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1. Introduction

1.1. Problem Context

The fast evolution of information technology services and the dynamic changes in the market, from having customers claiming to have a more efficient and fast service to a green consumerism trend, are deeply impacting the way of doing business. This is making the companies adapt through the search for new solutions to become as efficient as possible. In particular, e-commerce is becoming more relevant in the business world, which has a main role in influencing customers' behavior.

In more detail, the impact of e-commerce specifically in logistics has forced the industry to find better ways to increase the speed of response to the customers causing challenges in the distribution operation (Archetti & Bertazzi, 2021). Unfortunately, as companies are improving their responsiveness, other negatives impacts on the environment and society appear mainly due to transportation (Bektas & Laporte, 2011) accompanying the last-mile delivery which may be considered by many authors as the most challenging component of the distribution process due to its high cost and therefore the most impacting in the environment (Archetti & Bertazzi, 2021).

Considering the great negative impact of e-commerce on sustainability it is also important to understand its importance of it in the business world and why is relevant in the present study. According to Ho et al. (2007), the share of online retail business increased by more than $500 billion in 2020 compared with $373 billion in 2016 considering only the US. Only in 2020, this results in more than two billion people purchasing goods or services online, making consumers and providers get closer through a quicker, efficient, and reliable delivery (Statista, 2020).

Another concept that has accelerated the phenomenon of e-commerce is urbanization, which is considered a megatrend where the global land use has changed the world and according to Gerten et al. (2019), by 2050 almost 70% of the global population will be living in urbanized regions or cities. Moreover, it has been observed that the largest 750 cities in the world contribute to "more than 57% of the global gross domestic product (GDP), and this *share* is expected to increase to 61% by 2030" (Sampaio et al., 2019).

The urbanization growth, as it has been seen in the past years, obliges the planning of delivery routes to face multiple constraints inherent in a city such as street lights, traffic congestion, car accidents, modification in the speed limit, regulations on the fleet dimension, motor type or fleet control, bigger crowds and demonstrations which makes the setting dynamic adding up alternatives in routing design (Sampaio et al., 2019). This phenomenon is related to the concept of "city logistics" which impacts the logistics context and considers a global view of the logistics and transport activities, letting see the negative and positive impacts of the growing city's population (Sampaio et al., 2019).

1.1.1. E-Commerce

In the literature, there are plenty of definitions of e-commerce available. It is defined as "the use of the global Internet for purchase and sale of goods and services, including services and support after the sale" (Hultman, 2009), while it was also defined as "the delivery of information, products/services, or payments via telephone lines, computer networks or any other means" (Ho et al., 2007). Finally, it is emphasized that "the Internet is a medium for enabling end-to-end business transactions" (Ho et al., 2007).

E-commerce was lately defined as a commercial transaction including an area that supports the trade of goods around the world through the use of an electronic platform, covering production, promotion, sales, and distribution (Hamraoui, 2020). It is also stated, that the quantity of electronic transactions done is going beyond the traditional channel, and at the same time, a larger number of consumers is being attracted through targeted advertisements on websites (Hamraoui, 2020). In terms of growth, the e-commerce data shows the good performance of the industry, which for the past 10 years has been growing an average of 15% year-over-year, while in 2020 it had a double-digit growth (LeBaron, n.d.).

Hamraoui (2020) states that an e-commerce marketplace is represented by a website where different sellers which could be companies, organizations, or even self-service shops, offer the opportunity of buying their goods and services to final customers. These marketplaces can be defined as a B2C "Business to Customer" or B2B "Business to Business" (Hamraoui, 2020). The thesis will be primarily focused on B2C e-commerce, but it may also imply B2B operations.

1.1.2. Sustainability in E-Commerce

The constant growth of e-commerce discussed previously, may also have negative impacts mainly on the environmental subject, which will represent a fundamental part of the analysis of the present thesis. For this reason, during the past twenty years, the academia, scientists, and researchers have become more interested in the role of sustainability in the e-commerce industry, trying to identify how to integrate this concept into the companies' strategies and process creation of value (Hristov & Chirico, 2019). At the same time, sustainability may offer differentiation to the online retailers from competitors and improve their offered services to customers (Mathisen & Nordgarden 2020).

However, companies have found some difficulties linking sustainability to their strategy, mainly because they encounter obstacles in how to measure sustainable development by identifying which key performance indicators (KPIs) would be appropriate (Hristov & Chirico, 2019).

In this regard, several organizations have been pushed to act on the way and have developed some standards that may be applied to any given economic activity. One of these examples is the Global Sustainability Standard Board which issued the set of GRI Sustainability Reporting Standards (GRI Standards), which are intended for the use of diverse organizations to report the sustainability (economical, environmental, and societal perspective) impact derived from their operations (Jungho, 2020). The main concerns covered by this standard are the emissions which according to the Board, "impact living and non-living natural systems, including land, air, water, and ecosystems" (Jungho, 2020).

Furthermore, the United Nations (2020) progressed on this topic with the Sustainable Development Goals which are going to be considered as a starting point for the analysis. In 2015 the UN defined 17 targets to be accomplished in 2030 with the aim of "end poverty and set the world on a path of peace, prosperity, and opportunity for all on a healthy planet"

(United Nations, 2020). Of the 17 targets mentioned, in this thesis, only three goals are going to be assessed due to their relevance.

- "Goal 11: make cities and human settlements inclusive, safe, resilient, and sustainable (Sustainable Cities and Communities).
- Goal 12: ensure sustainable consumption and production patterns (Responsible Consumption and Production).
- Goal 13: take urgent action to combat climate change and its impacts (Climate Action)". (United Nations, 2020).

1.1.3. Last-mile in E-Commerce

Last-mile represents the final part of the distribution process, in which the delivery occurs from the last distribution point, such as a warehouse or a distribution center, to the home or collection point of the final customer (Archetti & Bertazzi, 2021). There may be many challenges in the last-mile but the focus of the current thesis will be on the transportation one, in which the daily operations are related to the distribution. Routing problems are an example of those challenges (Archetti & Bertazzi, 2021).

The last mile has a main role in the supply chain for any e-commerce company but also for its sustainability. One way to assure the integration of sustainability in their logistics is through the last mile service because it has been found that this one is a key area to work on due to the monetary and environmental aspects (Mathisen & Nordgarden, 2020).

Recent literature on routing problems reveals a higher interest in studying the challenges derived from the last-mile delivery services in the context of B2C e-commerce (Archetti & Bertazzi, 2021). According to Archetti & Bertazzi (2021), there are some features related to the last-mile delivery services which are generating challenges in routing problems such as:

- On-line orders.
- Short delivery times.
- Presence of release dates.
- Overlap of customers' time windows.

- New delivery strategies such as crowd-shipping in which ordinary people drop-off packages on their destination route.
- New delivery technologies such as using drones or bicycles to deliver the packages under the principle of reducing weight and volume.
- Failed deliveries (Archetti & Bertazzi, 2021).

1.1.4. Vehicle Routing Problem

The Vehicle Routing Problem (VRP) considers a central depot to deliver goods to identify the optimal route or set of routes covered by a fleet of vehicles, itself should start and end at the same central depot, to satisfy the demand of the final customers (Iori et al., 2005). One of the varieties of VRP is used in the production and distribution areas with different objectives such as: minimizing the route cost, minimizing the transportation costs (e.g., taxes, drivers, etc.), minimizing distance traveled, and minimizing the number of vehicles used (Sitek et al., 2021).

Nevertheless, this VRP refers to a traditional model in which the fleet quantity is homogeneous and it has the aim to satisfy a given number of customers (Asghari et al., 2021). Technological developments and greener solutions have been offered given the context of the negative effects produced by the logistics operation to reduce the environmental impact. The green vehicle routing problem (Green-VRP) arises as an alternative to the classic routing problem introduced in 2012 (Asghari et al., 2021). "The principal objective of Green-VRPs is to minimize fuel consumption and consider alternative-fuel powered vehicles (AFVs) solely or along with existing internal combustion engine vehicles (ICEVs)" (Asghari et al., 2021).

The routing problems aim at deriving the optimal arrangement of distribution routes to be deployed by the vehicles to supply the final customer (Baldacci, 2007). The current thesis is intended to leverage the efficiency of routing solutions linking them with the UN Sustainable Development Goals, to understand how this efficiency may help to reach them.

Real-life last-mile problems in e-commerce can usually be modeled as a specific VRP variant, being the VRP with Time Windows (VRPTW), in which the complexity increases mainly because it is appraised that deliveries should take place along the day during different moments (Calvete et al., 2004). In these problems, each final customer is associated with time windows of different lengths, within which the customer must be supplied and the vehicle capacity constraint should not be violated (Calvete et al., 2004). For these constraints it is needed to verify that the route is feasible identifying if the service of a customer is within the time windows, otherwise, it will become not feasible and hard to complete (Calvete et al., 2004).

On the other hand, a successful delivery occurs when the customer is available to receive the parcel at the exact moment, he is visited by the service delivery company saving the company to go back or making the customers pick up their parcel at another collection point (Florio et al., 2018). One of the greatest challenges related to attended home delivery or successful deliveries using time windows is that commonly the customers have similar preferences at specific times of the day making the time windows overlap with each other (Archetti & Bertazzi, 2021).

Considering the previous concepts, the thesis will be focused on assessing how different economical and sustainability KPIs may vary along with the impact due to two main delivery inefficiencies. These inefficiencies can be caused by (1) failed deliveries in an optimal VRP solution without time windows or (2) sub-optimal VRP solution with time windows, which may cause a lower number of failed deliveries (Duin et al., 2016).

1.2. Problem Statement

In the past decades, sustainability has arisen as a topic of interest for institutions, governments, universities, companies, organizations, and society in general. It is sufficient to refer to the increasing amount of word usage in the scientific journal environment (280,000 from 1980 to 2000, and 2,070,000 from 2000 to 2021) (Scholar, n.d.) to the simple use of Google for searching this type of term (with a popularity of 84 in 2004, and popularity of 96 in the present) (Google Trends, 2021). Because of its relevance, as stated in the last section, in 2015 the United Nations (UN) established the Sustainable Development Goals (SDGs), which contemplates 17 interlaced global goals with the mission of becoming "A blueprint to achieve a better and more sustainable future for all people and the world by

2030", (Im, 2020). These goals and the ones that are going to be particularly addressed in this thesis are developed in the Literature Review section.

Sustainability is often related only to environmental aspects, which may not be completely right considering that also the economic and social aspects have an impact on the sustainability concept for having an integrating term as defined by Santoyo in 2014 (Santoyo-Castelazo & Azapagic, 2014). In principle, environmental deterioration affects directly or indirectly to societies, but in this thesis, the concept of sustainability will be treated as the main concept, and therefore its Key Performance Indicators (KPIs) are more focused on the environmental and economic aspects.

One of the main concepts that have been helping companies to make more efficient deliveries is the VRP (Vehicle Routing Problem) using heuristics and metaheuristics approaches, which were introduced in 1955 and defined in the previous section (Laporte, 2007). Nevertheless, there is no single perfect solution for VRP given the number of alternatives and dynamic scenarios for cities and customers (Laporte, 2007). Consequently, it is important to note that trade-offs should be taken into account in the existing solutions, and not all the aspects can be solved at once to be concluded as the most efficient way to deliver or the most efficient delivery solution.

For having an efficient solution several considerations should be taken into account. Considering the vehicle routing solutions, the main concepts involved are the physical characteristics of the routing such as the fleet composition (number of vehicles, load capacity) (Laporte, 2007), the characteristics of the orders (amount, size, shape) (Moons & Ramaekers, 2018), and the customers' physical location (addresses, access to the delivery place, peak hours) (Cappanera et al., 2020). On the other hand, some restrictions are not considered in the seeking of the solution such as buying behavior, which is a concept that regularly falls under another research area more focused on the psychological part of the customer. To try to include this customer impact in the present thesis, time windows will be considered.

Time-window restrictions could be an important driver for finding a more optimal solution mainly because these may impact directly reduce the failed deliveries by offering precise time to deliver the parcel to the clients, which according to the literature, may lead to a reduction of failed deliveries in at least 10% (Florio et al., 2018). For further understanding of the positive impact of this concept, time windows also help to reduce the carbon emissions, considering that for 10%, 30%, and 50% of failed deliveries, there is respectively, 15%, 45%, and 75% increase in CO_2 emissions (Edwards & Mckinnon, 2009).

Furthermore, delivery time-windows restrictions might also behave as a double-edged sword, mainly because having time-window restrictions decrease the degrees of freedom, making a breach between the optimal and the resulting solution, and having higher distances, as a result, impacting sustainability KPIs (Edwards & Mckinnon, 2009). In this context, the variable of time windows is probably undesirable if imposed by the customer but probably helpful if guided by the delivery company. The cases where the customer imposes restrictions through a time window are crucial when customer service is of high importance, while the benefit of companies imposing them, gives them flexibility reducing substantially the travel time and failed deliveries according to Jabali et al. (2013).

The Research Questions in the following section will help the reader to reinforce the information included in this Problem Statement.

1.3. Research Questions

The purpose of this work is to provide an answer to the following central question:

1) To which extent is it convenient from an economical and sustainability perspective to choose between failed deliveries in an optimal VRP solution without time windows or a sub-optimal VRP solution with time windows?

For this, the next supportive research questions have been formulated:

2) Which are the most relevant KPIs to take into account when assessing sustainability in last-mile distribution for B2C e-commerce?

3) What is a failed delivery and how does it affect sustainability KPIs in e-commerce delivery?

4) Which parameters influence failed deliveries?

5) How do the appearance of time windows, time window width, and the number of customers in a given database affect a VRP solution?

6) How do these time window variances behave against adding more visits as a result of failed deliveries in a given VRP solution?

These research questions will be answered throughout the current thesis.

1.4. Structure of the Thesis

In the (1) Introduction section, the (1.1) Problem Context and its subsections were presented at glance including the most relevant concepts that are going to be the pillars for the following sections. The (1.2) Problem statement explains in a throughout form the author's motivation behind this work and the inherent relevance of the topics depicted for the construction of scientific knowledge and practitioners (e.g., policy-makers, activists, organization associates, employers and employees, business owners, consultants, managers, regulatory agency members) involved in these environments (e.g., e-commerce, sustainability, delivery, vehicle routing, Non-Governmental Organizations (NGOs) and more). Additionally, the (1.3) Research questions were built to guide this work through the different stages including from both literature and empirical points of view until the core of this dissertation. Finally, the actual (1.4) Structure of the Thesis section serves for closing the Introduction and makes way for the two main sections (2) the Literature review section and (3) the Empirical section, which conform to the main body of this dissertation.

The first part of the body, a detailed (2) Literature Review, will give the frame for the reader to understand in-depth the different topics, approaches, variables, and abbreviations needed. This (2) Literature Review section starts with the (2.1) Literature Research Methodology of how it was conceived and which research was included under its scope. This will be followed by a light (2.2) Overview presenting the main general topics that are going to be discussed with further detail, concepts not extensively described but already presented to the reader in the Introduction section. Then, an extensive discussion of the found literature will be included under five subsections, one for each of the topics: (2.3) E-commerce and the Last Mile, (2.4) Sustainability and The United Nations Sustainable

Development Goals, (2.5) The Vehicle Routing Problem and its Routing Solutions, (2.6) Delivery Time Windows and (2.7) Failed Deliveries (see 2.2 Overview).

The second part of the thesis' body will be related to the (3) Empirical Section. This section will begin with the (3.1) Empirical Research Methodology, which aims to describe thoroughly how the empirical study is going to be performed, stating the assumptions taken into account, factors for uniformizing the information, and the steps engaged in the simplification of the data treatment. Subsections for this section were included for better structure, reflected in the following: (3.1.1) Key Performance Indicators, (3.1.2) Assumptions and Parameters, (3.1.3) Cases and Scenarios, (3.1.4) Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017), (3.1.5) Failed Delivery Scoring Technique and the (3.1.6) Hypothesis. In addition, the selected parameters, the relationships within the incumbent KPIs, and the different time-window delivery guidance scenarios conducted will also be included.

Next, in the (3.2) Data collection subsection, it will be stated how the data was obtained, understanding the sources of information but also the unintentional or forced restrictions. It will explain how the analysis was made, starting with the spreadsheet solver VRP familiarization, actual constraints, simplification methods, development of scenarios (along with others), and ending under which tools and conditions the sensitivity analysis was performed.

(4) Results, consequent of the last sections will be presented in their respective section. Elaborating on the results for making them more comprehensive while comparing the variation of the incumbent KPIs under the different VRP (Vehicle Routing Problems) with time-window delivery guidance scenarios.

Lastly, the (5) Conclusion will give an answer to the Problem Statement and the more research questions, addressing also limitations and further research possibilities.

A (6) List of References including all the references from the quotes made in this dissertation will be found at the end in APA (American Psychological Association) format.

Appendices: (7) A, (8) B, and (9) C will give further detail to this thesis.

2. Literature Review

2.1. Literature Research Methodology

The Literature Research Methodology in this work started with considering which literature research would be supportive, as a complement for understanding and acquiring knowledge regarding the four main topics (see 1.4 Structure of the Thesis) but also, to give a basis for answering the (1.3) Research Questions directly or indirectly (if so, via the (3) Empirical Section).

Then, it was important to define how to obtain the sources. VUB's digital library was key for access to all the resources used to make the research of this thesis possible. This library provides multiple accesses to different Databases via its search engines (e.g., Google Scholar, Web of Science, Scopus, and EBSCOHost), which are the main source of information for retrieving mainly peer-reviewed research papers such as scientific journal articles but also, some books, dissertations, cases, encyclopedia articles, reports, patents and webpages which are quotes along with the thesis.

Literature sources were hardly limited in dates, although considering E-commerce as an evolving topic that has recently accelerated in knowledge and relevance caused by globalization to COVID-19 (see 1. Introduction and 2.3. E-commerce and the Last-mile sections), it was important to put some boundaries. These boundaries resulted in having 90% of the sources no older than 15 years since publication (only 1 reference older than 20 years), 85% of the sources no older than 10 years since publication, and at least one-third of the sources published between 2020 and 2022.

The research language was limited to Spanish (the mother tongue of the author and translated to English in this dissertation) and English (if official translations were found, the sources were also considered in the English language, even if they had been published originally in a different language than the ones mentioned in this paragraph).

The keywords used, which gave to some extent accurate results and followed the main topics to be discussed (see 2.2. Overview) were, in a not exhaustive list, the following (including its detailed variants between parenthesis):

(2.3) E-commerce (e.g., e-commerce development, e-commerce growth, e-commerce context, B2C e-commerce, e-commerce and CO_2, e-commerce and environment, e-commerce distribution, e-commerce orders, e-commerce and greenhouse emissions, e-commerce city logistics, e-commerce operations, e-commerce systems, e-commerce, and home delivery services, e-commerce volume, e-commerce business, last mile in e-commerce, and more).

(2.3) Last-mile (e.g., last-mile delivery, last-mile distribution, last-mile logistics, last-mile transit, last-mile solutions, last-mile efficiency and more).

(2.4) Sustainability and sustainable (both terms used while searching: e.g., sustainability in e-commerce, sustainability reporting, sustainability, and the environment, urban sustainability, sustainability in logistics, sustainability in delivery, sustainable solutions, Global Sustainability Standards, GRI, and more).

(2.4) The United Nations Sustainable Development Goals (e.g., UN SDGs, UN SDGs measurements, UN SDGs tracker, UN SDGs definitions, UN SDGs framework, UN SDGs, and business, and more).

(2.5) Vehicle routing problem(s) (using both abbreviations: VRP and close wording: e.g., green VRPs, vehicle routing problem types, vehicle routing problem optimization, vehicle routing problem constraints, vehicle routing problem efficiency, vehicle routing problem with time windows, capacitated vehicle routing problem, capacitated vehicle routing problem with time windows, VRPTW, CVRP, CVRPTW, vehicle routing problem innovations, and more).

(2.5) Routing solutions (most of them address within the specific VRP type, anyhow, e.g., vehicle routing solutions, vehicle routing heuristics, vehicle routing metaheuristics, vehicle routing exact solutions, vehicle routing software, vehicle routing with time windows, vehicle routing metrics, vehicle routing models, vehicle routing algorithms and more).

(2.6) Delivery time windows (TW, time windows constraints, time windows times, soft time windows, flexible time windows, hard time windows, time windows, and logistics, overlapping time windows, real-time windows, time windows optimization, and more).

(2.7) Failed deliveries (failed home deliveries, failed and successful deliveries, failed deliveries in e-commerce, failed deliveries in logistics, failed deliveries in the last-mile, reduce failed home deliveries, improved home failed deliveries).

Other supportive topics are not directly part of the four main topics: logistics, city logistics, efficiency in delivery, time flexibility, sharing economy, failed delivery, logistic KPIs, delivery KPIs, $PM_{2.5}$ pollutant, CO_2 emissions, specialized routing software, routing solvers, delivery parameters, sensitivity analysis, territory planners, spreadsheet solvers, urbanization, delivery in metropolitan areas, travel times, delivery and depots, Organization for Economic Co-operation and Development (OECD), tour problem, the traveling salesman problem, the truck dispatching problem, and more. Keywords are strongly related to answering the stated (1.3) Research Questions and in constant combination for relating one topic to another.

The titles on the first page displaying results in the database (e.g., Google Scholar) were read and the most appealing subjects were downloaded, after the keywords selection, this could be considered as the first filter ending in more than 250 sources. In addition, folders for each one of the main sections were created to store corresponding sources, to have the folder sections containing the sources that were going to be used for developing them.

The second filter was made after reading the Abstracts and Conclusions of these sources, maintaining the relevant ones (around 180 sources), which was assessed through the number of citations each article has (at least 100) and deleting all the others. Nevertheless, the exercise was insightful leaving knowledge and relationships to pursue to the author without spending more than 30 minutes on each paper.

Thirdly, by reading the Introduction of those sources, another filter was made, reducing the amount to approximately 110 sources. These gave the basis to start writing each section, like the (1) Introduction and (2) Literature Review sections.

In each step, the criteria for selecting the sources were to link them to the main topics but principally, to the (1.3) Research Questions. This was made by comparing and assessing sources within each other and towards each of the (1.3) Research Questions.

2.2. Overview.

The literature review will be focused on the following four topics: (2.3) E-commerce and the Last mile, (2.4) Sustainability and The United Nations Sustainable Development Goals, (2.5) The Vehicle Routing Problem and Routing Solutions, and (2.6) Delivery time windows and (2.7) Failed deliveries defining the structure of the Literature Review.

Since (2.3) E-commerce and the Last-mile share important concepts with (2.5) The Vehicle Routing Problem and Routing Solutions, they have raised interest from researchers around the world to be studied together as they are highly correlated. One of the factors both share is that they have had a great research advance in recent years, mainly due to the necessity to create more efficient routing solutions and reduce costs throughout the supply chain. For these concepts then, it is important to consider sources no older than 10 years since publication for maintaining the validity of the innovations, including to some extent, the latest trends and figures regarding these topics.

(2.4) Sustainability in last-mile delivery in E-commerce is embedded in the latter topic, but it is important to advocate the necessary structure to focus and be clear in the definition and scope of sustainability in this E-commerce in the last-mile delivery context.

In an effort to relate the last topic in this Master Thesis to current and recognized standards for sustainability, (2.4) the United Nations Sustainable Development Goals will be described and serve as the base for assessing most of the sustainability KPIs (Key Performance Indicators) that are going to be weighted up in both the Literature and Empirical Research Methodology sections.

For (2.5) The Vehicle Routing Problem and its Routing Solutions, it is important to mention that some general routing solutions may be stretched to include also the focus on last-mile delivery and that the aim is not to describe extensively the existing routing solutions but to make the reader understand the Vehicle Routing Problem. Moreover, to explain how the selected solution works while building a clear framework for the empirical research methodology, empirical data analysis, and interpretations results.

(2.6) Delivery time windows are to some extent embedded in (2.5) The Vehicle Routing Problem and its Routing Solutions, this topic being the pivot and the independent variable that will have an impact on the selected measurements consistent with sustainability KPIs (Key Performance Indicators). This concept is considered the main variable for the analysis and in the sensitivity analysis will be key to reaching the desired results. Through the literature review, it will be very important to understand this concept and its variants.

(2.7) Failed deliveries are a main topic for the current thesis as this will be a variable in the assessment. As it has been explained before, one of the main objectives of e-commerce companies is to reduce failed deliveries as these may cause higher costs and inefficiencies in the routing problem solution. This concept is highly related to delivery time windows as this is a solution offered to reduce failed deliveries.

2.3. E-commerce and the Last Mile

E-commerce is defined as a "specific part of e-business, including public relations for the sales of goods, services, and information via the Internet using all the available tools on the network" (Kwilinski et al., 2019). According to Kwilinski et al. (2019), researchers and scientists have been focused on the annual development and expansion of e-commerce around the world, which is demanding adaptation of the manufacturer, the consumer, and the government. On the side of the manufacturer, the objective is to gain a competitive advantage through higher performance. On the side of the consumer, the aim is to save time, and money and an improvement of quality service. While on the government side, it is seeking international integration to build an e-government system (Kwilinski et al., 2019).

E-commerce in a B2C context is a rapidly growing business on a global scale, it is enough to consider "that in 2018 the online market was worth more than 2,500 billion euros worldwide" (Mangiaracina et al., 2019). As stated before, B2C e-commerce also represents a big challenge for companies, due to the high expectations from customers in terms of service level, like punctuality and flexibility in deliveries, resulting in the necessity to deal with more complexities related to the logistics activities and the intangibility of online transactions (Mangiaracina et al., 2019).

While the e-commerce definition is very broad and may include all kinds of electronic transactions using any electronic tool through all kinds of digital platforms (Alt & Zimmermann, 2019), the term in this thesis will be limited to the order of goods from any place within a city via a mobile application (app) or a webpage to be delivered by a selling company.

According to Siragusa et al. (2022), the growth of e-commerce over the last years has had a great impact on transportation in urban areas due to the embedded necessity to improve the last-mile delivery. Thus, e-commerce has been named to be one of the main responsible for the increasing number of units of transportation (trucks and vans) moving around the cities which impacts directly the environmental sustainability (Siragusa et al., 2022). According to Mucowska (2020), it is expected that city congestion related to last-mile delivery will rise by 21% by 2030.

Considering the perspective of any e-commerce company, "the last-mile delivery is the least efficient and most expensive part of the delivery process, due to the challenging target service levels, the small dimension of orders, and the high level of dispersal destinations" (Mangiaracina et al., 2019). Considering this context, the B2C companies need to be efficient, through reducing costs, but also effective (Mangiaracina et al., 2019).

Conversely, other studies argue that online shopping may imply less CO_2 emissions favoring home deliveries, and therefore these are considered to be more sustainable and eco-friendly (Mucowska, 2020). Despite this, the fact that the increase in last-mile deliveries as a consequence of e-commerce growth has a real impact on the environment is unquestionable (Mucowska, 2020).

In the literature, e-commerce last-mile delivery in a B2C context has been mainly studied considering three different perspectives: environmental sustainability, effectiveness, which is defined by the customer service level linked to the customer satisfaction, and efficiency which is mainly linked to minimizing costs (Mangiaracina et al., 2019). Sustainability impact has raised the interest of academics and recent literature contribution has been focused on the development of innovative strategies for the last-mile, to reduce sustainability externalities (e.g., different types of pollution and traffic congestion) which have increased in the wake of the accelerated e-commerce growth (Ranieri et al., 2018). Moreover, other negative effects generated by e-commerce on the environment have been studied such as gas emissions, waste, and energy use (Bertram & Chi, 2018).

According to the literature, given an e-commerce environment, it has been estimated the number of kilometers and parcels that a courier can deliver during a working day with a duration of 7.5 to 8 hours a day (Villa & Monzon, 2021). It was found that in the UK a courier may deliver 120 parcels in an 80 km route, while in Poland he can deliver 60 parcels in a 150 km route, and finally, in Brussels, he can deliver 85 parcels in a 70 km route (Villa & Monzon, 2021).

On the other hand, many authors have studied and proposed other versions of the already mentioned vehicle routing problem (VRP), which consists of "defining the optimal route to deliver a set of parcels to dispersed destinations" (Shen & Chen, 2017). Some studies define the changes in the structure of the distribution network to better manage the deliveries, such as the use of a Mobile Depot (MD) which allows doing express pick-ups and deliveries in urban cities (Verlinde et al., 2014), vary the number of service depots, the capacity and moving time of the vehicles, the time for receiving and shipping but also the delivery time (Shen & Chen, 2017).

Other groups of papers are focused on increasing the last-mile delivery efficiency, such as parcel lockers, which consist of having new local depots located near consumption points closer to the final customer for them to pick up the parcel by themselves (Iwas et al., 2016), crowdsourcing logistics based on the principle of customers engaged to a social network built around friends to support the package delivery (Devary et al., 2017), reception boxes and pick-up points focused on the fact that customers' acceptance may lead to better policies for a more sustainable urban environment (Kedia et al., 2017), dynamic pricing policies and dynamic vehicle routing (Koch & Klein, 2020) and drones (Ha et al., 2018).

Lately, a new concept has been discussed in the literature which is known as the green last mile, attending to customers' demand of having a more sustainable focus (Mathisen & Nordgarden, 2020). This option is based on the selection of the mode of transportation, which is deriving in one of the most relevant decisions for logistics companies, to ensure that the green last-mile does not generate more greenhouse gas emissions (Mathisen & Nordgarden 2020).

Despite all the different contributions that have been published around the field of last-mile delivery, the knowledge about the solutions to tackle its negative impact of it mainly on the environment is still considered to be fragmented, in the sense of having a necessity to set clear directions for future works in the academic community (Mangiaracina et al., 2019).

In this thesis, the last-mile delivery plays an intensive and important role, because it is considered the most pollutant and costly in the delivery process. As has been mentioned, several authors have raised their interest in making it more efficient and the present work will contribute to this part of the research considering the last-mile delivery as a fundamental part of the analysis.

The last mile, as discussed in the previous section, has a great impact on the supply chain, especially for an e-commerce company, and it is justified to discuss its importance given the negative impacts on the environment and economy through a sustainable perspective. Considering this, the thesis will be focused on the last-mile delivery stage and not on long-haul distances, in which the driving distances are over 150 km (Mareev et al., 2018).

2.4. Sustainability and The United Nations Sustainable Development Goals

The concept of sustainable development was firstly developed by the UN Commission, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own need" (Mucowska 2020). The existing definitions of the concept are focused on the necessity to integrate the three principal constituents of sustainable development, which are "environmental protection, economic growth, and social equity", also known as the three pillars of sustainable development (Mucowska, 2020).

The growth of e-commerce has brought negative externalities of emissions due to the increase in urban freight transport (Mucowska, 2021), while a green consumerism trend has been growing from the side of the customers to fight against the natural resource degradation (Mathisen & Nordgarden, 2020). This trend has made the customer look for more green and environmental options with the objective of making more environmentally responsible choices, forcing the market to offer the customer greener services and products (Mathisen & Nordgarden, 2020).

Under this context, the United Nations Sustainable Development goals written in 2015, represent a solid background to work on a strategic plan with the main objective of offering the future generations more sustainable and greener societies (Mathisen & Nordgarden, 2020). By many authors, these goals are considered a response to the actual state of urgency for companies and businesses to diminish climate impact but at the same time to create innovative strategies and offer solutions to compete in sustainability (Mathisen & Nordgarden, 2020).

According to Mathisen & Nordgarden (2020), companies need to understand that being financially efficient should not be the core of their business, but they also need to focus on being socially and environmentally responsible. This is pushing the companies to add more sustainable logistics to the corporate strategy, which is also an important concept for investors and stakeholders (Mathisen & Nordgarden, 2020).

The concept of sustainability started gaining more attention from researchers in 2017. Since this year more than 50 papers appear with the concept while in the past five years it appeared no more than ten times (Mucowska, 2020). The objective of finding sustainable last-mile deliveries resulted in the appearance of green logistics in the literature and alternative methods of deliveries such as cargo bikes, crowd shipping, and electric vehicles (Mucowska, 2020).

On the other hand, green and sustainable logistics have gained importance to ease the environmental impact of supply chain management (Mathisen & Nordgarden, 2020). Among the strategies to build greener logistics, are the initiatives of public investment, also transferring the real cost of externalities to the responsible parties by imposing taxes on carbon and pollutant emissions. Nonetheless, the literature also implies that these strategies may not have the expected impact if the consumer does not get involved in the collaboration for building a more sustainable supply chain (Mathisen & Nordgarden, 2020). According to recent literature, the consumer will perceive value only if the company offers an enjoyable and secure service experience, which will lead the customer to participate in the co-creation of value (Mathisen & Nordgarden, 2020).

The literature provides several ways to measure sustainability, but to stay consistent with the Sustainable Development Goals, the global indicator framework established by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) settled at the 48^{th} session of the United Nations Statistical Commission held in March 2017 is going to be taken into account.

The KPIs that are going to be measured for the analysis are the annual levels of fine particulate matter in cities, linked to Goal 11 (Sustainable Cities and Communities). While supporting Goal 12 (Responsible Consumption and Production) this thesis is intended to inform people of having relevant information and awareness for sustainable development and finally, the CO_2 emissions are going to be measured, being a matter of Goal 13 (Climate Action). (United Nations General Assembly, 2020).

Transportation has multiple and dangerous "impacts on the environment, such as resource consumption, land use, the Greenhouse effect, acidification, toxic effects on ecosystems and humans, noise, and congestion" (Borken et al, 2003). According to Bektas & Laporte (2011), among all these impacts, the Greenhouse Gas (GHG), especially CO_2 emissions, are the riskiest ones as they repercuss directly on human health (like pollution) while some indirect ones exist, as it is the case for the ozone layer depletion.

Given the transportation framework, environmental sustainability is composed of the reductions of pollutants, reducing noise, and habitat loss, which are related to the impacts of city freight transport (Mucowska, 2020). Considering that not all impacts can be measured easily, numerous alternatives have been offered by authors to establish a set of quantitative and qualitative variables to identify the impact. According to the literature reviewed, pollution is the most commonly used indicator (Mucowska, 2020).

"Exposure to ambient fine particulate matter ($PM_{2.5}$) is a major global health concern" (Martin et al., 2019). "Exposure to $PM_{2.5}$ is a leading global mortality risk factor, with an estimated three to nine million attributable deaths in 2017" (Martin et al., 2019). While, the annual global welfare costs associated with premature deaths attributable to $PM_{2.5}$ are expected to increase from USD 3 trillion in 2015 to USD 18-25 trillion in 45 years (OECD, 2016).

Given the introduction of the previous concepts, it is understandable that companies are seeking a better way to fulfill the needs of more clients around the world which leads them to have a bigger vehicle fleet at their disposal, intending to have the option of traveling larger distances per trip or to make more round trips, impacting directly in the environment and to the sustainability concept. The main tangible and measurable impacts derived from this need are the kilometers traveled, the expenditures on oil and maintenance, and more pollution such as noise, moreover, the urban air polluter in form of particulate matter (e.g., $PM_{2.5}$ - particles with diameters less than 2.5 micrometers-, PM_{10}, PM_1, $PM_{0.1}$) with more GHE (Green House Emissions) (e.g., Co_2) which is directly transmitted to the environment (Bui, 2020).

Even though these impacts may be done by some companies, in the end, the effect impacts everyone, from companies to customers, organizations to governments, suppliers to customers, and in a few words, the society as a whole.

2.5. The Vehicle Routing Problem and its Routing Solutions

In the context of logistics and transportation, vehicle routing problems play a critical role and different variants found in the literature have been widely studied during the past decades (Braaten et al., 20187). Most of the available research is based on deterministic problems, where all the parameters related to the problem are known, however, in real life, it is common to observe uncertainty, which decision-makers need to consider (Braaten et al., 2017).

"The most common sources of uncertainty found in the literature are demand volumes, the presence of customers, and stochastic travel and service times" (Errico et al., 2018). In this paper, a deterministic approach will be considered and uncertainty is relevant because it will narrow the parameters to consider for the analysis.

First of all, to understand the different routing solutions, it is convenient to understand what is a vehicle routing problem. The beginnings of the vehicle routing problem (VRP) definition are related to "The Traveling-Salesman Problem", the problem which aims to minimize the total travel distance or total travel time of a salesman who, in his/her quest for executing sales, needs to visit n cities once, starting and finishing the route at home or starting and ending at a point zero (Flood, 1955).

Different researchers have defined VRP from different perspectives and angles but generally end in a similar concept with some variations. The VRP consists of the design of optimal routes (delivery or collection) from a central depot to different customers, located in a scattered way, impacted by several limitations and constraints, such as “vehicle capacity, route length, time windows, precedence relations between customers, etc.” (Laporte, 2007).

Comparably Irnich et al. (2014), define not only the classical VRP but the family of VRPs as the need to “determine a set of vehicle routes to perform all (or some) transportation requests with the given vehicle fleet at minimum cost; in particular, decide which vehicle handles which requests in which sequence so that all vehicle routes can be feasibly executed” with a given group of conditions described as a “set of transportation requests and a fleet of vehicles” (Irnich et al., 2014). This minimum “cost” may have different perspectives, mainly an economic one, but also from a societal or environmental focus. In addition, when expanding restrictions, from the number of vehicles or vehicle routes to the broad definition of “feasibility” it is explainable why many different definitions of VRP exist, and typically inspire real-life applications.

The VRP consists of different variants including the standard TSP, Multiple TSP, Capacitated VRP, VRP with time windows, dynamic VRP, pickup, and delivery VRP, and periodic VRP among others (Ibrahim et al., 2019). One of the most known problems in VRP is the Capacitated Vehicle Routing Problem (CVRP) in which the vehicles have limited carrying capacity (Irnich et al., 2014).

Some of the groupers mentioned by Irnich et al. (2014) in their article start from the basis of The Capacitated Vehicle Routing Problem which transportation requirements settle a distribution of goods from one point to another, for giving an overview of some of the most commonly studied variants with six different criteria: network, transportation type, individual restrictions, fleet characteristics, inter-route conditions, and objectives.

- Network characteristics consider the limitations of taking them as points in the space and understand how to treat connections, links, and divisions through extending the granularity of data (Irnich et al., 2014).
- For transportation types, several subdivisions were explained.
    - Delivery and collection/pick-ups in which delivery to customers refers to collection from customers, while collections are known as pickups (Irnich et al., 2014).
    - Point-to-point transportation. This concept refers to the fact that "each transportation request consists of the movement of goods between two particular locations" (Irnich et al., 2014).
    - Dynamic and stochastic routing. Where in the first, dynamic routing, known or partially known information, mainly about customers' locations and demands is discovered as the time moves on with an "online" version when heuristic methods are encouraged relating it to performance (Irnich et al., 2014). Vehicle dependency and travel duration affected by external factors (traffic volume, street maintenance, accidents, etc.) are also included as types of dynamic routing (Irnich et al., 2014).
- For intra-route constraints, related to a route 'feasibility', also different subdivisions were explained.
    - Loading, related to capacity constraints (CVRP), can go from two to three-dimensional loading constraints (Irnich et al., 2014).
    - Route length, related to travel time and distance under edges or arcs, is presented as DCVRP (Distance-constrained CVRP) (Irnich et al., 2014).
    - Multiple-use of vehicles, within the VRPM (VRP with multiple uses of vehicles) the VRP is based on one vehicle performing one route, while the MTVRP (Multi-trip VRP) leans on the idea that one vehicle will perform more than one route. Metaheuristics and the development of an exact algorithm can be found in the literature to find the best possible solution (Irnich et al., 2014).
    - Time windows and scheduling aspects are going to be discussed in section (2.6) Delivery Time Windows.

- Fleet characteristics, consider the different aspects and characteristics of the vehicles concerning speed, associated costs, vehicle and delivery capacity, location accessibility, and even the skills to load and unload from the vehicle.
    - Multiple depot VRP is the case when "the fleet of vehicles is homogeneous, but vehicles start and end their routes at different depots". (Irnich et al., 2014).
    - Heterogeneous or mixed Fleet VRP "considers groups or types of vehicles that can differ in capacity, variable and fixed costs, speeds, and the customers that they can access" (Irnich et al., 2014).
- Inter-route constraints, in this case, the solution depends on the combinations within the routes and schedules (Irnich et al., 2014).
- Objectives may model various goals apart from just routing cost minimization problems (Irnich et al., 2014).
    - Single Objective Optimization is considered "the simplest modification to the objective" where some of the objective components are set to zero or a sufficiently large number (Irnich et al., 2014).
    - Hierarchical Objectives, in which first an objective is optimized and in a hierarchical way the secondary objective will be optimized (Irnich et al., 2014).

In the literature, multiple variants of the VRP can be found, such as the capacity vehicle routing problem (CVRP), the periodic vehicle routing problem (PVRP), the multi-depot vehicle routing problem (MDVRP), and the vehicle routing problem with time window (VRPTW) (Shen & Chen, 2017).

Other studies have been developed, such as the model presented by Dress et al. (2007), named "Energy-Minimizing Vehicle Routing Problem which is an extension of the VRP where a weighted load function, rather than just the distance, is minimized". Also, a related study takes into account energy considerations in vehicle routing from a different perspective, where the authors considered a VRP in which perishable food needs to be distributed using vehicles with cold storage equipment (Chang et al., 2003).

Studies until 2010 were mainly focused on classic routing problems, but after this year, routing problems considering pollution emissions and energy consumption attracted researchers' attention and more studies can be found on this topic (Asghari et al., 2021). The objective of green transportation is to extend the concept of traditional VRP taking into account the social and environmental impacts related to fuel consumption and GHG emissions (Asghari et al., 2021). The routing problems with environmental considerations can be divided into economic (travel cost, fuel and charging cost, station installation cost), environmental (emissions, environmental impacts, and fuel consumption), and social (level of service, customer satisfaction, and responsibility) (Asghari et al., 2021).

As the vehicle routing problem is a combinational optimization problem, it is known to be a computationally consuming and demanding problem for which many heuristics, meta-heuristics, and exact problems/solutions have been studied and suggested in the literature (Nazari, 2018). Other authors propose a heuristic method that is claimed to derive approximate solutions of good quality with reduced running times (Braatan et al., 2017).

2.6. Delivery Time Windows

A delivery time window could be defined as the time interval where consumers who have done an online purchase, receive their delivery at the receiving point and therefore pinpoints the time in which they must be available at a given location to make reception of the delivery (Nguyen et al., 2019). Literature shows that time windows help to meet high expectations from customers, mainly because they give customers the opportunity to choose the time, they would prefer to receive their delivery (Ramaekers et al., 2018).

Yet, if more customers pick a time window, there would be an increase in the total costs for a given company (in the B2C e-commerce context) because this represents a restriction by giving less flexibility in the planning of the delivery routes (Ramaekers et al., 2018). What a lot of companies do to cover the cost increase, is to provide this service as an additional cost to the customer at the purchase moment (Ramaekers et al., 2018).

Nevertheless, time windows offer benefits to customers such as avoiding unnecessary waiting time, they "expect a fast and accurate delivery within tight time windows at a low cost or even free" in which delivery is promised to be done the same day or even the next one (Ramaekers et al., 2018). On the side of the e-commerce company, giving a promise of faster deliveries implies dealing with a higher pressure on the warehouse operations to deliver on time and having the necessity to create an efficient distribution network (Ramaekers et al., 2018).

Some authors made an extension of this problem by adding service times to their models modifying the existing ones adding more complexities, in which the travel time and windows are redefined (Irnich et al., 2014). In this new model, it was found that the driving rules and schedule regulations are some of the most concerning complexities. An important concept within the time windows is the constraints that have been already discussed, but there are distinct types of constraints supporting different analytical approaches. A constraint is called hard when it must be satisfied, while it is called soft when it can be violated (Sitek et al., 2019).

The vehicle routing problem with time windows (VRPTW), is an important variant of VRP, and as described before, "assumes that each customer must be served within a time window" (Hu et al., 2018). Customer windows can be "hard" or "soft". For the hard time windows, the deliverer cannot be either early or late, while in the soft time windows being early or late for the deliverer is allowed with a penalty (Hu et al., 2018).

In real-life applications, VRPs involve a fleet of vehicles that depart from a depot to supply many customers who have different associated demands within specific time windows (Zhang et al., 2020). It exists a problem called multiple vehicle routing problems with soft time windows (MVRPSTW), in which the time window can be sometimes violated with associated penalties, such as compensation to customers and negative evaluations, which is a constraint called soft time window constraint (Zhang et al., 2020). This problem has arisen interest of researchers and although heuristic algorithms have been proposed to address it, the option to provide a reliable solution is still a challenging task (Zhang et al., 2020). In the present thesis, hard time windows will be assumed.

Another variant discussed in the literature is the "VRPTW-ST (Vehicle Routing Problem with Time Windows and Stochastic Service Times) in which the service times are random variables" (Errico et al., 2018). This variant is part of the classical vehicle routing problem, there, service times are incidental variables while time window (TW) limits are hard constraints (Errico et al., 2018). The service to a given customer begins within the TW and deliverers can arrive before the beginning of the start window but not after it already finished (Errico et al., 2018). The main objective of this problem is to plan all routes before knowing the required time to attend to each one of the customers (Errico et al., 2018).

To understand the impact of time windows given by an e-commerce company, executing empirical scenarios is key to studying the reduction of negative impact on the environment through the use of adequate KPIs, complementing the existing research by adding variables of interest.

2.7. Failed Deliveries

Customer satisfaction has been studied to understand which factors influence it (Escudero et al., 2022). Results may indicate that delivery order fulfillment has a higher relevance for the customer than the pre-purchase stage, meaning that the delivery of products on time, in the right quantity, and quality is critical to customer satisfaction, thus to the development of e-commerce (Escudero et al., 2022).

As discussed before, a successful delivery happens when the customer is available to receive the parcel and from an operational perspective, this is desirable mainly because the company avoids costs related to new delivery attempts, package handling, or contracting a third-party company to store or deliver the parcels (Florio et al., 2018). However, ensuring successful deliveries is not an easy task, since many customers may not be at home during the entire delivery period, moreover, time windows, which may help to assure a successful delivery, are not common in the delivery of small parcels (Florio et al., 2018). As discussed in the previous section, fixing time windows for each customer may lead to severe constraints and very high operational costs (Florio et al., 2018).

In the literature, different solutions can be found to reduce the failed deliveries in e-commerce. The main strategies used today are home delivery and customer pick-up, also shared delivery locations, such as lockers and shops, have recently gained attention from e-commerce companies (Escudero et al., 2022). Recently also a lot of companies have started considering giving the option to the customer to choose a time slot to have their parcel delivered and authors have detected the willingness of the customer to pay for this service (Escudero et al., 2022).

Other solutions such as reception boxes, delivery boxes, collection points, lockers, and controlled access systems have been offered as alternatives to home delivery, and more recently, smart boxes which are operated through the smartphones of the consumers can be found as an alternative solution (Florio et al., 2018).

In the literature, a problem was introduced named the delivery problem (DP), in which the provider tries to maximize the rate of successful deliveries by introducing a concept called availability profile instead of using time windows (Florio et al., 2018). In this problem, each customer is associated with an availability profile which can be estimated through historical data and map their availabilities to receive the parcel (Florio et al., 2018). The objective of the DP is to set routes expecting the number of successful hits to be maximized (Florio et al., 2018).

Five main subsections elaborating on different topics were onboarded in this literature review. Starting with (2.3) e-commerce and the last mile with their relevance and complications, then linking this with (2.4) sustainability and how the UN SDGs assess this important matter. It was found how relevant it was and some possible actions to be taken, but a gap in the literature found is about particular cases of companies using these suggestions and reportings and how they have fared in a general sustainable perspective: economical, societal, and ecological pillars. Real success stories and applications differ from objectives and targets, a lot of actions towards the future were found but only a few positive tangible impacts of past actions.

Afterward, (2.5) the VRP and its solutions developed the complexity and needs for an enormous possibility of delivery scenarios. Being one of the utmost important factors for the latest point and this work the (2.6) delivery time windows. Lastly, the counterpart effect of the sustainability tradeoff, (2.7) failed deliveries concept was introduced giving the reader notion and information of its relevance, and also as a basic framework for the upcoming empirical part.

Additionally, from the literature review, it can be deduced that last-mile operation is influenced mainly by the customer and it is important to offer a solution in which the customer is involved and interested in optimizing the supply chain. This will of course help the e-commerce company to reduce operational costs and offer the customer a better quality of service.

Today, it may be concluded that customers may be willing to accept some restrictions such as time windows through some incentives but in the present thesis, the intention is to assess different economic and sustainability KPIs which may vary along with the impact due to failed deliveries in an optimal VRP solution without time windows and another sub-optimal solution with a hard time window, to reduce the number of failed deliveries.

As a general remark, the empirical part of this thesis will consider that time windows are being imposed by the delivery company or courier. In contrast, time windows chosen by the customers may have a larger impact on the efficiency of the routing solution but also on the potential reduction in failed deliveries. In addition, this consideration avoids the possibility of persuading the customer to choose one time window over another which could be interesting for another work.

Empirical research will be run supported by quantitative analysis made with a spreadsheet solver for VRP and different tools (see 3.1 Empirical Research Methodology section). Practical considerations, the scope boundaries, and factors from the Literature Review section will be taken into account for simplifying the data modeling and enabling a broader achievement of results (see 3.1 Empirical Research Methodology and its subsections). With this comprehensive variety of results, the research will measure how the selected KPIs behave in different scenarios and a sensitivity analysis will be done for answering the research questions.

For this reason, this dissertation aims to generate further knowledge of the crucial considerations for evaluating the impact of last-mile delivery efficiency in e-commerce on sustainability through varying time window parameters. And to what extent defined Key Performance Indicators (KPIs) which are derived from three of the seventeen United Nations

Sustainable Development Goals are positively or negatively affected. The latter results in a range of calculated cost points (traveled distance, transportation costs, CO_2 emissions, and $PM_{2.5}$) that will support the dimension of the relevance of the named time windows.

3. Empirical Section

3.1. Empirical Research Methodology

This section aims to describe how the empirical quantitative study will be performed. Its focus is to investigate the behavior of the incumbent KPIs in different Capacitated-VRPTW scenarios. These will vary along time window delivery changes considering the cost of failed deliveries in the last mile within an e-commerce context. The before called "incumbent" KPIs are the dependent variables of the experiment, which will be addressed in Section (3.1.1. Key Performance Indicators).

In other words, this work aims to characterize and later compare two delivery suboptimal effects:

1. The effect of time windows on specific Capacitated-VRPTW scenarios ([Effect A]).
2. The effect of failed deliveries when having these time windows ([Effect B]).

An assessment developing a sensitivity analysis for different time window scenarios will be performed and will serve as support to understanding this comparison. More in Section (3.1.3. Cases and Scenarios). Each of the mentioned effects is influenced by different independent variables and has a different treatment when executing the calculations.

For instance, the effect of time windows on specific Capacitated-VRPTW scenarios [Effect A], carries as input, related independent variables, such as the number of customers in the database, the delivery time window size, and the delivery time window frequency. In the understanding that narrow time windows tend to have low rates of failed deliveries and, larger time windows have high rates of failed deliveries (Ramaekers et al., 2018) [Effect B].

These variables impact the Capacitated-VRPTW solution [Effect A] while affecting failed deliveries [Effect B]. All the different Capacitated-VRPTW scenarios will be solved by using

Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017) [Effect A], for abbreviation in this work: "ESSVRP". More on the usage, parametrization, and limitations of this tool will be discussed in Section (3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems).

In this work, failed deliveries are counted as an additional average visit. A given percentage in failed deliveries adds to the same percentage of additional 'cost' obtained from Erdogan's Spreadsheet Solver result (Erdogan, 2017). This comes from the fact that this thesis considers visiting the customer locations of the failed deliveries a second (and only a second) time. Also, it is possible to have more than one failed delivery with the same customer, but this possibility has been excluded. An explanation of which 'cost' a given percentage is applied, will be mentioned when describing the tool.

Furthermore, to compute the effect on failed deliveries [Effect B], a simple randomized technique taking into consideration time windows was developed. More in Section (3.1.5. Failed Delivery Scoring Technique).

Different assumptions were either computed or taken from the literature. This is mainly for parametrizing Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017) and serving as a basis for final calculations. More in Section (3.1.2. Assumptions and Parameters).

Since this dissertation is focused on last-mile delivery within an e-commerce context, a city with at least 500,000 inhabitants with a population density above 400 hab/km^2 was foreseen. In countries such as Mexico, there are more than 30 cities with these requirements, adding the author's access to reliable data of most of them, justify that the experiment will be performed in this country: Mexico. With the same logic, the city of Cancún in the Mexican state of Quintana Roo appears as the most suitable to conduct this study. More information is to be described in (3.2) Data Collection section.

From "The Research Onion Model" (Melnikovas, 2018) this dissertation is influenced by Positivism and Realism philosophies, taking a deductive approach and a strategy with various scenarios (experiments). Since the values of the parameters will be the ones changing in each scenario and not the method itself, the vehicle routing solutions quantitative analysis are mono methods configured within the spreadsheet add-in solver for VRP. Techniques and procedures will be explained in the following sections subsections and section (3.2) Data Collection.

The applications of this work may vary, to serve the enterprise market, it could also support decision-making in some public organizations and consultancy firms. Its reach and scope will be further delimited and discussed in the conclusions of this work.

3.1.1. Key Performance Indicators

From the literature review, sustainability key performance indicators (KPIs) and their environmental and economic aspects have been linked to the UN Sustainable Development Goals (United Nations General Assembly, 2020).

Three main KPIs relate to the last paragraph:

- Levels of fine particulate matter in cities are linked to Goal 11 (Sustainable Cities and Communities) in the form of: **PM2.5 (g).**
- The economic side: direct logistics **costs from ESSVRP Solution (in USD $)**. This is partially linked to Goal 12 (Responsible Consumption and Production).
- **CO2 emissions (g)** are linked to Goal 13 (Climate Action).

Although, for comparing the solutions as a whole, this work must translate each KPI to the same units of measurement. Hence, it is convenient to transform CO2 and PM2.5 grams of particles per million into a monetary value. Deriving in an overall KPI: **Total Cost (USD $).**

As mentioned before, these KPIs can be understood also as dependent variables. And to compute them, some intermediate KPIs were required to be calculated (see list below including the KPIs already mentioned):

- Number of vehicles used in the solution
- Total Unitary Cost (Total net profit) – from ESSVRP Solution
- Distance traveled from ESSVRP Solution (in kilometers)
- Additional Distance caused by Failed Deliveries (km)

- Total Distance -*Adjusted*- (km) – which refers to the sum of the 'Distance traveled from ESSVRP Solution (km)' plus the "Additional Distance caused by Failed Deliveries (km)'.
- Costs from ESSVRP Solution (USD $)
- CO2 Emissions (g)
- CO2 cost (USD $)
- PM2.5 (g)
- PM2.5 cost (USD $)
- Total Cost (USD $)

The optimized values of these KPIs will be computed based on the independent variables causing [Effect A] and [Effect B], as well as from specific assumptions and parameters (next section).

Lastly, in Mexico, the legal currency is the Mexican Peso (MXN), but a conversion to United States Dollars (USD) is made for an agile understanding of a broader audience.

3.1.2. Assumptions and Parameters

The assumptions for the orders that the clients can place on any given e-commerce company are going to be taken from the literature. According to a study made to identify the packages ordered by a person and the cost of the order, it could be considered that each person places 1.2 orders per month with a total value of 38 USD (Sakai et al., 2020).

It is also of significance to understand the width of time windows for each calculation. According to Raemekers et al. (2018), the width of the time windows may be narrow or wide, for the first case from one hour to two hours is considered to be narrow, while in the second case more than 2 hours may be considered as wide.

Regarding the failed deliveries, it was found that successful first-time delivery attempts oscillated from 10% to 50% where specific delivery times were not prearranged (Voigt et al., 2021). Failed-delivery costs depend on the policy and practice in dealing with the failed deliveries, some possible cost scenarios would be delivery to a neighbor, delivery to a parcel shop, or return to the depot and starting a new delivery attempt during the next few days (Voigt et al., 2021). Pan et al. (2017) did a study with a methodological approach that mentioned that by mining the customer data and using it for an optimized solution, the total traveled distance could be reduced from 3 to 20%, while the success rate of first-round delivery was reduced by 18 to 26%.

From now on, the parameters and assumptions for the type of vehicle that is going to be used, general assumptions for the calculations, and the general operation of the vehicles considering an e-commerce company are going to be described. The type of vehicle that is going to be used is the one named light good vehicles (up to and including 3.5 tons gross weight), which "are used for many different purposes including goods transport, servicing activities, and commuting with the former making up a significant component of total LGV activity in urban areas" (Allen et al., 2021). The vehicles considered will be homogeneous.

For the cost of kilometers traveled by the vehicle, the consumption of diesel in liters/kilometer is obtained, considering an urbanized zone (similar to Cancun) which leads to 18.6 l/100 km (Canada, 2018). The cost of petrol in Mexico is around $1.19 USD per liter (Gasolina Mexico, 2022) and, the maintenance and operation (M&O) cost per km is $0.1004 USD (Topal, 2018). This results in $0.3211/km traveled which to some extent is consistent with the empirical value of $0.4538/km traveled, from an undisclosed delivery company the author got information from. This will be discussed at the end of this subsection.

Since the purpose of the experiments is to find the optimal solution and fixed costs are not a major KPI of this work, these will only be considered as an indication for avoiding unpractical solutions (e.g., 20 vehicles serving 20 customers, each vehicle serving only one customer). In other words, fixed costs will only be considered for steering the solution to find the minimum number of vehicles to be required for satisfying the solution, but the core of the solution to find the most efficient route remains in place.

For the assessment of the CO2 emissions, four main categories affect fuel consumption and therefore the CO2 emissions which are the type of vehicle, traffic and environmental conditions, and driver behaviors (Nocera et al., 2018). To calculate the CO2 emissions, the paper of Naderipour & Alinaghian (2016) is going to be considered.

$$e = \left(110 + 0.000375v^3 + \frac{8702}{v}\right) \times GC \times LC$$

Where:
e = emissions factor (g/km)
v = vehicle speed (km/h)
GC = correction coefficient for the road gradient
LC = correction coefficient for the vehicle load (Naderipour & Alinaghian, 2016).

The total emission will be obtained with the following equation.

$$E = e \times D$$

Where:
E = emission produced (g)
D = distance traveled (km) (Naderipour & Allinaghian, 2016).

It is considered that speed is the factor that affects most of the emissions, due to the wheels and air resistance (Naderipour & Allinaghian, 2016). The "gross vehicle weight rating (GVWR) is the maximum total weight permitted for the vehicle" including equipment, driver, fuel, and load (Naderipour & Allinaghian, 2016). The source considers that this formula applies to vehicles with a GVWR from 3.5 – 7.5 tons. As this paper is considering vehicles with 3.5 tons, this formula may be applied.

To calculate the road gradient influence coefficient, which also increases emissions, the following formula will be considered:

$$GC = \exp\left((0.0059v^2 - 0.0775v + 11.936)\gamma\right)$$

Where:
GC = the road gradient influence coefficient
ɣ = the road gradient (%)
v = vehicle speed (km/h) (Naderipour & Allinaghian, 2016).

Finally, the vehicle load affects vehicle inertia because heavier loads imply more power from the engine (Naderipour & Allinaghian, 2016). The following formula is going to be used.

$$LC = (0.27)x + 1 + 0.0614\gamma x - 0.0011\gamma^3 x - 0.00235vx - \left(\frac{1.33}{v}\right)x$$

Where:
LC = vehicle load influence coefficient
ɣ = the road gradient (%)
v = vehicle speed (km/h)
x = ratio of vehicle load to vehicle capacity (Naderipour & Allinaghian, 2016).

The percentage of road gradient (ɣ) to be used in this work, will be consistent with the one found in the literature of 10% (Naderipour & Allinaghian, 2016), this is consistent with Cancun city which is rather plain than mountainous. Although in the high range for an urban context, the vehicle speed to be taken is 31 km/h (more in the following paragraphs) and the ratio of vehicle load to vehicle capacity is 1. Truck-fills of 100% are rarely achieved within delivery companies, but the assumption of one vehicle being able to satisfy all customers and taking the value as a 'worst-case scenario', justifies this decision.

Applying the discussed formulas, the vehicle load influence coefficient (LC) results in a value of 1.1604 and the road gradient influence coefficient (GC) is 5.6822. Both serve as input for computing emissions factor (e), resulting in e = 2650 (g/km). This value will be multiplied by the distance of all 1425 cases, for obtaining the total CO2 emission (E) (Naderipour & Allinaghian, 2016).

For obtaining the cost of the CO_2 emissions, the data for the carbon tax rates from the World Bank will be considered. The information is provided by country, but as the tax rate in Mexico is one of the lowest, an average will be taken. 16 countries were presented and the average is USD 24 per ton of CO_2 emitted (World Bank Group, 2017).

For measuring $PM_{2.5}$, the factors given by Fauzie & Venkataramana (2016) are going to be used. In their study, they estimated the vehicular $PM_{2.5}$ and PM_{10} emissions given an urban area (Fauzie & Venkataramana, 2016). The average emission factor for a diesel light commercial vehicle (LCV) is 0.332 g/km.

To obtain the cost of the $PM_{2.5}$, a paper where "a reduced-form model derived from tagged chemical transport model (CTM) simulations" was made, they presented "$PM_{2.5}$ mortality costs per ton of inorganic air pollutants with the 36 km x 36 km spatial resolution of source location in the United States, providing comprehensive estimates" (Heo et al., 2016). The cost considered will be USD 88,000 per ton of $PM_{2.5}$ emitted (Heo et al., 2016).

Considering what has been described, the following assumptions will be done based on the literature research.

The total deliveries per day will be considered as 100, 150, and 200, which will be classified in different databases depending on the number of customers. The average speed will be taken by the solver (more in Section 3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems). By doing a simulation with 100 customers (Cost per km and Fixed costs calculation), it was found that the speed range went from 8 km/h to 83 km/h (dividing the total distance covered by each route between the time it employed in its tour), with an average speed of 31 km/h. This is consistent with the literature which gives an average speed of between 24 and 34 km/h in an urbanized context (Allen et al., 2021).

Hard time windows, a given time spent with each customer, and considering a limited number of available vehicles will be considered for making the delivery routes, and special treatment will be given to fixed costs in the solution (more in Section 3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems).

For understanding better the number of customers chosen in the context of Cancun, it is important not just to mention that Erdogan's Spreadsheet Solver for Vehicle Routing Problems is limited to 200 customers but how these customers were obtained since this amount seems very low for an entire city. This amount (200) is an extract of a larger database, where the customers are spread over the entire city and its surroundings. These are real customers with real locations. More will be explained in a later section.

Various parameters for the analysis will be described in Table 1.0.

Parameter	Measurement	Values
Database type: Small Medium Large	Number of customers	 100 150 200
Narrow Time Width (minutes): Narrow Wide	Duration of time windows in minutes	 60 120
Customers with Narrow Window (NTW)	Percentage of customers with a narrow window	10% 50% 90%
Failed Deliveries	Percentage of overall failed deliveries	10% 20% 30% 40% 50%

Table 1.0 Parameters for the analysis

All the generation of the information until now was done in a spreadsheet of Excel. The last considerations for this part were the consideration that each client asks for an order, while the assumptions for the vehicle were that vehicle has a capacity of carrying the necessary orders for attending to all customers on its own (up to 200 orders) in total and can only travel a maximum of 300 km per day considering the driving time limit (8 hours) and working time limit of 10 hours (more on 3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems section).

The working hours are considered to be 10, from 08:00 am till 06:00 pm and depending on the width of the time windows, the deliveries go from 09:00 am to 10:00 am for the first customer and from 05:00 pm to 06:00 pm for the last one in the case of the time window of 60 minutes, while the deliveries go from 09:00 am to 11:00 am for the first customer and from 03:00 pm to 05:00 pm for the last customer for the case of the time window of 120 minutes.

How the data was retrieved will be described in the following section (3.2) Data Collection.

Another parameter to be developed, fixed costs, are inputs for Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017). A simulation for comparing the relationship between the variable and fixed cost was made using a Microsoft Excel spreadsheet, information from the literature review, and public data (Cost per km and Fixed costs calculation).

As mentioned in a previous paragraph, variable costs in a grouped form, are mainly petrol and maintenance and operations (M&O). From section 3.1.2. Assumptions and Parameters, a consumption of 18.6 (l/100km) (Canada, 2018) and an M&O of 0.1004 (USD/km) (Topal, 2018) are being considered. Including the petrol cost in Mexico: $24.22 MXN (Gasolina Mexico, 2022) and a USD/MXN exchange rate of 20.411 (Yahoo Finance, 2022), a Total 1 (USD/km) value of $0.3211 were reached. This is to some extent in the same order that the mentioned $0.4538 USD/km (Total 2 (USD/km)). An average of these two values was used for this simulation, Average 1-2 (USD/km): $0.3875.

Consumption (l/100km)		18.6
Consumption (l/km)		0.186
Cost (MXN/l)	$	24.22
Exchange rate (USD/MXN)	$	20.4110
Subtotal (MXN/km)	$	4.50
Subtotal (USD/km)	$	0.22
M&O (USD/km)	$	0.1004
Total 1 (USD/km)	$	0.3211
Total 2 (USD/km)	$	0.4538
Average 1-2 (USD/km)	**$**	**0.3875**

Table 2.0 Average 1-2 (USD/km) inputs and detail

Meanwhile, fixed costs are mainly driven by the activation of an additional vehicle. Since in this simulation, the vehicle is already at hand for the delivery company, drivers' salaries and wages are the most important costs driver. Research on job posts requiring drivers with similar tasks was made on two websites, monthly driver wage fluctuates between $11,000 and $18,000 MXN (around 500-900 USD) as per one website (Indeed, 2022), while lower wages of $8,000 MXN (around 400 USD) were found in the other one (Talent, 2022). An average was taken concluding on an Average Daily Wage 1-3 (USD) of $23.26. Naturally, this is a low-end scenario, since wages have a larger cost for employers when including social security and taxes, but will serve the purpose of the experiment.

Monthly Driver Wage 1 (MXN)	$	11,000
Monthly Driver Wage 2 (MXN)	$	18,000
Monthly Driver Wage 3 (MXN)	$	8,000

Daily Driver Wage 1 (MXN)	$	423
Daily Driver Wage 2 (MXN)	$	693
Daily Driver Wage 3 (MXN)	$	308

Average Daily Wage 1-3 (MXN)	$	475
Exchange rate (USD/MXN)	$	20.4110
Average Daily Wage 1-3 (USD)	**$**	**23.26**

Table 3.0 Average Driver Daily Wage (USD/km)

Other considerations were avoided for ending with high fixed costs concerning the variable costs. A 60:1 ratio result (fixed costs are considered 60 unitary values of variable costs) assures that an extra vehicle will only be activated when it is mandatory for fulfilling the deliveries, thus the routing solution becomes more realistic.

3.1.3. Cases and Scenarios

For the analysis, a total of 90 scenarios were developed, taking into consideration 5 different customer database sets (see Table 1.0 and Table 4.0). From each one of these sets, variations came in the form of 3 different database sizes (size = number of customers included in the database). Each one of them with 3 levels of customers having a narrow time window (10%, 50%, and 90% of them), and then disaggregating on 2 widths (60 minutes and 120 minutes) of the narrow time window.

In addition, a baseline without time windows for all five sets was also developed. For each set (5) and amount of customers in the database 100, 150, or 200 customers (3) a baseline scenario was made, finalizing in 15 'baseline' scenarios.

Having these combinations, an additional factor was added which is the failed deliveries. This was treated in two dimensions. First, a given percentage of failed deliveries (5 different percentages) impacted all scenarios. Then, depending on the time windows size and percentage of customers having them, a percentage of failed delivery reduction was applied in 3 different levels of impact (more on Section 3.1.5. Failed Delivery Scoring Technique).

These 15 combinations, give in a total of 1425 cases that are going to be considered for the sensitivity analysis. 75 cases for the baseline and 1350 cases for the initial 90 scenarios.

A	Database Set (1:5)	5
B	Number of Customers (100, 150, 200)	3
C	Customers with NTW (10%, 50%, 90%)	3
D	NTW width (60min, 120min)	2
1	Scenarios (A*B*C*D)	90
E	Percentage of Failed Deliveries (10%, 20%, 30%, 40%, 50%)	5
F	Failed Delivery Reduction Range (Lower, Mid, Upper)	3
2	Combinations Cases (A*B*C*D*E*F)	1350
G	Baseline Scenarios	15
3	Baseline Scenarios Combinations (E*G)	75
	Total Number of Cases (2+3)	1425

Table 4.0 Total number of cases and scenarios.

These independent variables are then further described:

1. **Database Set:** where 5 sets of 200 customers were extracted from the master database holding 1000 customers.
2. **Number of customers:** where three options were considered, the first is a database of 100 customers, the second one of 150, and the third one of 200. The way the data was retrieved will be described in section (3.2) Data Collection section.
3. **Customers with narrow time window:** the percentages of the number of customers who will be served under a narrow time window are 10%, 50%, and 90%. Naturally, the baseline database has a 0% of customers with a narrow time window (NTW).
4. **Narrow time window width:** where two options were considered: 60 and 120 minutes. The width for the baseline was considered to be 0 minutes.
5. **Number of customers with narrow time window:** this factor results from the multiplication of the total number of customers by the percentage of customers with a narrow time window.
6. **Number of customers without a narrow time window:** this factor results from the subtraction of the total number of customers minus the customers with a narrow time window.

7. **Narrow time window failed delivery score:** 6 different possible values which are the basis for the characterization of the following attributes (more on Section 3.1.5. Failed Delivery Scoring Technique).
8. **Percentage of Failed Deliveries:** 5 possible values of failed delivery percentages applied to all baseline cases: 10%, 20%, 30%, 40%, and up to 50%.
9. **Failed Delivery Reduction Range:** 3 levels of reduction: Lower, Mid, and Upper range, proportionally adjusted that will serve for the next point.
10. **Percentage of Failed Delivery Reduction:** 18 different values which depend directly on the narrow time window failed delivery score and the failed delivery reduction range (more on Section 3.1.5. Failed Delivery Scoring Technique).
11. **Percentage of overall failed delivery variation:** Applying the percentage of failed delivery reduction to the percentage of failed deliveries. The final values, varying from 1% to 50% (depending on the original percentage of failed deliveries) are to some extent consistent with data obtained from the literature (5% to 40% in some cases).
12. **Number of Failed Deliveries with Variation:** which was calculated by multiplying the percentage of failed deliveries by the total number of customers.
13. **Additional Distance caused by Failed Deliveries (km):** which was calculated by multiplying the average distance traveled per customer (more on Section 3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems) by the number of failed deliveries with a variation.

3.1.4. Erdogan's Spreadsheet Solver for Vehicle Routing Problems

This subsection aims to explain how the analysis using Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017) was made. Starting with the spreadsheet solver tool familiarization, actual constraints, and simplification methods.

Most of the information described in the (3.2) Empirical Research Methodology is going to be introduced to a spreadsheet solver for Vehicle Routing Problems to obtain the optimized route. In the following paragraphs, the tool will be described to give a better understanding of it.

According to Erdogan (2017), “although there exist many commercial software packages to solve VRPs, any package must be integrated with the existing software infrastructure of the company and needs to be learned by the planning managers”. That is why the author explains that the Spreadsheet Solver offers a tool easy to use and understand for the user which offers flexibility and accessibility, while other commercial software is difficult to use mainly because developers try to protect their intellectual property (Erdogan, 2017).

An important restriction of this tool is that it does not accept more than 200 customers, this and its application possibilities and value decrease significantly for more realistic variants that include features such as a heterogeneous fleet or distance constraints (Erdogan, 2017).

One of the reasons for the accessibility of the solver is that it was developed using Visual Basic for Applications (VBA), which is described by the author as “an open-source that can be understood and modified by medium-level programmers” (Erdogan, 2017). “The VRP Spreadsheet Solver has built-in functions to query a GIS web service, from which the distances, driving times, and maps can be retrieved” (Erdogan, 2017).

The application of the Spreadsheet Solver will be described. The first and most straightforward applications of the VRP are found in the logistics sector, in which for example small companies are interested in keeping the routes as consistent as possible while minimizing the routing cost (Erdogan, 2017).

The worksheets contained in the solver are the worksheet named VRP Solver Console, 1. Locations, 2. Distances, 3. Vehicles, 4. Solution and 5. Visualization (Erdogan, 2017).

- “The cells with a black background are set by the worksheets and should not be modified, while the green cells are parameters or decisions to be made by the user” (Erdogan, 2017).
- “The yellow cells are to be computed by the worksheets, but they can be edited by the user for what-if analysis, and finally, the orange cells signal warning and red cells signal an error” (Erdogan, 2017).

The VRP Solver Console keeps and provides data to all the worksheets, the parameters included are regarding the size of the problem and its characteristics such as number of depots, number of customers, number of types of vehicles, and the width of the time windows (Erdogan, 2017). Another good functionality of the tool is that it allows the user set the time it will take to work on the problem (Erdogan, 2017). The parameters used for this dissertation are the following, where only variations were made on 1. Locations (Number of customers) and 6. Solver (CPU time limit (seconds)):

Sequence	Parameter	Value	Remarks
0.Optional - GIS License	Bing Maps Key	Ajmz1y_c6kdPPkPJdB2H4mPp5zgGl	You can get a free trial key at https://www.bingmapsportal.com/
1.Locations	Number of depots	1	[1,20]
	Number of customers	100	[5,200]
2.Distances	Distance / duration computation	Bing Maps driving distances (km)	Recommendation: Use 'postcode, country' format for addresses
	Bing Maps route type	Fastest	Recommendation: Use 'Fastest'
	Average vehicle speed	30	Not used for the 'Bing Maps driving distances' options
3.Vehicles	Number of vehicle types	1	Heterogeneous VRP if greater than 1
4.Solution	Vehicles must return to the depot?	Yes	Open VRP if no return
	Time window type	Hard	
	Backhauls?	No	If activated, delivery locations must be visited before pickup locations
5.Optional - Visualization	Visualization background	Bing Maps	
	Location labels	Location IDs	
6.Solver	Warm start?	No	
	Show progress on the status bar?	No	May slow down the optimization algorithm
	CPU time limit (seconds)	100	Recommendation: At least 600 seconds

Table 5.0 VRP Solver Console tab – ESSVRP (Erdogan, 2017)

In other words, all 90 scenarios and its 15 baselines make use of Bing Maps and work with: one depot, one vehicle type (homogeneous fleet), with all the vehicles returning to the depot, hard time windows, and no backhauls. From last section 3.1.3. Cases and Scenarios, 1. Locations (Number of customers) can only be 100, 150, or 200.

For 6. Solver (CPU time limit (seconds)) a recommendation is given taking into account a given formula: the number of customers to the 3rd power divided by 100,000, then multiplied by 60. However, a pragmatic approach was taken for executing the computations in a more agile way, defining a lower CPU time limit (seconds) for each number of customers.

To guarantee that the quality of the solutions was not diminished, some simulations were developed ("Timing Simulations Results Comparison"). A given scenario for each 100, 150, and 200 customers were developed several times for 6 different CPU time limits, then their solution average and was compared, deriving the most efficient CPU time limits:

For a database with 100 customers, 100 seconds were taken for the solver instead of the initially recommended 600 seconds. The quality of information was high enough and variations started at the next cut of 50 seconds.

CPU time limit	Cost Values
600 s	688.07
400 s	688.19
200 s	688.46
100 s	688.61
50 s	692.42
20 s	692.48

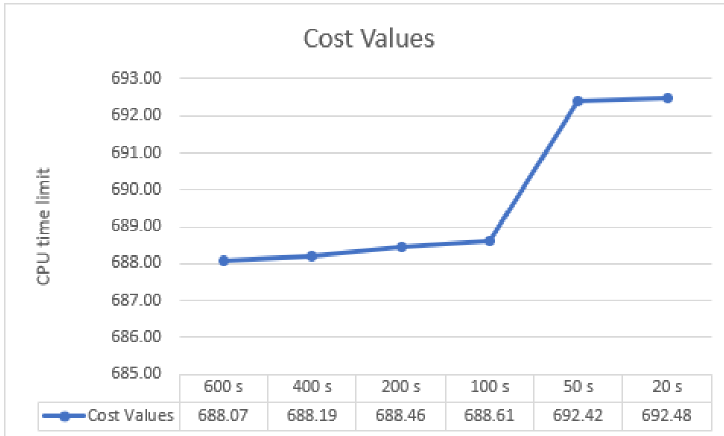

Table 6.0 Time simulations results comparison for 100 customers.

Similarly, for a database with 150 customers, 500 seconds were taken for the solver instead of the initially recommended 2040 seconds. The quality of information was high enough and the only outlier came up at 1500 seconds.

CPU time limit	Cost Values
2040 s	831.30
1500 s	829.16
1000 s	831.85
500 s	831.39
200 s	832.05
100 s	832.02

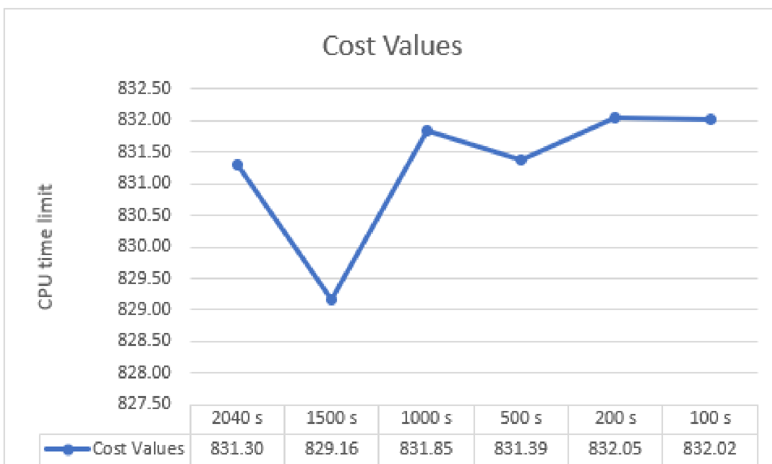

Table 7.0 Time simulations results comparison for 150 customers.

Lastly, for a database with 200 customers, 1000 seconds were taken for the solver instead of the initially recommended 4800 seconds. The quality of information was high enough and variations started at the next cut of 500 seconds.

CPU time limit	Cost Values
4800 s	852.88
2040 s	850.38
1000 s	852.85
500 s	862.98
200 s	860.26
100 s	868.19

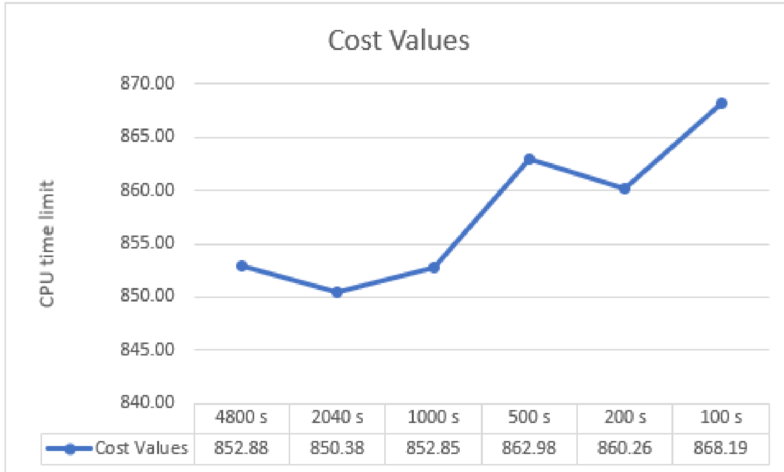

Table 8.0 Time simulations results comparison for 200 customers.

In the worksheet named 1. "Locations", all the details of them can be found, including names, addresses, coordinates, time windows, and pickup and delivery service requirements (Erdogan, 2017). The coordinates can be written manually or copied from other sources (Erdogan, 2017). In this case, coordinates for Longitude (x) and Latitude (y), as well as time window start and end, were taken directly from the databases that are going to be described in 3.2. Data Collection section. Additionally, a service time of 2 minutes was given at each stop. This comes from the fact, that for serving the maximum amount of 200 customers, no more than this number of rounded minutes can be taken for fulfilling the accepted working hours when considering having only one driver per vehicle.

In the worksheet named 2. "Distances": distances and travel durations between every two points are integrated (Erdogan, 2017). "The solver provides an estimate of the time required for this step by simply multiplying the number of entries in the distance matrix by a factor of 0.1 s" (Erdogan, 2017). The parameter about the type of route (shortest or fastest) is crucial. If the user chooses the shortest route, usually the solution will imply going through city centers adding speed limits and traffic restrictions, while the fastest one will use the peripheral highways (Erdogan, 2017). For this work, the "fastest" option was considered.

The worksheet is named 3. "Vehicles" contains data about the vehicle types and the user can set the number of vehicles of each type that are kept at the depot (Erdogan, 2017). "The data includes cost parameters such as the cost per unit distance and the cost per trip, as well as operational parameters" (Erdogan, 2017). Since there is only one vehicle type, and as explained before, a unitary capacity was considered only comments on the remaining parameters will be given.

- Cost per unit distance: where unitary values (1.00) are taken, then the Cost per unit distance is equal to the number of kilometers traveled.
- Distance limit: with the intention of not imposing harsh limits on the distance to be covered by unit, and comparing the solutions in a more purely manner, a limit of 300 kilometers was included.
- Work start time: 08:00am
- Driving time limit: 08:00 hours.
- Working time limit: 10:00 hours.
- Return depot: yes, all vehicles must return to the depot after finishing their delivery route.
- Number of vehicles: in the same tenor as the distance limit, a rather high number of vehicles for the number of customers was taken into consideration, 20 vehicles. This is for avoiding this being another variable to influence the KPIs.
- Fixed cost per trip: 60. While there are more than enough vehicles to satisfy the solutions, high fixed costs per trip were included to steer the solution to use the minimum amount of vehicles. A relationship with the unitary value of cost per unit distance was computed (Cost per km and Fixed costs calculation) as explained in the previous section ending in this value (60:1 relation).

"Worksheet 4. "Solution" is generated to contain the list of stops for each vehicle specified in 3. Vehicles, and it uses the information in 1. Locations regarding service times and pickup/delivery amounts, as well as the distance and duration in 2. Distances to compute the departure and arrival times and the cost of traveling between customers" (Erdogan, 2017). "The worksheet computes the net profit rather than cost, to accommodate variants of the VRP that accumulate profits when customers are selectively visited" (Erdogan, 2017). "Total net profit" (only the spreadsheet's cell name, but not considering profits in this work) considers the sum of fixed and variable costs, in this work it is relevant to distinguish this value from the Distance traveled from ESSVRP Solution (km) parameter. The latter can be calculated by subtracting the additional vehicle costs from the cell called "Total net profit"

(Total Unitary Cost), where each vehicle has a cost of 60 as from the previously explained relationship.

Finally, "the worksheet named 5. Visualization contains the locations and the routes of the vehicles that can be visually inspected by generating this optional worksheet" (Erdogan, 2017). "This worksheet contains a scatter graph with the map of the region retrieved from the GIS web service and it can be formatted" (Erdogan, 2017).

After having the results from the spreadsheet solver, the additional distance related to the failed deliveries will be added in Excel to the distance resulting from the solver. Where one failed delivery amounts to one extra customer, for this the percentage of failed deliveries will be considered and will be multiplied by the optimized distance. More on failed deliveries and their treatment in the next section.

3.1.5. Failed Delivery Scoring Technique

For the analysis it was necessary to make a narrow time window (NTW) "Scoring system" in which a weight of importance is given to the width of the time window and the percentage of customers with them, considering that having a narrower time window and more customers choosing a time window would help to reduce the failed deliveries.

Two possible values can be selected from the previously characterized narrow TW width (min): 60min or 120min. For the percentage of customers with NTW, three possibilities were previously discussed: 10%, 50%, and 90%. A decimal scale was built giving the higher score (10 'points') with the scenario that could reduce the most the failed deliveries: 5 'points' for NTW of 60min with (5 'points') 90% of customers with NTW. The remaining combinations were assigned an arithmetical proportional score and are depicted in Table 9.0:

Narrow Time Window (NTW) Scoring System				
Narrow TW width (min)	**Customers with NTW (%)**	**NTW width Score**	**Customers with NTW Score**	**NTW Failed Delivery Score (3.5-10)**
60	10	5.0	1	6.000
60	50	5.0	3	8.000
60	90	5.0	5	10.000
120	10	2.5	1	3.500
120	50	2.5	3	5.500
120	90	2.5	5	7.500

Table 9.0 Narrow Time Window Scoring System

In parallel, from Section 3.1.3. Cases and Scenarios, 5 possible values of failed delivery percentages were applied to all baseline cases. A score of zero was given in these situations. Serves as a basis for the second step of this technique.

Percentage of Failed Deliveries		
Number	Score	Possible values
1	0	10%
2	0	20%
3	0	30%
4	0	40%
5	0	50%

Table 10.0 Overall Failed Delivery Variation as a function of the Score

Depending on the NTW Failed Delivery Score, a Percentage of Failed Delivery Reduction was randomly considered. It was also mentioned, that 3 levels of reduction will be applied: Lower, Mid, and Upper range.

Computations start with the upper range, for maintaining the logic that a higher score will bring higher reductions, scores can be at first instance perceived as the applied reduction. For example, a NTW Failed Delivery Score of 10 could be 100%, 8 – 80%, 7.5 - 75%, 6 - 60%, 5.5 - 55% and 3.5 - 35%. But it seems unfeasible to reduce by 100% the original failed deliveries. Therefore, the NTW Failed Delivery Score is now subtracted from this intermediate value. The 100% reduction will be reduced to 90%, 80% to 72%, 75% to 68%, and so on.

Then, the lower range will possess half of this percentage. And the mid-range will be a middle value, an average between the upper and lower range values. This can be better appreciated in Table 11.0:

Overall Failed Delivery Variation			
NTW Failed Delivery Score (3.5-10)	**Lower Range**	**Mid-Range**	**Upper Range**
10.000	45%	68%	90%
8.000	36%	54%	72%
7.500	34%	51%	68%
6.000	27%	41%	54%
5.500	25%	37%	50%
3.500	16%	24%	32%

Table 11.0 Overall Failed Delivery Variation as a function of the Score

3.1.6. Hypothesis

The hypothesis of this dissertation will answer the central research question. *A suboptimal VRP solution with time windows that reduces failed deliveries will tend to be more convenient to choose from an economical and sustainability perspective than an optimal VRP solution with failed deliveries.*

In other words, [Effect B] – The (negative) effect of failed deliveries when having these time windows will be superior to [Effect A] - The (negative) effect of time windows on specific Capacitated-VRPTW scenarios

The acceptance or rejection of this hypothesis will be discussed in the (5) Conclusions section of this work.

3.2. Data Collection

From the INEGI (National Institute of Statistics and Geography, from its Spanish acronym) website (Inegi, 2021), and previously manual fieldwork of pointing and correcting coordinates made by the writer, different city databases in Microsoft Excel (.xls) files from Mexico was at the author's reach.

A swift analysis was made to leverage which database was the most "suitable" to be extracted, "suitable" referring in this case to a light, clean, straightforward database with information of at least 3000 addresses and coordinates, including households and small shops of traditional sales channels.

For this number of MS Excel lines, around 10 different databases appeared as alternatives, but in the last mile context with an urbanized, yet not completely saturated area, the only suitable ones were related to 3 options: Tlalpan municipality in Mexico City, Irapuato municipality in the state of Guanajuato and Cancún in the state of Quintana Roo, all of them within the boundaries of the national territory of Mexico.

The following criteria for simplifying the solution were databases related to sites with only one depot, therefore Cancun database was selected and was used in this dissertation.

As stated before, it is important to note that the customers in this database were mixed between households and small shops of traditional sales channels; but there was enough data to delete these shops without the need of doing any analogies and just maintaining households that are more common in an e-commerce environment (see 2.3 E-commerce and the Last Mile). Another deletion made was the customers which were far enough to fall in more rural areas and falling outside the urban environment, a criterion of customers far away of a radius of 40 kilometers from the depot was taken to slim down the database.

After this pair of actions, personal information, and coding not relevant for this study were taken out, helping in complying with GDPR (General Data Protection Regulation) rules and lightening the database. The only relevant information kept for the analysis was the following: longitude and latitude in the form of coordinates X and Y, and the address of some customers whose name was changed only to “Customer”.

With this criterion, around 1200 customers remained, reducing the Cancun master database to 1000 customers and 1 depot. From this database, 5 sets of exactly 200 customers each were randomly (random =RAND () function was used in MS Excel) extracted, leaving the depot data in each one of them. For being consistent with the parametrization selected, and considering that large “L” databases were already at hand with these 200 customers, further randomized extracts were made for obtaining the medium “M” databases (150 customers) and the small “S” databases (100 customers). Consequently, all 100 customers in the small “S” databases appear also in the medium “M” and large “L” ones; whereas, all 150 customers in the medium “M” database are included in the large “L” ones. This applies to every set. Sets were taken for avoiding a relevant randomness effect.

Explaining further the processes performed in the last paragraph: Since the main database was accurate enough, a random =RAND ( ) function was used in MS Excel. A filter ordered the data rows from largest to smaller, then all customers were numbered from 1 to 1000. A selection of the first 200 customers was made for just extracting the first large "L" database for Set 1, ending in one of the final databases. In the same way, Set 2 will include customers 201-400, Set 3 customers 401-600, Set 4 customers 601-800, and Set 5 customers 801-1000. This numbering will serve for identifying each customer, with the Depot being "0". For the medium "M" and small "S" databases, again a random =RAND ( ) function and filter for ordering the rows were used, but the customers maintain their numbering. For example, for Set 1, a small "S" database will include a group of 100 customers out of customers #1 to #200.

In other words, the data set with 150 customers is a subset of the one with 200 customers, and the data set with 100 customers is a subset of the one with 100 customers.

A visualization of the customers' database can be found in the following Figures 1.0 to 30.0 (only one example will be included in the text body -Figures 1.0 and 2.0-), the rest (Figures 3.0 to 30.0 can be found in Appendix B).

<u>Large database of 200 customers:</u>

<u>Set 1</u>

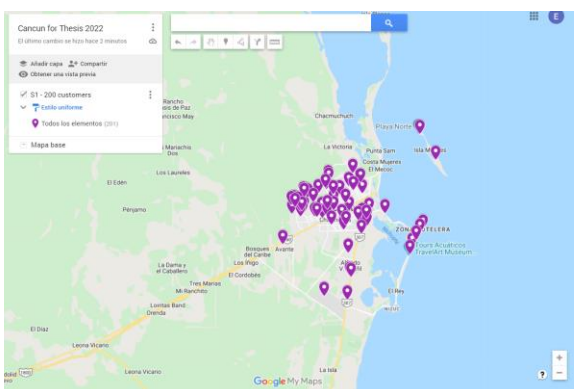

Figure 1.0 Visualization of customers in Google Maps

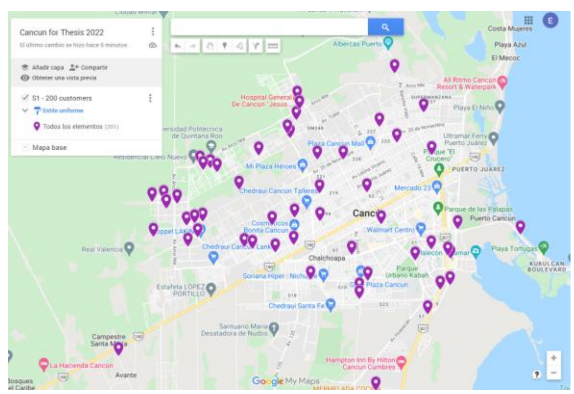

Figure 2.0 Visualization of customers in Google Maps

For simplifying the use of the Spreadsheet Solver for VRP selected (Erdogan, 2017), three tabs were built in each one of the databases. One tab for each percentage of customers with a Narrow time window (NTW) parameter (10%, 50%, or 90%). The selection of which 10%, 50%, or 90% of the customers was also made with the random MS Excel function, the largest random numbers adding up for the coherent number of customers with NTW were highlighted with an "NTW" legend in the corresponding cell. These customers were maintained selected for both scenarios of NTW width (60 or 120 minutes).

All databases can be found in the attachment of this work in a .zip file "Cancun Databases", from the master one "Cancun Database Master_1000" to the 90 databases which serve the 90 scenarios. Those 90 databases were simplified in 45 Excel files with separated columns for NTW widths of 60min and 120min, with the following structure:

- Database_Set number_Number of customers_Percentage of customers with NTW

As an example, "Database_S2_c150M_10pp" is related to Set 2, including 150 customers (medium) and with 10% of them having an NTW. So, these 15 customers with NTW, will have a pair of columns for NTW of 60 and 120min. NTWs' width impacts the same customers whether a width of 60 or 120 minutes was considered.

NTWs of 60min width start at 09:00 am (to 10:00 am) and can appear until 04:00 pm (to 05:00pm). If more customers have NTW, this process repeats. For NTWs of 120min width a similar process is applied, starting at 09:00 am (but to 11:00 am), and appearing until 03:00 pm (to finish at 05:00 pm).

4. Results

Parametrization and inputs mentioned in the previous section will support a better understanding of Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017) outputs. The structure of this ESSVRP in its Worksheet 4. "Solution" is further presented in Figure 31.0, here it is possible to visualize the routing solution attributes.

From the stop count (sequence), the location name (customer), the accumulative distance traveled and driving time, the arrival and departure time with each customer (time windows will be a constraint for these attributes), and the accumulative working time and others.

In addition, a summary result for each vehicle appears with the total number of "Stops" (number of customers attended), as well as a summed "Net profit". This "Net profit" is calculated by adding the fixed costs (60) to the total distance traveled. In the example, a distance traveled of 298.46, results in a "Net profit" of 358.46.

Total net profit:	-765.64							
Vehicle:	V1	Stops:	37	Net profit:	-358.46			
Stop count	Location name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0.00	0:00		08:00	0:00	0	0
1	Customer 63	8.42	0:21	08:21	08:23	0:23	0	0
2	Customer 41	9.81	0:26	08:28	08:30	0:30	0	0
3	Customer 72	11.31	0:30	08:34	08:36	0:36	0	0
4	Customer 44	18.83	0:38	08:44	08:46	0:46	0	0
5	Customer 78	71.15	1:20	09:28	09:30	1:30	0	0
6	Customer 98	74.20	1:26	09:36	09:38	1:38	0	0
7	Customer 77	75.43	1:30	09:42	09:44	1:44	0	0
8	Customer 11	76.43	1:34	09:48	09:50	1:50	0	0
9	Customer 9	76.83	1:36	09:52	09:54	1:54	0	0
10	Customer 29	77.34	1:38	09:56	09:58	1:58	0	0
11	Customer 60	80.70	1:47	10:07	10:09	2:09	0	0
12	Customer 10	81.73	1:50	10:12	10:14	2:14	0	0
13	Customer 37	83.08	1:55	10:19	10:21	2:21	0	0
14	Customer 68	83.72	1:57	10:23	10:25	2:25	0	0
15	Customer 35	104.09	2:16	10:44	10:46	2:46	0	0
16	Customer 2	104.64	2:19	10:49	10:51	2:51	0	0
17	Customer 89	104.82	2:20	10:52	10:54	2:54	0	0
18	Customer 39	105.06	2:21	10:55	10:57	2:57	0	0
19	Customer 54	105.51	2:22	10:58	11:00	3:00	0	0
20	Customer 6	105.96	2:24	11:02	14:02	6:02	0	0
21	Customer 94	106.42	2:26	14:04	14:06	6:06	0	0
22	Customer 91	122.60	2:41	14:21	14:23	6:23	0	0
23	Customer 34	122.87	2:43	14:25	14:27	6:27	0	0
24	Customer 19	130.42	2:52	14:36	14:38	6:38	0	0
25	Customer 100	148.69	3:07	14:53	14:55	6:55	0	0
26	Customer 67	148.86	3:07	14:55	14:57	6:57	0	0
27	Customer 7	152.00	3:15	15:05	15:07	7:07	0	0
28	Customer 95	152.75	3:18	15:10	15:12	7:12	0	0
29	Customer 51	156.93	3:29	15:23	15:25	7:25	0	0
30	Customer 65	160.53	3:38	15:34	15:36	7:36	0	0
31	Customer 47	161.22	3:41	15:39	15:41	7:41	0	0
32	Customer 61	188.27	4:04	16:04	16:06	8:06	0	0
33	Customer 92	196.56	4:10	16:12	16:14	8:14	0	0
34	Customer 75	224.85	4:34	16:38	16:40	8:40	0	0
35	Customer 58	225.32	4:36	16:42	16:44	8:44	0	0
36	Customer 57	292.84	5:35	17:43	17:45	9:45	0	0
37	Depot	298.46	5:50	18:00		10:00	0	0
38								

Figure 31.0 ESSVRP Worksheet 4. "Solution" structure.

This structure will be followed for each vehicle used, with a maximum of 20 vehicle layouts available. The sum of all vehicles "Net Profit" leads to the "Total net profit". A register of how many vehicles were used in each scenario, as well as the respective values of "Total net profit" and the pure distance, traveled (Distance traveled from ESSVRP Solution (km)). As mentioned in previous sections, this can be calculated by subtracting the additional vehicle costs (60 for each vehicle) from the "Total net profit".

As stated before, 90 scenarios were solved using Erdogan's Spreadsheet Solver for Vehicle Routing Problems (Erdogan, 2017), the structure of each solution is similar to the one used for the customer databases:

"Scenario #_VRP_Spreadsheet_Solver_Set #_Number of Customers_Percentage of customers with NTW_NTW width. xlsm".

As an example: "1_VRP_Spreadsheet_Solver_S1_c100S_10pp_60min.xlsm" refers to Scenario #1, solved from database Set 1, with 100 customers (small "S), 10% of them with an NTW and each NTW width being 60 minutes. A list of all 90 scenarios can be found in Appendix A: List of ESSVRP Scenarios. In each one of them, it is possible to visualize the solution (Worksheet 5. "Visualization").

After running the 90 scenarios, the rest of the quantitative analysis was made in MS Excel "Results Reporting.xls", laying back in the previous part mentioned. All the information was deployed in a principal table (sheet: "Results"), its 34 columns and 1425 rows did not make it practical to include in this section of the thesis. Most of it had been described in the form of parameters (number of customers in the database, NTW width, % of customers with NTW, Overall Failed Delivery %), calculations anteceding the usage of the VRP Spreadsheet Solver (Erdogan, 2017). Likewise, the number of customers with NTW, number of customers with LTW -large-, number of failed deliveries with the variation included, NTW failed delivery score, but also more calculations from the "Distance traveled from ESSVRP Solution (km)" coming from the VRPSS (VRP Spreadsheet Solver).

The first part of these additional calculations was to obtain the "Additional Distance caused by Failed Deliveries" in kilometers. This was made straightforwardly with an increasing percentage over the "Distance traveled from ESSVRP Solution", the percentage computed from the “Overall Failed Delivery Variation (%)” divided by the number of customers. Adding up this, the cells “Total Distance -Adjusted- (km)” were filled up.

This concept was the first incumbent KPI calculated and conformed to the basis for obtaining the “Costs from ESSVRP Solution (USD $)”, the CO_2 Emissions (g), the CO_2 cost (USD $), the amount of $PM_{2.5}$ (g), and the $PM_{2.5}$ cost (USD $) with all the factors stated in the (3.1) Empirical Research Methodology.

From this point, the three amounts in monetary values, our UN SDG KPIs: Costs from ESSVRP Solution (USD $), CO_2 cost (USD $), and $PM_{2.5}$ cost (USD $) were summed in the final column: “Total Cost (USD $)”.

Until this moment, VRP NTW solutions and adjustments for “compensating” these extra costs (of having more NTW or narrower TW by reducing the failed deliveries), have been explained and integrated into the solution. This leads the path to show relations, variations, and graphs coming from the cases and scenarios previously described.

An extract of the 90 scenarios and the 15 baseline scenarios with the most relevant information about the experiment are included in Appendix B.

All sets and scoring variations were grouped in summary Table 12.0 for showing how the main KPIs varied on average along with the main parameters: number of customers, NTW width, and percentage of customers with NTW.

Number of customers NTW width % of cust w NTW	Average of NTW Failed Delivery Score (3.5-10)*	Average of Overall Failed Delivery Variation (%)	Average of Distance traveled from ESSVRP Solution (km)	Average of Total Unitary Cost (Total net profit)	Average of Total Distance - Adjusted (km)	Average of Costs from ESSVRP Solution (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of PN2.5 (g)	Average of PM2.5 cost (USD $)	Average of Total Cost (USD $)
L - 200	**6.4**	**17**	**1251**	**1628**	**1451**	**$ 1,035**	**3,844,709**	**$ 92**	**481.71**	**$ 42**	**$ 1,170**
Baseline (0)	**0.0**	**30**	**802**	**1018**	**1043**	**$ 689**	**2,763,816**	**$ 66**	**346.28**	**$ 30**	**$ 786**
60	**8.0**	**14**	**1379**	**1795**	**1561**	**$ 1,124**	**4,135,646**	**$ 99**	**518.16**	**$ 46**	**$ 1,269**
10	6.0	18	934	1222	1102	$ 788	2,919,671	$ 70	365.81	$ 32	$ 890
50	8.0	14	1486	1942	1694	$ 1,225	4,489,226	$ 108	562.46	$ 49	$ 1,382
90	10.0	10	1718	2222	1886	$ 1,360	4,998,040	$ 120	626.21	$ 55	$ 1,535
120	**5.5**	**19**	**1172**	**1528**	**1386**	**$ 985**	**3,673,871**	**$ 88**	**460.30**	**$ 41**	**$ 1,114**
10	3.5	23	881	1145	1084	$ 756	2,872,234	$ 69	359.87	$ 32	$ 856
50	5.5	19	1217	1589	1446	$ 1,028	3,832,384	$ 92	480.16	$ 42	$ 1,163
90	7.5	15	1418	1850	1629	$ 1,171	4,316,995	$ 104	540.88	$ 48	$ 1,323
M - 150	**6.4**	**17**	**1057**	**1375**	**1228**	**$ 875**	**3,252,886**	**$ 78**	**407.56**	**$ 36**	**$ 989**
Baseline (0)	**0.0**	**30**	**670**	**850**	**871**	**$ 575**	**2,307,172**	**$ 55**	**289.07**	**$ 25**	**$ 656**
60	**8.0**	**14**	**1150**	**1506**	**1302**	**$ 947**	**3,450,875**	**$ 83**	**432.36**	**$ 38**	**$ 1,068**
10	6.0	18	779	995	919	$ 633	2,434,685	$ 58	305.04	$ 27	$ 718
50	8.0	14	1212	1596	1382	$ 1,011	3,662,815	$ 88	458.92	$ 40	$ 1,140
90	10.0	10	1460	1928	1606	$ 1,197	4,255,125	$ 102	533.13	$ 47	$ 1,346
120	**5.5**	**19**	**1006**	**1302**	**1193**	**$ 837**	**3,159,976**	**$ 76**	**395.92**	**$ 35**	**$ 948**
10	3.5	23	791	1031	973	$ 682	2,578,286	$ 62	323.04	$ 28	$ 772
50	5.5	19	1075	1375	1281	$ 881	3,393,176	$ 81	425.14	$ 37	$ 1,000
90	7.5	15	1152	1500	1324	$ 949	3,508,464	$ 84	439.58	$ 39	$ 1,072
S - 100	**6.4**	**17**	**861**	**1122**	**1001**	**$ 715**	**2,653,334**	**$ 64**	**332.44**	**$ 29**	**$ 808**
Baseline (0)	**0.0**	**30**	**590**	**758**	**767**	**$ 516**	**2,032,406**	**$ 49**	**254.64**	**$ 22**	**$ 587**
60	**8.0**	**14**	**929**	**1217**	**1053**	**$ 766**	**2,789,009**	**$ 67**	**349.44**	**$ 31**	**$ 863**
10	6.0	18	651	843	769	$ 541	2,038,047	$ 49	255.35	$ 22	$ 612
50	8.0	14	942	1230	1076	$ 776	2,851,369	$ 68	357.25	$ 31	$ 876
90	10.0	10	1194	1578	1312	$ 980	3,477,610	$ 83	435.71	$ 38	$ 1,101
120	**5.5**	**19**	**824**	**1068**	**9+N21+G29**	**$ 687**	**2,586,652**	**$ 62**	**324.08**	**$ 29**	**$ 778**
10	3.5	23	630	810	776	$ 532	2,057,171	$ 49	257.75	$ 23	$ 604
50	5.5	19	862	1114	1027	$ 718	2,720,437	$ 65	340.85	$ 30	$ 813
90	7.5	15	978	1278	1125	$ 811	2,982,348	$ 72	373.66	$ 33	$ 915

Table 12.0 Extract of KPIs Results (Cases Averages)

From Table 12.0, in only one 'case average' of the 18 shown, NTW failed delivery savings compensate for the additional costs of having extra restrictions in a VRPTW with the use of the ESSVRP. This was the case for a database with 150 customers, an NTW of 60 minutes, and 10% of customers with NTW. Comparison against a similar case (150 customers, 10% of customers with NTW) but with an NTW width of 120 minutes helps to understand this point. Making the time window narrower, was convenient in the overall solution for compensation in the reduction of failed deliveries. Average of Total Distance -Adjusted and Average of Total Cost for M-60-10 was 919km and $718 USD respectively, meanwhile for M-120-10, the values were slightly higher: 973km and $772 USD.

For the rest of the scenarios, having a higher percentage of customers with NTW, or having narrower NTWs' width, results in higher distances traveled, emissions and costs. Moreover, the 3 baselines for all database sizes (number of customers: 100, 150, and 200), which have a null effect from time windows were always the optimal value for the solution.

Another comparison perspective is to analyze each scenario and its variants versus the corresponding baseline. For a given set (1-5) and the number of customers (100, 150, 200), its corresponding baseline and 6 combinations from the time windows parameters (NTW width: 60min and 120min, and % of customers with NTW: 10%, 50%, and 90%) were grouped in 15 distinct tables. More detail can be found in Sheet: "Scenarios" in the "Results Reporting" Excel file attached to this thesis.

Detailed results of the 90 scenarios from Table 13.0 to 27.0, and Figure 32.0 to 46.0, can be found on Appendix B. From these results, a relevant outtake is that 8% of the scenarios (7/90) have a lower Total Cost (USD $) than their respective baseline: Scenarios 13, 14, 19, 38, 55, 73 and 79. 13_S1_c200L_10pp_60min

- 14_S1_c200L_10pp_120min
- 19_S2_c100S_10pp_60min
- 38_S3_c100S_10pp_120min
- 55_S4_c100S_10pp_60min
- 73_S5_c100S_10pp_60min
- 79_S5_c150M_10pp_60min

Four of them relate to databases with 100 customers, two for 200 customers, and one for 150 customers. Four had an NTW width of 60min and for two, the NTW width was 120min. The only consistent component was that this only happens for databases with small percentages of customers with NTW (10%).

Obtaining an average of all these scenarios will help to understand these effects:

Averages	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
Baselines	0.0	30	687	875	894	594	2,367,798	$ 56.83	296.66	$ 26.11	$ 676
10pp_60min	6.0	18	788	1020	930	654	2,464,134	$ 59.14	308.73	$ 27.17	$ 740
10pp_120min	3.5	23	767	995	944	657	2,502,564	$ 60.06	313.55	$ 27.59	$ 744
50pp_60min	8.0	14	1213	1589	1384	1004	3,667,803	$ 88.03	459.54	$ 40.44	$ 1,133
50pp_120min	5.5	19	1051	1359	1251	876	3,315,332	$ 79.57	415.38	$ 36.55	$ 992
90pp_60min	10.0	10	1458	1910	1601	1179	4,243,592	$ 101.85	531.68	$ 46.79	$ 1,327
90pp_120min	7.5	15	1183	1543	1360	977	3,602,603	$ 86.46	451.37	$ 39.72	$ 1,103

Table 28.0 – Averages of Baselines and Scenarios 1-90.

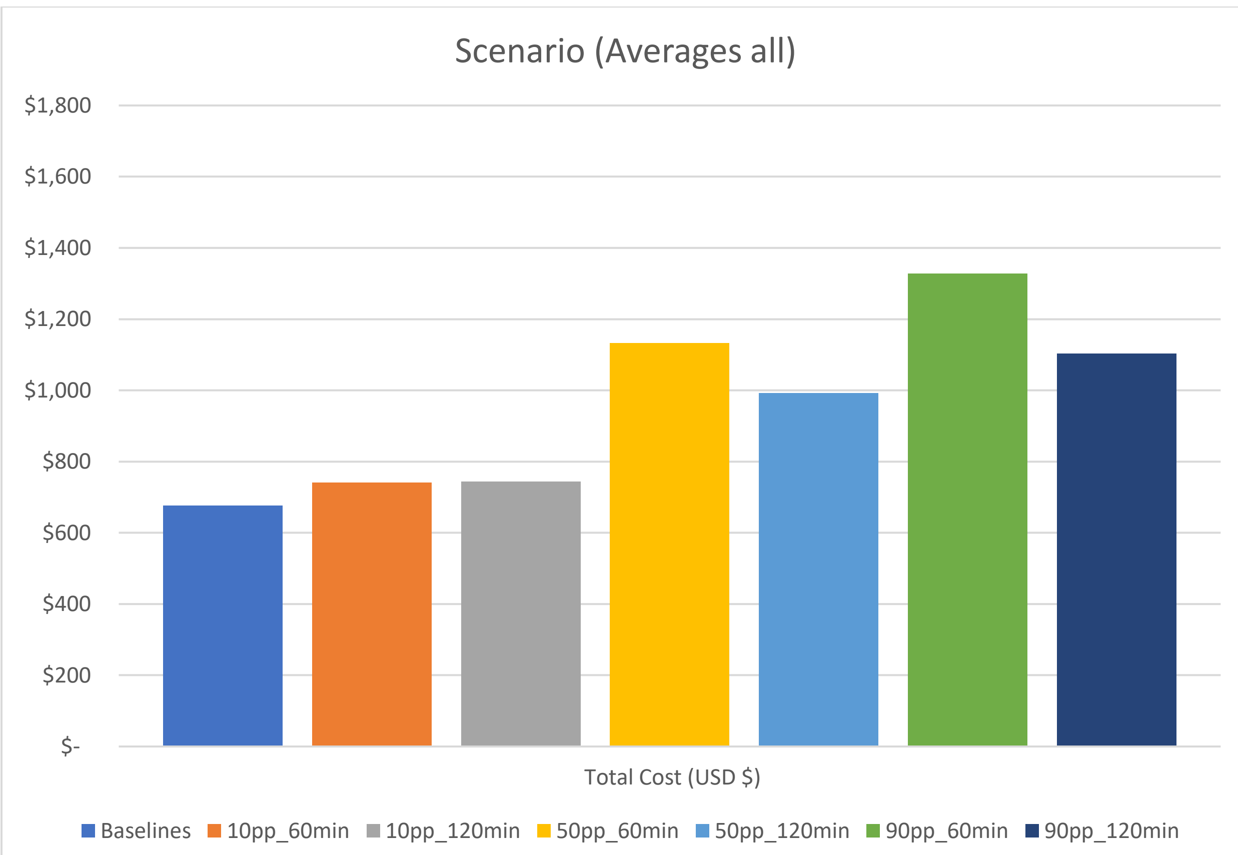

Figure 47.0 Averages of Baselines and Scenarios 1-90.

Solutions can be grouped into 3 tiers. The costliest solution was an NTW occurrence of 90% and a width of 60min: Total Distance -Adjusted- (km) of 1601 and a Total Cost (USD $) of $1,327. This is followed by 50% and 60min with 1384km and $1,133 respectively; then closely trailing 90% and 120min with 1360km and $1,103 to close Tier 1.

For Tier 2, the solution with an NTW occurrence of 50% and a width of 120min stands alone with a Total Distance -Adjusted- (km) of 1251 and a Total Cost (USD $) of $992.

Finally, lower percentages of the customers with time windows (10%) are quite close. For a 120min width 944km and $744, and for the 60min one: 930km and $740. The baseline closes Tier 3 as the best average solution with 894km in Total Distance -Adjusted and $676 USD in Total Cost.

For displaying the KPIs as clearer as possible, different graphs in the form of figures will be shown. Starting with comparisons between the "normal" distance from the ESSVRP solution and the escalated adjustment caused by the diminution of failed deliveries. Nevertheless, although the differences become smaller, the adjustment is not enough to inflect the behavior of the distance parameter, as in ESSVRP distance or total adjusted distance.

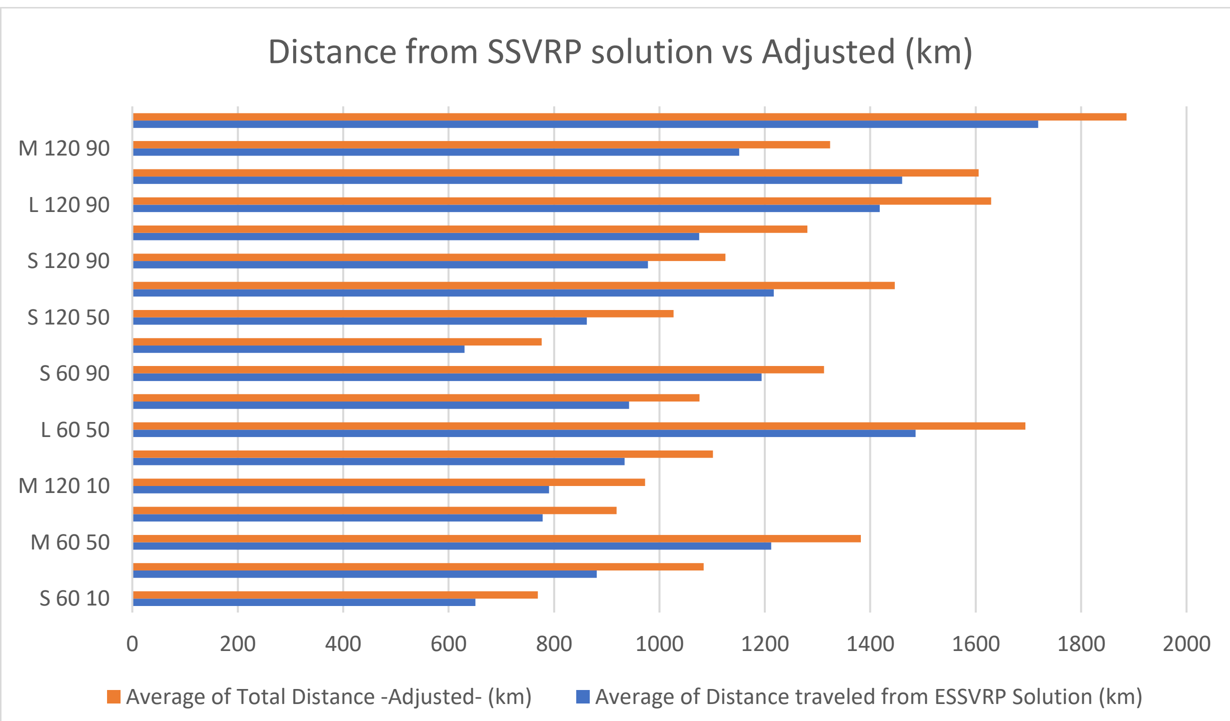

Figure 48.0 Comparison of distances: ESSVRP Solution vs Adjusted (Failed Delivery effect)

Not surprisingly, as CO_2 and $PM_{2.5}$ were described as functions of the distances covered in kilometers, even though there were some factors previously stated taken into consideration, they followed an intuitive result as higher distances covered generated larger CO_2 and $PM_{2.5}$ emissions.

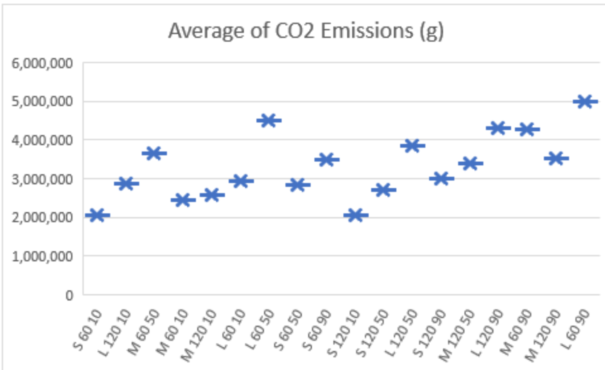

Figure 49.0 Average CO_2 Emissions (g) per Scenario

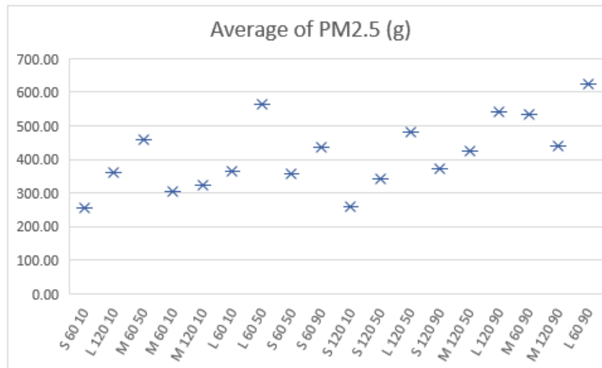

Figure 50.0 Average $PM_{2.5}$ Emissions (g) per Scenario

Another relevant graph (Figure 51.0) allows us to compare the total cost components. In other words, how this total cost is composed. Costs from the ESSVRP Solution added for 88% of the Total Cost on average. And although CO_2 is by far more commonly used and searched, CO_2 costs represented 'only' the double of the $PM_{2.5}$ costs. CO_2 costs summed for 8% and $PM_{2.5}$ for 4% of the Total Costs.

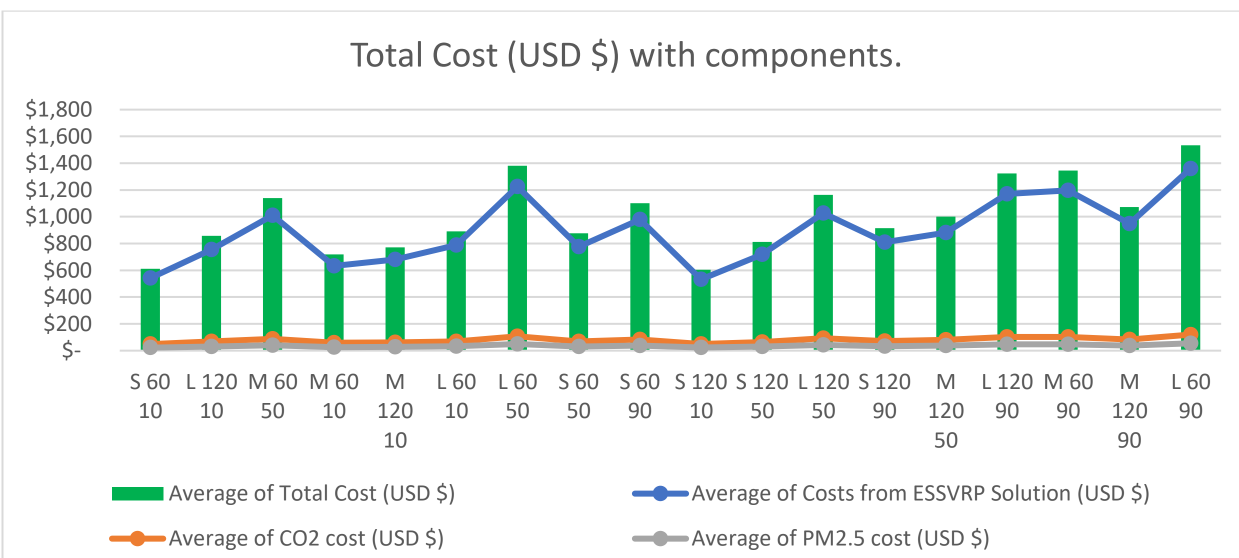

Figure 51.0 Total Cost (USD $) with components: SSRVP Solution km cost, CO_2 cost. and $PM_{2.5}$ cost.

Figures (52.0 to 66.0) showing the sensitivity analysis of the time window width mentioned in the (1.2) Problem Statement can be found in Appendix B.

5. Conclusions

Table 12.0 is the most important output of this work. It supports the **rejection** of the stated hypothesis since an optimal VRP solution with a given number of failed deliveries tends to be more convenient to choose from an economical and sustainability perspective than a suboptimal VRP solution with time windows that reduces failed deliveries.

This is in the assumption that time windows are randomly generated one after another and that the work considers a relatively low demand. Further research having different considerations might expand knowledge in this field.

The (negative) effect of failed deliveries when having these time windows [Effect B] was then inferior to the (negative) effect of time windows on specific Capacitated-VRPTW scenarios [Effect A]. With an average cost difference percentage of almost 50%.

The hypothesis could have worked better in smaller databases, as values for databases with 100 customers were closer than the ones with 150 or 200 customers. NTW size played a smaller role, although the differences tended to be smaller in wider NTW, as of 120min than in NTW width of 60min. The most important driver of the independent variables was the percentage of customers with NTW, or in other words, the number of customers with an NTW. Only for small percentages (e.g., 10%), it is possible to see some benefits of including TW which positive effect on failed deliveries and will overcome the negative effect of the VRP solution.

From the results, as more constraints were put in the time windows (more customer percentage with NTW and smaller NTW widths), the difference between both Effects grew consistently and even accelerated for the percentage of NTW.

From the tiers grouped in the Results, the influence of the independent variables on the KPIs may be ranked as follows:

1) A large percentage of customers with an NTW (e.g., 90%).
2) Small NTW width (e.g., 60min).
3) A middle percentage of customers with an NTW (e.g., 50%).
4) The presence of an NTW (e.g., 120min).
5) A small percentage of customers with an NTW (e.g., 10%).

Another conclusion is that solutions with a larger distance traveled (more kilometers), were always costlier. The fixed costs of additional vehicles did not change any scenario. For example, a scenario with a total of fewer kilometers covered and more vehicles were always better than larger amounts of kilometers traveled and a diminution in fixed costs.

For answering the (1.2) Problem Statement and as shown in Table (11), first it is important to notice that in only 8% of the scenarios NTW failed delivery savings compensated for the additional costs of having extra restrictions in a VRP TW with the use of the ESSVRP.

For the rest of the scenarios, having a higher percentage of customers with NTW resulted in higher distances traveled, emissions and costs. On the other hand, having a lower percentage of customers with NTW (10% vs 50% vs 90%) made the ESSVRP solution much more efficient, this efficiency absorbed the additional costs of having a larger percentage of failed deliveries and even maintained a better overall performance (kilometers, USD spent, CO_2 and $PM_{2.5}$ emissions) for 83 of the 90 scenarios. Interesting behavior was encountered during this quantitative analysis.

First, the Average Total Cost (USD $) was impacted heavily not only for the size of the database, where intuitively needing to deliver more customers increases the cost of the solutions but indeed for the size of the NTW and the % of customers served with these NTWs.

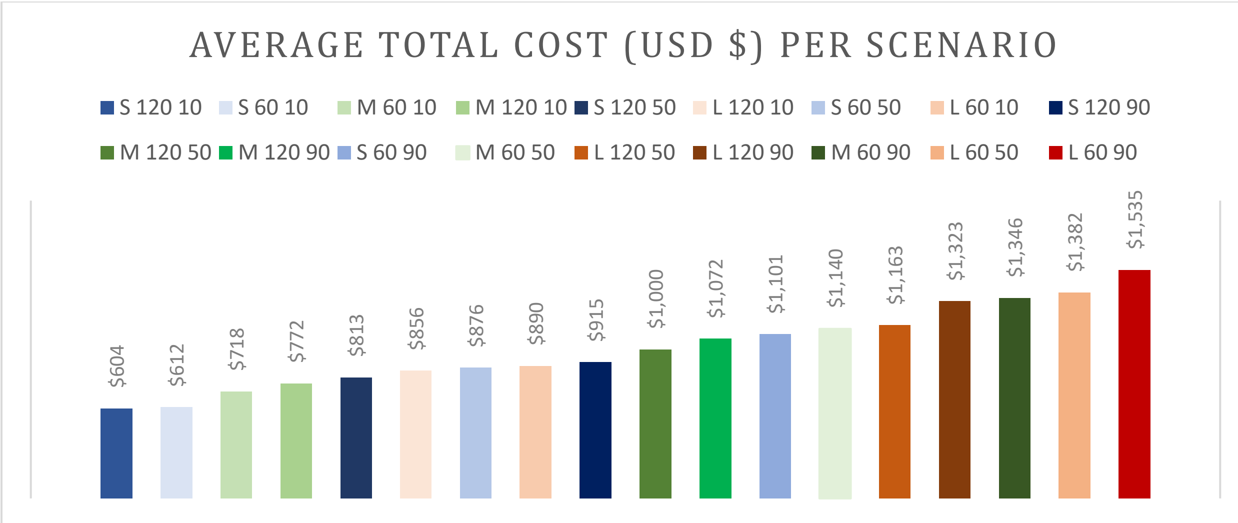

Figure (67.0) Average total cost (USD $) per scenario.

From Figure (67.0), the average total cost (USD $) was driven not only by database type but also by the other two variables that influenced directly the result. Here the interval of the cheapest to the most expensive scenario is enormous: $931 USD, more than 250% from the less costly $604 USD up to $1,535 USD for the costliest; this might be justified by the database size (small "S" to large "L" ones) but even within Large "L" scenarios of 200 customers the ranges go from $856 USD to $1,535 USD; $718 USD to $1,346USD with the Medium "M" databases types and $604 USD to $1,101USD for the Small "S" databases.

Moving ahead, this was explained by the fact that wider NTW (120min vs 60min) had better results, being on average 13% less costly. In only one case, an NTW of 120min was more expensive than 60min: in the Medium "M" database type with 10% of customers having an NTW: 60min cost $718 USD and 120min cost $772 USD.

Average Total Cost (USD)	L				M				S			
NTW Width	0	10	50	90	0	10	50	90	0	10	50	90
0	$786	n/a	n/a	n/a	$ 656	n/a	n/a	n/a	$587	n/a	n/a	n/a
60	n/a	$ 890	$1,382	$1,535	n/a	$ 718	$1,140	$1,346	n/a	$612	$ 876	$1,101
120	n/a	$ 856	$1,163	$1,323	n/a	$ 772	$1,000	$1,072	n/a	$604	$ 813	$ 915

Figure (68.0) NTW width (min) average total cost ($) against database and % of customers w NTW.

The percentage of Customers with NTW also played a relevant role, as in all cases percentages of 90% were the more expensive, and the cases with 50% of customers with NTW were also more expensive than the solutions for 10% of customers with NTW. On average increasing from 10% to 50% made the total cost a staggering 30% more expensive, and a smaller growth of 13% happened for moving from 50% to 90% of customers with NTW. The increase from 10% to 90%, was 39%.

Average Total Cost (USD)	L			M			S		
% of Customers w NTW	0	60	120	0	60	120	0	60	120
0	$786	n/a	n/a	$ 656	n/a	n/a	$ 587	n/a	n/a
10	n/a	$ 890	$ 856	n/a	$ 718	$ 772	n/a	$ 612	$604
50	n/a	$1,382	$1,163	n/a	$1,140	$1,000	n/a	$ 876	$813
90	n/a	$1,535	$1,323	n/a	$1,346	$1,072	n/a	$1,101	$915

Figure (69.0) % of customers w NTW average total cost ($) against database type and NTW width (min).

The score calculated for applying different ranges of failed delivery reductions to the established percentages of failed deliveries was the reflection of the supposed convenience of having a bigger percentage of customers with NTW and narrower TWs.

Score and the Averages Failed Delivery Parameters (in Average)				
Score	Av-Av of Overall Failed Delivery Variation (%)	Av-Av of Distance traveled from ESSVRP Solution (km)	Av-Av of Total Distance - Adjusted- (km)	Δ Total Distance: SSRVP vs Adjusted (%)
3.500	23	767	944	81%
5.500	19	1051	1251	84%
6.000	18	788	930	85%
7.500	15	1183	1360	87%
8.000	14	1213	1384	88%
10.000	10	1458	1601	91%

Figure (70.0) Score and the Averages Failed Delivery Parameters (in Average)

From Figure (70.0), it is clear that the difference for distinct score values was bigger than the ones stated in the literature; from an 81% less impact by failed deliveries with cases with a score of 3.50, to 91% for the ones with the highest score of 10.00.

Therefore, it would be difficult to imply better reactions from the improvement of failed delivery costs by guiding time window deliveries into more frequent and narrower among its customers. From this, the conclusion is that there is not a clear advantage of trying to lead time window deliveries for avoiding delivery failures by using a Spreadsheet Solver for VRP in the last mile in an e-commerce context.

Lastly, sustainability KPIs in the form of CO_2 and $PM_{2.5}$ emissions were differently impacted by the different scenarios. The first one, although being an in-vogue term, is softly influenced by the kilometers traveled and not that relevant in monetary values (10x less) in comparison to the costs of traveling per se (e.g., oil consumption, maintenance, and operation).

The second KPI ($PM_{2.5}$ emissions) in this thesis represented half of the latter impact, with a weight of 4% in the total cost computed. It is relevant to mention that $PM_{2.5}$ impact depends strongly on the existing receptors along a given route. It becomes easier to understand when considering this factor to be associated with serious respiratory diseases and even deaths (see 2.4 Sustainability section). Anyhow, this is a very local phenomenon that is influenced by different variables, but the number of people nearby who can inhale these particles is probably the most relevant one. Therefore, in an urban context, these values should be tracked and assessed from the difficulty of transforming grams (which can be the cause of death of a human being) to monetary values.

Further thoughts were raised during the development of this dissertation, first, the ESSVRP tool used (Erdogan, 2017) was simple to use and useful for running different scenarios. The openness for accepting different parameters and constraints even has limited software capabilities in processing big amounts of data. From a sustainability perspective, small companies might use this kind of tool to address related UN SDGs without the need for specialized software requiring the budget of a stock exchange company. Optimizing solutions and developing scenarios might help not only cost savings but leading these external costs to society, further than CO_2 tax policies, towards a $PM_{2.5}$ reduction.

Even for a small database and fleet for an e-commerce market, this, if extrapolated to a larger number of customers and companies could be the key to reaching 2030 UN SDG objectives. Objectives that only with actions made in the near present may be achieved.

The limitations and further research might come in the form of having more accurate measures for the amount, predictability, and costs/savings related to failed deliveries in e-commerce last mile. Also, including external environmental costs, like $PM_{2.5}$, in VRP research might modify the optimal solutions if a more robust analysis is made (e.g., considering not only distance and a homogeneous vehicle but different kinds of the fleet, slopes in the terrain, the efficiency depending on the average speed, and more). Lastly, "a bi-objective modeling approach can explicitly incorporate the trade-off between costs and customer service" (Raemekers et al., 2018) could also be incorporated for further research.

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7. Appendix A: List of ESSVRP Scenarios.

- 1_BL1_VRP_Spreadsheet_Solver_S1_c100S.xlsm
- 1_VRP_Spreadsheet_Solver_S1_c100S_10pp_60min.xlsm
- 2_VRP_Spreadsheet_Solver_S1_c100S_10pp_120min.xlsm
- 3_VRP_Spreadsheet_Solver_S1_c100S_50pp_60min.xlsm
- 4_VRP_Spreadsheet_Solver_S1_c100S_50pp_120min.xlsm
- 5_VRP_Spreadsheet_Solver_S1_c100S_90pp_60min.xlsm
- 6_VRP_Spreadsheet_Solver_S1_c100S_90pp_120min.xlsm
- 7_BL2_VRP_Spreadsheet_Solver_S1_c150M.xlsm
- 7_VRP_Spreadsheet_Solver_S1_c150M_10pp_60min.xlsm
- 8_VRP_Spreadsheet_Solver_S1_c150M_10pp_120min.xlsm
- 9_VRP_Spreadsheet_Solver_S1_c150M_50pp_60min.xlsm
- 10_VRP_Spreadsheet_Solver_S1_c150M_50pp_120min.xlsm
- 11_VRP_Spreadsheet_Solver_S1_c150M_90pp_60min.xlsm
- 12_VRP_Spreadsheet_Solver_S1_c150M_90pp_120min.xlsm
- 13_BL3_VRP_Spreedsheet_Solver_S1_c200.xlsm
- 13_VRP_Spreedsheet_Solver_S1_c200L_10pp_60min.xlsm
- 14_VRP_Spreedsheet_Solver_S1_c200L_10pp_120min.xlsm
- 15_VRP_Spreedsheet_Solver_S1_c200L_50pp_60min.xlsm
- 16_VRP_Spreedsheet_Solver_S1_c200L_50pp_120min.xlsm
- 17_VRP_Spreedsheet_Solver_S1_c200L_90pp_60min.xlsm
- 18_VRP_Spreedsheet_Solver_S1_c200L_90pp_120min.xlsm
- 19_BL4_VRP_Spreadsheet_Solver_S2_c100S.xlsm
- 19_VRP_Spreadsheet_Solver_S2_c100S_10pp_60min.xlsm
- 20_VRP_Spreadsheet_Solver_S2_c100S_10pp_120min.xlsm
- 21_VRP_Spreadsheet_Solver_S2_c100S_50pp_60min.xlsm
- 22_VRP_Spreadsheet_Solver_S2_c100S_50pp_120min.xlsm
- 23_VRP_Spreadsheet_Solver_S2_c100S_90pp_60min.xlsm
- 24_VRP_Spreadsheet_Solver_S2_c100S_90pp_120min.xlsm
- 25_BL5_VRP_Spreadsheet_Solver_S2_c150M.xlsm
- 25_VRP_Spreadsheet_Solver_S2_c150M_10pp_60min.xlsm
- 26_VRP_Spreadsheet_Solver_S2_c150M_10pp_120min.xlsm
- 27_VRP_Spreadsheet_Solver_S2_c150M_50pp_60min.xlsm
- 28_VRP_Spreadsheet_Solver_S2_c150M_50pp_120min.xlsm
- 29_VRP_Spreadsheet_Solver_S2_c150M_90pp_60min.xlsm
- 30_VRP_Spreadsheet_Solver_S2_c150M_90pp_120min.xlsm
- 31_BL6_VRP_Spreadsheet_Solver_S2_c200L.xlsm
- 31_VRP_Spreadsheet_Solver_S2_c200L_10pp_60min.xlsm
- 32_VRP_Spreadsheet_Solver_S2_c200L_10pp_120min.xlsm
- 33_VRP_Spreadsheet_Solver_S2_c200L_50pp_60min.xlsm
- 34_VRP_Spreadsheet_Solver_S2_c200L_50pp_120min.xlsm
- 35_VRP_Spreadsheet_Solver_S2_c200L_90pp_60min.xlsm

- 36_VRP_Spreadsheet_Solver_S2_c200L_90pp_120min.xlsm
- 37_BL7_VRP_Spreadsheet_Solver_S3_c100S.xlsm
- 37_VRP_Spreadsheet_Solver_S3_c100S_10pp_60min.xlsm
- 38_VRP_Spreadsheet_Solver_S3_c100S_10pp_120min.xlsm
- 39_VRP_Spreadsheet_Solver_S3_c100S_50pp_60min.xlsm
- 40_VRP_Spreadsheet_Solver_S3_c100S_50pp_120min.xlsm
- 41_VRP_Spreadsheet_Solver_S3_c100S_90pp_60min.xlsm
- 42_VRP_Spreadsheet_Solver_S3_c100S_90pp_120min.xlsm
- 43_BL8_VRP_Spreadsheet_Solver_S3_c150M
- 43_VRP_Spreadsheet_Solver_S3_c150M_10pp_60min.xlsm
- 44_VRP_Spreadsheet_Solver_S3_c150M_10pp_120min.xlsm
- 45_VRP_Spreadsheet_Solver_S3_c150M_50pp_60min.xlsm
- 46_VRP_Spreadsheet_Solver_S3_c150M_50pp_120min.xlsm
- 47_VRP_Spreadsheet_Solver_S3_c150M_90pp_60min.xlsm
- 48_VRP_Spreadsheet_Solver_S3_c150M_90pp_120min.xlsm
- 49_BL9_VRP_Spreedsheet_Solver_S3_c200L
- 49_VRP_Spreedsheet_Solver_S3_c200L_10pp_60min.xlsm
- 50_VRP_Spreedsheet_Solver_S3_c200L_10pp_120min.xlsm
- 51_VRP_Spreedsheet_Solver_S3_c200L_50pp_60min.xlsm
- 52_VRP_Spreedsheet_Solver_S3_c200L_50pp_120min.xlsm
- 53_VRP_Spreedsheet_Solver_S3_c200L_90pp_60min.xlsm
- 54_VRP_Spreedsheet_Solver_S3_c200L_90pp_120min.xlsm
- 55_BL10_VRP_Spreadsheet_Solver_S4_c100S
- 55_VRP_Spreadsheet_Solver_S4_c100S_10pp_60min.xlsm
- 56_VRP_Spreadsheet_Solver_S4_c100S_10pp_120min.xlsm
- 57_VRP_Spreadsheet_Solver_S4_c100S_50pp_60min.xlsm
- 58_VRP_Spreadsheet_Solver_S4_c100S_50pp_120min.xlsm
- 59_VRP_Spreadsheet_Solver_S4_c100S_90pp_60min.xlsm
- 60_VRP_Spreadsheet_Solver_S4_c100S_90pp_120min.xlsm
- 61_BL11_VRP_Spreedsheet_Solver_S4_c150M
- 61_VRP_Spreedsheet_Solver_S4_c150M_10pp_60min.xlsm
- 62_VRP_Spreedsheet_Solver_S4_c150M_10pp_120min.xlsm
- 63_VRP_Spreedsheet_Solver_S4_c150M_50pp_60min.xlsm
- 64_VRP_Spreedsheet_Solver_S4_c150M_50pp_120min.xlsm
- 65_VRP_Spreedsheet_Solver_S4_c150M_90pp_60min.xlsm
- 66_VRP_Spreedsheet_Solver_S4_c150M_90pp_120min.xlsm
- 67_BL12_VRP_Spreadsheet_Solver_S4_c200L
- 67_VRP_Spreadsheet_Solver_S4_c200L_10pp_60min.xlsm
- 68_VRP_Spreadsheet_Solver_S4_c200L_10pp_120min.xlsm
- 69_VRP_Spreadsheet_Solver_S4_c200L_50pp_60min.xlsm
- 70_VRP_Spreadsheet_Solver_S4_c200L_50pp_120min.xlsm
- 71_VRP_Spreadsheet_Solver_S4_c200L_90pp_60min.xlsm
- 72_VRP_Spreadsheet_Solver_S4_c200L_90pp_120min.xlsm

- 73_BL13_VRP_Spreadsheet_Solver_S5_c100S
- 73_VRP_Spreadsheet_Solver_S5_c100S_10pp_60min.xlsm
- 74_VRP_Spreadsheet_Solver_S5_c100S_10pp_120min.xlsm
- 75_VRP_Spreadsheet_Solver_S5_c100S_50pp_60min.xlsm
- 76_VRP_Spreadsheet_Solver_S5_c100S_50pp_120min.xlsm
- 77_VRP_Spreadsheet_Solver_S5_c100S_90pp_60min.xlsm
- 78_VRP_Spreadsheet_Solver_S5_c100S_90pp_120min.xlsm
- 79_BL14_VRP_Spreedsheet_Solver_S5_c150M
- 79_VRP_Spreedsheet_Solver_S5_c150M_10pp_60min.xlsm
- 80_VRP_Spreedsheet_Solver_S5_c150M_10pp_120min.xlsm
- 81_VRP_Spreedsheet_Solver_S5_c150M_50pp_60min.xlsm
- 82_VRP_Spreedsheet_Solver_S5_c150M_50pp_120min.xlsm
- 83_VRP_Spreedsheet_Solver_S5_c150M_90pp_60min.xlsm
- 84_VRP_Spreedsheet_Solver_S5_c150M_90pp_120min.xlsm
- 85_BL15_VRP_Spreadsheet_Solver_S5_c200L
- 85_VRP_Spreadsheet_Solver_S5_c200L_10pp_60min.xlsm
- 86_VRP_Spreadsheet_Solver_S5_c200L_10pp_120min.xlsm
- 87_VRP_Spreadsheet_Solver_S5_c200L_50pp_60min.xlsm
- 88_VRP_Spreadsheet_Solver_S5_c200L_50pp_120min.xlsm
- 89_VRP_Spreadsheet_Solver_S5_c200L_90pp_60min.xlsm
- 90_VRP_Spreadsheet_Solver_S5_c200L_90pp_120min.xlsm

8. Appendix B.

<u>Visualization of the Solver.</u>

<u>Set 2:</u>

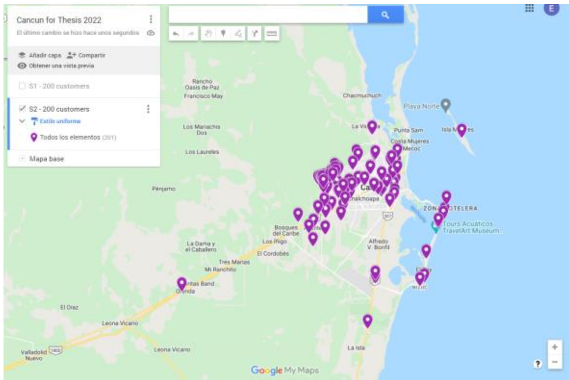


Figure 3.0 Visualization of customers in Google Maps

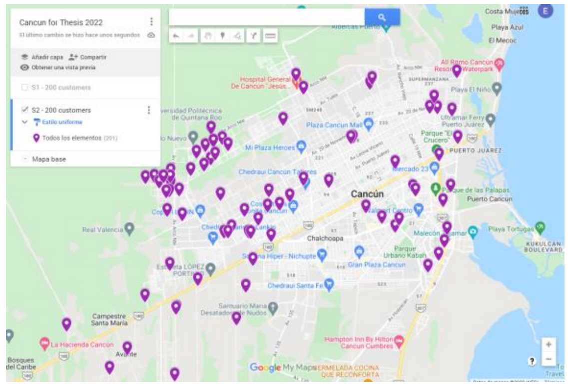


Figure 4.0 Visualization of customers in Google Maps

<u>Set 3:</u>

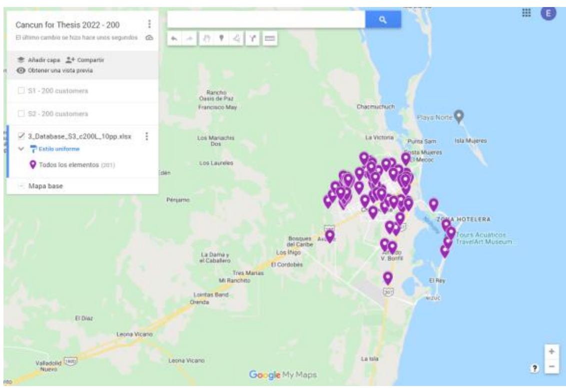


Figure 5.0 Visualization of customers in Google Maps

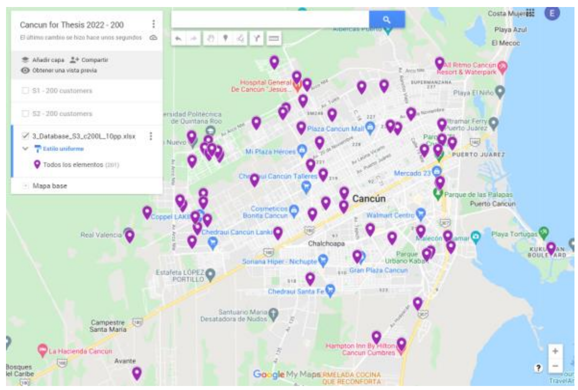


Figure 6.0 Visualization of customers in Google Maps

<u>Set 4:</u>

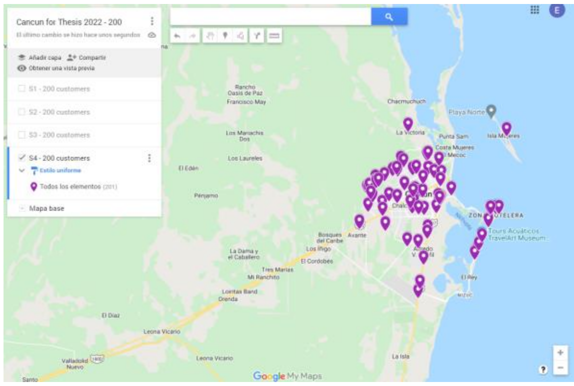


Figure 7.0 Visualization of customers in Google Maps

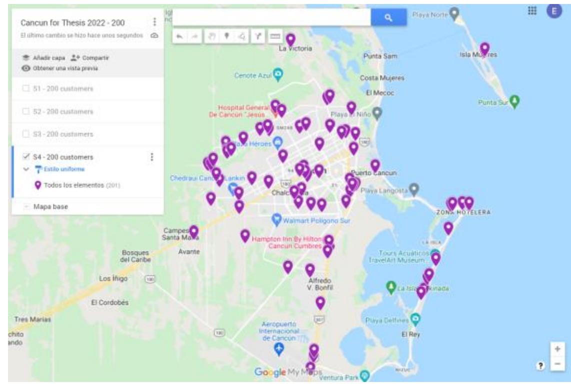


Figure 8.0 Visualization of customers in Google Maps

Set 5:

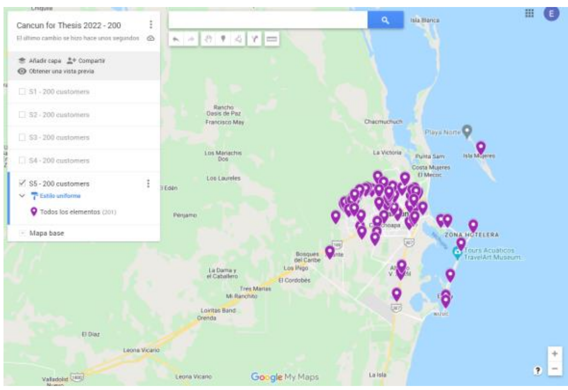


Figure 9.0 Visualization of customers in Google Maps

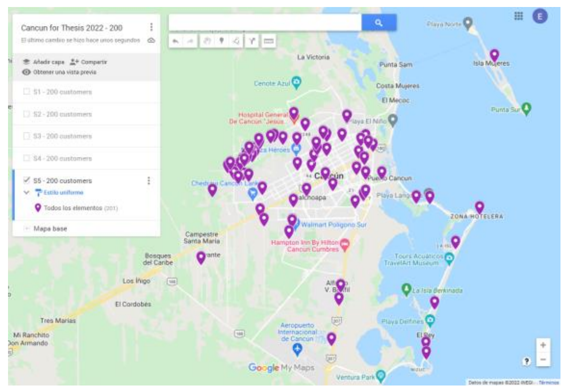
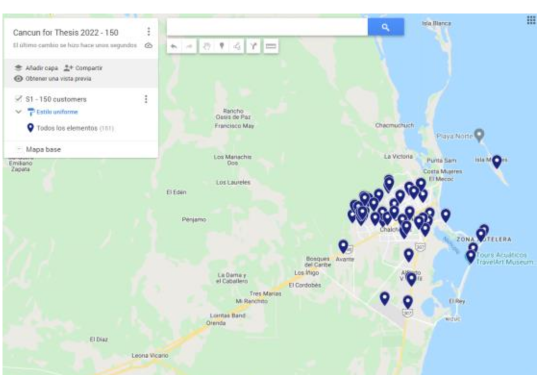


Figure 10.0 Visualization of customers in Google Maps

Medium database of 150 customers.

Set 1



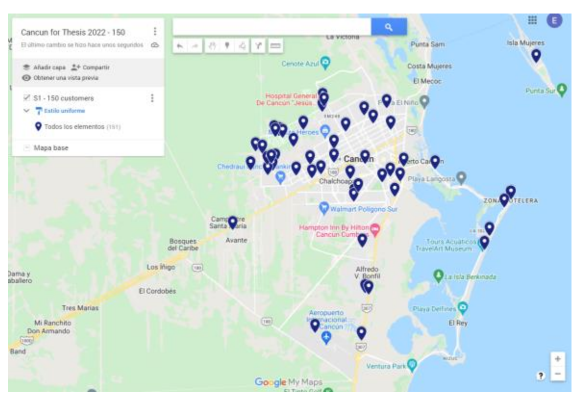


Figure 11.0 Visualization of customers in Google Maps

Figure 12.0 Visualization of customers in Google Maps

Set 2

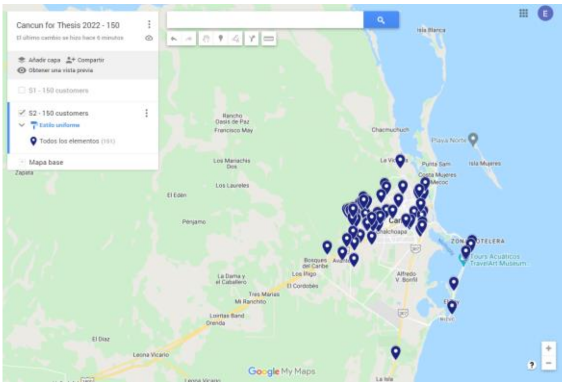


Figure 13.0 Visualization of customers in Google Maps

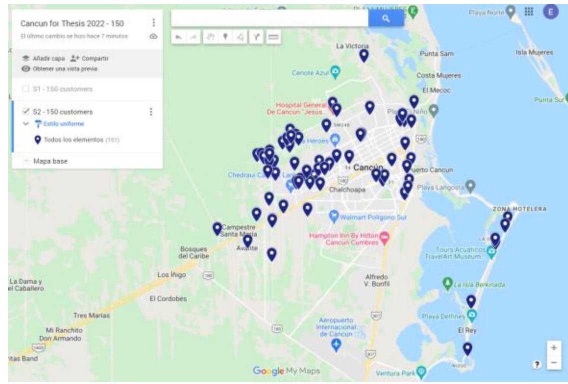


Figure 14.0 Visualization of customers in Google Maps

Set 3

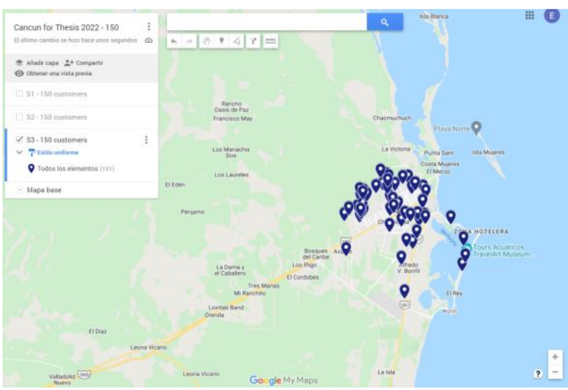


Figure 15.0 Visualization of customers in Google Maps

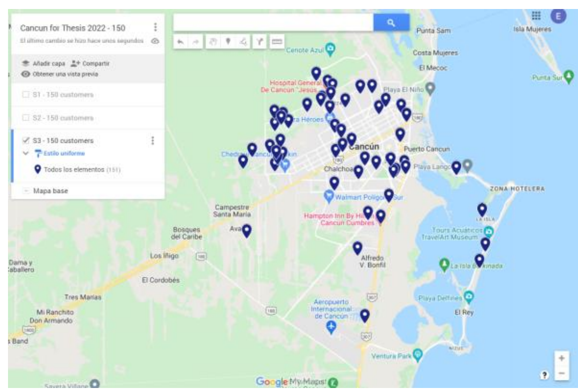
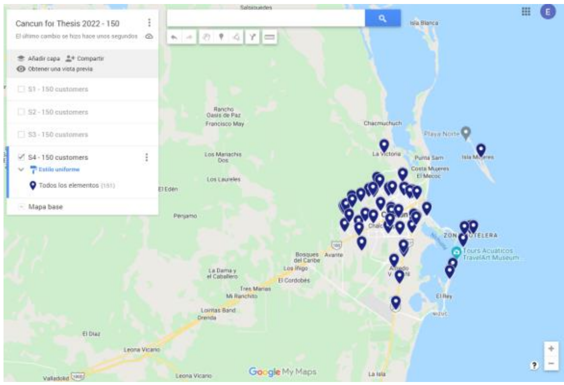


Figure 16.0 Visualization of customers in Google Maps

Set 4



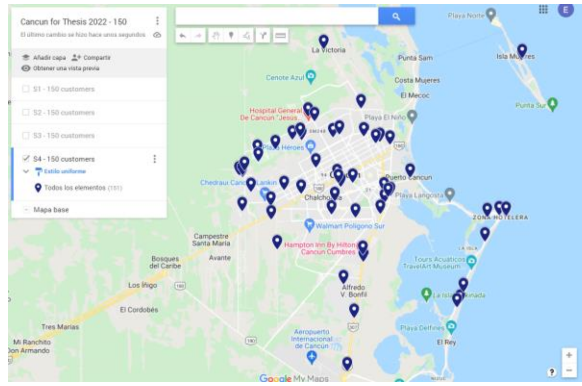
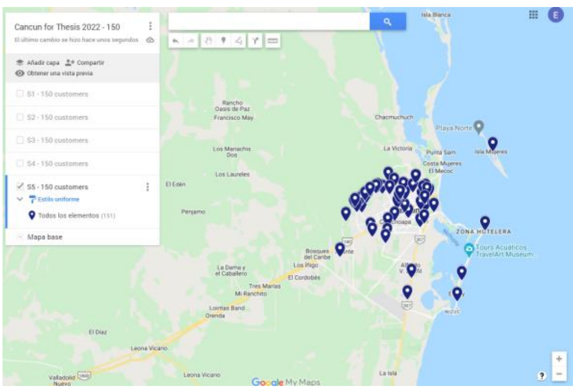


Figure 17.0 Visualization of customers in Google Maps

Figure 18.0 Visualization of customers in Google Maps

Set 5



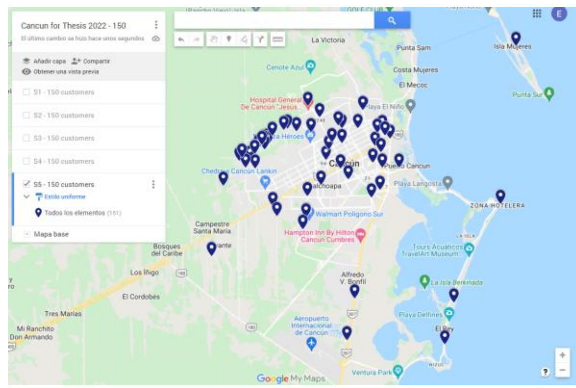
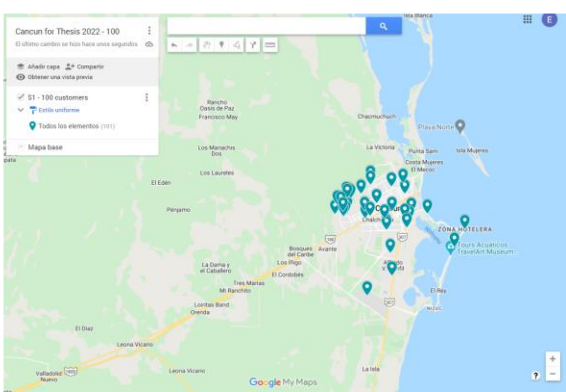


Figure 19.0 Visualization of customers in Google Maps

Figure 20.0 Visualization of customers in Google Maps

Small database of 100 customers.

Set 1



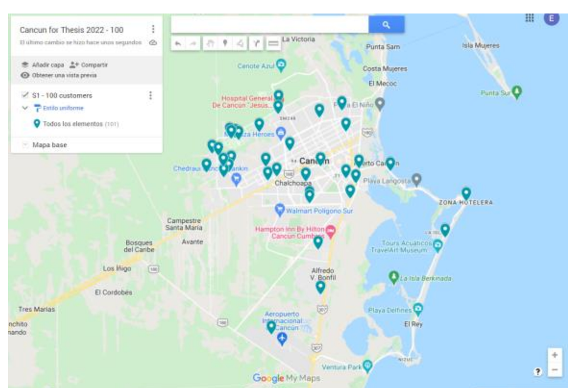
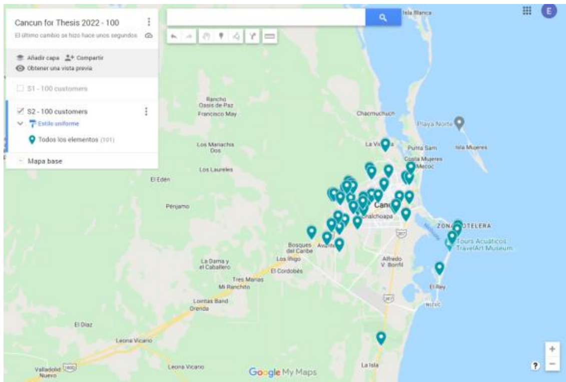


Figure 21.0 Visualization of customers in Google Maps   *Figure 22.0* Visualization of customers in Google Maps

Set 2



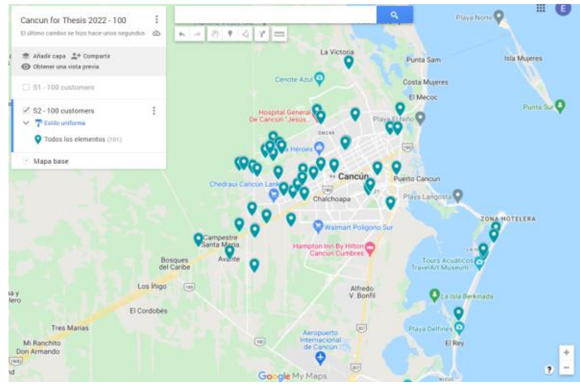
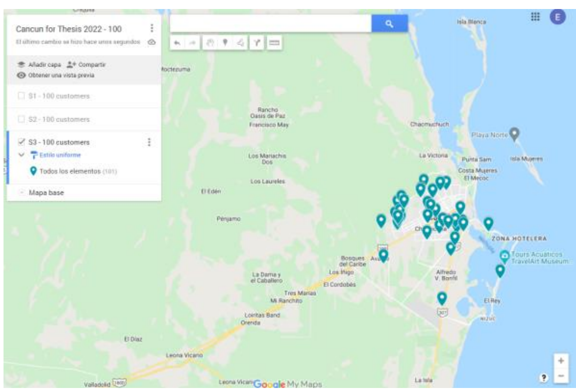


Figure 23.0 Visualization of customers in Google Maps   *Figure 24.0* Visualization of customers in Google Maps

Set 3



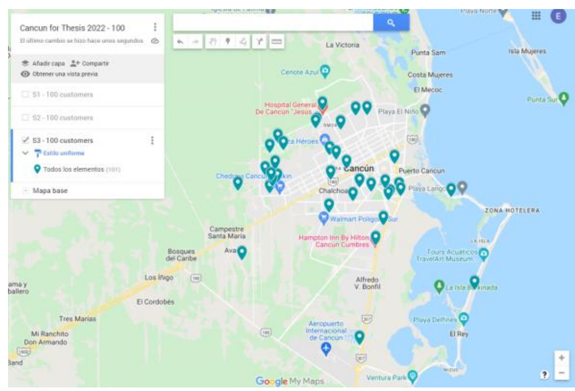


Figure 25.0 Visualization of customers in Google Maps   *Figure 26.0* Visualization of customers in Google Maps

Set 4

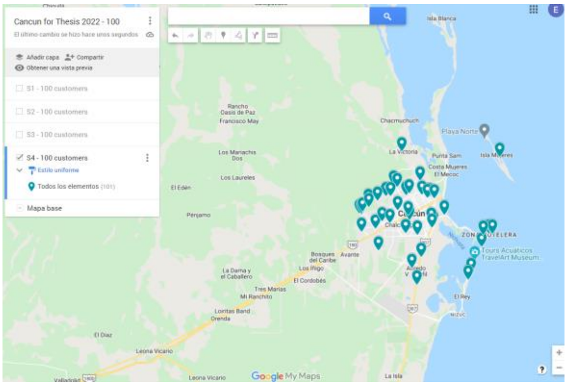


Figure 27.0 Visualization of customers in Google Maps

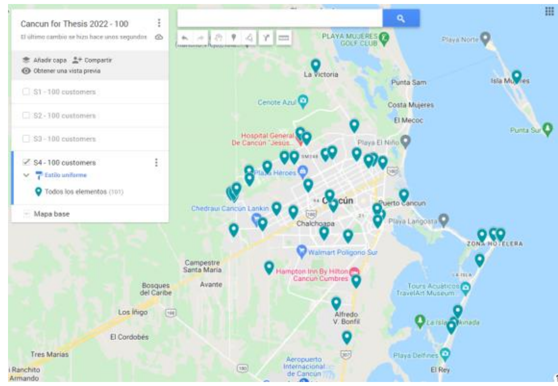


Figure 28.0 Visualization of customers in Google Maps

Set 5

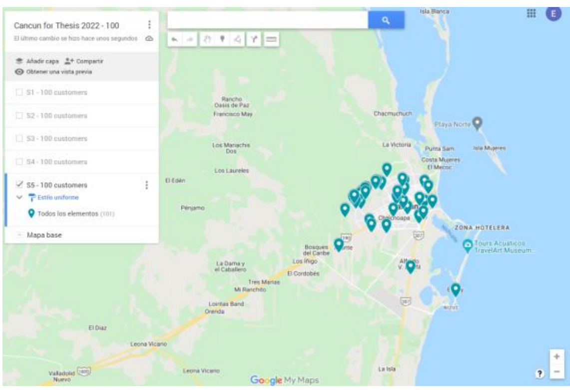


Figure 29.0 Visualization of customers in Google Maps

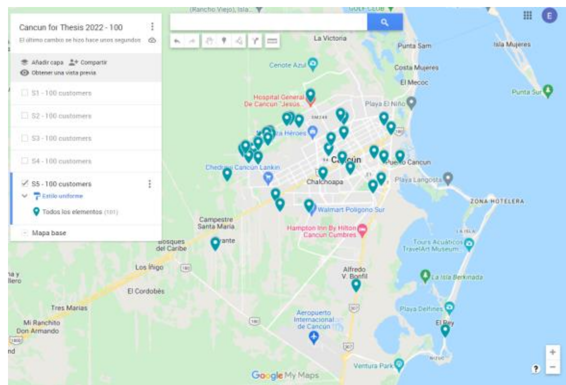


Figure 30.0 Visualization of customers in Google Maps

List of Scenarios (1-90) and Baseline (BL1 - BL13) Results:

List of Scenarios (1-90) and Baseline (BL1 - BL13)	Average of NTW Failed Delivery Score (3.5-10)*	Average of Overall Failed Delivery Variation (%)	Average of Distance traveled from SSVRP Solution (km)	Average of Total Unitary Cost (Total net profit)	Average of Total Distance -Adjusted (km)	Average of Costs from ESSVRP Solution (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of PN2.5 (g)	Average of PM2.5 cost (USD $)	Average of Total Cost (USD $)
S - 100	**6.4**	**17**	**861**	**1122**	**1001**	**$ 715**	**2,653,334**	**$ 64**	**332**	**$ 29**	**$ 808**
0	**0.0**	**30**	**590**	**758**	**767**	**$ 516**	**2,032,406**	**$ 49**	**255**	**$ 22**	**$ 587**
1_BL1	0.0	30	534	654	694	$ 435	1,838,724	$ 44	230	$ 20.27	$ 499
19_BL4	0.0	30	574	754	746	$ 519	1,977,800	$ 47	248	$ 21.81	$ 588
37_BL7	0.0	30	635	815	825	$ 554	2,185,761	$ 52	274	$ 24.10	$ 631
55_BL10	0.0	30	603	783	784	$ 536	2,077,515	$ 50	260	$ 22.91	$ 609
73_BL13	0.0	30	604	784	786	$ 537	2,082,231	$ 50	261	$ 22.96	$ 610
10	**4.8**	**20**	**640**	**826**	**773**	**$ 537**	**2,047,609**	**$ 49**	**257**	**$ 23**	**$ 608**
1	6.0	18	586	766	692	$ 494	1,834,286	$ 44	230	$ 20.22	$ 558
2	3.5	23	562	742	692	$ 494	1,833,662	$ 44	230	$ 20.22	$ 558
19	6.0	18	625	805	739	$ 515	1,956,998	$ 47	245	$ 21.58	$ 584
20	3.5	23	609	789	751	$ 521	1,988,981	$ 48	249	$ 21.93	$ 590
37	6.0	18	759	999	897	$ 647	2,377,936	$ 57	298	$ 26.22	$ 731
38	3.5	23	648	828	798	$ 542	2,114,805	$ 51	265	$ 23.32	$ 616
55	6.0	18	646	826	764	$ 527	2,023,768	$ 49	254	$ 22.31	$ 597
56	3.5	23	684	864	842	$ 562	2,231,893	$ 54	280	$ 24.61	$ 640
73	6.0	18	638	818	754	$ 522	1,997,246	$ 48	250	$ 22.02	$ 592
74	3.5	23	648	828	799	$ 542	2,116,516	$ 51	265	$ 23.34	$ 617
50	**6.8**	**16**	**902**	**1172**	**1051**	**$ 747**	**2,785,903**	**$ 67**	**349**	**$ 31**	**$ 845**
3	8.0	14	865	1165	988	$ 748	2,618,552	$ 63	328	$ 28.87	$ 840
4	5.5	19	863	1103	1027	$ 706	2,721,718	$ 65	341	$ 30.01	$ 801
21	8.0	14	887	1187	1013	$ 760	2,685,293	$ 64	336	$ 29.61	$ 854
22	5.5	19	818	1058	974	$ 682	2,581,501	$ 62	323	$ 28.46	$ 773
39	8.0	14	1018	1318	1163	$ 828	3,081,718	$ 74	386	$ 33.98	$ 936
40	5.5	19	947	1247	1128	$ 812	2,988,485	$ 72	374	$ 32.95	$ 916
57	8.0	14	1035	1335	1182	$ 836	3,132,108	$ 75	392	$ 34.53	$ 946
58	5.5	19	863	1103	1028	$ 707	2,724,211	$ 65	341	$ 30.04	$ 802
75	8.0	14	905	1145	1034	$ 709	2,739,172	$ 66	343	$ 30.20	$ 805
76	5.5	19	820	1060	976	$ 683	2,586,272	$ 62	324	$ 28.52	$ 774
90	**8.8**	**12**	**1086**	**1428**	**1219**	**$ 895**	**3,229,979**	**$ 78**	**405**	**$ 36**	**$ 1,008**
5	10.0	10	1133	1493	1246	$ 925	3,300,992	$ 79	414	$ 36.40	$ 1,041
6	7.5	15	905	1145	1042	$ 713	2,760,826	$ 66	346	$ 30.44	$ 810
23	10.0	10	1115	1475	1226	$ 916	3,248,109	$ 78	407	$ 35.81	$ 1,030
24	7.5	15	847	1147	974	$ 742	2,581,120	$ 62	323	$ 28.46	$ 832
41	10.0	10	1236	1596	1359	$ 977	3,600,068	$ 86	451	$ 39.69	$ 1,103
42	7.5	15	1135	1435	1306	$ 892	3,459,352	$ 83	433	$ 38.14	$ 1,014
59	10.0	10	1202	1622	1321	$ 1,020	3,501,307	$ 84	439	$ 38.60	$ 1,142
60	7.5	15	952	1312	1095	$ 857	2,902,245	$ 70	364	$ 32.00	$ 959
77	10.0	10	1283	1703	1410	$ 1,060	3,737,575	$ 90	468	$ 41.21	$ 1,191
78	7.5	15	1052	1352	1211	$ 849	3,208,200	$ 77	402	$ 35.37	$ 962
M - 150	**6.4**	**17**	**1057**	**1375**	**1228**	**$ 875**	**3,252,886**	**$ 78**	**408**	**$ 36**	**$ 989**
0	**0.0**	**30**	**670**	**850**	**871**	**$ 575**	**2,307,172**	**$ 55**	**289**	**$ 25**	**$ 656**
25_BL5	0.0	30	654	834	851	$ 566	2,253,712	$ 54	282	$ 24.85	$ 645
43_BL8	0.0	30	673	853	874	$ 577	2,316,624	$ 56	290	$ 25.54	$ 658
61_BL11	0.0	30	640	820	832	$ 558	2,205,385	$ 53	276	$ 24.32	$ 635
7_BL2	0.0	30	678	858	881	$ 580	2,335,298	$ 56	293	$ 25.75	$ 662
79_BL14	0.0	30	704	884	915	$ 595	2,424,838	$ 58	304	$ 26.74	$ 680
10	**4.8**	**20**	**785**	**1013**	**946**	**$ 657**	**2,506,486**	**$ 60**	**314**	**$ 28**	**$ 745**
7	6.0	18	832	1072	982	$ 686	2,602,018	$ 62	326	$ 28.69	$ 777
8	3.5	23	831	1071	1022	$ 704	2,708,878	$ 65	339	$ 29.87	$ 799
25	6.0	18	661	901	780	$ 594	2,067,349	$ 50	259	$ 22.79	$ 666
26	3.5	23	751	991	924	$ 659	2,448,525	$ 59	307	$ 27.00	$ 745
43	6.0	18	841	1021	992	$ 630	2,628,271	$ 63	329	$ 28.98	$ 722
44	3.5	23	851	1091	1048	$ 715	2,776,414	$ 67	348	$ 30.61	$ 813
61	6.0	18	833	1073	982	$ 686	2,603,450	$ 62	326	$ 28.70	$ 777
62	3.5	23	803	1043	989	$ 689	2,619,708	$ 63	328	$ 28.88	$ 780
79	6.0	18	727	907	858	$ 569	2,272,335	$ 55	285	$ 25.05	$ 649
80	3.5	23	717	957	882	$ 640	2,337,907	$ 56	293	$ 25.78	$ 722
50	**6.8**	**16**	**1144**	**1486**	**1331**	**$ 946**	**3,527,996**	**$ 85**	**442**	**$ 39**	**$ 1,070**
9	8.0	14	1184	1544	1351	$ 973	3,579,374	$ 86	448	$ 39.46	$ 1,098
10	5.5	19	1129	1429	1344	$ 910	3,562,207	$ 85	446	$ 39.28	$ 1,035
27	8.0	14	1175	1535	1340	$ 968	3,551,723	$ 85	445	$ 39.16	$ 1,093
28	5.5	19	896	1196	1067	$ 784	2,826,605	$ 68	354	$ 31.17	$ 883
45	8.0	14	1249	1609	1425	$ 1,007	3,775,461	$ 91	473	$ 41.63	$ 1,139
46	5.5	19	1210	1510	1441	$ 954	3,818,079	$ 92	478	$ 42.10	$ 1,088
63	8.0	14	1304	1784	1487	$ 1,155	3,939,443	$ 95	494	$ 43.43	$ 1,293
64	5.5	19	1062	1362	1265	$ 874	3,352,112	$ 80	420	$ 36.96	$ 991
81	8.0	14	1148	1508	1309	$ 954	3,468,075	$ 83	435	$ 38.24	$ 1,075
82	5.5	19	1080	1380	1286	$ 883	3,406,877	$ 82	427	$ 37.56	$ 1,003
90	**8.8**	**12**	**1306**	**1714**	**1465**	**$ 1,073**	**3,881,795**	**$ 93**	**486**	**$ 43**	**$ 1,209**
11	10.0	10	1364	1844	1499	$ 1,160	3,973,152	$ 95	498	$ 43.81	$ 1,300
12	7.5	15	1154	1514	1327	$ 962	3,517,047	$ 84	441	$ 38.78	$ 1,086
29	10.0	10	1527	2007	1679	$ 1,242	4,448,907	$ 107	557	$ 49.05	$ 1,398
30	7.5	15	962	1262	1106	$ 802	2,931,783	$ 70	367	$ 32.32	$ 905
47	10.0	10	1465	1885	1610	$ 1,151	4,267,196	$ 102	535	$ 47.05	$ 1,300
48	7.5	15	1302	1662	1497	$ 1,039	3,966,312	$ 95	497	$ 43.73	$ 1,178
65	10.0	10	1542	2022	1695	$ 1,249	4,491,420	$ 108	563	$ 49.52	$ 1,406
66	7.5	15	1139	1499	1309	$ 954	3,469,789	$ 83	435	$ 38.26	$ 1,076
83	10.0	10	1405	1885	1545	$ 1,181	4,094,951	$ 98	513	$ 45.15	$ 1,325
84	7.5	15	1200	1560	1380	$ 986	3,657,391	$ 88	458	$ 40.33	$ 1,114

L - 200	**6.4**	**17**	**1251**	**1628**	**1451**	**$ 1,035**	**3,844,709**	**$ 92**	**482**	**$ 42**	**$ 1,170**
0	**0.0**	**30**	**802**	**1018**	**1043**	**$ 689**	**2,763,816**	**$ 66**	**346**	**$ 30**	**$ 786**
13_BL3	0.0	30	814	1054	1058	$ 720	2,803,980	$ 67	351	$ 30.92	$ 818
31_BL6	0.0	30	796	976	1035	$ 650	2,742,915	$ 66	344	$ 30.24	$ 746
49_BL9	0.0	30	854	1094	1110	$ 744	2,940,469	$ 71	368	$ 32.42	$ 847
67_BL12	0.0	30	720	900	936	$ 605	2,478,966	$ 59	311	$ 27.33	$ 691
85_BL15	0.0	30	828	1068	1077	$ 729	2,852,748	$ 68	357	$ 31.45	$ 828
10	**4.8**	**20**	**908**	**1184**	**1093**	**$ 772**	**2,895,953**	**$ 70**	**363**	**$ 32**	**$ 873**
13	6.0	18	860	1100	1015	$ 701	2,689,972	$ 65	337	$ 29.66	$ 795
14	3.5	23	835	1075	1027	$ 706	2,720,731	$ 65	341	$ 30.00	$ 801
31	6.0	18	1174	1474	1385	$ 929	3,670,250	$ 88	460	$ 40.47	$ 1,057
32	3.5	23	939	1239	1155	$ 824	3,059,322	$ 73	383	$ 33.73	$ 931
49	6.0	18	870	1170	1026	$ 766	2,719,170	$ 65	341	$ 29.98	$ 861
50	3.5	23	886	1126	1090	$ 735	2,887,796	$ 69	362	$ 31.84	$ 836
67	6.0	18	871	1171	1028	$ 766	2,723,626	$ 65	341	$ 30.03	$ 862
68	3.5	23	863	1163	1061	$ 782	2,812,170	$ 67	352	$ 31.01	$ 880
85	6.0	18	894	1194	1055	$ 779	2,795,339	$ 67	350	$ 30.82	$ 877
86	3.5	23	884	1124	1087	$ 733	2,881,150	$ 69	361	$ 31.77	$ 834
50	**6.8**	**16**	**1351**	**1765**	**1570**	**$ 1,127**	**4,160,805**	**$ 100**	**521**	**$ 46**	**$ 1,272**
15	8.0	14	1435	1855	1636	$ 1,162	4,335,515	$ 104	543	$ 47.80	$ 1,314
16	5.5	19	1293	1653	1538	$ 1,058	4,074,176	$ 98	510	$ 44.92	$ 1,200
33	8.0	14	1577	2057	1798	$ 1,296	4,763,861	$ 114	597	$ 52.52	$ 1,463
34	5.5	19	1066	1426	1267	$ 935	3,356,645	$ 81	421	$ 37.01	$ 1,052
51	8.0	14	1419	1839	1618	$ 1,154	4,287,115	$ 103	537	$ 47.27	$ 1,304
52	5.5	19	1154	1514	1372	$ 983	3,635,667	$ 87	456	$ 40.09	$ 1,110
69	8.0	14	1498	1918	1707	$ 1,195	4,524,067	$ 109	567	$ 49.88	$ 1,353
70	5.5	19	1249	1609	1485	$ 1,034	3,934,809	$ 94	493	$ 43.38	$ 1,172
87	8.0	14	1501	2041	1712	$ 1,317	4,535,570	$ 109	568	$ 50.01	$ 1,476
88	5.5	19	1321	1741	1570	$ 1,133	4,160,621	$ 100	521	$ 45.87	$ 1,278
90	**8.8**	**12**	**1568**	**2036**	**1758**	**$ 1,266**	**4,657,518**	**$ 112**	**584**	**$ 51**	**$ 1,429**
17	10.0	10	1663	2143	1825	$ 1,308	4,837,102	$ 116	606	$ 53.33	$ 1,478
18	7.5	15	1537	2017	1766	$ 1,282	4,680,461	$ 112	586	$ 51.61	$ 1,445
35	10.0	10	1800	2340	1976	$ 1,437	5,235,026	$ 126	656	$ 57.72	$ 1,620
36	7.5	15	1328	1748	1526	$ 1,112	4,043,542	$ 97	507	$ 44.58	$ 1,254
53	10.0	10	1810	2350	1987	$ 1,442	5,264,627	$ 126	660	$ 58.05	$ 1,626
54	7.5	15	1508	1928	1733	$ 1,206	4,591,417	$ 110	575	$ 50.62	$ 1,367
71	10.0	10	1580	2060	1734	$ 1,267	4,594,477	$ 110	576	$ 50.66	$ 1,428
72	7.5	15	1296	1716	1489	$ 1,096	3,944,929	$ 95	494	$ 43.50	$ 1,234
89	10.0	10	1739	2219	1909	$ 1,346	5,058,969	$ 121	634	$ 55.78	$ 1,524
90	7.5	15	1420	1840	1632	$ 1,161	4,324,627	$ 104	542	$ 47.68	$ 1,312
Total Average	**6.4**	**17**	**1056**	**1375**	**1227**	**$ 875**	**3,250,310**	**$ 78**	**407**	**$ 36**	**$ 989**

Results for Scenarios (detail):

Scenario name (1-6)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
1_BL1_S1_c100S	0.0	30	534	654	694	435	1,838,724	$ 44.13	230.38	$ 20.27	$ 499
1_S1_c100S_10pp_60min_Sc6	6.0	18	586	766	692	494	1,834,286	$ 44.02	229.82	$ 20.22	$ 558
2_S1_c100S_10pp_120min_Sc3.5	3.5	23	562	742	692	494	1,833,662	$ 44.01	229.74	$ 20.22	$ 558
3_S1_c100S_50pp_60min_Sc8	8.0	14	865	1165	988	748	2,618,552	$ 62.85	328.08	$ 28.87	$ 840
4_S1_c100S_50pp_120min_Sc5.5	5.5	19	863	1103	1027	706	2,721,718	$ 65.32	341.01	$ 30.01	$ 801
5_S1_c100S_90pp_60min_Sc10	10.0	10	1133	1493	1246	925	3,300,992	$ 79.22	413.59	$ 36.40	$ 1,041
6_S1_c100S_90pp_120min_Sc7.5	7.5	15	905	1145	1042	713	2,760,826	$ 66.26	345.91	$ 30.44	$ 810

Table 13.0 – Results for Scenarios 1-6.

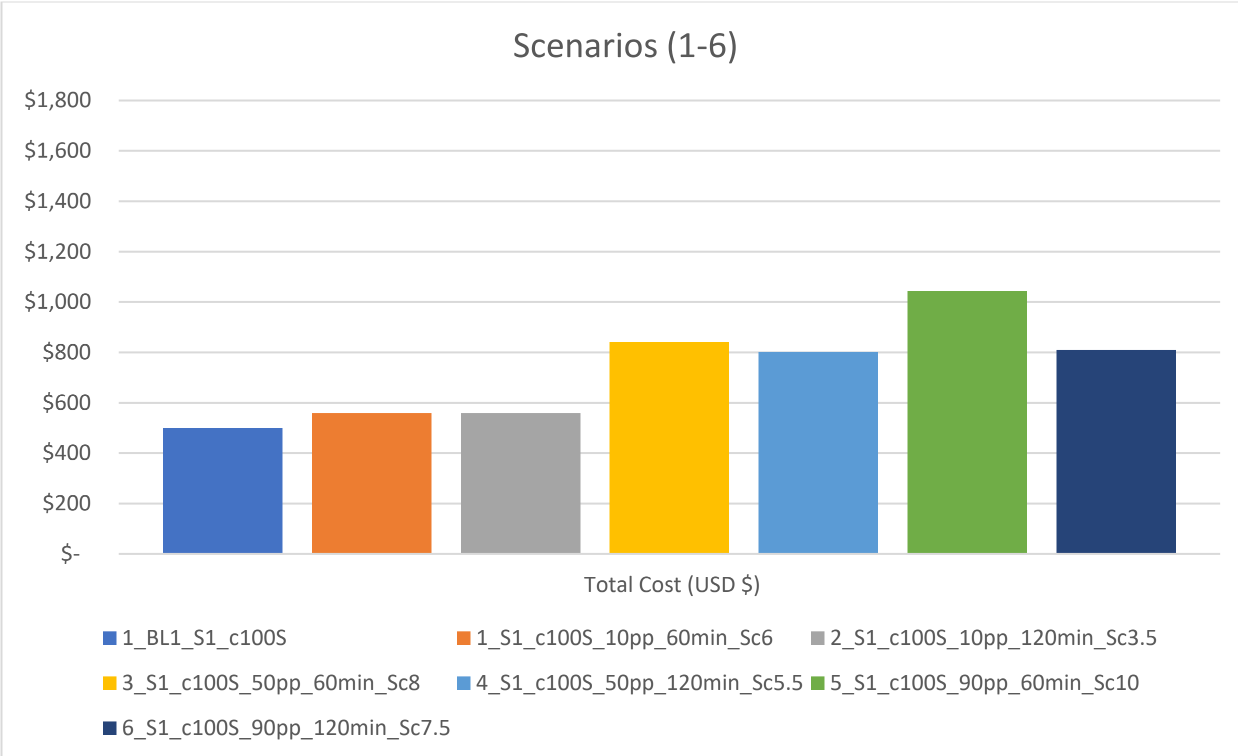


Figure 32.0 – Results for Scenarios 1-6.

Scenario name (7-12)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
7_BL2_S1_c150M	0.0	30	678	858	881	580	2,335,298	$ 56.05	292.59	$ 25.75	$ 662
7_S1_c150M_10pp_60min_Sc6	6.0	18	832	1072	982	686	2,602,018	$ 62.45	326.01	$ 28.69	$ 777
8_S1_c150M_10pp_120min_Sc3.5	3.5	23	831	1071	1022	704	2,708,878	$ 65.01	339.40	$ 29.87	$ 799
9_S1_c150M_50pp_60min_Sc8	8.0	14	1184	1544	1351	973	3,579,374	$ 85.90	448.46	$ 39.46	$ 1,098
10_S1_c150M_50pp_120min_Sc5.5	5.5	19	1129	1429	1344	910	3,562,207	$ 85.49	446.31	$ 39.28	$ 1,035
11_S1_c150M_90pp_60min_Sc10	10.0	10	1364	1844	1499	1160	3,973,152	$ 95.36	497.80	$ 43.81	$ 1,300
12_S1_c150M_90pp_120min_Sc7.5	7.5	15	1154	1514	1327	962	3,517,047	$ 84.41	440.66	$ 38.78	$ 1,086

Table 14.0 – Results for Scenarios 7-12.

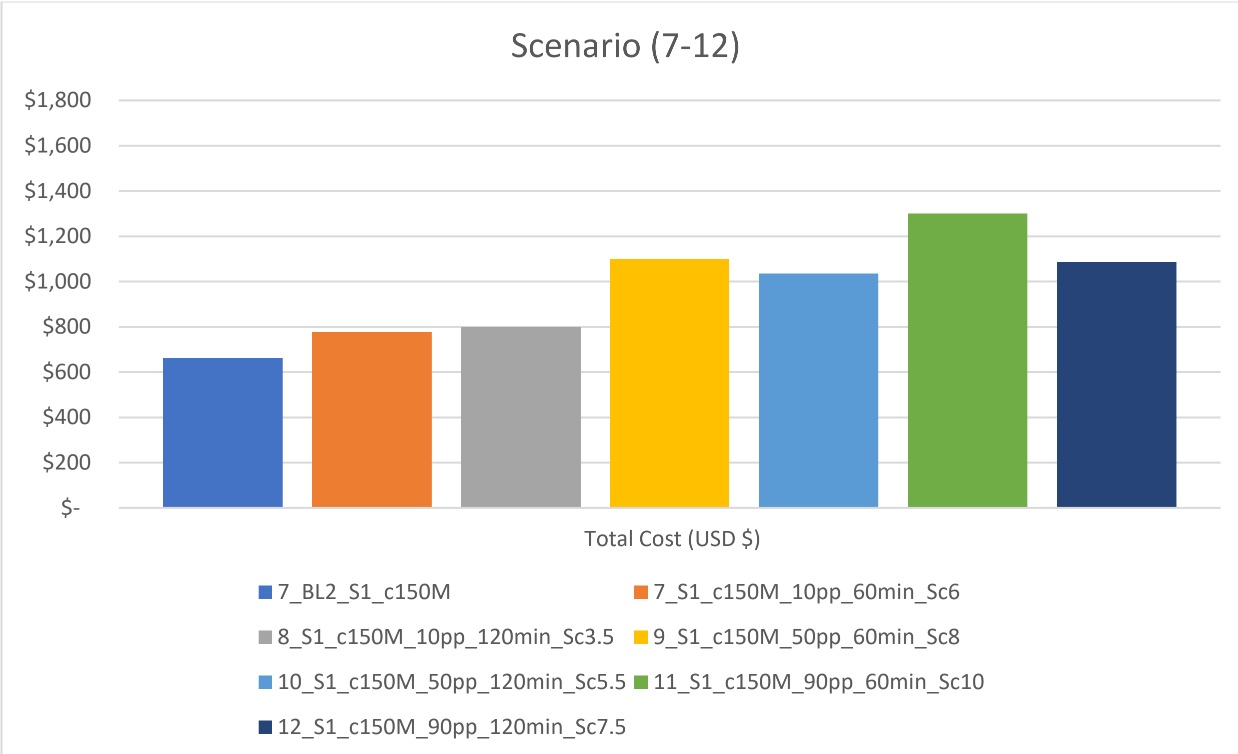


Figure 33.0 – Results for Scenarios 7-12.

Scenario name (13-18)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
13_BL3_S1_c200L	0.0	30	814	1054	1058	720	2,803,980	$ 67.30	351.31	$ 30.92	$ 818
13_S1_c200L_10pp_60min_Sc6	6.0	18	860	1100	1015	701	2,689,972	$ 64.56	337.03	$ 29.66	$ 795
14_S1_c200L_10pp_120min_Sc3.5	3.5	23	835	1075	1027	706	2,720,731	$ 65.30	340.88	$ 30.00	$ 801
15_S1_c200L_50pp_60min_Sc8	8.0	14	1435	1855	1636	1162	4,335,515	$ 104.05	543.20	$ 47.80	$ 1,314
16_S1_c200L_50pp_120min_Sc5.5	5.5	19	1293	1653	1538	1058	4,074,176	$ 97.78	510.46	$ 44.92	$ 1,200
17_S1_c200L_90pp_60min_Sc10	10.0	10	1663	2143	1825	1308	4,837,102	$ 116.09	606.05	$ 53.33	$ 1,478
18_S1_c200L_90pp_120min_Sc7.5	7.5	15	1537	2017	1766	1282	4,680,461	$ 112.33	586.42	$ 51.61	$ 1,445

Table 15.0 – Results for Scenarios 13-18.

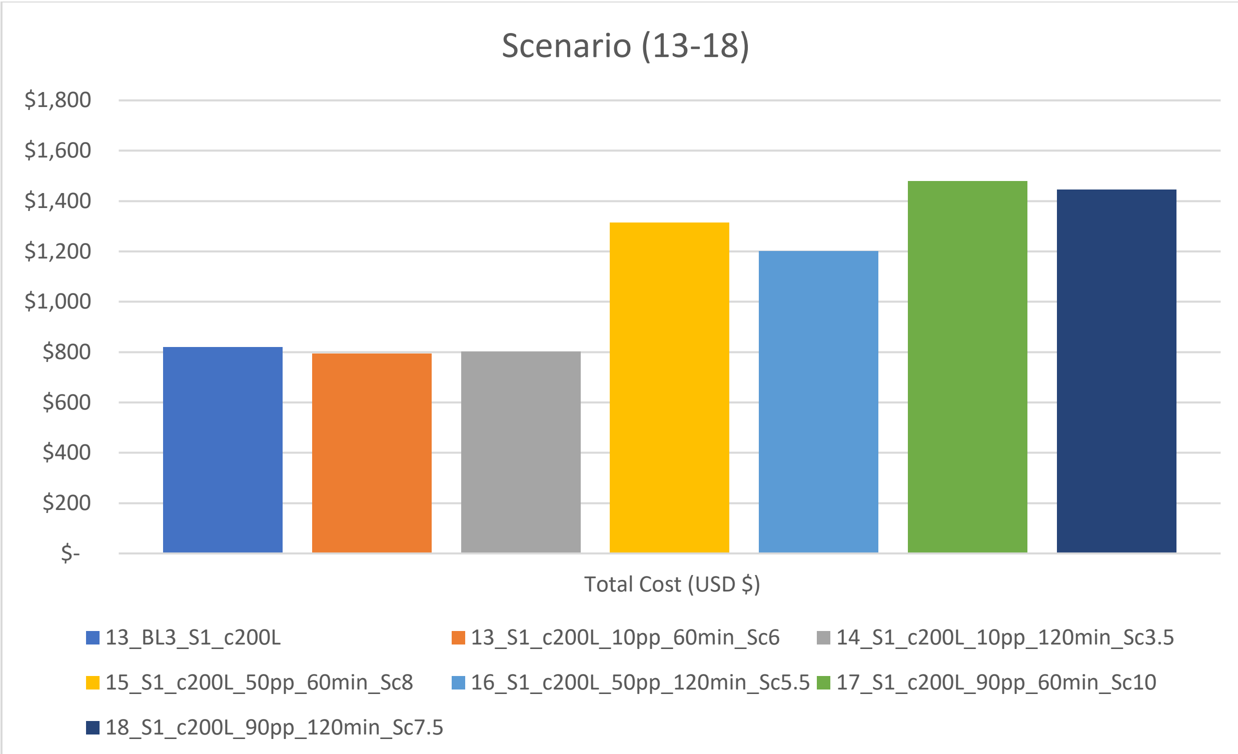


Figure 34.0 – Results for Scenarios 13-18.

Scenario name (19-24)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
19_BL4_S2_c100S	0.0	30	574	754	746	519	1,977,800	$ 47.47	247.80	$ 21.81	$ 588
19_S2_c100S_10pp_60min_Sc6	6.0	18	625	805	739	515	1,956,998	$ 46.97	245.19	$ 21.58	$ 584
20_S2_c100S_10pp_120min_Sc3.5	3.5	23	609	789	751	521	1,988,981	$ 47.74	249.20	$ 21.93	$ 590
21_S2_c100S_50pp_60min_Sc8	8.0	14	887	1187	1013	760	2,685,293	$ 64.45	336.44	$ 29.61	$ 854
22_S2_c100S_50pp_120min_Sc5.5	5.5	19	818	1058	974	682	2,581,501	$ 61.96	323.44	$ 28.46	$ 773
23_S2_c100S_90pp_60min_Sc10	10.0	10	1115	1475	1226	916	3,248,109	$ 77.95	406.96	$ 35.81	$ 1,030
24_S2_c100S_90pp_120min_Sc7.5	7.5	15	847	1147	974	742	2,581,120	$ 61.95	323.39	$ 28.46	$ 832

Table 16.0 – Results for Scenarios 19-24.

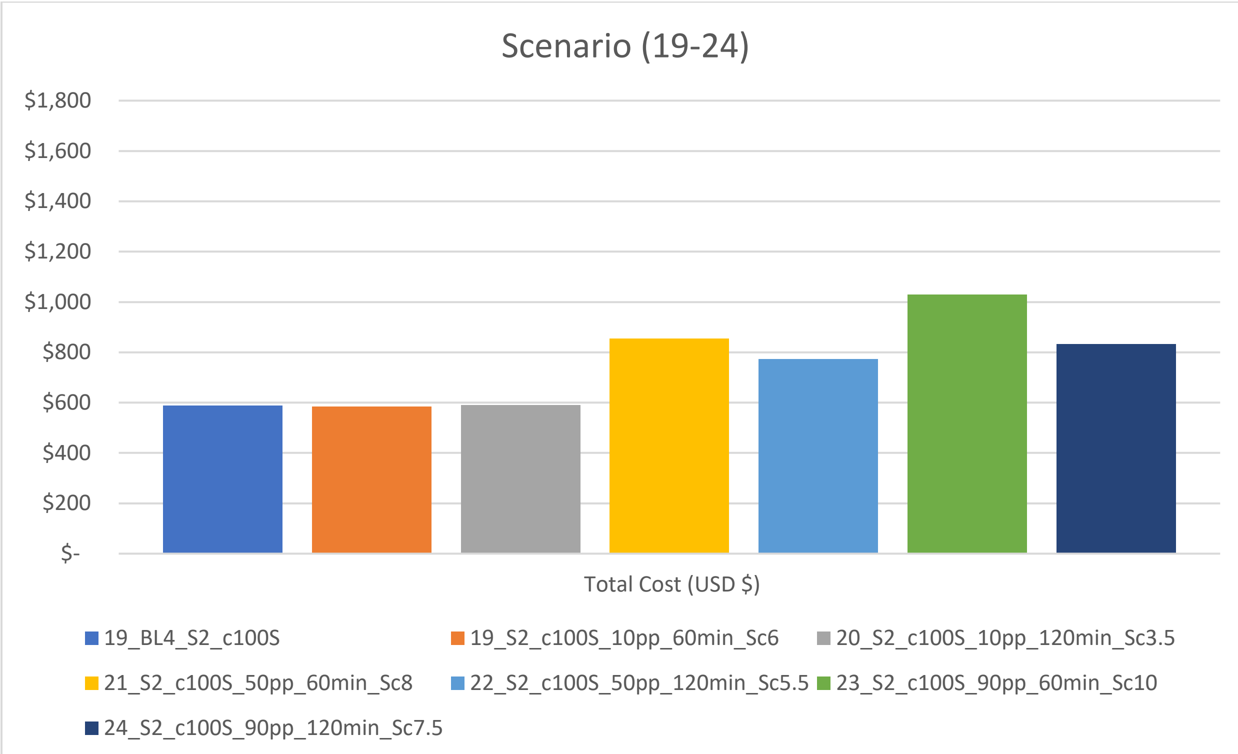


Figure 35.0 – Results for Scenarios 19-24.

Scenario name (25-30)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
25_BL5_S2_c150M	0.0	30	654	834	851	566	2,253,712	$ 54.09	282.37	$ 24.85	$ 645
25_S2_c150M_10pp_60min_Sc6	6.0	18	661	901	780	594	2,067,349	$ 49.62	259.02	$ 22.79	$ 666
26_S2_c150M_10pp_120min_Sc3.5	3.5	23	751	991	924	659	2,448,525	$ 58.76	306.78	$ 27.00	$ 745
27_S2_c150M_50pp_60min_Sc8	8.0	14	1175	1535	1340	968	3,551,723	$ 85.24	445.00	$ 39.16	$ 1,093
28_S2_c150M_50pp_120min_Sc5.5	5.5	19	896	1196	1067	784	2,826,605	$ 67.84	354.15	$ 31.17	$ 883
29_S2_c150M_90pp_60min_Sc10	10.0	10	1527	2007	1679	1242	4,448,907	$ 106.77	557.41	$ 49.05	$ 1,398
30_S2_c150M_90pp_120min_Sc7.5	7.5	15	962	1262	1106	802	2,931,783	$ 70.36	367.33	$ 32.32	$ 905

Table 17.0 – Results for Scenarios 25-30.

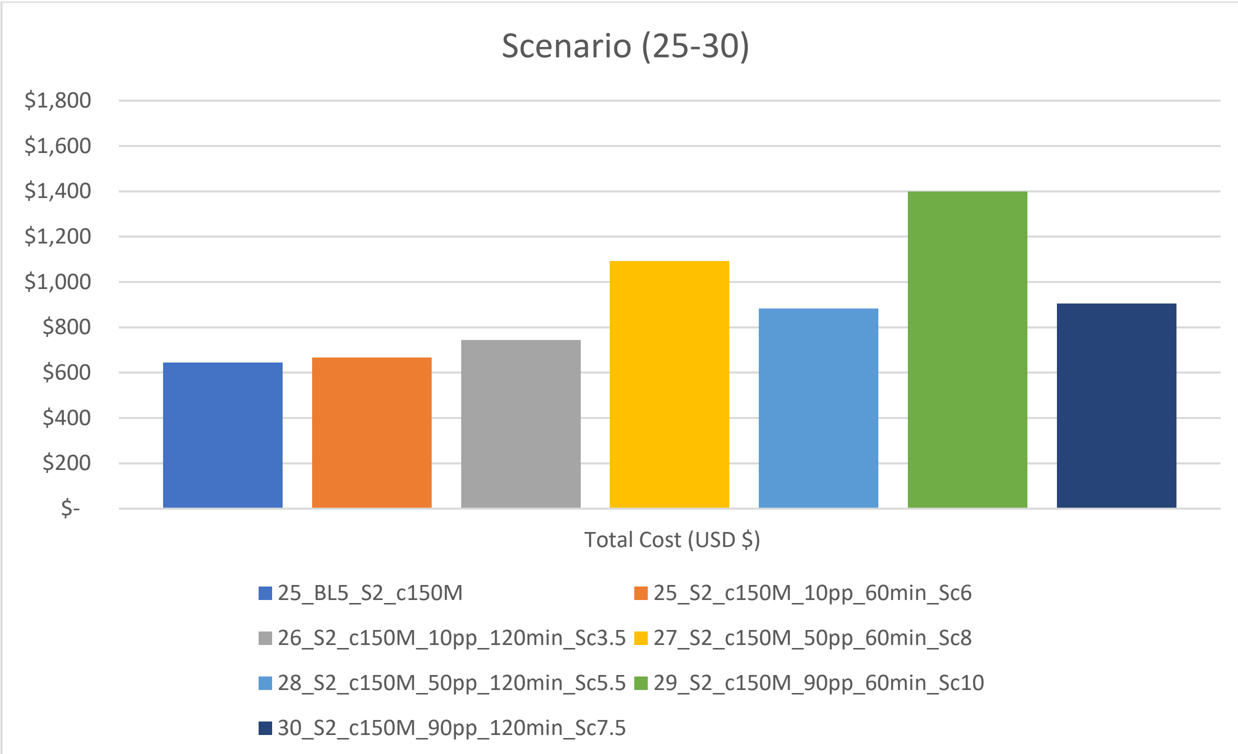


Figure 36.0 – Results for Scenarios 25-30.

Scenario name (31-36)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
31_BL6_S2_c200L	0.0	30	796	976	1035	650	2,742,915	$ 65.83	343.66	$ 30.24	$ 746
31_S2_c200L_10pp_60min_Sc6	6.0	18	1174	1474	1385	929	3,670,250	$ 88.09	459.85	$ 40.47	$ 1,057
32_S2_c200L_10pp_120min_Sc3.5	3.5	23	939	1239	1155	824	3,059,322	$ 73.42	383.31	$ 33.73	$ 931
33_S2_c200L_50pp_60min_Sc8	8.0	14	1577	2057	1798	1296	4,763,861	$ 114.33	596.87	$ 52.52	$ 1,463
34_S2_c200L_50pp_120min_Sc5.5	5.5	19	1066	1426	1267	935	3,356,645	$ 80.56	420.56	$ 37.01	$ 1,052
35_S2_c200L_90pp_60min_Sc10	10.0	10	1800	2340	1976	1437	5,235,026	$ 125.64	655.90	$ 57.72	$ 1,620
36_S2_c200L_90pp_120min_Sc7.5	7.5	15	1328	1748	1526	1112	4,043,542	$ 97.05	506.62	$ 44.58	$ 1,254

Table 18.0 – Results for Scenarios 31-36.

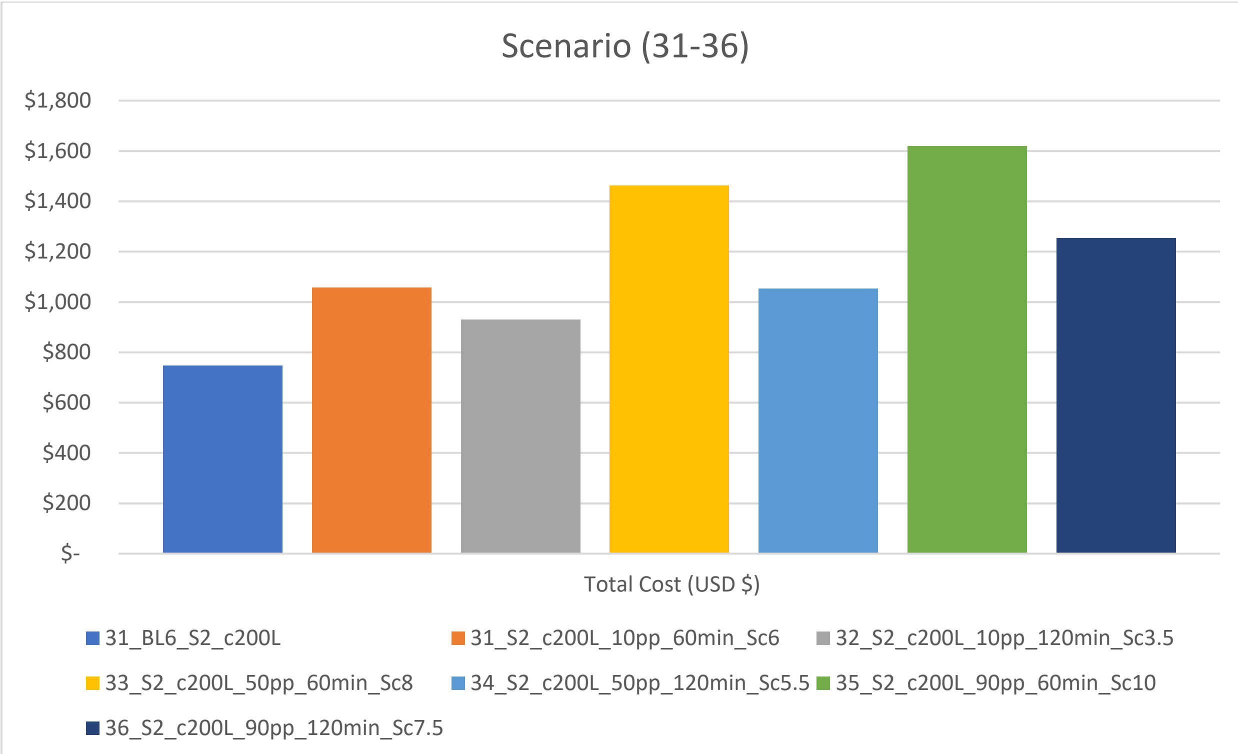


Figure 37.0 – Results for Scenarios 31-36.

Scenario name (37-42)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
37_BL7_S3_c100S	0.0	30	635	815	825	554	2,185,761	$ 52.46	273.86	$ 24.10	$ 631
37_S3_c100S_10pp_60min_Sc6	6.0	18	759	999	897	647	2,377,936	$ 57.07	297.93	$ 26.22	$ 731
38_S3_c100S_10pp_120min_Sc3.5	3.5	23	648	828	798	542	2,114,805	$ 50.76	264.97	$ 23.32	$ 616
39_S3_c100S_50pp_60min_Sc8	8.0	14	1018	1318	1163	828	3,081,718	$ 73.96	386.11	$ 33.98	$ 936
40_S3_c100S_50pp_120min_Sc5.5	5.5	19	947	1247	1128	812	2,988,485	$ 71.72	374.43	$ 32.95	$ 916
41_S3_c100S_90pp_60min_Sc10	10.0	10	1236	1596	1359	977	3,600,068	$ 86.40	451.06	$ 39.69	$ 1,103
42_S3_c100S_90pp_120min_Sc7.5	7.5	15	1135	1435	1306	892	3,459,352	$ 83.02	433.43	$ 38.14	$ 1,014

Table 19.0 – Results for Scenarios 37-42.

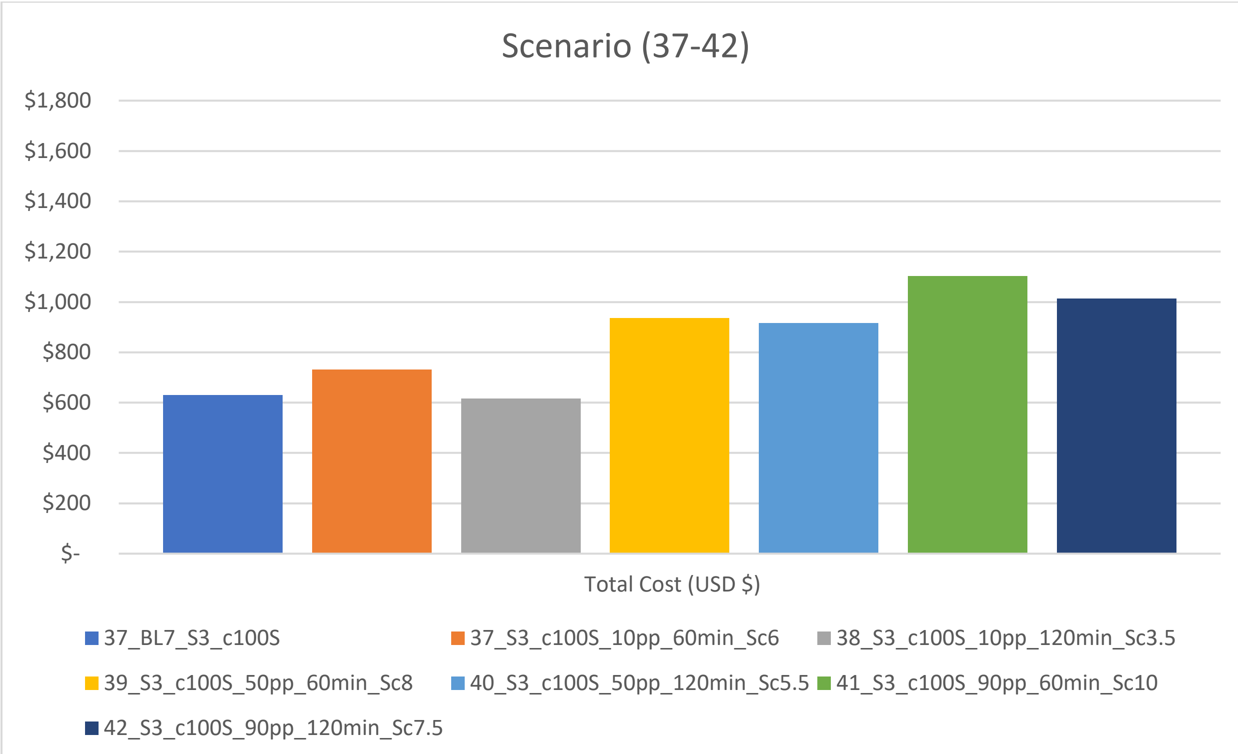


Figure 38.0 – Results for Scenarios 37-42.

Scenario name (43-48)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
43_BL8_S3_c150M	0.0	30	673	853	874	577	2,316,624	$ 55.60	290.25	$ 25.54	$ 658
43_S3_c150M_10pp_60min_Sc6	6.0	18	841	1021	992	630	2,628,271	$ 63.08	329.30	$ 28.98	$ 722
44_S3_c150M_10pp_120min_Sc3.5	3.5	23	851	1091	1048	715	2,776,414	$ 66.63	347.86	$ 30.61	$ 813
45_S3_c150M_50pp_60min_Sc8	8.0	14	1249	1609	1425	1007	3,775,461	$ 90.61	473.03	$ 41.63	$ 1,139
46_S3_c150M_50pp_120min_Sc5.5	5.5	19	1210	1510	1441	954	3,818,079	$ 91.63	478.37	$ 42.10	$ 1,088
47_S3_c150M_90pp_60min_Sc10	10.0	10	1465	1885	1610	1151	4,267,196	$ 102.41	534.64	$ 47.05	$ 1,300
48_S3_c150M_90pp_120min_Sc7.5	7.5	15	1302	1662	1497	1039	3,966,312	$ 95.19	496.94	$ 43.73	$ 1,178

Table 20.0 – Results for Scenarios 43-48.

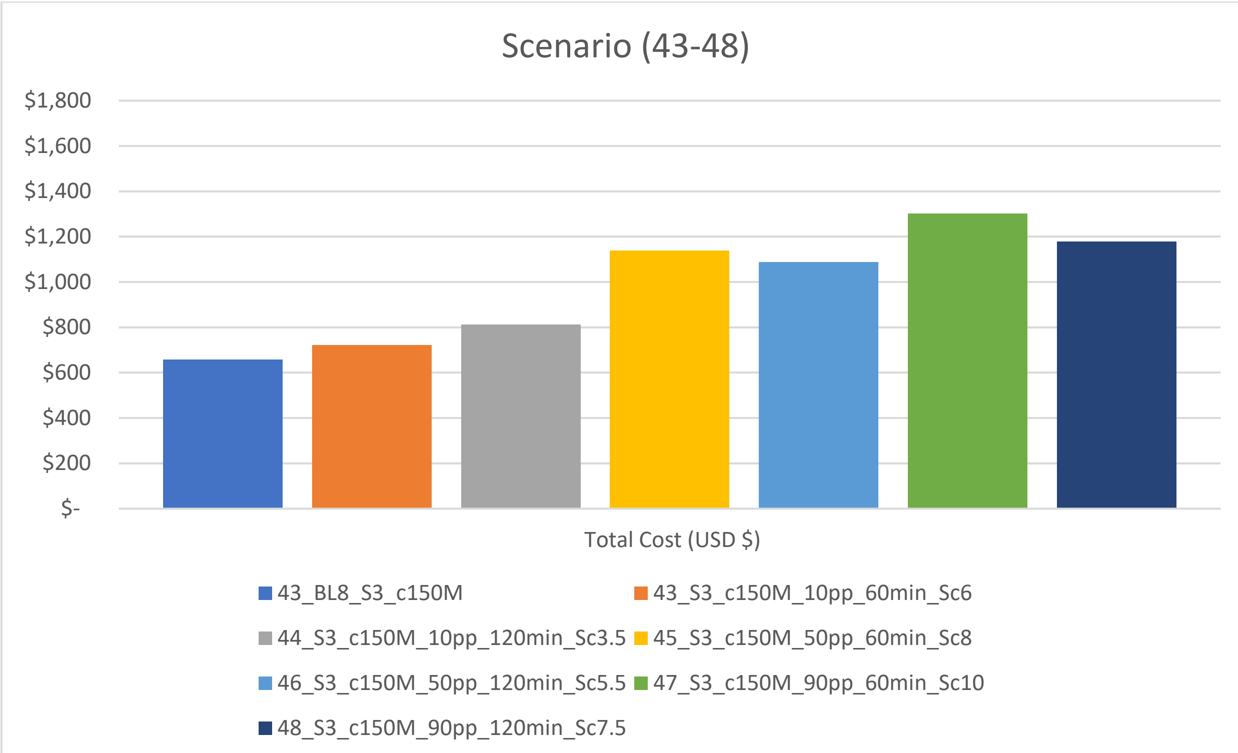


Figure 39.0 – Results for Scenarios 43-48.

Scenario name (49-54)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
49_BL9_S3_c200L	0.0	30	854	1094	1110	744	2,940,469	$ 70.57	368.42	$ 32.42	$ 847
49_S3_c200L_10pp_60min_Sc6	6.0	18	870	1170	1026	766	2,719,170	$ 65.26	340.69	$ 29.98	$ 861
50_S3_c200L_10pp_120min_Sc3.5	3.5	23	886	1126	1090	735	2,887,796	$ 69.31	361.82	$ 31.84	$ 836
51_S3_c200L_50pp_60min_Sc8	8.0	14	1419	1839	1618	1154	4,287,115	$ 102.89	537.14	$ 47.27	$ 1,304
52_S3_c200L_50pp_120min_Sc5.5	5.5	19	1154	1514	1372	983	3,635,667	$ 87.26	455.52	$ 40.09	$ 1,110
53_S3_c200L_90pp_60min_Sc10	10.0	10	1810	2350	1987	1442	5,264,627	$ 126.35	659.61	$ 58.05	$ 1,626
54_S3_c200L_90pp_120min_Sc7.5	7.5	15	1508	1928	1733	1206	4,591,417	$ 110.19	575.26	$ 50.62	$ 1,367

Table 21.0 – Results for Scenarios 49-54.

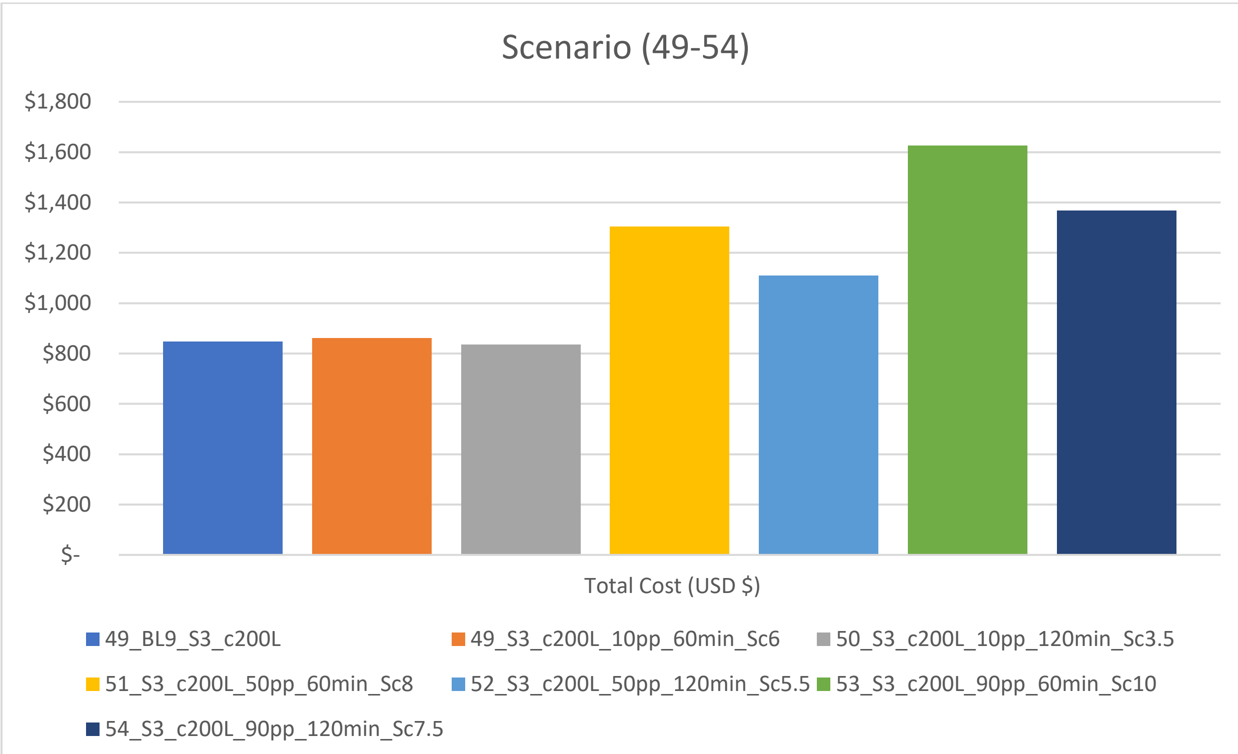


Figure 40.0 – Results for Scenarios 49-54.

Scenario name (55-60)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
55_BL10_S4_c100S	0.0	30	603	783	784	536	2,077,515	$ 49.86	260.29	$ 22.91	$ 609
55_S4_c100S_10pp_60min_Sc6	6.0	18	646	826	764	527	2,023,768	$ 48.57	253.56	$ 22.31	$ 597
56_S4_c100S_10pp_120min_Sc3.5	3.5	23	684	864	842	562	2,231,893	$ 53.57	279.64	$ 24.61	$ 640
57_S4_c100S_50pp_60min_Sc8	8.0	14	1035	1335	1182	836	3,132,108	$ 75.17	392.43	$ 34.53	$ 946
58_S4_c100S_50pp_120min_Sc5.5	5.5	19	863	1103	1028	707	2,724,211	$ 65.38	341.32	$ 30.04	$ 802
59_S4_c100S_90pp_60min_Sc10	10.0	10	1202	1622	1321	1020	3,501,307	$ 84.03	438.68	$ 38.60	$ 1,142
60_S4_c100S_90pp_120min_Sc7.5	7.5	15	952	1312	1095	857	2,902,245	$ 69.65	363.63	$ 32.00	$ 959

Table 22.0 – Results for Scenarios 55-60.

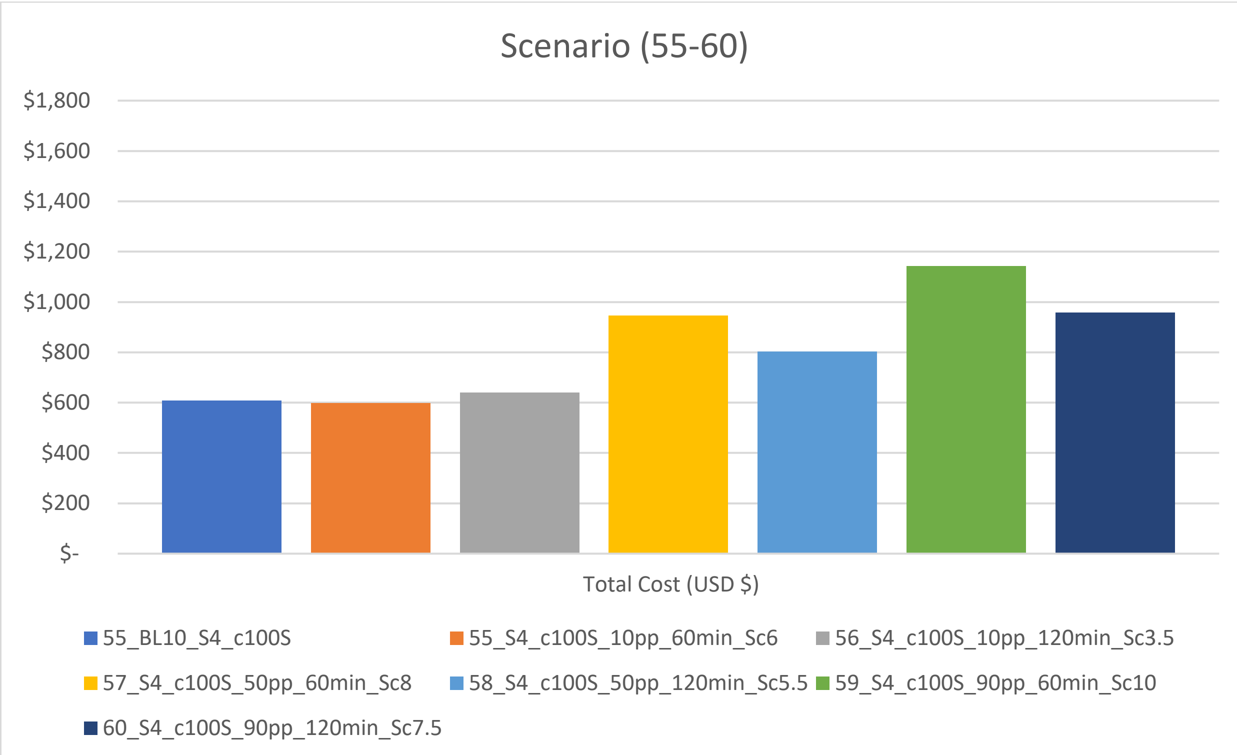


Figure 41.0 – Results for Scenarios 55-60.

Scenario name (61-66)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
61_BL11_S4_c150M	0.0	30	640	820	832	558	2,205,385	$ 52.93	276.32	$ 24.32	$ 635
61_S4_c150M_10pp_60min_Sc6	6.0	18	833	1073	982	686	2,603,450	$ 62.48	326.19	$ 28.70	$ 777
62_S4_c150M_10pp_120min_Sc3.5	3.5	23	803	1043	989	689	2,619,708	$ 62.87	328.23	$ 28.88	$ 780
63_S4_c150M_50pp_60min_Sc8	8.0	14	1304	1784	1487	1155	3,939,443	$ 94.55	493.58	$ 43.43	$ 1,293
64_S4_c150M_50pp_120min_Sc5.5	5.5	19	1062	1362	1265	874	3,352,112	$ 80.45	419.99	$ 36.96	$ 991
65_S4_c150M_90pp_60min_Sc10	10.0	10	1542	2022	1695	1249	4,491,420	$ 107.79	562.74	$ 49.52	$ 1,406
66_S4_c150M_90pp_120min_Sc7.5	7.5	15	1139	1499	1309	954	3,469,789	$ 83.27	434.73	$ 38.26	$ 1,076

Table 23.0 – Results for Scenarios 61-66.

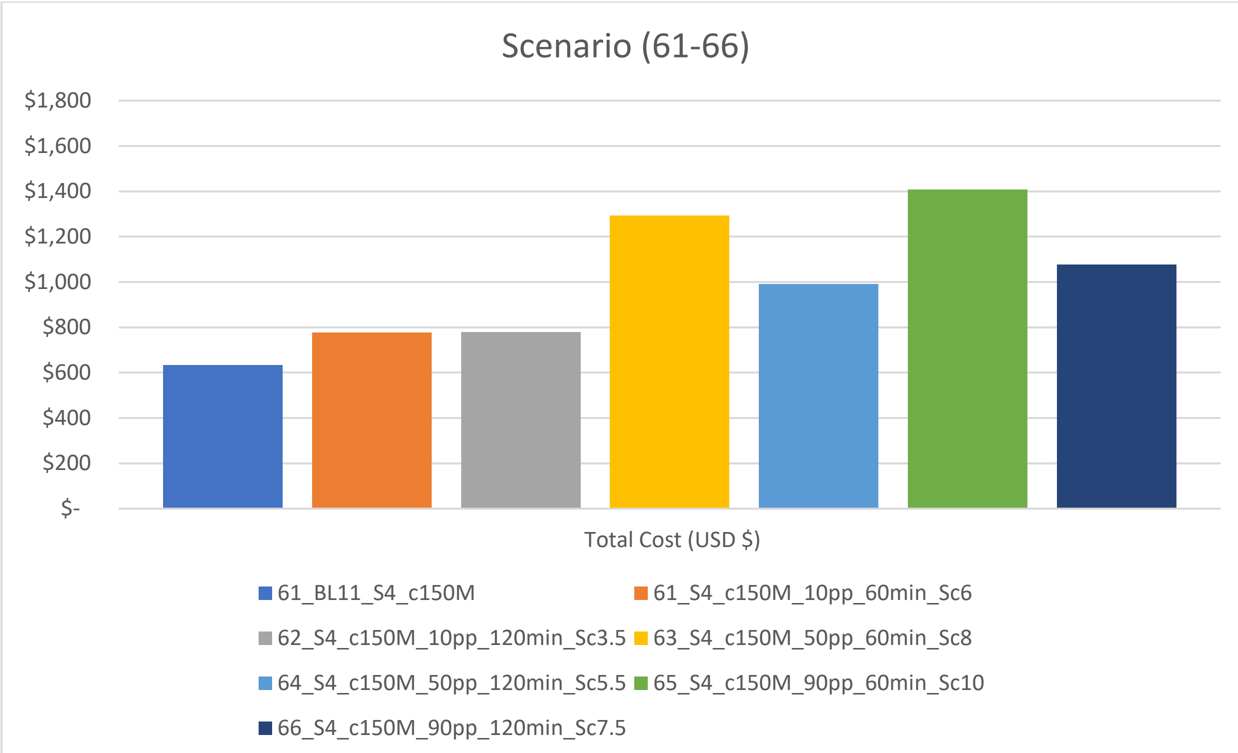


Figure 42.0 – Results for Scenarios 61-66.

Scenario name (67-72)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
67_BL12_S4_c200L	0.0	30	720	900	936	605	2,478,966	$ 59.50	310.59	$ 27.33	$ 691
67_S4_c200L_10pp_60min_Sc6	6.0	18	871	1171	1028	766	2,723,626	$ 65.37	341.25	$ 30.03	$ 862
68_S4_c200L_10pp_120min_Sc3.5	3.5	23	863	1163	1061	782	2,812,170	$ 67.49	352.34	$ 31.01	$ 880
69_S4_c200L_50pp_60min_Sc8	8.0	14	1498	1918	1707	1195	4,524,067	$ 108.58	566.83	$ 49.88	$ 1,353
70_S4_c200L_50pp_120min_Sc5.5	5.5	19	1249	1609	1485	1034	3,934,809	$ 94.44	493.00	$ 43.38	$ 1,172
71_S4_c200L_90pp_60min_Sc10	10.0	10	1580	2060	1734	1267	4,594,477	$ 110.27	575.65	$ 50.66	$ 1,428
72_S4_c200L_90pp_120min_Sc7.5	7.5	15	1296	1716	1489	1096	3,944,929	$ 94.68	494.27	$ 43.50	$ 1,234

Table 24.0 – Results for Scenarios 67-72.

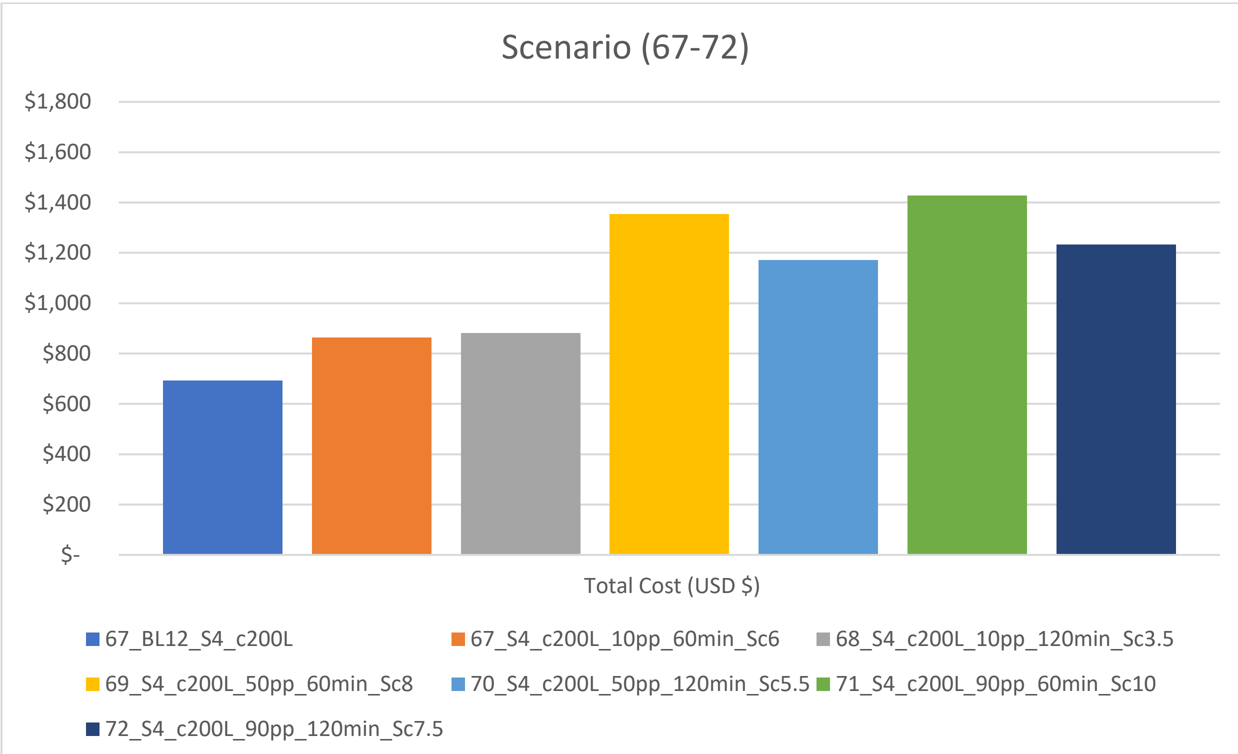


Figure 43.0 – Results for Scenarios 67-72.

Scenario name (73-78)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
73_BL13_S5_c100S	0.0	30	604	784	786	537	2,082,231	$ 49.97	260.89	$ 22.96	$ 610
73_S5_c100S_10pp_60min_Sc6	6.0	18	638	818	754	522	1,997,246	$ 47.93	250.24	$ 22.02	$ 592
74_S5_c100S_10pp_120min_Sc3.5	3.5	23	648	828	799	542	2,116,516	$ 50.80	265.18	$ 23.34	$ 617
75_S5_c100S_50pp_60min_Sc8	8.0	14	905	1145	1034	709	2,739,172	$ 65.74	343.19	$ 30.20	$ 805
76_S5_c100S_50pp_120min_Sc5.5	5.5	19	820	1060	976	683	2,586,272	$ 62.07	324.04	$ 28.52	$ 774
77_S5_c100S_90pp_60min_Sc10	10.0	10	1283	1703	1410	1060	3,737,575	$ 89.70	468.29	$ 41.21	$ 1,191
78_S5_c100S_90pp_120min_Sc7.5	7.5	15	1052	1352	1211	849	3,208,200	$ 77.00	401.96	$ 35.37	$ 962

Table 25.0 – Results for Scenarios 73-78.

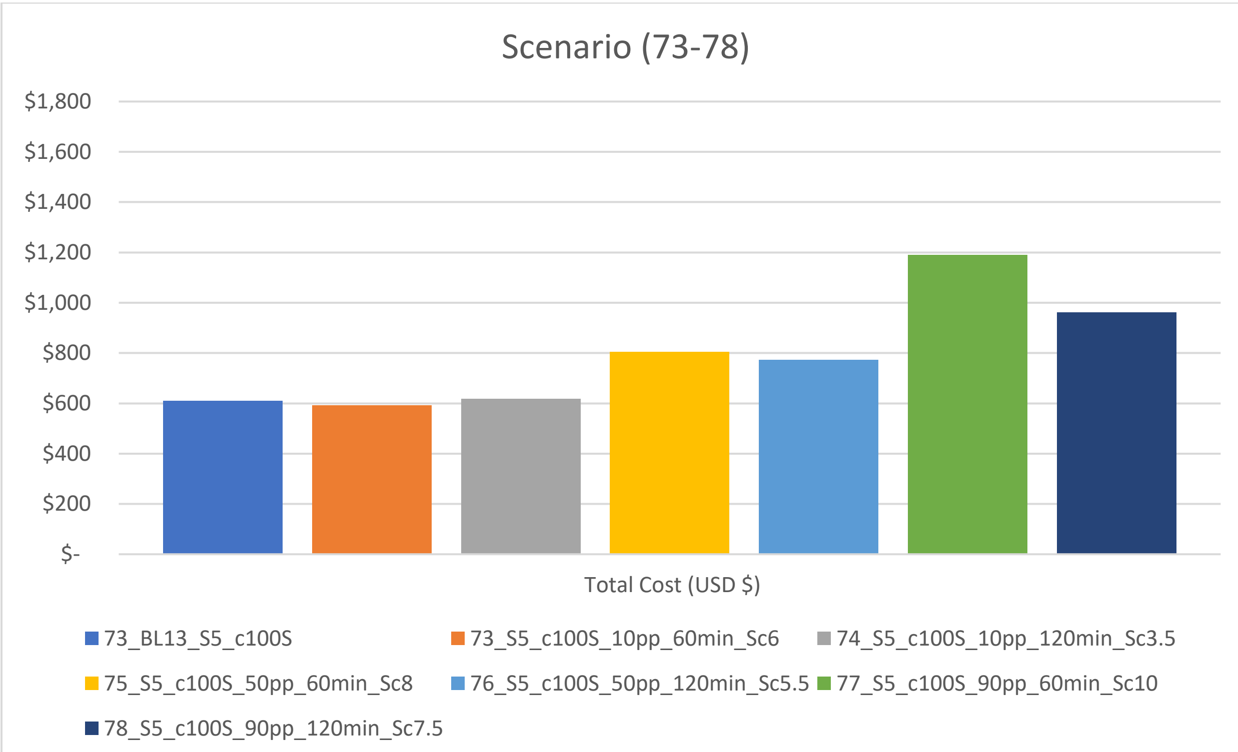


Figure 44.0 – Results for Scenarios 73-78.

Scenario name (79-84)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
79_BL14_S5_c150M	0.0	30	704	884	915	595	2,424,838	$ 58.20	303.81	$ 26.74	$ 680
79_S5_c150M_10pp_60min_Sc6	6.0	18	727	907	858	569	2,272,335	$ 54.54	284.70	$ 25.05	$ 649
80_S5_c150M_10pp_120min_Sc3.5	3.5	23	717	957	882	640	2,337,907	$ 56.11	292.92	$ 25.78	$ 722
81_S5_c150M_50pp_60min_Sc8	8.0	14	1148	1508	1309	954	3,468,075	$ 83.23	434.52	$ 38.24	$ 1,075
82_S5_c150M_50pp_120min_Sc5.5	5.5	19	1080	1380	1286	883	3,406,877	$ 81.77	426.85	$ 37.56	$ 1,003
83_S5_c150M_90pp_60min_Sc10	10.0	10	1405	1885	1545	1181	4,094,951	$ 98.28	513.06	$ 45.15	$ 1,325
84_S5_c150M_90pp_120min_Sc7.5	7.5	15	1200	1560	1380	986	3,657,391	$ 87.78	458.24	$ 40.33	$ 1,114

Table 26.0 – Results for Scenarios 79-84.

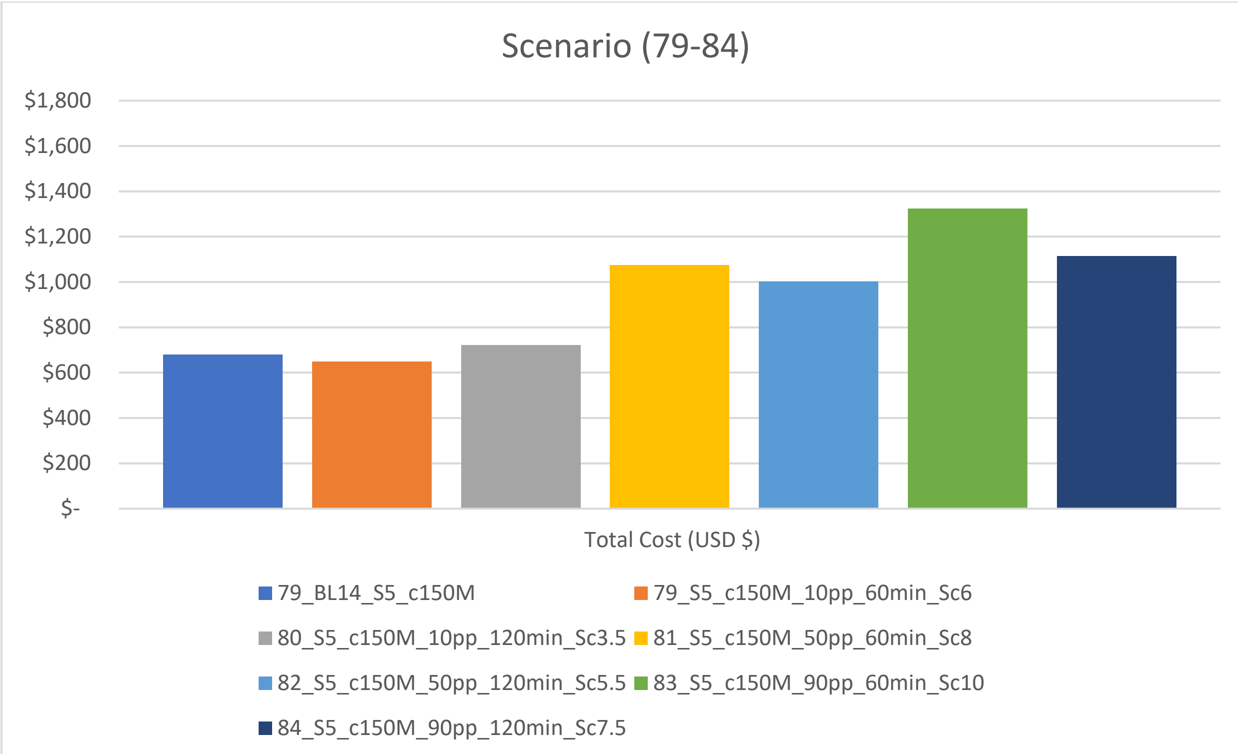


Figure 45.0 – Results for Scenarios 79-84.

Scenario name (85-90)	NTW Failed Delivery Score (3.5-10)*	Overall Failed Delivery Variation (%)	Distance traveled from ESSVRP Solution (km)	Total Unitary Cost	Total Distance - Adjusted- (km)	Costs from ESSVRP Solution (USD $)	CO2 Emissions (g)	CO2 cost (USD $)	PM2.5 (g)	PM2.5 cost (USD $)	Total Cost (USD $)
85_BL15_S5_c200L	0.0	30	828	1068	1077	729	2,852,748	$ 68.47	357.42	$ 31.45	$ 828
85_S5_c200L_10pp_60min_Sc6	6.0	18	894	1194	1055	779	2,795,339	$ 67.09	350.23	$ 30.82	$ 877
86_S5_c200L_10pp_120min_Sc3.5	3.5	23	884	1124	1087	733	2,881,150	$ 69.15	360.98	$ 31.77	$ 834
87_S5_c200L_50pp_60min_Sc8	8.0	14	1501	2041	1712	1317	4,535,570	$ 108.85	568.27	$ 50.01	$ 1,476
88_S5_c200L_50pp_120min_Sc5.5	5.5	19	1321	1741	1570	1133	4,160,621	$ 99.85	521.29	$ 45.87	$ 1,278
89_S5_c200L_90pp_60min_Sc10	10.0	10	1739	2219	1909	1346	5,058,969	$ 121.42	633.84	$ 55.78	$ 1,524
90_S5_c200L_90pp_120min_Sc7.5	7.5	15	1420	1840	1632	1161	4,324,627	$ 103.79	541.84	$ 47.68	$ 1,312

Table 27.0 – Results for Scenarios 85-90.

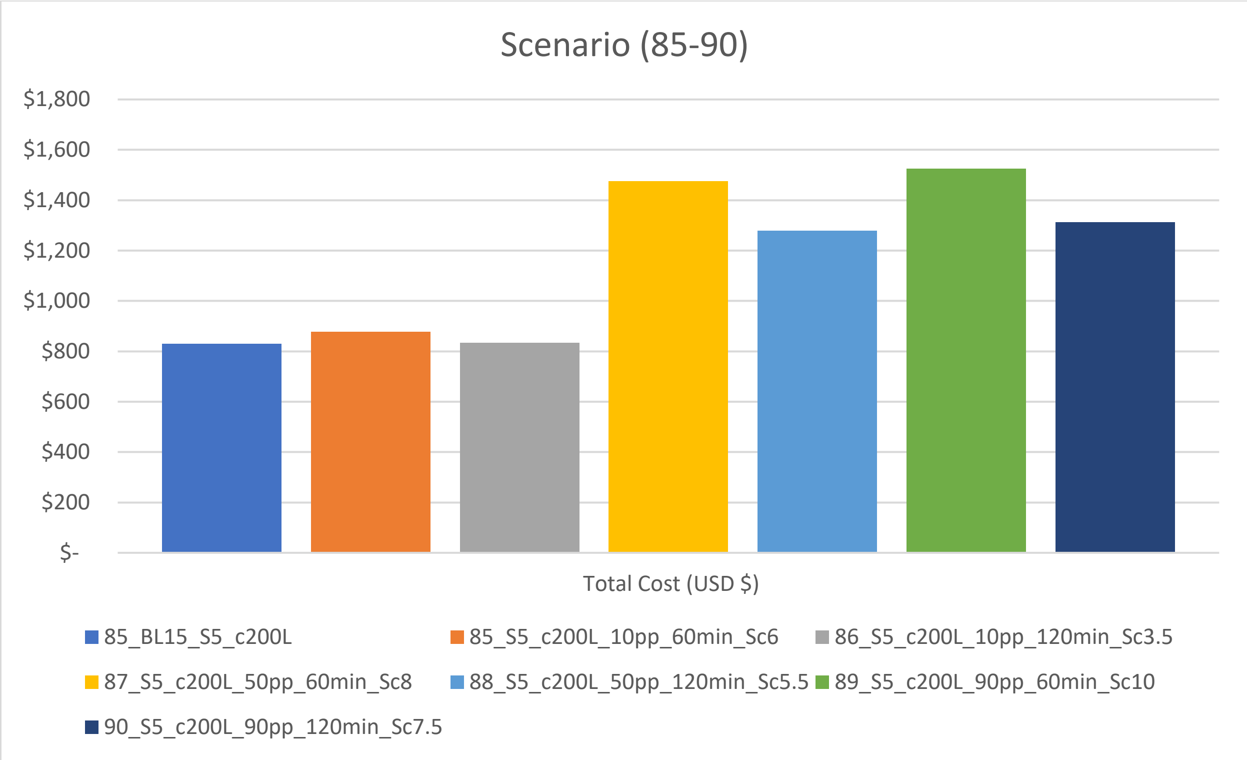


Figure 46.0 – Results for Scenarios 85-90.

Figures from Sensitivity Analysis

Average of Total Cost (USD $)	NTW Width (min)		
Database Type	0	60	120
L	$ 786	$ 1,269	$ 1,114
M	$ 656	$ 1,068	$ 948
S	$ 587	$ 863	$ 778

Figure 52.0

Average of Total Distance -Adjusted- (km)	NTW Width (min)		
Database Type	0	60	120
L	1043	1561	1386
M	871	1302	1193
S	767	1053	976

Figure 55.0

Average of Distance traveled from ESSVRP Solution (km)	NTW Width (min)		
Database Type	0	60	120
L	802	1379	1172
M	670	1150	1006
S	590	929	824

Figure 58.0

Average of Total Cost (USD $)	% of Customers w NTW			
Database Type	0	10	50	90
L	$ 786	$ 873	$ 1,272	$ 1,429
M	$ 656	$ 745	$ 1,070	$ 1,209
S	$ 587	$ 608	$ 845	$ 1,008

Figure 53.0

Average of Total Distance -Adjusted- (km)	% of Customers w NTW			
Database Type	0	10	50	90
L	1043	1093	1570	1758
M	871	946	1331	1465
S	767	773	1051	1219

Figure 56.0

Average of Distance traveled from ESSVRP Solution (km)	% of Customers w NTW			
Database Type	0	10	50	90
L	802	908	1351	1568
M	670	785	1144	1306
S	590	640	902	1086

Figure 59.0

Average of Total Cost (USD $)	NTW Width (min)		
% of Customers w NTW	0	60	120
0	$ 676	n/a	n/a
10	n/a	$ 740	$ 744
50	n/a	$ 1,133	$ 992
90	n/a	$ 1,327	$ 1,103

Figure 54.0

Average of Total Distance -Adjusted- (km)	NTW Width (min)		
% of Customers w NTW	0	60	120
0	894	n/a	n/a
10	n/a	930	944
50	n/a	1384	1251
90	n/a	1601	1360

Figure 57.0

Average of Distance traveled from ESSVRP Solution (km)	NTW Width (min)		
% of Customers w NTW	0	60	120
0	687	n/a	n/a
10	n/a	788	767
50	n/a	1213	1051
90	n/a	1458	1183

Figure 60.0

	NTW Width (min)					
	0		60		120	
Database Type	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)
L	2,763,816	$ 66	4,135,646	$ 99	3,673,871	$ 88
M	2,307,172	$ 55	3,450,875	$ 83	3,159,976	$ 76
S	2,032,406	$ 49	2,789,009	$ 67	2,586,652	$ 62

Figure 61.0

	% of Customers w NTW							
	0		10		50		90	
Database Type	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)
L	2,763,816	$ 66	2,895,953	$ 70	4,160,805	$ 100	4,657,518	$ 112
M	2,307,172	$ 55	2,506,486	$ 60	3,527,996	$ 85	3,881,795	$ 93
S	2,032,406	$ 49	2,047,609	$ 49	2,785,903	$ 67	3,229,979	$ 78

Figure 62.0

	NTW Width (min)					
	0		60		120	
% of Customers w NTW	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)	Average of CO2 Emissions (g)	Average of CO2 cost (USD $)
0	2,367,798	$ 57	n/a	n/a	n/a	n/a
10	n/a	n/a	2,464,134	$ 59	2,502,564	$ 60
50	n/a	n/a	3,667,803	$ 88	3,315,332	$ 80
90	n/a	n/a	4,243,592	$ 102	3,602,603	$ 86

Figure 63.0

	NTW Width (min)					
	0		60		120	
Database Type	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)
L	346	$ 30	518	$ 46	460	$ 41
M	289	$ 25	432	$ 38	396	$ 35
S	255	$ 22	349	$ 31	324	$ 29

Figure 64.0

	% of Customers w NTW							
	0		10		50		90	
Database Type	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)
L	346	$ 30	363	$ 32	521	$ 46	584	$ 51
M	289	$ 25	314	$ 28	442	$ 39	486	$ 43
S	255	$ 22	257	$ 23	349	$ 31	405	$ 36

Figure 65.0

	NTW Width (min)					
	0		60		120	
% of Customers w NTW	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)	Average of PM2.5 (g)	Average of PM2.5 cost (USD $)
0	297	$ 26	n/a	n/a	n/a	n/a
10	n/a	n/a	309	$ 27	314	$ 28
50	n/a	n/a	460	$ 40	415	$ 37
90	n/a	n/a	532	$ 47	451	$ 40

Figure 66.0

- *Figure (52.0)* Average total cost (USD $): Data base type vs NTW width (min).
- *Figure (53.0)* Average total cost (USD $): Database type vs % of customers with NTW.
- *Figure (54.0)* Average total cost (USD $): % of customers with NTW vs NTW width (min).
- *Figure (55.0)* Average total distance adjusted (km): Database type vs NTW width (min).
- *Figure (56.0)* Average total distance adjusted (km): Database type vs % of customers with NTW.
- *Figure (57.0)* Average total distance adjusted (km) % of customers with NTW vs NTW width (min).
- *Figure (58.0)* Average distance ESSVRP (km): Data base type vs NTW width (min).
- *Figure (59.0)* Average distance ESSVRP (km): Database type vs % of customers with NTW.
- *Figure (60.0)* Average distance ESSVRP (km) % of customers with NTW vs NTW width (min).
- *Figure (61.0)* Average of CO2 Emissions (g) and Average of CO2 cost (USD $): Database type vs NTW width (min).
- *Figure (62.0)* Average of CO2 Emissions (g) and Average of CO2 cost (USD $): Database type vs % of customers with NTW.
- *Figure (63.0)* Average of CO2 Emissions (g) and Average of CO2 cost (USD $): % of customers with NTW vs NTW width (min).
- *Figure (64.0)* Average of PM2.5 Emissions (g) and Average of PM2.5 cost (USD $): Database type vs NTW width (min).
- *Figure (65.0)* Average of PM2.5 Emissions (g) and Average of PM2.5 cost (USD $): Database type vs % of customers with NTW.
- *Figure (66.0)* Average of PM2.5 Emissions (g) and Average of PM2.5 cost (USD $): % of customers with NTW vs NTW width (min).

9. Appendix C: Attachments.

- Excel file: “1_Cost per km and Fixed Costs Calculation”.
- Excel file: “2_Failed Delivery Scoring Technique”.
- ZIP file “3_Timing Simulations Results Comparison”: Including Excel file “Timing Simulations Results Comparison”, and folders “Timing Simulations for c100S”, “Timing Simulations for c150M” and “Timing Simulations for c200L”. Each of the folders contains 6 simulations from the ESSVRP which helped build and get to the results depicted in the Excel file.
- ZIP file: “4_Cancun Databases”: Including the Excel file “Cancun Database Master_1000”, and the described customer databases used in this thesis. In each of the 45 databases, both NTW widths can be found: 60min and 120min. The structure followed the previously explained logic of “Database_Set #_Number of customers_% of customers with NTW” (e.g., “Database_S1_c100S_10pp”).
- ZIP file: “5_Baseline_VRP_Spreadsheet_Solver”: Including the 15 baseline solvers used in this work.
- ZIP file: “6_VRP_Spreadsheet_Solver”: Including the 90 solvers performed for the 90 scenarios analyzed in this work.
- Excel file: “7_Results Reporting” containing most of the tables and graphs, as well as the results explained in this dissertation.
- Excel file: “8_References Comparison” containing the analysis of sources included in 2.1. Literature Research Methodology.