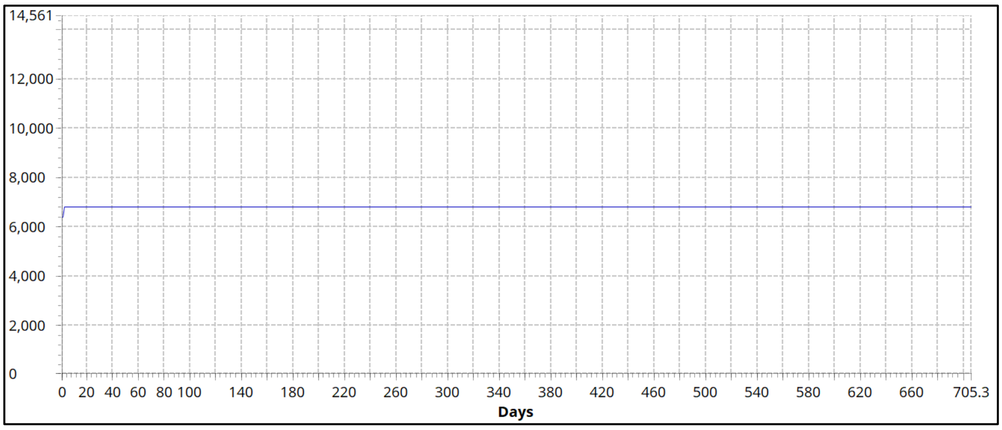

Figure 9. Average daily inventory in Kg

For the lead time, figure 10 below shows the daily lead time in days for the original model. It was observed that the cucumber was delivered between 0 and half a day against the expected delivery of less than a day. The longest expected lead time was one day. Thus, all products were delivered within the targeted timelines for the entire period.

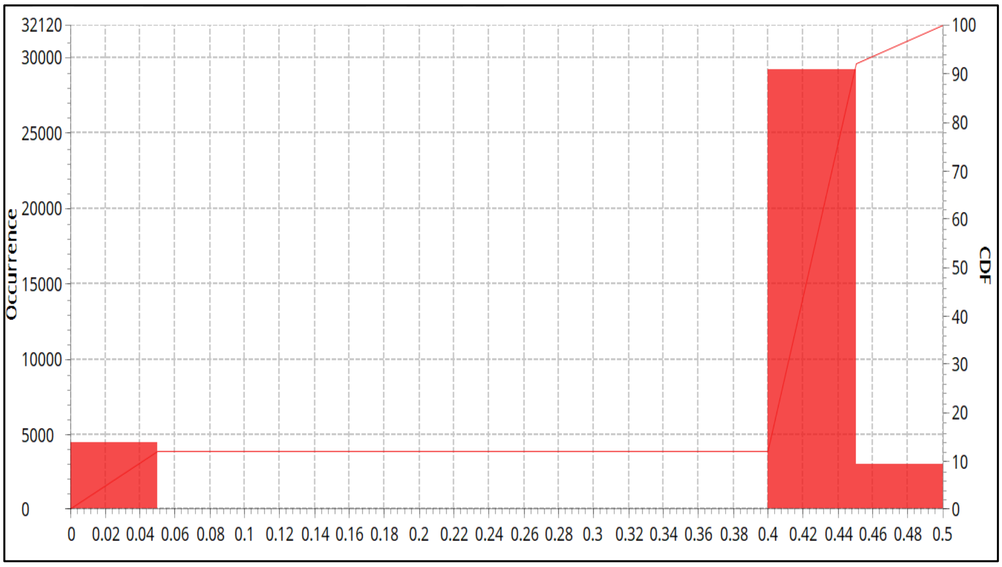

Figure 10. Lead time

As shown in figure 11 below of the ELT Service Level for the original model, 100% of orders were delivered without delays and within the expected timeframe of less than a day.

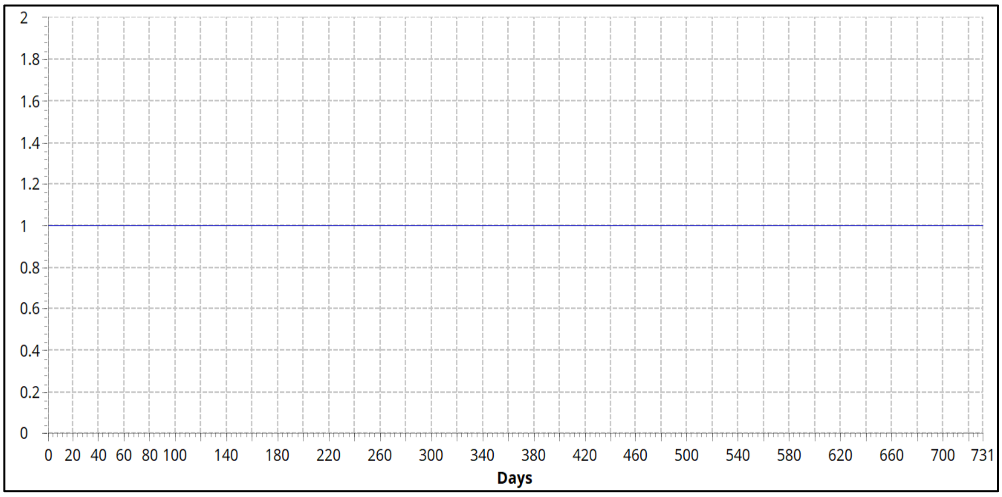

Figure 11. Expected Lead Time service level

4.7.2 Scenario 1 (1 GFA DC)

In scenario 1, a GFA was conducted, which determined the new location of the DC at a latitude of 25.655 and a longitude of 51.456, as shown in figure 12 below. This simulation was done to establish the impact on the robustness and resilience of the Agrico supply chain by using 1 DC.

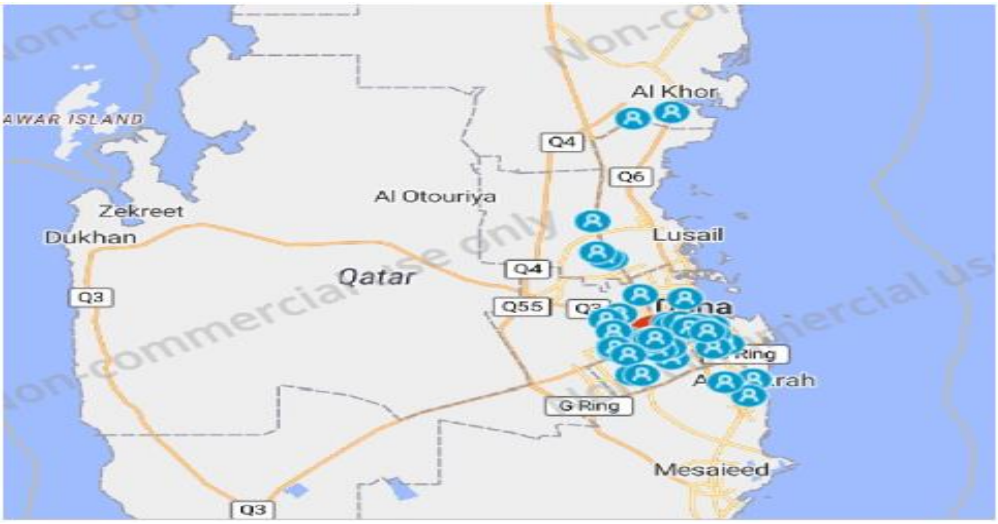

Figure 12. Map showing the location of the new GFA DC in red

Figure 13 below shows financial performance metrics for scenario 1. Compared to the original model, scenario 1 had lower inventory carrying total and transportation costs. Thus, it resulted in slightly more profit due to increased revenues. Other costs were, however, the same for both scenarios.

Supply chain cost centers		Value in QAR
1	Inventory carrying cost	3,036
2	Other cost	5,117,000
3	Profit	10,324,045
4	Revenue	16,365,427
5	Total cost	6,041,382
6	Transportation cost	921,346

Figure 13. Scenario 1 financial metrics

4.7.3 Scenario 2 (2 GFA DCS)

Scenario 2 corresponded to conducting a GFA to establish the optimal locations of 2 new DCs as shown in figure 14 below. This simulation was done to establish the impact on the robustness and resilience of the Agrico supply chain by using 2 DCs. The outcome of the GFA identified strategic locations where the newly identified distribution centers should be strategically placed to optimize the processes and reduce transportation costs. The optimization can significantly improve lead times for deliveries to retailers.

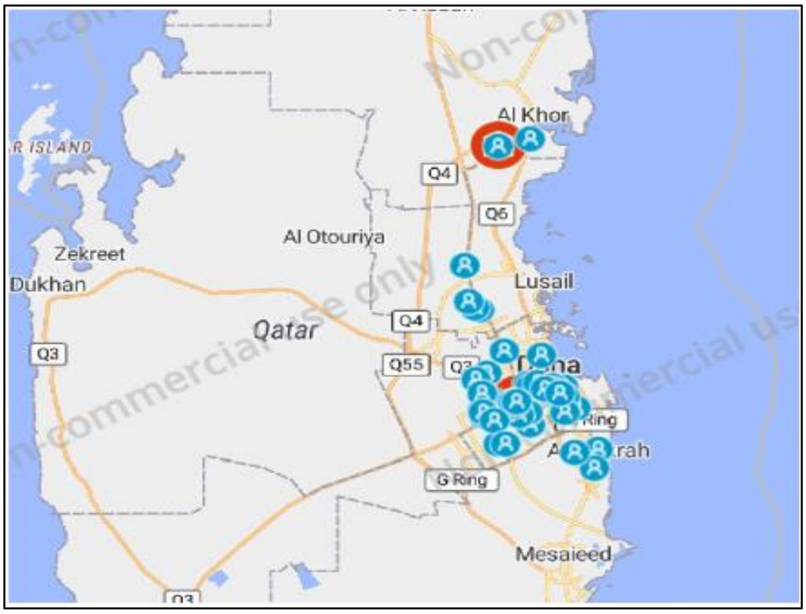

Figure 14. Location of the 2 new GFA DC in red (scenario 2)

Figure 15 below shows financial performance metrics for scenario 2. Compared to the original model, scenario 2 resulted in less total cost and transportation costs. On the other hand, it had an increase in other costs and inventory carrying costs while the revenues generated remained the same. The previous scenario with only one optimal GFA DC was more profitable due to the additional costs due to the additional DC.

Supply chain cost centers		Value in QAR
1	Inventory carrying cost	402,572
2	Other cost	5,848,000
3	Profit	9,425,783
4	Revenue	16,365,427
5	Total cost	6,939,643
6	Transportation cost	689,071

Figure 15. Scenario 2 financial metrics

4.7.4 Scenario 3: Increased Demand for Specific Periods

Scenario 3 was done by increasing the demand to enable risk analysis. Different disruption lengths for increased demand were analyzed and compared. This simulation was important because increased product demand is highly likely to occur mainly due to sports events, natural disasters, or pandemics and can significantly affect different supply chain sectors. The demand increase was performed for scenarios characterized by different severity ranging from 30% (i.e., low demand increase) to 80% (i.e., high demand increase) for generality and practical reasons. Moreover, the disruptions were scheduled in the middle of the simulation period in order to see clearly the pre-disruption and post-disruption effects. This simulation was done to evaluate the impact on the robustness and resilience of the Agrico supply chain by increasing demand for the existing condition. The variations of demand defined are shown in fugure 16 below.

Item	Period	Demand Increase (%)
1	01/01/2019 - 05/03/2019	0%
2	06/03/2019 - 20/08/2019	30%
3	21/08/2019 - 31/08/2019	0%
4	01/10/2019 - 31/09/2020	0%
5	03/01/2020 - 15/01/2020	80%
6	16/01/2020 - 31/01/2020	0%
7	01/10/2020 - 31/11/2020	0%
8	01/12/2020 - 21/12/2020	50%
9	22/12/2020 - 02/01/2020	0%

Figure 16. Periods and percentage of the demand increase (scenario 3)

Additionally, figure 17 below shows the financial performance metrics obtained by simulating scenario 3 in AnyLogistix.

Statistics name		Value
1	Inventory carrying cost	1,269
2	Other cost	5,117,000
3	Profit	22,836,958
4	revenue	28,715,099
5	Total cost	5,878,141
6	Transportation cost	759,872

Figure 17. Scenario 3 financial metrics in QAR

Compared to the original model, scenario 3 resulted in less inventory carrying cost and total cost. However, there was an increase in the profit and the revenue generated. Other costs were the same for both scenarios 2 and 3.

The visual results in figure 18 below show that the available stock was stable in the first year and increased drastically in the second year due to increased demand. However, there were fluctuations in demand in the second year. Throughout the period, stock levels did not return to initial levels.

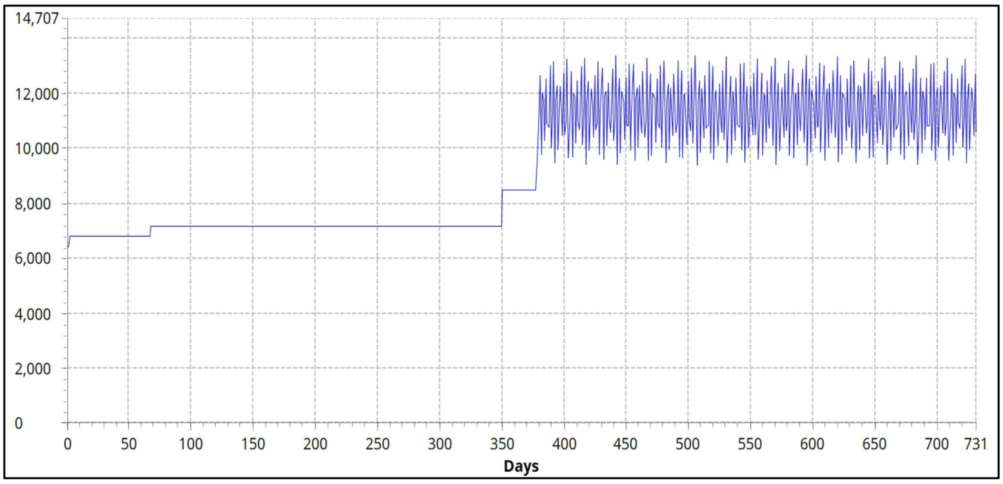

Figure 18. Average daily inventory in Kg

In scenario 2, as shown in figure 19 below, the lead time for most orders was above one day. It was observed that some orders took more than 138 days to be delivered and closed. In this case, the lead time was expected to be less than a day under normal circumstances. Based on these results, it was concluded that, as demand increased, the order processing rate took longer, leading to delivery delays.

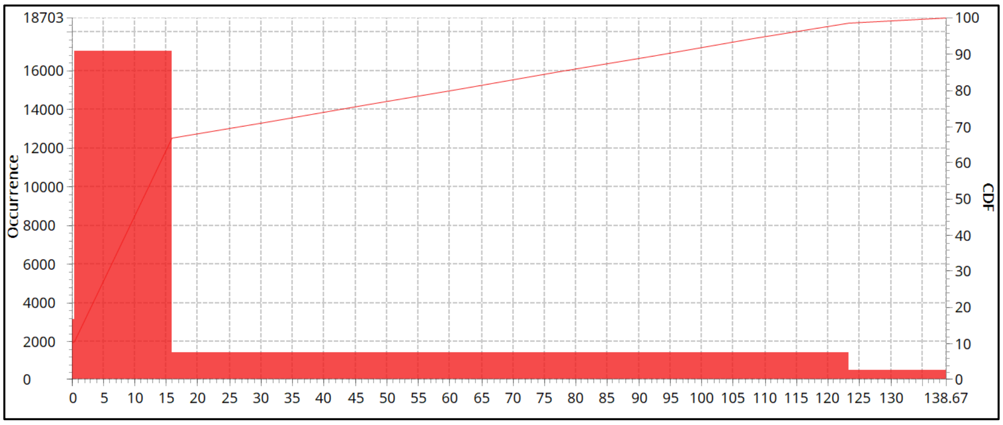

Figure 19. Lead time

Figure 20 below shows that the ELT service level was 100% in the first year and dropped significantly in the second year to about 30%. The drop in the second year signified decreased customer satisfaction which could be attributed to the increased trend of delayed orders due to increased demand that reduced order processing rates.

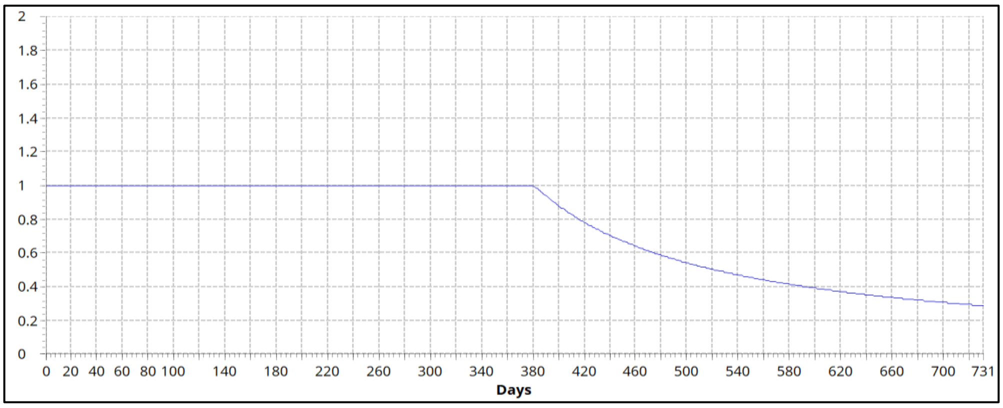

Figure 20. ELT service level

According to the results, fulfillment (Late Orders) is affected when lead time increases. In figure 21 below, there was an increased trend of late orders in the second year representing late orders. This was attributed to increased demand, hence reducing the order processing rate.

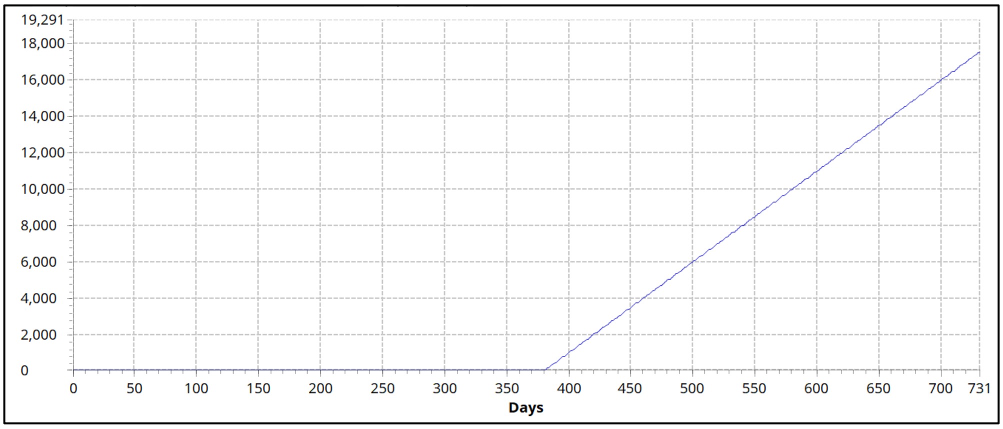

Figure 21. Fulfillment (Late orders)

Scenario 4: Closed Roads

This simulation evaluated the impact on the robustness and resilience of the Agrico supply chain by closing various key roads on different dates. Various disruption lengths with closed roads were analyzed, and comparisons were made. Road closures have a high probability to occur mainly due to natural disasters, pandemics, or sports events and can significantly affect different supply chain sectors. Additionally, the disruptions were scheduled in the middle of the simulation period in order to evaluate the pre-disruption and post-disruption impacts. Figure 22 below shows the closed roads along with the dates and duration of the closure.

Item	Period	Road closed	Number of days
1	22/10/2019 – 25/10/2019	SAIC farm to DC	4 days
2	29/12/2019 – 31/12/2019	Agrico farm to DC	3 days
3	4/4/2020 – 5/4/2020	DC to all the customers	1 day

Figure 22. Periods of road closure and demand increase

Figure 23 below shows the first closed road from SAIC Farm to the DC from 22/10/2019 – 25/10/2019 for a total of 4 days.

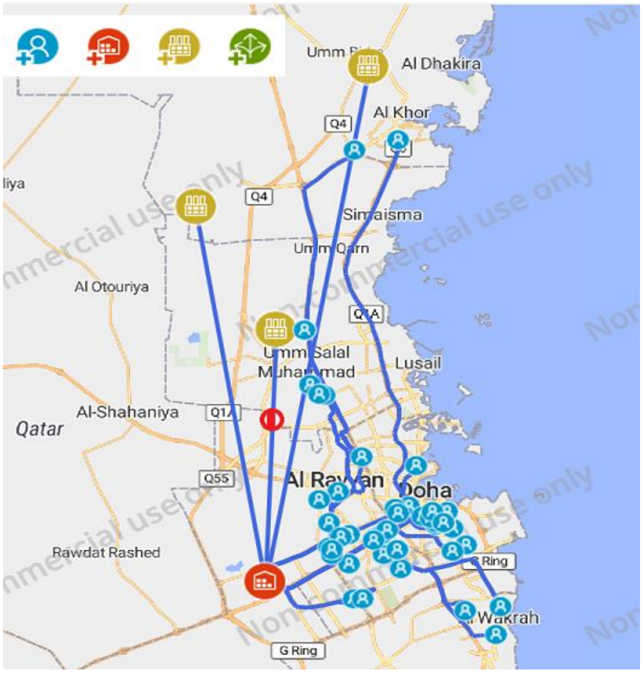

Figure 23. Closed one road from SAIC Farm to the DC

Figure 24 below shows the closed road from Agrico farm to DC from 29/12/2019 – 31/12/2019 for three days.

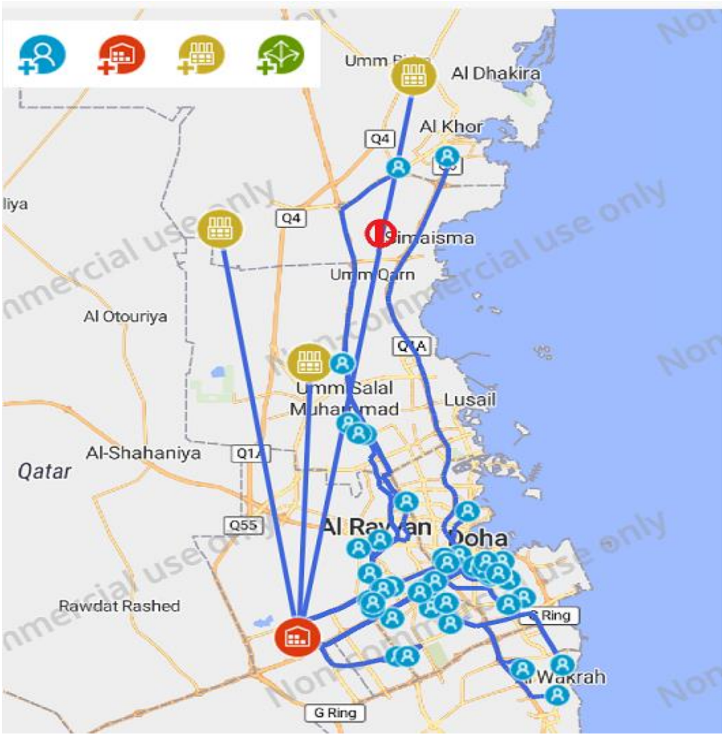

Figure 24. Closed road from Agrico Farm to DC

Figure 25 below shows the closed roads from DC to all the customers from 4/4/2020 – 5/4/2020 for a day.

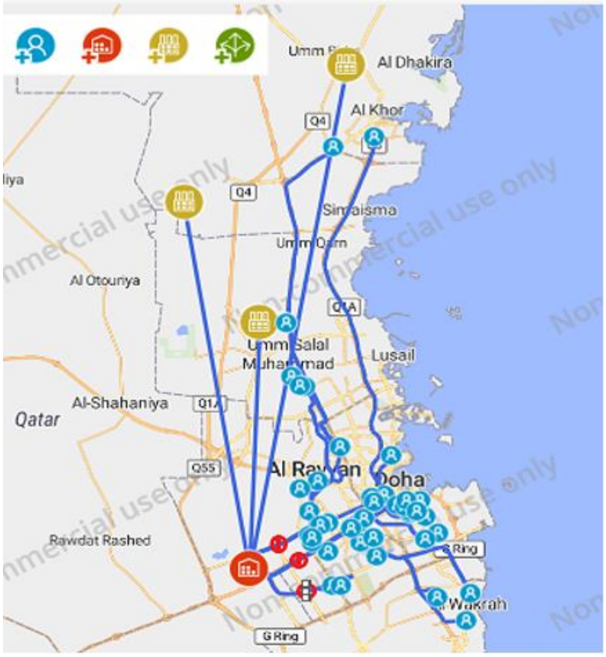

Figure 25. Closed 3 roads from DC to all the customers

Figure 26 below shows financial metrics representing simulation for two years covering the three events (disruptions) of roads closure. The key road networks closed in different periods were from SAIC Farm to DC for 4 days, from Agrico Fam to DC for 3 days, and from the DC to all the customers for 1 day.

Supply chain cost centers		Value in QAR
1	Inventory carrying cost	966,914
2	Other cost	5,117,000
3	Profit	2,202,246
4	Revenue	8,656,044
5	Total cost	6,453,798
6	Transportation cost	369,884

Figure 26. Scenario 4 financial metrics

Figure 27 below shows average daily inventory was stable at slightly below 7000 kg in the first year before it significantly dropped to between 3500 kg to 5000 kg. The drop was attributed to disruption due to closed roads which made the inventory unstable for some period before it again increased and became stable at 6000 kg.

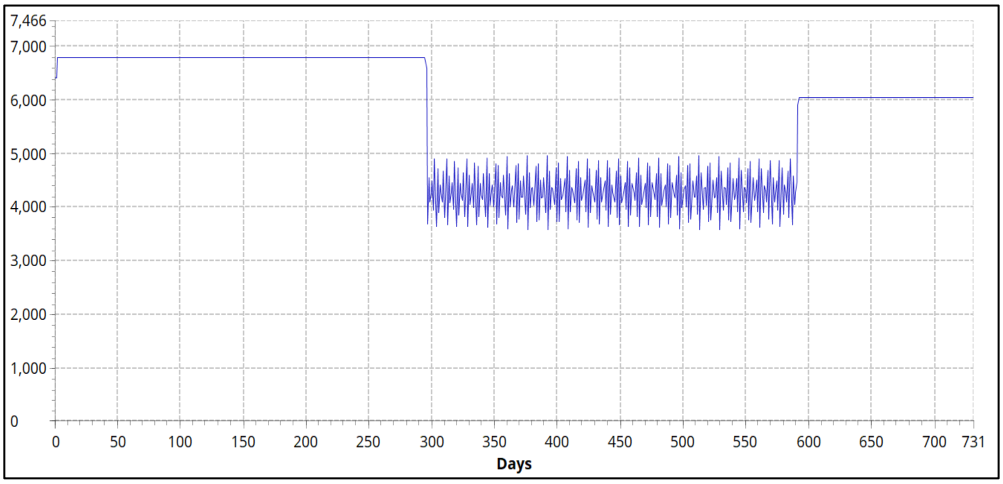

Figure 27. Average daily inventory in Kg

In scenario 4, as shown in figure 28 below, the lead time for most orders was above one day. Some orders took more than 81 days to be delivered and closed. The lead time could be less than a day under normal circumstances. Based on these results, we can infer that order processing took longer than expected hence leading to delivery delays to the customers.

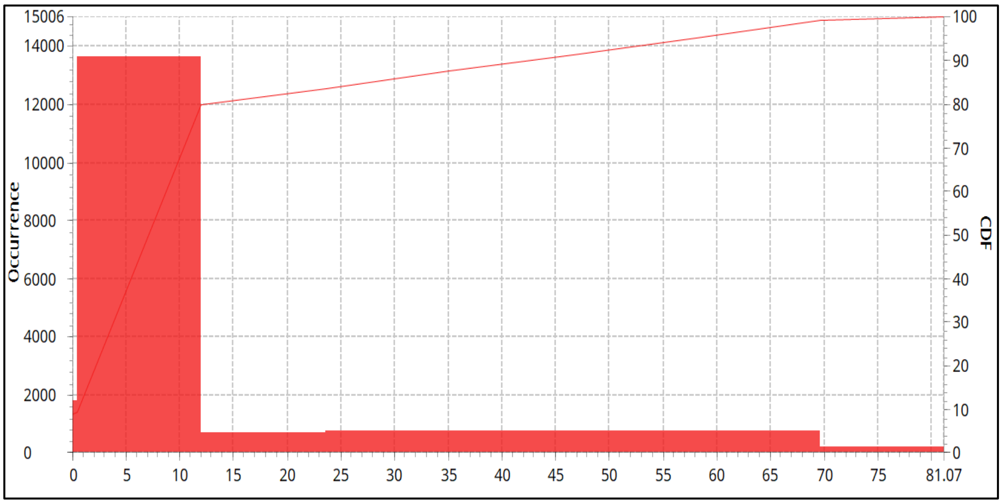

Figure 28. Lead Time

Figure 29 below shows that the ELT Service Level was stable at 100% in the first year and dropped significantly at the start of the second year before stabilizing again at slightly above 60% until the end of year 2. The drop in the second year signified decreased customer satisfaction which could be attributed to the increased trend of delayed orders due to the disruption of the road closure.

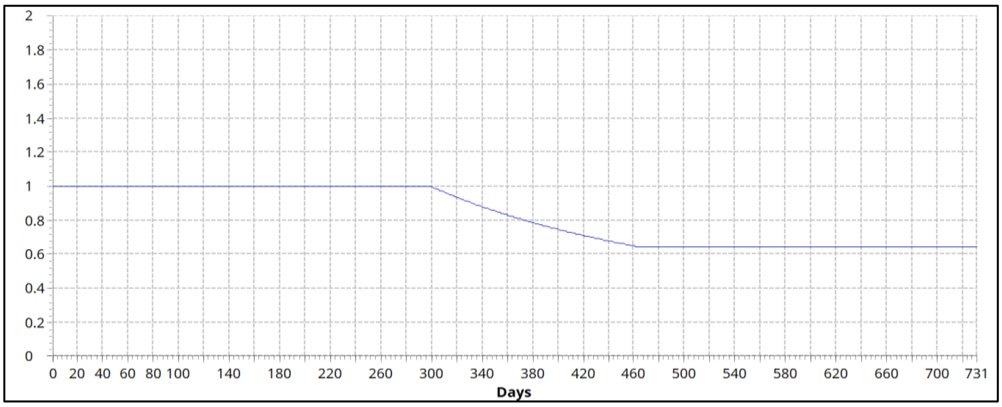

Figure 29. Expected Lead Time service level

According to the results of this scenario, road closures had smaller visual impacts on supply chain performance than demand increases. During the disruptions, cucumber inventory levels are reduced slightly as farmers stop delivering the cucumber within the expected normal period of less than a day (see figure 30). As far as fulfillment (late orders) is concerned, the trend increased and stabilized over time. The delivery of a significant number of orders was delayed throughout the period.

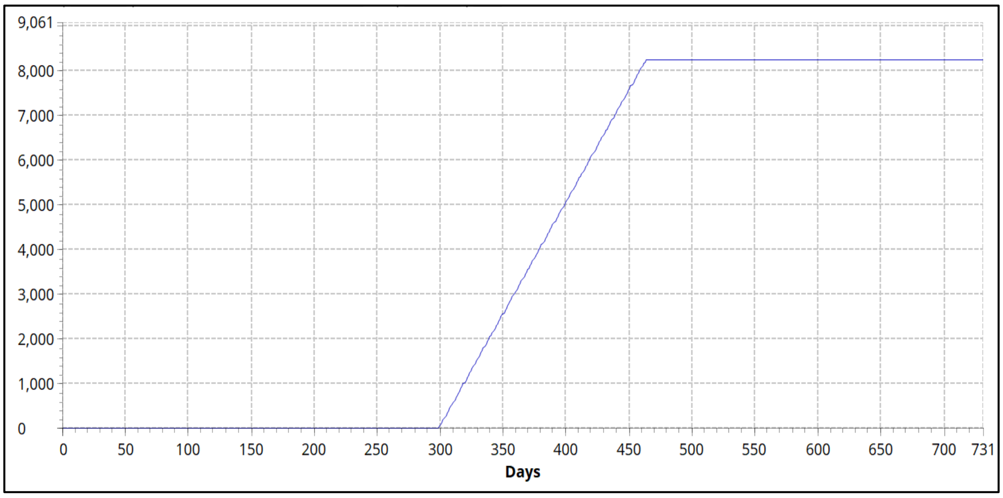

Figure 30. Fulfillment (late orders)

4.8 Summary of the Simulations

One of the key aspects of a robust and resilient supply chain is the lead time or the time it takes to make deliveries after customers have placed the orders. In this study, scenario 1 emerged as the best optimization option compared to other scenarios. This is because it had the lowest lead time, less than a day. Scenarios 3 and 4 had lead times greater than 1 day. Additionally, scenario 1 had second highest profits after scenario 3. This is shown in figure 31 below.

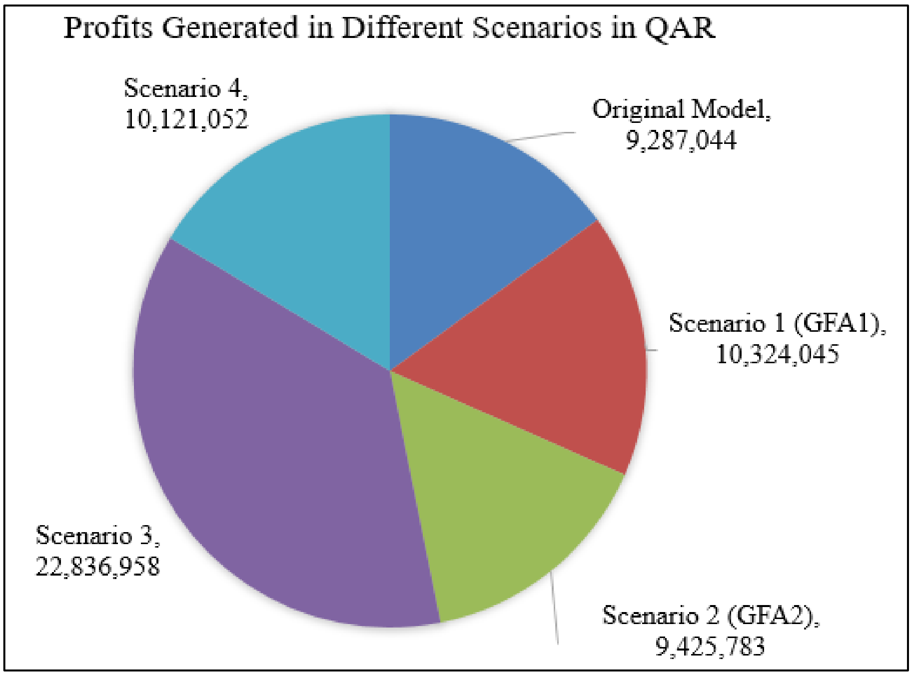

Figure 31. Profits recorded for various scenarios

Moreover, transportation cost was evaluated to identify opportunities for improvement in the performance of a supply chain. Figure 32 below shows transportation costs for all the scenarios. As shown in the graph, scenario 2 had the lowest transportation cost.

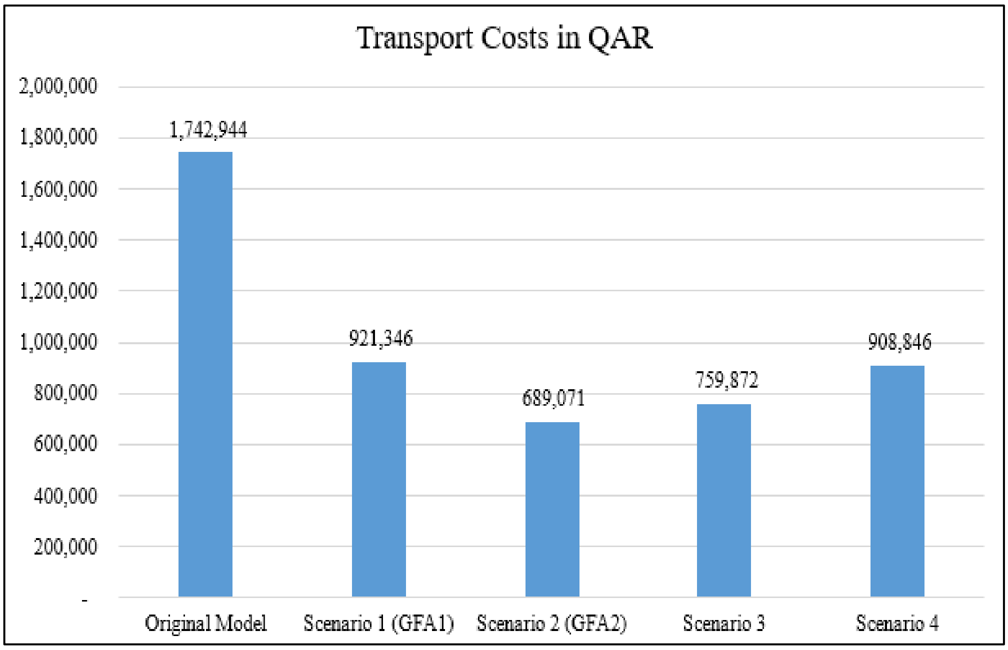

Figure 32. Transport costs for different scenarios

4.8.1 Comparison of Scenarios 1 and 2

The first condition corresponds to the original scenario where there was no disruption in the system. Compared to the original condition, the differences between scenarios 1 and 2 showed insignificant results. Hence they were more or less similar. Scenario 1 had higher inventory carrying costs, profits, and transportation costs than scenario 2. On the other hand, scenario 2 had higher total costs and other costs than scenario 1. Revenues generated were the same for both scenarios. A comparison of the two scenarios indicates that scenario 1 was better in optimization than scenario two because scenario 1 had a better lead time of less than a day and generated more profits within the two years.

4.8.2 Comparison of Scenarios 3 and 4

Simulations for scenarios three and four involved demand increase and road closure respectively, where various disruption lengths were analyzed and compared. The study compared scenarios 3 and 4 to establish their levels of robustness and resilience. Scenario 3 had higher profits and revenues than scenario four over the same period. On the other hand, scenario 4 recorded higher inventory carrying costs, total, and transportation costs. Other costs were the same for these two scenarios. However, scenarios 3 and 4 had lead times greater than one day, which implied that a significant amount of food stock would be damaged before actual deliveries were made to the customers. Both need robust improvements.

4.0 B. MATHEMATICAL MODELING

4.9 Introduction

Mathematical modeling was done to optimize the location of the distribution centers for Agrico Food Company. Given their cheaper cost and better capabilities, mathematical models are gaining popularity for supply chain optimization. Mathematical modeling is applied at any phase (operational, tactical, or strategic) of the supply chain management process to understand better and optimize crucial aspects of the chain's functioning, such as the most efficient transportation routes, distribution channels, and storage facility layouts. According to Lee et al. (2016), the common mathematical modeling techniques applied to supply chain issues comprise "linear programming, mixed-integer/integer linear programming, nonlinear programming, multi-objective programming, fuzzy mathematical programming, stochastic programming, heuristics algorithms, metaheuristics, and hybrid models."

Organizations can benefit from mathematical models by using them to make effective predictions (Stren, 2022). As a math problem, predicting is one of the most typical challenges for the supply chain management. It is all about predicting what people will want to buy in the future. Maintaining the appropriate stock of goods calls for precise forecasting. Methods such as trend and regression analysis can be used to make predictions. Besides, optimization is also the typical issue that mathematical models solve in supply chains (Stren, 2022). Finding the optimal allocation of resources is essential for achieving goals. For instance, a supply chain supervisor may optimize routes to cut expenses. This is not always easy to do because there are so many limitations that must be taken into account. Optimization issues can be approached in several ways, one of which is using linear programming.

Notably, keeping tabs on and managing stock is crucial to the success of any business. Every step of the supply chain's logistics depends on the processes involved in making the raw materials. Supply chain management, defined by low operational costs and greater productivity and efficiency, relies on well-controlled and managed inventories. In this regard, inventory management can benefit from applying numerous mathematical and modeling methodologies. Combining these and other model types is possible with many different abstract structures in a single model. A simulation is a model that mimics the behavior of a real-world system to learn more about it and make better decisions in the future. The user is immersed in a more realistic environment (Basiri & Heydari, 2017). A mathematical model for inventory management will include noise and random characteristics. Along these lines, inventory management can benefit from various mathematical models, as explained below;

4.10 The dynamic inventory modeling technique.

In this case, companies can simulate all facets of their supply chain thanks to dynamic simulation models that contain operational norms (Basiri & Heydari, 2017). Besides, they can get descriptive information about their supply chain's operations and a time series depiction of how the system behaves with a dynamic simulation model

4.11 Stochastic mathematical models

These are mainly used to streamline their supply chain management. It should be noted that stochastic simulations are models of systems in which the variables change randomly based on their probabilities; using random numbers in computer programs to generate random variables is widespread. Additionally, probabilistic modeling with price-dependent demand is developed for an item over a fixed time horizon (Tat, Heydari & Rabbani, 2020). In this case, we are considering a probabilistic lead time and allowing for shortages. Most businesses require some down payment before accepting an order.

4.12 The discrete inventory modeling approach.

A discrete system consists of the governing law of dynamics, the control domain, and the performance criterion. It is a tool for modeling stock-keeping activities; the performance metric, however, lets you evaluate and contrast various ordering strategies. The optimal procedure is identified using simulation-based optimization. In this aspect, it makes more sense to utilize a discrete temporal framework to depict inventory dynamics. A model of inventory dynamics using a discrete system control can be used as an optimization tool to achieve optimal control according to predefined performance metrics.

4.13 Game theory inventory modeling.

Notably, game theory simulates the complicated interactions among different persons in a system with incorporated conditions of outcomes (Tat, Heydari & Rabbani, 2020). The fields of economics and management extensively use game theory, particularly when maintaining stock levels in supply chain management. Several less obvious features of situations with competing interests are illuminated by game theory. In this aspect, the correct supplier can be determined by management using the modeling strategy.

4.14 Deterministic inventory modeling

It is worth noting that deterministic models assume that demand and stock replenishment can be predicted and that all other relevant factors and variables related to an inventory level are also known (Lee et al., 2016). Future events can be exactly calculated in a deterministic framework, eliminating the element of chance. If every factor can be predicted, organizations can make an informed prediction. Given that the ratios of future demand and the estimated sales return are calculated and verified by management, it reduces the likelihood of making mistakes and having either a shortage or an oversupply.

4.15 Application of the model to Agrico farm:

The goal was to centrally locate a facility serving different customers or other facilities to minimize the distance or miles traveled (d) between the facility and customers. Using the formula,

$$d = \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

Where:

(x,y) = coordinates of the proposed facility

(x_i,y_i) = coordinates of customer or location facility I

We Minimize total miles $d = \sum d_i t_i$, where:

d_i = distance to town i

t_i =annual trips to town, i

Therefore, the Rescue Squad Facility Location:

X = 25.29386128, Y = 51.49505647, Total Annual Distance = 169.49 as shown in figure 33 below:

Optimization Scenario	X	Y	Total Annual Distance (Km)
By solver	25.29386	51.49506	169.49
One GFA	25.20447	51.3657	291.9
Original Condition	25.655	51.456	435.04

Figure 33. Output of the mathematical model

Figure 33 above represents the optimal option for the location of the distribution center, which minimizes the annual distance to 169 km. There are three different values for distance for the three different GPS where the solver indicates the shortest distance. This was followed by one GFA whose GPS was provided by the AnyLogistix program. The original condition recorded the longest distance of 435 km.

CHAPTER FIVE: CONCLUSION, RECOMMENDATION, AND FUTURE WORK

5.1 Conclusion

The food supply chain in Qatar has been modeled by its different components, including farms, distribution centers, and retailers. Several disruptions might lead to various disturbances in the supply chain, such as a demand increase, transportation bottlenecks, and natural disasters. The AnyLogistix program was used to carry out various simulations to optimize the supply chain process through GFA analysis, improve efficiencies and reduce costs.

Green Field Analysis (GFA) was carried out using AnyLogistix to optimize the locations of distribution centers in Scenarios 1 and 2. The simulation of the original condition of the Agrico supply chain showed that the location of the distribution center needs to be optimized. On the other hand, a significant decrease in transportation costs was observed with the newly identified location in scenario 2, compared to scenario one and the original condition. A comparison of the two scenarios indicates that scenario 1 was better in optimization than scenario two because scenario 1 had a better lead time of less than a day and generated more profits within the two years.

Scenario 3 was a dynamic simulation with increased demand for two years, while scenario 4 evaluated the effects of closing key road networks within Agrico supply locations. Scenario 3 had higher profits and revenues than scenario four over the same period. On the other hand, scenario 4 recorded higher inventory carrying costs, total, and transportation costs. Other costs were the same for these two scenarios. Both scenarios had lead times of greater than one day, meaning the delivery of products took longer than in other scenarios. However, scenario 3 was better in performance than scenario 4.

Overall, the evaluation of all relevant parameters and metrics showed that scenario 1 was the best optimization option for Agrico Farm because it recorded lead times of less than a day as opposed to other scenarios, with lead times of greater than one day.

5.2 Recommendation

This study focused on the robustness and resilience of the supply chain for medium to large-scale agricultural farms. A similar study should be carried out to determine the effects of disruptions on small-scale farmers. Furthermore, research is also required to establish both the long short-term and short-term impacts of disruptions to key customers.

5.3 Future Work

Future research needs to dwell more on below areas:

1. Check the impact of the transportation mode on the food supply chain.
2. If scenarios 3 and 4 occur, what is needed to be done, and how will the supply chain be optimized maintain the same performance level and satisfy customers' demands with high profit and less food waste?

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APPENDICES

Appendix 1: Project Activity Planning (Gantt Chart)

Gantt Chart of Activities			Jun-22					Jul-22				Aug-22				Sep-22					Oct-22		
	No.	Activity	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8
Proposal	1	Preparation to carry out the project (meeting and instructions from supervisor)	■																				
	2	Introduction (background, problem statement, aims & objectives, study questions, significance of the study)		■	■	■																	
		Submission, feedback and correction					■	■															
	3	Literature review (conceptual framework, summary of literature review).							■	■	■												
Research		Submission, feedback and correction										■	■	■	■								
	4	Study methodology (design, data collection, analysis)													■								
		Submission, feedback and correction														■							
	5	Results, findings, discussion & implementation															■						
Report		Submission, feedback and correction																■					
	6	Conclusion and recommendation, references, initial pages, general formating																	■	■			
		Submission, feedback and correction																			■	■	■

Appendix 2: Sample generating demand data for the year 2019

Sell To Cust No.	Sell To Cust Description	CUCUMBER
CUST-TA-0612	SOUQ AL BALADI-VEG.	36,846
CUST-TA-0129	MAJID AL FUTTAIM HM-CARREFOUR-CITY CENTRE	61,596
CUST-TA-0305	MAJID AL FUTTAIM HM-CARREFOUR -VILLAGIO	51,800
CUST-TA-0425	FRUITLINE FOR FRUIT & VEGETABLE	27,391
CUST-TA-0268	UNI FRUTTI (AL RAED FRESH FOODS)	17,580
CUST-TA-0619	AL RAWABI GRAND HYPERMARKET KHARTIYAT-VEG.	18,564
CUST-TA-0134	GOURMET FRUITS CO - STORE	25,763
CUST-TA-0599	LULU HYPERMARKET TRADING-AIRPORT-VEG.	16,309
CUST-TA-0304	MAJID AL FUTTAIM HM-CARREFOUR-LAND MARK	28,584
CUST-TA-0535	CASH SALES-(AGRICO)-NOORDEEN	10,445
CUST-TA-0128	FAMILY FOOD CENTRE-RAYYAN BRANCH	10,887
CUST-TA-0449	SOUQ AL BALADI	7,347
CUST-TA-0171	GOURMET FRUITS CO - HYAT PLAZA	8,471
CUST-TA-0307	MAJID AL FUTTAIM HM-CARREFOUR-LAGOONA	16,061
CUST-TA-0605	LULU HYPERMARKET TRADING-AL MESSILA-VEG.	6,390
CUST-TA-0600	LULU HYPERMARKET TRADING-BARWA CITY-VEG.	7,930
CUST-TA-0002	LULU HYPERMARKET TRADING OLD AIRPORT	5,575
CUST-TA-0775	CASH SALE AGRICO (ANWAR MOHAMED)-OLD	9,975
CUST-TA-3622	JAWAD INTERNATIONAL PROJECTS-PAPA JOHN'S	672
CUST-TA-0168	GOURMET FRUITS CO - NUAIJA	5,030

Appendix 3: Sample generating demand data for the year 2020

Sell To Cust No.	Sell To Cust Description	CUCUMBER
CUST-TVF-0115	WORLD FRUITS CENTER-SHAHANIYA-VEG.	69,407
CUST-TVF-0022	FRUITLINE FOR FRUIT & VEGETABLE	48,375
CUST-TVF-0015	UNI FRUTTI (AL RAED FRESH FOODS)-VEG.	31,778
CUST-TVF-0045	SOUQ AL BALADI-VEG.	27,006
CUST-TVF-0129	FOOD WORLD GHARAFA-VEG.	25,295
CUST-TVF-0088	PAHAMA DUHEIL COMPLEX-CASH-VEG.	20,325
CUST-TVF-0071	FAMILY FOOD CENTRE AL KHEESHA BRANCH-VEG.	27,097
CUST-TVF-0099	MAJID AL FUTTAIM-CARREFOUR-VILLAGIO_VEG.	24,024
CUST-TVF-0097	MAJID AL FUTTAIM-CARREFOUR-CITY CENTR_VEG.	24,609
CUST-TVF-0006	NEW INDIAN SUPERMARKET-AIRPORT-VEG.	8,023
CUST-TVF-0074	KHALID BIN MOHAMED FOOD STUFF-K.B.M-VEG.	8,170
CUST-TVF-0052	AL RAWABI GRAND HYPERMARKET KHARTIYAT-VEG.	11,947
CUST-TVF-0062	FAMILY FOOD CENTRE AL NASER-VEG.	18,444
CUST-TVF-0138	GOURMET FRUITS CO. GROUP-VEG.	19,308
CUST-TVF-0098	MAJID AL FUTTAIM-CARREFOUR-LAND MARK_VEG.	17,349
CUST-TVF-0170	SPAR FRUITS & VEGETABLES DISTRIBUTION CENTRE	13,233
CUST-TVF-0032	LULU HYPERMARKET TRADING OLD AIRPORT-VEG.	12,107
CUST-TVF-0038	LULU HYPERMARKET TRADING AL MESSILA-VEG.	13,572
CUST-TVF-0096	LULU CENTER TRADING CO. WLL, AL SADD-VEG.	5,561
CUST-TVF-0033	LULU HYPERMARKET TRADING BARWA CITY-VEG.	11,114
CUST-TVF-0101	MAJID AL FUTTAIM-CARREFOUR-LAGOONA_VEG.	18,649
CUST-TVF-0034	LULU HYPERMARKET TRADING GHARAFA-VEG.	11,046

Appendix 4: Retailers served by Agrico DCs

Abc - Salwa	Day Mart - Old Airport
Ajmal Market - Al Aziziyah	Doha Day Mart - Najma
Al Ansari Group-Veg.	Falcon - Al Dafna
Al Mersal Shopping - Najma	Falcon Shipping Co - Al Mansoura
Al Rawabi Doha Food Center Wakra-Veg.	Family Food Land - Salwa
Al Rawabi Food Center Rayyan-Veg.	Family Hypermarket - Al Murra
Al Rawabi Grand Hypermarket Khartiyat-Veg.	Family Shopping - Al-Rayyan
Al Rawabi Hypermarket Al Murrah-Veg.	Farm Fresh Mart ,Com - Najma
Al Rawabi Hypermarket New Rayyan-Shafi Road-Veg.	Food City - Al Nasr / Al Sadd
Al Rawabi Mini Hypermarket-Ummsalal Ali-Veg.	Food Plus - Al Khor
Al Safeer - Salwa	Food World Gharafa-Veg.
Al Safeer Centre - Al Hilal	Fresh Express - Umm Ghuwailina
Al Sidra Trading & Contracting-Veg.	Freshqa Farms - Abu Hamour
Al Wusel - Umm Salal	Gourmet Fruits Co. Group-Veg.
Amana Puregold - Al Sadd	Grand Express Al Wukair-Veg.
Amana Shopping Mart - Najma	Grand Mall Hypermarket-Veg.
Ansar Gallery Barwa-Veg.	Grand Mart - Doha Al Jadeeda
Ansar Gallery-Al Khor-Veg.	Grand Shopping - Abu Hamour
Arwa Shopping - Khartiyat	Grandex - Al Aziziyah
Black Olive Restaurant - Ain Khaled	Great Hyper Market Umm Salal
Dana Express - Al Muntazah	Green Chilli - Al Wakrah
Dana Hypermarket - Salwa	Green Valley - Al Thumama
Day Fresh - Abu Hamour	Green Valley - Al Wakrah
ing-Veg.	Green Valley - Najma
	Green Valley Fruit & Vegetables
	Gulf Quality Fresh Fruits-Veg.
	Haidari Trad