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Master Degree Program in
Data Science and Advanced Analytics

**Modeling and Optimization of Traffic for Enhanced Operational
Efficiency in the Automated Process at Postal Service**

Beatriz Sofia Subtil Proença

Master Thesis

presented as partial requirement for obtaining a Master's Degree in Data Science and Advanced Analytics

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

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by
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Master Thesis presented as partial requirement for obtaining the Master's Degree in Data Science and Advanced Analytics, with a specialization in Business Analytics.

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledged the Rules of Conduct and Code of Honor from the NOVA Information Management School.

Marinhais, July 15th 2024

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ABSTRACT

The postal sector is undergoing significant transformation due to the decline in traditional mail volumes and the rise of e-commerce. This shift requires improved operational efficiency and optimized logistics operations, particularly in treatment phase. This dissertation aims to enhance business performance at CTT by automating and optimizing traffic assignment processes in their operational centers. This study develops a model using advanced linear programming techniques to optimize the allocation of traffic to the exits of the treatment machines. The study follows a systematic approach, starting with the definition of the problem and the identification of the main decision variables and constraints that is followed by the construction of a mathematical model. The solution phase employs optimization algorithms to determine the most efficient traffic distribution, to minimize manual intervention, and the model is validated by comparing historical data to ensure its accuracy and reliability. The results indicate a reduction in manual division time, which translates into improved operational efficiency. This reduction allows the reallocation of staff to other essential tasks, enhancing overall productivity. Additionally, faster and more accurate parcel processing improves delivery times and reduces errors, contributing to customer satisfaction and loyalty.

KEYWORDS

Linear Programming Problem; Operational Research; Optimization Algorithm; Postal Service; Treatment Process;

Sustainable Development Goals (SDG):



TABLE OF CONTENTS

STATEMENT OF INTEGRITY	I
ACKNOWLEDGEMENTS	II
ABSTRACT.....	III
LIST OF FIGURES.....	VI
LIST OF TABLES	VII
LIST OF ABBREVIATIONS AND ACRONYMS.....	VIII
1. INTRODUCTION	1
1.1. BACKGROUND AND PROBLEM IDENTIFICATION	1
1.2. OBJECTIVES	3
1.3. IMPORTANCE AND RELEVANCE	5
1.4. THESIS STRUCTURE	6
2. LITERATURE REVIEW	7
2.1. PROCESS OPTIMIZATION – OVERVIEW.....	7
2.2. CHARACTERISTICS OF OPERATIONAL RESEARCH.....	8
2.2.1. APPLICATIONS IN INDUSTRY.....	9
2.2.2. OR IN POSTAL SERVICES.....	10
2.3. LINEAR PROGRAMMING.....	12
2.3.1. MAIL SORTING OPTIMIZATION: A CASE STUDY OVERVIEW	14
2.4. OPERATIONAL EFFICIENCY IN POSTAL SERVICES	16
3. METHODOLOGY	18
3.1. DESIGN SCIENCE RESEARCH	18
3.2. DSR IMPLEMENTATION.....	19
4. SITUATION ANALYSIS	21
4.1. CTT’S TREATMENT PROCESS.....	21
4.1.1. OPERATIONAL MODEL.....	21
4.1.2. POSTAL CODES	22
4.1.3. SORTER MACHINES.....	22
4.1.4. TREATMENT PROCESS	23
4.2. PROBLEM SPECIFICATIONS	25
4.2.1. DATA EXTRACTION	25
4.2.2. PROBLEM FORMULATION.....	26
5. RESULTS AND DISCUSSION	29

5.1. TOY PROBLEM	29
5.2. MAIN PROBLEM.....	33
6. CONCLUSIONS AND FUTURE WORKS	42
6.1. LIMITATIONS.....	43
6.2. FUTURE WORK.....	44
BIBLIOGRAPHICAL REFERENCES	45
APPENDIXES.....	50
A. DATASETS USED IN THE MODEL	50
B. PYTHON CODE THAT GENERATED THE MPS FILE	55
C. PART OF THE MPS FILE GENERATED TO USE IN CPLEX	56
D. SOME ANALYSIS OF THE RESULTS	57

LIST OF FIGURES

Figure 1.1 – Evolution in the number of letters and parcels delivered in Portugal.....	1
Figure 3.1 – DSR Process	19
Figure 4.1 – Flow of CTT postal service	21
Figure 4.2 – Illustration of a route from dataset $a(i,j,k)$	27
Figure 5.1 – Defined routes for the parcels to be delivered	29
Figure 5.2 – Admissible routes from Zone1 to Zone9.....	30
Figure 5.3 – Admissible routes from Zone1 to Zone10.....	30
Figure 5.4 – Admissible routes from Zone1 to Zone10.....	31
Figure 5.5 – Illustration of some of the dataset's routes $a(i,j,k)$	35
Figure 5.6 – Illustration of some of the dataset's routes $a(i,j,k)$	36

LIST OF TABLES

Table 5.1 – Actual scenario of journeys	32
Table 5.2 – LP solution details minimizing manual divisions	32
Table 5.3 – List of origins, destinations and intermediate points.....	34
Table 5.4 – Illustration of some chosen routes.....	37
Table 5.5 – Comparison of results between what was and what happened after the optimization model, regarding manual divisions at destinations.....	37
Table 5.6 – Number of persons allocated to manual division at each destination	38
Table 5.7 – Capacity of the sorter of each origin, in objects per hour.....	38
Table 5.8 – Number of routes, and the correspondent traffic, that have a direct division to the destination on the first pass through the sorter, at each origin.....	39
Table 5.9 – Time saved by dividing objects to destination directly at the sorter, instead of doing it manually.....	39
Table 5.10 – Time spent in manual division in origin Zone3.....	40

LIST OF ABBREVIATIONS AND ACRONYMS

ANACOM	Autoridade Nacional de Comunicações (p. 1)
CDP	Postal Distribution Center (pp. 21, 23, 25, 33)
CLD	Logistics and Distribution Center (pp. 21-23, 25)
CO	Operational Center (pp. 21-25, 26-28, 33, 40, 44)
CTT	CTT – Correios de Portugal, S.A. (pp. iii-v, vii, 2, 3, 5, 6, 15, 21, 22, 25, 26, 28, 29, 33, 38, 41-44)
DSR	Design Science Research (pp. v, vii, 18-20)
DVRP	Dynamic Vehicle Routing Problem (p. 11)
GE	Routing Group (pp. 21, 23-25, 33)
ILP	Integer Linear Programming (pp. 5, 13)
LP	Linear Programming (pp. viii, 3-5, 12, 13, 18, 32)
MILP	Mixed Integer Linear Programming (pp. 14, 15)
MPS	Mathematical Programming System (pp. vi, 31, 32, 36, 55, 56)
NP	National Plan (pp. 23, 24, 33, 35)
OR	Operations Research (pp. v, 3, 4, 7-12)
RB	Base Network (pp. 22-25, 27, 29, 30, 31, 33)
RE	Express Network (pp. 22, 23, 26, 27, 29-31, 33)
RP	Regional Plan (pp. 23, 24, 35)

1. INTRODUCTION

1.1. BACKGROUND AND PROBLEM IDENTIFICATION

The postal sector, as an integral part of the global ecosystem, has long connected people, companies and governments across borders. This sector, which includes both the official postal service operators of various countries and private document and parcel delivery services, is undergoing a significant transformation. Although postal operators have a centuries-long legacy as state institutions, the emergence of digital communication methods such as email and instant messaging has contributed to a sharp decline in traditional mail volumes (Sund & Anson, 2021).

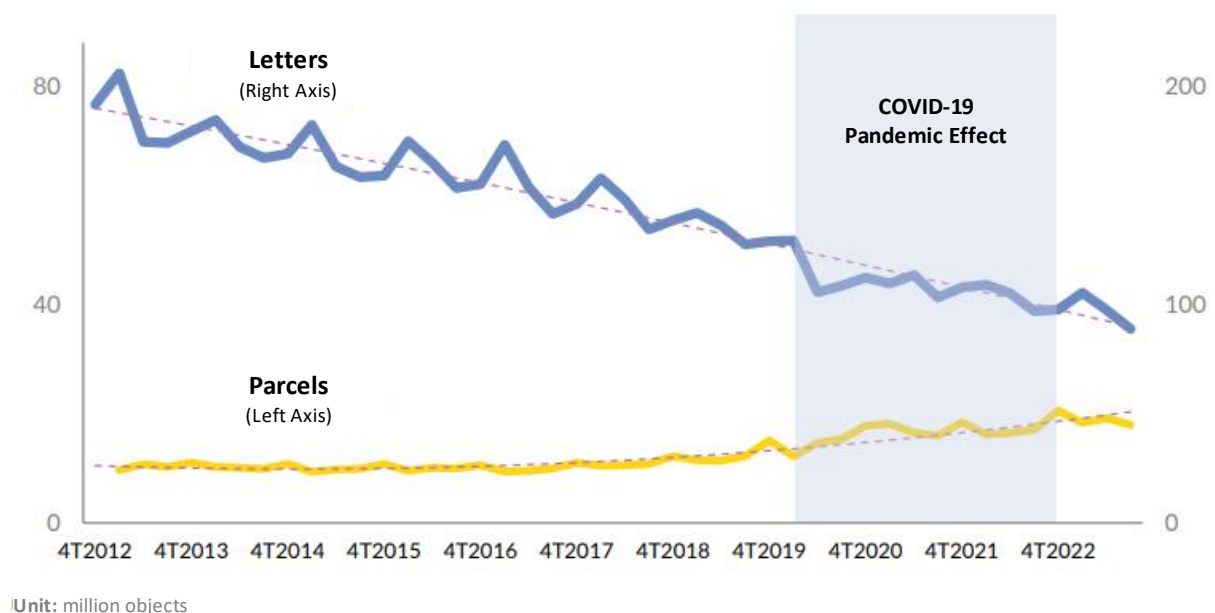


Figure 1.1 – Evolution in the number of letters and parcels delivered in Portugal. Source: (ANACOM, 2023)
Adapted

According to recent data released by ANACOM, postal traffic in Portugal saw a notable drop of 8.7% in the third quarter of 2023, when compared to the same quarter in 2022. On the other hand, due to the increase in online shopping, which has intensified even more with the COVID-19 pandemic, the number of parcel deliveries has been increasing. As a result, there was a 5.0 % increase in parcel deliveries in the third quarter of 2023 compared to the same period in 2022 (ANACOM, 2023). The trends are clear and indicate that e-commerce will continue to gain ground, as illustrated in Figure 1.1.

At the same time, the rise of e-commerce represents both an opportunity and a challenge. Consumers are increasingly comfortable with online shopping, both on emerging platforms and in traditional outlets that are transitioning to digital spaces. The growing volume of online sales requires efficient and cost-effective delivery channels, positioning postal services with

extensive national networks and last-mile delivery experience as potential e-commerce partners. However, the competitiveness of the parcel market requires postal services to fundamentally rethink their operating models and adopt customer-centric strategies to remain relevant (Briest et al., 2019).

Incorporating information from recent analysis, the postal sector is undergoing significant changes, particularly in last-mile delivery, driven by customer expectations and technological advances. According to Joerss and Schröder, the disruption in last-mile delivery arises from new business models that respond to the growing demand for faster deliveries, taking advantage of technologies such as drones and autonomous vehicles. This reflects a larger trend in which consumer preferences are crucial in the previously business-oriented parcel delivery market, with a notable segment willing to pay a premium for same-day or instant delivery (Joerss et al., 2016).

In addition, with the shift to e-commerce, new competitors are entering the logistics and delivery market, further increasing the challenges for traditional postal services. These new players are reshaping consumer expectations and setting new standards for logistical efficiency, taking advantage of their technological capabilities and exhaustive data analysis to optimize their operations. A study by Copenhagen Economics points out that the increase in parcel volumes, driven above all by the rise of e-commerce, has attracted new players to the market, who focus mainly on last-mile delivery. This is intensifying competition, forcing traditional postal services to adapt and innovate to remain competitive in this changing landscape (Möller Boivie et al., 2022).

To remain competitive and relevant in this rapidly evolving landscape, postal services are being urged to adopt technological innovations and optimize their operations, focusing especially on improving the efficiency and transparency of last-mile deliveries. This adaptation implies not only operational changes, but also a strategic shift towards a more agile and customer-centric service approach (Schröder et al., 2018).

Concurrently, data and analysis are emerging as vital tools in this scenario. Harnessing data to optimize routes, forecast demand and improve decision-making is becoming indispensable for postal services looking to improve operational efficiency and responsiveness. The sector also has to navigate global and regional market trends, including the impacts of phenomena such as the COVID-19 pandemic, which has accelerated the shift to online shopping and delivery services (Seyedan & Mafakheri, 2020).

CTT, Portugal's national postal service, operates a robust infrastructure designed to manage both traditional mail and the growing volume of parcel deliveries. With a network that includes operational centers equipped with advanced sorting machinery, CTT faces a significant challenge: optimize the assignment of traffic from the different postal codes to the exits of the machines in their centers. This task is about logistical precision and encompasses the broader objective of improving operational efficiency in an increasingly digital and

automated environment. As e-commerce continues to expand, CTT must adapt its processing and distribution strategies, integrating data analysis and predictive modeling to improve route optimization and operational efficiency. This strategic shift is vital for CTT to meet the high expectations of today's consumers for fast and reliable delivery services, thus maintaining its competitiveness in the evolving logistics landscape.

In addressing this task, CTT must explore the details of modern technology to establish an optimal traffic assignment system. This system must effectively manage the flow of postal items, ensuring their correct classification and routing to the designated postal codes. The economic impacts of implementing such optimization strategies are substantial and can lead to increased revenues, reduced costs, and to greater operational efficiency. Rodrigue presents a perspective on how technological innovations in transportation systems can increase the efficiency of logistics operations, thus improving the economic results of companies such as postal services (Rodrigue, 2020).

In conclusion, this dissertation seeks to answer a central question: "How can optimizing the destinations to be assigned to each machine exit improve business performance at CTT and what are the potential operational impacts and challenges of this implementation?" By exploring this question, the research aims to contribute to the theoretical understanding of traffic optimization in postal services and to offer practical solutions for CTT's operations, marking a significant step towards a more efficient and technologically advanced postal services system.

1.2. OBJECTIVES

The main objective of this dissertation is to automatize the processes on CTT, by modelling and optimizing traffic assignment, in order to try to significantly improve CTT operational efficiency.

Given CTT's critical role in providing postal services in Portugal, it is essential that the company efficiently manages the receipt, treatment and delivery of parcels. To do this, it is necessary to optimize the allocation of traffic to the appropriate machine exits, corresponding to specific postal codes, within CTT's operational centers.

Despite CTT's robust infrastructure, the postal sector faces challenges such as varying mail volumes and the need to adapt to changing market demands. In this sense, at the front line of this study is the development of a Linear Programming (LP) model, a technique of Operational Research (OR), to improve the efficiency of traffic allocation in CTT's sorting centers.

OR formally began in England during the Second World War, with a team evaluating the use of military resources using scientific principles. In the post-war period, these methods were applied to improve efficiency in the civilian sector. Nowadays, general guidelines can be drawn

up for implementing OR in practice. According to Taha, the main stages of OR implementation in practice is specified below (Taha, 2017).

The **problem definition** entails delineating the boundaries of the issue under investigation. The goal is to pinpoint key aspects of the decision problem: articulating the available options, clarifying the study's objectives, and detailing the operational constraints of the modeled system.

Model construction, that involves translating a problem into mathematical terms. If the model aligns with standard mathematical frameworks like linear programming, existing algorithms can typically find a solution. For more complex models that defy analytical solutions, simplification, heuristic methods, or simulation might be employed. Sometimes, a combination of mathematical, simulation, and heuristic approaches is necessary to tackle a decision-making problem.

The **solution phase** in OR is relatively straightforward, utilizing established optimization algorithms. A key part of this phase is sensitivity analysis, which examines how changes in model parameters affect the optimal solution, especially when these parameters are uncertain. This analysis helps understand the robustness of the solution to variations in the input values.

Model validation in OR ensures the model accurately reflects the system it aims to represent, particularly in predicting system behavior. Validation often involves comparing the model's outputs with historical data to see if it can replicate past results under similar conditions. This process helps affirm the model's relevance, although it doesn't guarantee future accuracy. When no historical data is available, especially for new systems, simulation may serve as an alternative validation method.

The **implementation** of a model's solution requires converting its outcomes into clear directives for the personnel overseeing the new system, ensuring they understand and can execute the recommended strategies effectively.

LP, as a technique of OR, has emerged as a significant advance in decision-making for complex real-world problems. It has made it possible to define broad objectives and map out a detailed decision path to obtain optimal results. The process involves the creation of mathematical models, the application of algorithmic techniques and the use of computing power. This change in approach to problem solving began around 1947, after the Second World War, and evolved with the rapid growth of computer technology (Hillier & Lieberman, 2010).

The first contributions to this field were made by notable figures such as von Neumann and Kantorovich, among others, some of whom were later recognized with Nobel Prizes. Despite its current widespread application and importance, before 1947, there was a notable lack of interest in optimization, with only isolated exceptions in literature. Thus, the personal

contributions of the author, George Dantzig, to LP were strongly influenced by his experiences during the Second World War and his later work at the Pentagon, which eventually led to the development of linear programming (Hillier & Lieberman, 2010).

Allocation models, which are a subset of LP problems, focus on the optimal distribution of limited resources across various applications to achieve the best possible outcome. This includes allocating financial resources for investment, assigning machine time for production, distributing manpower to different roles within an organization, and other similar resource division to enhance economic activities, reduce costs, or fulfill other efficiency goals set by decision-makers (Eiselt & Sandblom, 2007).

Summarizing, it can be said that LP is a powerful mathematical method used to optimize various systems, such as network design, resource allocation and traffic routing, by maximizing or minimizing a linear objective function subject to a set of linear constraints. Although LP is usually solvable in polynomial time due to the efficiency of algorithms such as the simplex method and interior point methods, computational complexity can increase under certain circumstances (Vanderbei, 2020).

In particular, variations of LP, such as Integer Linear Programming (ILP), in which the decision variables are limited to integers, are NP-hard. This means that no efficient algorithm has been proven to solve all instances of the problem in polynomial time as the input size increases. The NP-hardness of ILP underlines the significant challenges in dealing with real-world applications where discrete decisions are required, such as in the scheduling and assignment problems found in postal services (Cygan et al., 2015).

1.3. IMPORTANCE AND RELEVANCE

The importance of this research lies in its direct impact on the business performance of CTT, one of the main players in the postal services sector. In an era when digital communication and e-commerce are reshaping traditional postal services, optimizing traffic in sorting centers is not just a logistical necessity, but a strategic imperative. This research is particularly relevant as it addresses the need for postal services to adapt to the changing reality, marked by a decline in traditional mail volumes and an increase in parcel deliveries.

From a practical point of view, it is hoped that the results of this study will go some way to helping CTT achieve better performance. By optimizing traffic allocation, CTT expects to obtain tangible benefits such as reducing sorting times and manual intervention, minimizing errors and speeding up delivery times. These improvements are crucial to maintaining competitiveness in a market where customer expectations are continually rising.

From an academic point of view, this research contributes to the growing knowledge base in the field of logistics and postal service operations. It offers a unique perspective by combining theoretical modeling with practical application in a real-world context. The research also has

the potential to contribute to the discourse on the impact of digitalization and automation on logistics, providing insights into how traditional postal services can evolve to meet modern demands.

Consequently, the importance and relevance of this dissertation is underlined by its potential to provide actionable solutions for CTT, contribute to academic training in postal logistics and offer knowledge on efficient operational practices in the face of changing market dynamics and technological advances.

1.4. THESIS STRUCTURE

The first chapter of this dissertation contains a concise description of what will be covered in this project, its main objectives to be achieved, as well as the importance and relevance of the topic. Following this section, a review of possible approaches to resolving this issue is given, with an overview of a case study in the area. Complementary, the following section discusses the methodology used in this dissertation and its main characteristics.

Additionally, in the Chapter 4 it can be seen a framework for the processes used by CTT and the specificities to be considered in this problem, including the development of a toy problem. In the final chapter, some considerations are made about all the work carried out in this dissertation. The limitations encountered are analyzed and discussed, and objectives for future work are defined.

2. LITERATURE REVIEW

This section will include an overview of Process Optimization, with reference to the technologies and tools in this field, as well as their challenges. Furthermore, as an important science in process optimization, due to its applicability in solving real problems, the impact of OR and the link that can be established with the postal services industry will be mentioned.

2.1. PROCESS OPTIMIZATION – OVERVIEW

Process optimization can be seen as a systematic approach to improving various organizational procedures. This field uses traditional and modern methodologies to improve the efficiency and effectiveness of operations in various sectors, including postal services. At the beginning of the 20th century, process optimization began to be more studied and explored, largely due to the increase in industrialization. The need to improve manufacturing processes and increase productivity led to the development of various optimization techniques (Vagaská et al., 2023).

Frederick Winslow Taylor is often considered one of the pioneers in this field, with reference to his developments in introducing the principles of scientific management. Taylor's work focused on improving industrial efficiency through the scientific analysis of workflows and labor productivity (Taylor, 2004).

The work of Gantt on production planning was another important reference to consider, who also made a significant contribution during this period, developing planning and scheduling methods that improved the management of tasks in shipbuilding and other industries. Gantt's diagrams were very well established by the mid-1920s as a general production planning tool. He first described a version of his diagrams in an article published alongside Frederick W. Taylor's article on store management. However, Gantt's work did not become as well-known as Taylor's, since the latter decided to publish only his article, without Gantt's contribution (Wilson, 2003).

After a significant change in the way companies approached production and operations management through Taylor and Gantt's methodologies, the repercussions of their work led to wider adoption and the evolution of systematic approaches in various sectors. In the 1920s, Walter Shewhart introduced statistical control processes, which laid the foundations for quality control techniques. Shewhart's development of control charts became an essential tool for monitoring production processes and identifying points of deviation from expected performance standards. This approach complemented the work of Taylor and Gantt, and also introduced the concept of continuous process improvement (Shewart, 1931).

At the beginning and middle of the 20th century, as a consequence of the evolution of process optimization, the complexity of industrial challenges required more sophisticated analytical

tools and methodologies. With this transition came OR, a field that combines mathematical modelling, statistical analysis and optimization techniques to make better decisions and solve complex problems (Gass & Assad, 2005).

2.2. CHARACTERISTICS OF OPERATIONAL RESEARCH

Considering what Hillier and Lieberman said, OR can be defined as an analytical problem-solving and decision-making method that is useful in the management of organizations. This area is inherently interdisciplinary, integrating techniques and knowledge from mathematics, statistics, economics and computer science. In more technical terms, it can be said that it uses mathematical models to simulate real-world systems and assess the potential outcomes of different decisions under varying conditions. These models typically involve optimizing performance criteria, such as minimizing costs or maximizing efficiency (Hillier & Lieberman, 2010).

This systematic approach allows OR to be highly adaptable and applicable to a wide range of domains, from logistics and finance to healthcare and public service administration. By drawing on these varied disciplines, OR is able to solve complex problems that require a broad perspective to be understood and solved effectively. Consequently, the interdisciplinary nature of OR can be seen as crucial in today's interconnected and complex business environments, where solutions often must unite several areas of expertise (Hillier & Lieberman, 2010).

Essentially, OR is dedicated to finding the best possible solutions to problems by optimizing specific performance criteria under certain constraints. This may involve minimizing costs, maximizing efficiency, or balancing various trade-offs within an operational framework. In this way, Winston considers that the emphasis on optimization is what distinguishes OR from other analytical and decision-making disciplines (Winston, 2004).

It is not just about understanding or modeling systems, but actively improving them to achieve specific, often quantifiable objectives. This emphasis is reflected in the development of sophisticated models and algorithms that can simulate and optimize complex processes. These algorithms often have to deal with large volumes of data and complex constraints, which is typical in sectors such as telecommunications and transportation (Winston, 2004).

OR provides fundamental support in decision-making, offering both quantitative and qualitative knowledge. Through rigorous analysis and modeling, it helps decision-makers understand potential outcomes and make choices based on solid empirical data. As a result, these capabilities have become especially valuable in strategic planning, resource allocation and policy formulation, where decisions can have far-reaching consequences (Winston, 2004).

As can be read in Taha's book, the support that OR offer is not limited to suggesting optimal decisions, but also involves assessing the potential risks and benefits of various alternatives,

thus enabling managers and political decision-makers to plan future scenarios with greater confidence. This is possible with the help of statistical analysis, which is used to interpret data and estimate the future behavior of systems. As such, this approach is crucial in environments where data uncertainty plays a significant role, such as forecasting demand in supply chains or understanding variability in manufacturing processes (Taha, 2017).

2.2.1. APPLICATIONS IN INDUSTRY

OR has firmly established itself in improving operational efficiency and decision-making processes in a wide range of industries. Every sector benefits from OR's robust problem-solving and optimization capabilities, which can deal with complex challenges such as scheduling, logistics, resource allocation and risk management (Winston, 2004).

In the manufacturing industry, OR techniques streamline production processes and optimize inventory management, ensuring greater productivity and reduced costs (Hillier & Lieberman, 2010). According to Winston, the logistics sector benefits considerably from sophisticated routing algorithms that minimize travel times and fuel consumption, essential for companies in the postal sector (Winston, 2004). Telecommunications companies use OR to design robust network infrastructures that maximize coverage and minimize costs (Medhi & Karthik, 2017).

In the financial sector, OR models help to create less risky investment portfolios and define loan distribution strategies (Fabozzi et al., 2007). The public sector, including urban planning and emergency services, uses OR to optimize resource allocation and response strategies, significantly improving service delivery and conflict management (Altay & Green, 2006). In the health sector, OR has become an indispensable tool for increasing efficiency and improving results for patients. Rais and Viana provide an exhaustive survey of OR applications in healthcare, demonstrating its fundamental role in various areas, such as resource allocation, scheduling and optimization of medical processes (Rais & Viana, 2011).

In the postal services sector, the strategic application of OR is essential to optimize network design and mail routing, crucially improving operational efficiency. This sector often faces logistical challenges as those encountered in airlines, railways and container shipping, where OR has been successfully applied to manage and mitigate disruption. According to Clausen, sophisticated OR techniques, including advanced mathematical models, are used to design robust networks capable of adapting to disruptions and maintaining service reliability. These models are key to developing optimal routing and scheduling strategies that significantly reduce operating costs while improving the speed and reliability of mail delivery services. By applying these proven disruption management strategies in other transport sectors, postal services can achieve a higher level of efficiency and customer satisfaction (Clausen et al., 2010).

2.2.2. OR IN POSTAL SERVICES

OR has played a crucial role in transforming the postal services sector, improving operational efficiency, optimizing logistics operations and significantly reducing costs. The application of operational exploitation techniques has enabled postal services to tackle complex logistical challenges, streamline operations and adapt to the growing demands of a rapidly evolving digital landscape (Boysen et al., 2021).

In the postal services sector, optimizing mail delivery routes and schedules is essential for increasing operational efficiency, reducing delivery times and improving customer satisfaction. OR is central to these optimizations, making use of sophisticated algorithms to design the most efficient delivery routes. Hemmelmayr and Crainic explore the use of an adaptive large neighborhood search heuristic in their study of Two-Echelon Vehicle Routing Problems. Although their research is focused on urban logistics, the principles and methodologies they discuss are crucial for postal services, with the aim of minimizing redundancies and reducing the distance travelled by delivery vehicles. Their findings highlight the potential for significant improvements in route efficiency and the overall reliability of the service, illustrating how OR interventions can result in substantial operational benefits (Hemmelmayr et al., 2012).

Another area in which OR has been fundamental is in the design of robust postal networks that efficiently connect sorting centers to local post offices, thus optimizing the flow of mail and parcels. Effective network design in the postal service involves complex decisions regarding the placement of facilities and the routing of vehicles, considering factors such as the geographical distribution of customers, the expected volume of parcels and the costs associated with transportation and sorting. Hemmelmayr and Vigo discuss advanced models and algorithms for the integrated planning of logistics networks, mainly in the context of waste management. These principles are directly transferable to the postal services sector, where they can be used to design flexible and efficient networks. The study highlights the use of integer programming and route optimization to reduce overall operating costs and improve service efficiency (Hemmelmayr et al., 2014).

In the postal services sector, the strategic location of facilities has a significant impact on operational efficiency. OR plays a vital role in this area through the application of sophisticated location and allocation models. These models help postal services determine the optimal location of new facilities, ensuring a balance between customer accessibility and cost efficiency. Owen and Daskin provide a detailed analysis of strategic facility location strategies used in various sectors, focusing on methodologies that prioritize operational efficiency and customer service. Their discussion of multiple facility location problems is especially relevant to postal services, where decisions about facility placement directly affect logistical efficiency and overall service quality (Owen & Daskin, 1998).

Regarding the efficient allocation of resources - such as manpower, vehicles and equipment - it can be said that this is fundamental to maintaining cost-effectiveness and achieving service levels. OR models can help optimize resource allocation, considering the variability of demand and the complexity of operational constraints. Angelelli and Mansini address these issues in their study of the vehicle routing problem with time windows and simultaneous collection and delivery, which is directly applicable to postal services. Their research highlights how advanced OR techniques can effectively manage and schedule fleet operations to meet delivery deadlines while minimizing operating costs. The study demonstrates the effectiveness of integrating sophisticated routing algorithms to optimize daily operations in the postal sector, ensuring that resources are used as productively as possible (Toth & Vigo, 2014).

With the incorporation of operational research techniques in various sectors, highlighting their use in the postal sector, Pillac and Medaglia contributed to a case study focused on the dynamic routing of vehicles in postal services. This case study explores the application of OR techniques, specifically dynamic vehicle routing, in a postal service context to meet the challenges of modern delivery requirements. In response to the growing complexity of delivery logistics, a leading postal services company has harnessed insights from the Dynamic Vehicle Routing Problem (DVRP) to optimize its delivery operations. Building on the fundamental work of Pillac and Medaglia, the company implemented a state-of-the-art route optimization system designed to dynamically adjust to daily variations in delivery requirements and operating conditions (Pillac et al., 2013).

The system implemented uses sophisticated mathematical models and algorithms that consider a multitude of variables, such as real-time traffic conditions, variable order volumes and fluctuating delivery time windows. These factors are essential for minimizing route lengths and delivery times, significantly reducing operating costs and environmental impact. The system's basis in dynamic programming and machine learning algorithms allows it to learn from ongoing operations, enabling predictive adjustments and route optimization in real time (Pillac et al., 2013).

The adoption of dynamic vehicle routing has resulted in substantial improvements in the logistics efficiency of the postal service. The ability to adjust routes in real time has improved the reliability of deliveries, crucial in an era dominated by e-commerce and customer expectations of fast service. In addition, the dynamic routing system has enabled the company to optimize the use of resources, leading to a reduction in fuel consumption and emissions, thus supporting sustainability objectives (Pillac et al., 2013).

In summary, as highlighted in the comprehensive review by Pillac and Medaglia, the implementation of dynamic vehicle routing addresses critical challenges in the postal services sector by improving the adaptability and efficiency of delivery operations. This application of OR meets high service standards and contributes to economic and environmental

sustainability, illustrating the significant impact of OR in transforming postal logistics (Pillac et al., 2013).

After clarifying the evidence of using the ORs to improve postal operations, the role of the LP becomes clear. LP is a crucial subset of OR that applies a systematic approach to solving optimization problems, which makes it highly effective in managing the complex logistics of postal operations. Bazaraa, Jarvis and Sherali in "Linear Programming and Network Flows" offer a comprehensive exploration of how linear programming techniques are integral to solving complex problems in logistics. Their work details the optimization of transportation networks and the effective management of flows in these networks, providing essential strategies for improving operational efficiency and service quality in logistics-oriented industries (Bazaraa et al., 2010).

2.3. LINEAR PROGRAMMING

The integration of OR into the postal services has significantly transformed their operational efficiency and service performance. The principles of OR, especially LP, have been fundamental to optimizing resource allocation and logistics in the sector.

In "Introduction to Operations Research", Hillier and Lieberman explore how OR methodologies, in particular LP, can be effectively applied to optimize postal operations, solving complex logistical challenges and improving efficiency. Their work provides a solid theoretical background, enriched with practical examples that illustrate the impact of OR in the postal sector, highlighting its role in optimizing resource allocation and improving service delivery (Hillier & Lieberman, 2010).

Based on the extensive analysis by Luenberger and Ye in their work on Linear and Nonlinear Programming. LP is characterized by several foundational properties that enable it to be a powerful tool in various fields such as economics, manufacturing, and logistics (Luenberger & Ye, 2008).

LP models are particularly well known for their structure, which is defined by linearity, determinism and divisibility. Linearity is fundamental since both the objective function and the constraints in LP are linear. This structure simplifies both the analysis and the solutions, making problems computationally tractable through methods such as the simplex algorithm, which efficiently navigates the space of solutions to find optimal points (Luenberger & Ye, 2008).

The deterministic nature of LP means that all the parameters involved - coefficients of the variables in the objective function and constraints - are known with certainty and remain constant throughout the decision-making process. This predictability allows for precise planning and forecasting, which is crucial in strategic operations such as supply chain management and resource allocation (Luenberger & Ye, 2008).

In addition, LP's divisibility feature assumes that the decision variables can take on any fractional values, which is essential in scenarios where partial quantities of resources can be used, such as chemicals or time. However, when the decision variables have to be integers, such as when assigning tasks to individuals or counting objects, ILP becomes necessary (Luenberger & Ye, 2008).

In a complementary way, another fundamental characteristic of LP is the fact that its set of feasible solutions, if it exists, forms a convex polytope. This convexity ensures that any local optimum found is also a global optimum, and the optimum solution, if it exists, is located at a vertex or edge of this polytope (Luenberger & Ye, 2008).

These characteristics ensure that LP can be applied effectively to solve optimization problems with linear constraints, optimizing results within a clearly defined feasible region. The ability to linearly model such a wide range of real-world problems and solve them efficiently is what is behind the general application and usefulness of LP in both academic and practical contexts. Through this analytical framework, Luenberger and Ye highlight the adaptability of LP to meet the challenges posed by various optimization scenarios (Luenberger & Ye, 2008).

Although LP provides robust solutions to a wide range of optimization issues, its applicability is essentially limited to problems that can be expressed with linear relationships. This limitation becomes particularly evident when addressing more complex scenarios involving non-linear or discrete variables, leading us into the realm of NP-hard problems. These problems, characterized by their significant computational demands and resistance to conventional polynomial-time algorithms, require more sophisticated approaches. As the discussion of NP-hard problems gets deeper, it becomes crucial to explore alternative algorithms and strategies capable of effectively tackling these computational challenges, opening the door to a variety of heuristic and exact methods designed to manage the complexities of these demanding optimization tasks (Cormen et al., 2009).

Hence, optimization solvers are essential for solving NP-hard problems with the aim of achieving optimality. In the competitive field of optimization software, commercial solvers have consistently strived to incorporate state-of-the-art algorithms to offer superior performance. While the programming community often recognizes the merits of free and open-source software, commercial solvers have demonstrated a clear advantage in optimization tasks. Considering the benchmarking carried out by Jablonský, the most successful linear and mixed optimization solvers are IBM ILOG CPLEX, Gurobi and FICO XPRESS (Jablonský, 2015).

To select the best one, it is important to measure its performance when faced with a problem such as the one discussed in this dissertation. In the comprehensive study by Meindl and Templ, these solvers are evaluated on their effectiveness in solving complex linear optimization problems, a central component of this research. The analysis shows that while

all three solvers are capable, each has distinct strengths and areas of expertise (Templ et al., 2012).

Gurobi is known for its excellent high-performance computing and sophisticated parallel algorithms, as well as for its user-friendly programming environment and broad support for various programming languages, which increase its flexibility. FICO Xpress stands out for its proficiency in mixed integer programming problems and its extensive set of tools for developing models. Regarding CPLEX, it is known for its accuracy and for consistently delivering optimal solutions quickly. According to Meindl and Templ's research, CPLEX excels in benchmark tests, and in real-world applications, which makes it exceptionally suitable for solving the type of problems addressed in this dissertation (Templ et al., 2012).

Based on the detailed performance evaluations and the comparative strengths highlighted by Meindl and Templ, CPLEX is the most complete and capable and has consequently been selected as the best to meet the specific challenges presented in this project (Templ et al., 2012).

2.3.1. MAIL SORTING OPTIMIZATION: A CASE STUDY OVERVIEW

The article "Mail sorting optimization: a case study of the French postal company La Poste", by Amann, Gurevsky, Laurent and Mebarki, addresses a critical operational challenge faced by La Poste, a leading French mail delivery service, focusing on the optimization of their mail sorting process. Traditional sorting methods can struggle to keep pace, as mail volumes increase and operational demands intensify, leading to inefficiencies and delays. This study explores the uneven distribution of mail between the different outputs of sorting machines - one of the main bottlenecks in the mail sorting flow (Amann et al., 2023).

Consequently, the aim of optimization is to balance the mail load more evenly across all outputs, helping to speed up the sorting process and increase the overall operational efficiency of the postal system. This balance is crucial for dealing with peak mail flows and for minimizing the downtime of sorting machines. By optimizing mail distribution, La Poste aims to increase the reliability and efficiency of its sorting operations, ensuring that mail is processed and delivered on time, despite the complexities inherent in handling large quantities of postal items (Amann et al., 2023).

To resolve this issue, the approach adopted in this study involves the implementation of a Mixed Integer Linear Programming (MILP) model complemented by a heuristic method inspired by simulated annealing - a strategy often used in complex optimization tasks where traditional methods are not sufficient. Specifically, the MILP model is designed to minimize the variation in workload between the different sorting outputs. By defining constraints and mathematical objectives, the model systematically identifies the optimal distribution of mail,

so that the workload is distributed as evenly as possible. This helps to reduce bottlenecks and improve the efficiency of the sorting process (Amann et al., 2023).

To reinforce the robust methodology of the study, recognizing the limitations of traditional optimization methods in dealing with large-scale, dynamic environments, the study introduces a heuristic method based on the principles of simulated annealing. This approach is particularly effective in solving complex scenarios to find near-optimal solutions in a reasonable amount of time. The heuristic iteratively adjusts the mail distribution, gradually improving the solution by exploring the feasible set of distributions and focusing on minimizing the standard deviation of the mail load at different outputs (Amann et al., 2023).

Moreover, the combined use of the MILP model and simulated annealing heuristics allows the study to address both theoretical and practical challenges. It offers a robust framework that can be adapted to various scales of operation - from smaller, controlled academic settings to large, unpredictable industrial environments. This methodology proves effective in achieving a more balanced mail distribution and provides a scalable solution that can be adapted as operational requirements evolve (Amann et al., 2023).

The rigorous application of the MILP model and the simulated annealing heuristic demonstrated significant improvements in the efficiency of mail distribution at La Poste. The computational results confirmed that these methods effectively minimized workload discrepancies between sorting outputs, leading to a more balanced and efficient sorting process. Particularly, the heuristic approach showed exceptional adaptability and performance in dealing with real industrial scenarios, suggesting its suitability for immediate practical implementation. This ability to improve operational efficiency without the need for extensive reconfiguration of existing systems marks a significant advance in postal technology operations (Amann et al., 2023).

Overall, the research clearly demonstrates the significant advantages of using advanced optimization techniques, such as MILP and simulated annealing heuristics, in mail sorting operations. By systematically reducing variability in workload distribution, these methods improve the efficiency and reliability of sorting processes. The results underline the critical need for optimization strategies that are theoretically sound and practically feasible in various operating environments (Amann et al., 2023).

The integration of MILP heuristics and simulated annealing can significantly improve logistics and operational efficiency in postal services. These techniques offer robust solutions to common logistical challenges, such as the challenge addressed in this master's thesis, helping to simplify operations, reduce costs and increase service reliability. The successful application of these methods in the study with La Poste exemplifies their potential to revolutionize standard operating procedures. With this, it can be said that adopting similar optimization strategies in the study targeting CTT could help increase operational efficiency and provide a

competitive advantage by improving the consistency and speed of sorting processes in operational centers (Amann et al., 2023).

2.4. OPERATIONAL EFFICIENCY IN POSTAL SERVICES

Operational efficiency is crucial in the postal services sector for several key reasons, each of which contributes to the overall objective of maintaining a competitive and sustainable service. Improving operational efficiency has a direct impact on cost-effectiveness, allowing postal services to reduce waste, minimize unnecessary expenses and optimize the use of resources such as manpower, vehicles and equipment. A pertinent study by Çetiner, Sepil and Süral explores the combined problem of hubbing and routing in postal delivery systems, developing a two-stage iterative solution that optimizes hub locations and routes within hub regions. His approach significantly improves operational efficiency by reducing travel distances and associated costs, thus directly contributing to a reduction in fuel consumption and vehicle maintenance costs (Çetiner et al., 2010).

Increased efficiency also leads to better service quality and customer satisfaction. In the digital age we find ourselves in, where customers expect fast, reliable and transparent services, operational efficiency is crucial. The study by Kubáňová illustrates the significant impact of implementing barcode technology on a company's logistics processes, which can be directly applied to the postal sector. Their research demonstrated how barcode technology simplified logistics operations, reducing error rates in inventory and shipping processes, and significantly increased operational speed and accuracy. Specifically, the implementation of barcodes has enabled more accurate tracking and faster processing of shipments, which directly contributes to customer satisfaction by providing timely updates and reducing the likelihood of delivery errors. This approach has been proven to increase efficiency and improve the reliability of the services provided to customers, guaranteeing a higher level of satisfaction and trust in the postal system (Kubáňová et al., 2022).

Furthermore, operational efficiency also contributes to environmental sustainability. With growing environmental concerns, postal services are under pressure to adopt more sustainable practices. Grant, Wong and Trautrim stress that these efforts meet regulatory requirements, and significantly improve public perception and support broader sustainability goals. They highlight the adoption of integrated supply chain practices that include route optimization and fleet management as critical steps towards reducing greenhouse gas emissions and increasing energy efficiency (Grant et al., 2017).

The generalized application of optimization, deeply rooted in everyday life and business operations, finds particular relevance in the postal sector, especially in the field of express postal services. As the market for fast and efficient postal services becomes increasingly competitive, the importance of an optimized postal network is more pronounced than ever. This need for optimization in the postal sector is in line with the broader trend of applying

systematic techniques and increasing efficiency in various industries. In the context of express mail services, where the rapid transfer of mail is essential, the design and operation of the postal network requires rigorous optimization. This involves complex coordination of several interconnected phases - dispatch, sorting, forwarding, transportation and delivery - each subject to specific time and frequency constraints (Khir et al., 2021).

Recent increases in e-commerce have fundamentally changed the dynamics of last-mile logistics, bringing new challenges to the entire supply chain. These developments are reshaping the way companies approach delivery services and affecting urban environments with increased traffic, use of public space and environmental concerns. This scenario underlines the urgent need to optimize last-mile delivery operations, a crucial task for both commercial entities and public administrations wishing to improve the quality of urban life. Current research in this field has expanded beyond traditional optimization methods, increasingly incorporating sensor technology, the IoT and data analysis, including big data and machine learning, to tackle these complex challenges (Giuffrida et al., 2022).

3. METHODOLOGY

The Design Science Research (DSR) methodology focuses on the systematic creation and evaluation of practical solutions to complex problems, through the design and analysis of innovative artifacts in which each one is designed to solve specific real-world problems, making it the methodology chosen for this research. This methodology assumes that knowledge is created through the construction and application of these artifacts, making it a dynamic and iterative problem-solving process (Peffer et al., 2007).

In the context of postal services worldwide, the implementation of an optimization model through DSR can offer a substantial opportunity for operational improvements across the sector. This model, developed as a DSR artifact, is intended to increase operational efficiency and contribute to the academic knowledge base by demonstrating how LP can be effectively applied to logistics and operational strategies in postal services. The practical implications of this research are many, as it can promote greater speed, accuracy and cost efficiency in postal operations, responding directly to the pressures of increasing e-commerce traffic and customer service expectations. In addition, DSR's iterative process - design, development, evaluation and improvement - aligns harmoniously with the needs of dynamic industries such as postal services, where operating models and market conditions change continuously (Baskerville et al., 2018).

The following sections will analyze the DSR methodology. The discussion will detail the practical application of DSR within the scope of this research, illustrating how it will be used to achieve the objectives.

3.1. DESIGN SCIENCE RESEARCH

DSR represents a strict and systematic approach to scientific research that aims to understand the world and dynamically change it through the development of innovative technological and methodological artifacts. These artifacts, designed to address specific and complex challenges, go further than mere academic experimentation - they act as practical tools designed to solve real-world problems (Hevner et al., 2004).

DSR is actively focused on pragmatism, differently from traditional research patterns that focus mainly on theoretical developments and explanations. It does not stop at the boundaries of theory, but moves into the domain of application, involving the creation of functional innovations that can be directly implemented. Consequently, the essence of DSR resides in its dual orientation, where it aims to advance knowledge through the precise elaboration of solutions that are immediately useful in the real world (Hevner et al., 2004).

Moreover, DSR is characterized by its inclusive nature, synthesizing existing knowledge from various domains to create new paths that are both challenging and useful. It works at the

intersection of theory and practice, drawing on diverse fields such as information systems, engineering, healthcare and others. This approach allows researchers to combine a mix of theories and methods to design solutions that are both innovative and based on scientific accuracy (Gregor & Hevner, 2013).

The result of DSR is usually a concrete artifact - be it a process, a product, a model or a system. These artifacts are not end results in themselves but are elaborated as part of a broader effort to provide practical solutions to complex problems. For example, in information systems, they can be software applications or digital structures that improve business operations or user experiences. In engineering, they could be prototypes or new material compounds, while in healthcare they could be diagnostic tools or treatment protocols (Peffer et al., 2007).

Furthermore, another advantage of DSR is that it is inherently iterative, characterized by cycles of creation, testing, evaluation and improvement. This iterative process ensures that the artifacts developed are technically sound, and continuously improved to better meet the evolving needs of society. It underlines the commitment to solving problems, and refining solutions in response to changing conditions and feedback (March & Smith, 1995).

3.2. DSR IMPLEMENTATION

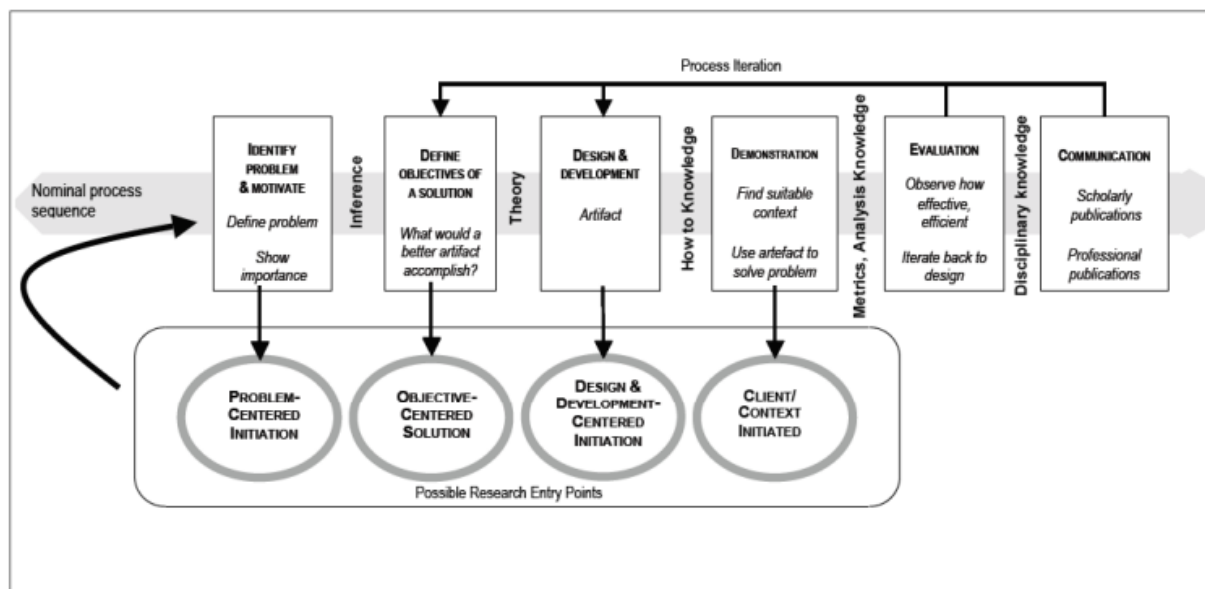


Figure 3.1 – DSR Process. Source: (Peffer et al., 2007)

The process of DSR is structured into six primary activities, illustrated Figure 3.1. It begins with identifying and motivating the problem. This phase is about articulating the importance of the problem and building a strong justification for solving it. The approach then moves on to defining the objectives of a solution. Here, the understanding of the problem is translated into a vision of a successful outcome, where the objectives for the artifact are established, according to which the problem will be solved (Hevner et al., 2004).

In the third activity of DSR methodology, design and development focus on the creation of the artifact. This encompasses a wide range of potential outcomes, such as constructs, models, methods or instantiations, which can include new technical, social or informational components. Integrating theory into the design process is crucial, as it ensures that the resulting artifact is innovative and based on established research, thus increasing its applicability and value (Peppers et al., 2007).

The next phase is demonstration, in which the usefulness of the developed artifact is demonstrated by applying it to solve one or more instances of the problem in question. To do this successfully, it is necessary to have a comprehensive understanding of how the artifact works in the context of the problem. Subsequently, in the evaluation phase, the performance of the artifact is critically assessed. This evaluation consists of observing and measuring the effectiveness of the artifact in providing a solution and comparing the results with the initial objectives set for the solution. Metrics and analytical techniques are key at this stage, providing the necessary tools to quantify the performance of the artifact. If the evaluation highlights areas for improvement, the process can return to Design and Development, where the artifact is refined until the desired results are achieved (Venable et al., 2012).

Finally, the last phase of this methodology, communication, is characterized by the effective dissemination of the conclusions and knowledge resulting from the research. This crucial phase involves articulating the nature and significance of the problem, detailing the design and usefulness of the artifact, and highlighting its innovation and effectiveness. A deep knowledge of the disciplinary culture is essential during this phase to ensure that communication is tailored to the expectations and standards of the target audiences (Gregor & Hevner, 2013).

4. SITUATION ANALYSIS

This segment will explore the technical dimensions of the activities carried out by CTT. It will illustrate the comprehensive attributes of the challenge being addressed and detail the process that established the basis for this thesis.

4.1. CTT'S TREATMENT PROCESS

CTT's parcel processing and distribution encompasses a variety of procedures and follows a flow illustrated in Figure 4.1. For this reason, numerous facets of the entire operation need consideration to enhance the process's efficiency. To help explain the whole process, some nomenclature will be defined, used internally by CTT. For instance, an Operational Center (CO) is the place where parcels are processed. A Postal Distribution Center (CDP) is the place where parcels are deposited after leaving the CO before being sent for delivery. It is assigned a geographical area and is responsible for delivering CP7s within that area. A Logistics and Distribution Centers (CLD) are postal centers that handle all the logistics of parcels. Finally, a Routing Group (GE) is used to designate an aggregation of CP4s in the same area of influence.



Figure 4.1 – Flow of CTT postal service. Source: (Shutterstock, n.d.) Adapted

4.1.1. OPERATIONAL MODEL

The first important aspect to consider is how the operational model is designed. CTT has a large history in the postal sector, more than 500 years, considered the largest postal delivery service in Portugal. Its operational network is organized into regions, areas and, in turn, arteries, where the number of the existing quantity of each of these components is indicated in brackets:

Region (14): characterized by the first digit of postal code

Area (507): characterized by the first four digits of postal code

Artery (184 803): characterized by the full seven-digit postal code

Besides these aggregations, regarding the number of spaces dedicated to postal activity, which have already been described, there are:

- six CLD and their respective areas of influence;
- seven CO dedicated to parcel treatment;
- six CO with cross-docking activities only.

Among these nineteen, there are seven that are equipped with a machine, known as a Sorter, which automatically processes the parcels. The study conducted by this dissertation will highlight these seven ones: **Zone1, Zone2, Zone3, Zone4, Zone5, Zone6, Zone7**.

Throughout the explanation of CTT's handling processes, fictitious names such as "Zone" will be used. These names will be assigned to origins, destinations and any specific CO or CLD that needs to be mentioned. The original names cannot be used to protect CTT data.

For a concise introduction on parcel distribution (the stage following processing), there are two channels through which a parcel can be distributed, with the following designations:

Base Network (RB): when the parcel is transported and distributed by a postal carrier.

Express Network (RE): when the parcel, due to certain characteristics, is transported and distributed through a network of CTT partners.

4.1.2. POSTAL CODES

The Portuguese territory is segmented into postal codes. A postal code is a sequence of seven digits representing a specific geographic area, which is further subdivided into four digits. The first four digits of a postal code are known as CP4 and, when the remaining three digits are added, usually separated by a hyphen, the full postal code, called CP7, is formed. Although this dissertation will only consider CP4 and CP7, there is another subdivision known as CP10, which is used to identify a locality along with its postal address.

4.1.3. SORTER MACHINES

In each of the 7 Zones mentioned earlier, there is a sorter. These sorters are based on a decision server, which is parameterized as a decision tree and results in various exits that can practically be seen as carpet. Specific CP4s, whether aggregated or not, are allocated to each exit.

Within each sorter, parcels undergo several queries, which help to determine the path they will take to reach their destination. The two main questions are:

- Will the parcel be distributed through the RB or the RE?
- What is the CP4 of the parcel?

These questions, along with others parameterized in the decision server, define the path that each parcel takes from the moment it enters the first CO until it reaches its destination. Each time a parcel passes through the sorter, it is said to have entered a plan. Each CO has many different plans, but in this study, only the National Plan (NP) and the Regional Plan (RP) will be addressed.

Delving deeper, the NP is the initial stage, when the parcel has not yet undergone any decision-making or parameterization. In this plan, the possible exits can vary in their configuration, which means there can be:

- Exits that have a certain number of different CDP (i.e. all objects that go to CP4 from the areas of influence of those CDPs fall on that carpet);
- Exits designated for a single CDP;
- Exits leading to another CO.

Regarding the RP, it can be considered the second phase of a parcel's journey, typically representing the second time the parcel goes through the sorter. A parcel undergoes this second phase if, during its first pass, the specific CDP to which it should be routed was not determined. This subsequent phase further refines the parcel's routing based on additional criteria or decisions that couldn't be finalized during the first pass through the NP.

4.1.4. TREATMENT PROCESS

In this section, the focus is on the design of the treatment process. The process of handling a parcel has several stages. Once a parcel has been picked up at its delivery point, the first processing-related moment is when the object enters the first CO (usually near the point where it was picked up). Once inside the center, the parcel passes through the sorter and is then forwarded to an exit.

This decision will be made considering the specificities of the object, namely its weight and size (which are two important characteristics for deciding whether it will be distributed by RB or RE), and CP4 (which will determine if the object falls on a carpet already divided at its destination or if it still must pass through the RP or manual division).

The carpet it falls on determines the “future of the object”, where there are several alternatives. It could fall on a carpet:

1. Already divided at the final destination and then transported to the corresponding CDP for distribution (may also pass through another CO or CLD for cross-docking);
2. In which there are several CP4s mixed (a maximum of 4) which then must be split manually. This manual division can take place in the CO where it is located or only in that of the corresponding GE (destination), and depending on this decision, the object can still have two alternative carpets;

3. With the designation of a RP, and if it is to follow the plan in the center where it is located (origin) it comes out on a carpet and if it is to make the plan in the CO of the destination GE, it comes out on another carpet;
4. With the designation of a NP in another CO .

To make it clearer, an illustrative scenario (of what is currently happening) will be described for each of the possible situations, numbered above:

1. A parcel (or a group of parcels) arrives at Zone1 with CP4 6050 (Alpalhão), which belongs to the GE Castelo Branco and to be distributed by RB: This parcel will be forwarded to the NP and will leave on the carpet already divided at its destination. In other words, it falls onto the carpet where there are only parcels belonging to the same CP4 and then all it has to do is wait for the transport that will take it to Zone8;
2. A parcel (or group of parcels) arrives at Zone5 with CP4 3100, which belongs to the GE Coimbra and to be distributed by RB: This parcel will enter the Zone5 NP and will leave on a shared carpet with three other CP4s. When it falls onto the carpet, it will be split manually (to separate the CP4s) in the Zone5 and will wait for transportation to the Zone7, where it will then be distributed;
3. A parcel (or group of parcels) arriving at Zone5 with CP4 4470, which belongs to the Maia GE: This parcel is going to make the NP in Zone5 and will fall on a carpet labeled Maia RP. This means that the object hasn't been split up, it's mixed up with other CP4s from the GE Maia, and will wait for a transport to take it to this one, where it will enter the RP;
4. A parcel (or group of parcels) arrives at the Zone3 with CP4 9500, which belongs to the GE Açores: This parcel will enter the Leiria NP and will fall on a carpet without division at its destination and with the information that it will be going on to the Zone1 NP.

This illustrative scenario was made based on the routes that are currently designed, which means that at the end of the work carried out in this dissertation, these scenarios may no longer be effective.

4.2. PROBLEM SPECIFICATIONS

Within the scope of this dissertation, the problem in question will be approached as a linear programming problem, as mentioned in Chapter 1, the aim of which is to arrive at the optimal solution. In this case, at the conclusion of this dissertation, the route of each object must be defined, with a specific origin and destination, from the moment it enters the first CO, until its distribution. With this, the aim is to understand which sorter exits each object should be allocated to.

4.2.1. DATA EXTRACTION

To solve the optimization problem, it was necessary to use some data as input to define the model's parameters and constraints. All the data was extracted for the same period, February 2024.

Firstly, it was necessary to have access to the masks, that is the name given by CTT, to the moment when an object arrives at a CO, enters the sorter and drops off at a specific exit. There are different masks for each CO with sorter, and these will be considered in this problem. Based on these masks, and considering the entire journey of an object and not only inside one CO, alternative ones were built and incorporated in the model. To facilitate the analysis of the solutions obtained, instead of all the CP4s, the corresponding GE were considered as the origins of the routes. In this way, the 7 GE (Zone1, Zone2, Zone3, Zone4, Zone5, Zone6 and Zone7), that have a sorter, were considered as origins.

Secondly, the maximum capacities of each intermediate point through which an object can pass had to be collected. These intermediate points represent COs or CLDs that form part of an object's route before it reaches the CDP to be distributed. The maximum capacities considered are the maximum number of objects that each sorter can handle during its processing time or, if the objects are handled manually, represent the maximum number of objects that the intermediate point can handle manually, considering the number of people working there.

Related to capacities, is also the information requested regarding the maximum number of exits of the machines at each center. Another important piece of data was the traffic (number of parcels) handled at each origin (GE) to be considered in this model. Also, as part of the input for the model, the number of employees assigned to the manual division at each intermediate point was requested.

Traffic and number of employees were estimated, since CTT did not have this direct information by origin and destination. With the source data provided, traffic was weighted based on the history of traffic arriving at each destination. The traffic from the origin was therefore distributed to each destination taking these weightings into account. It is important to note that the number of parcels that go through RB is usually different from the number

that go through RE. Regarding the number of people, as the aim was to understand the maximum capacity of the manual division at each destination, this capacity was calculated using 30% of the number of people per destination (considering that, on average, 30% of the people at each intermediate point do manual division), the maximum number that each person divides per hour and estimating that each manual division can last up to 3 hours per day, in each CO.

4.2.2. PROBLEM FORMULATION

Complex problems like this, to be solved by optimization packages like CPLEX, must go through rigorous mathematical modulation and the corresponding translation into machine-readable code. This chapter will describe the entire process.

That said, based on the existing formulations of other similar projects and conversations with elements of CTT's operations, the sets, parameters and variables for this work was made:

Sets

I : set of Operational Centers, $I = \{1, \dots, i\}$
 J : set of Postal Distribution Centers, $J = \{1, \dots, j\}$
 K : set of routes, $K = \{1, \dots, k\}$
 R : set of resources, $R = \{1, \dots, r\}$

Parameters

$a(i, j, k)$ = mapping the route k of an object with origin i and destination j

$$\beta(k, r) = \begin{cases} 1, & \text{if the route } k \text{ uses the occupancy availability of } r \\ 0, & \text{otherwise} \end{cases}$$

γ_r = availability of resources in each r (intermediate point)

s_i = maximum number of exits on the machines at each origin

$c(i, j, k)$ = cost (capacity) associated with manual division

Variables

$$x_k^{ij} = \begin{cases} 1, & \text{if objects with origin } i \text{ and destination } j \text{ take route } k \\ 0, & \text{otherwise} \end{cases}$$

Before going into the formulation in detail, it is important to explain what each parameter means and how it was created.

$\mathbf{a}(i, j, k)$: This parameter, and probably the most important one, is a dataset in which each line represents an admissible route k for an object with origin i and destination j . This route describes everything that happens to an object from the moment it enters the first CO to the last center it passes through in the treatment process. In these routes are included the various intermediate points through which the object can pass, the number of possible exits on the sorter it will use and the traffic that must be considered on each route k .

For a better understanding, Figure 4.2 shows an example of a route with origin i and destination j .



Figure 4.2 – Illustration of a route from dataset $\mathbf{a}(i,j,k)$. Source: (istockphoto.com, n.d.) Adapted

$\beta(k, r)$: This binary matrix stores all the intermediate points (the same ones mentioned in the previous parameter) assigned to each available route. For each route, the number one will be assigned to the intermediate points through which the object will pass and the number zero to those which have no interference with that route.

$\mathbf{Y}_R$: This dataset has all intermediate points and the corresponding capacities

$\mathbf{S}_i$: In this dataset will be the maximum number of exits that can exist on the sorters at each origin

The number zero can appear in the above dataset, because sometimes RB and RE can share the same exits from the sorter and therefore each available exit will only appear once, either on the RB or RE routes.

$\mathbf{c}(i, j, k)$: This dataset contains information on whether there is a manual division at any intermediate point of each combination of origin i , destination j and route k . This means that it will have the number 1 if a certain combination has a manual division at any intermediate point and zero otherwise.

After this explanation, the formulation can be written as follows:

$$\text{Minimize } \sum_i \sum_j \sum_k c_k^{ij} x_k^{ij} \quad (4.1)$$

Subject to the following constraints:

$$\sum_k x_k^{ij} = 1 \quad (4.2)$$

$$\sum_i \sum_j \sum_k x_k^{ij} \beta(k, r) \leq \gamma_r \quad (4.3)$$

$$\sum_j \sum_k x_k^{ij} a[saida1]_k^{ij} \leq s_i \quad (4.4)$$

$$x_k^{ij} \in \{0, 1\} \quad (4.5)$$

In the formulation, $a[saida1]$ refers to the “Saída1” column of $\mathbf{a}(i, j, k)$ dataset that have the number of machine exits used on each route.

The objective function (4.1) aims to minimize manual divisions of an order with origin i and destination j making the route k . The constraint (4.2) ensures that each parcel with origin i and destination j only has one admissible route k . With constraint (4.3), it is guaranteed that the capacity of each resource r is not exceeded. The last restriction (4.4) serves to guarantee that for each origin i , the sum of the exits used on all routes does not exceed the maximum number established.

Objective Function

There were two possible approaches identified by CTT to represent the objective function. The first one will consider the minimization of time consumed on each route. This approach is more complex because the time consumed is the sum of time spent in each CO (inside the sorter and when the objects are waiting for the transport), and the time spent between COs (sometimes one object has to be transported over long distances). After some conversations with CTT, it was decided that in this first interaction with the problem, a simplest approach will be adopted.

The second option and the one that was chosen, is the objective function that minimizes the number of manual divisions, in the origin i and intermediate points that one object making the route k must pass through. This approach also contributes to less time spent, because manual divisions take much more time than an automatic division (sorter division).

5. RESULTS AND DISCUSSION

This chapter will cover the steps for solving the model, such as using CPLEX as a solver, and will also analyze the results obtained, as well as the contributions to CTT. There will be a conclusion to all the work in this dissertation, mentioning the main difficulties, limitations and future work that can be developed based on this project.

To simplify things and give a smaller view of the whole problem, before starting to explain and develop the problem that will be part of the study in this dissertation, the well-known toy problem was created.

5.1. TOY PROBLEM

The goal of this toy problem is to take a concrete example, with a specific number of objects, with a certain origin and destination and see how the solution looks. Based on this, consider there are sixteen parcels arrived at Zone1 today, to be distributed to the Portuguese postal codes 8100-012 (Alter), 4800-180 (Guimarães), 8135-034 (Almancil), 4810-003 (Calvos GMR), 8150-146 (São Brás de Alportel) and 4805-001 (Guimarães).

Given this postal code scenario, the journeys currently defined for these parcels to reach their destination are as illustrated in Figure 4.2. In total, there will be 4 journeys, because for each of these destinations there is one that uses RB and another that uses RE.



Figure 5.1 – Defined routes for the parcels to be delivered

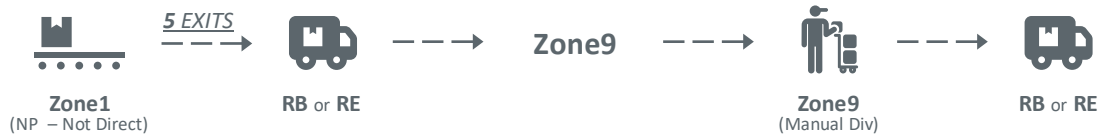
Figure 5.1 illustrates how such a route would look conceptually. To reach the destination, there are several possibilities (for each origin-destination) that the model can choose from, according to routes in dataset $\alpha(i, j, k)$ dataset, which are illustrated in Figure 5.2 and Figure 5.3, but in a more conceptual way and not exactly as the dataset α is constructed, because in the toy problem, this dataset was not yet completely the same as the one that will be considered in the main problem. The illustrations also only show the RB routes, but for RE it will be the same, just swapping RB for RE on the routes below.

For Zone1 – Zone9, there are four options for RB (and another four for RE – 5, 6, 7, 8):

Route [1] & [5]



Route [2] & [6]



Route [3] & [7]



Route [4] & [8]

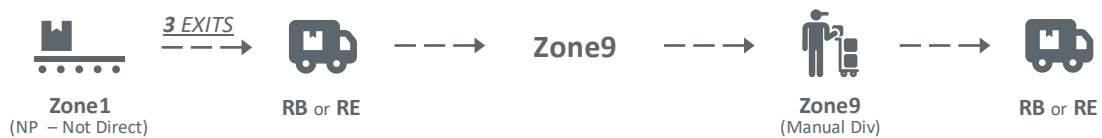


Figure 5.2 – Admissible routes from Zone1 to Zone9. Source: (svgrepo.com, n.d.) Adapted

For Zone1 – Zone10, there are five options for RB (and another five for RE – 14, 15, 16, 17, 18):

Route [9] & [14]



Route [10] & [15]

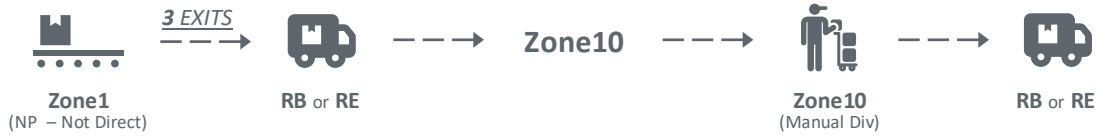


Figure 5.3 – Admissible routes from Zone1 to Zone10. Source: (svgrepo.com, n.d.) Adapted

Route [11] & [16]



Route [12] & [17]



Route [13] & [18]

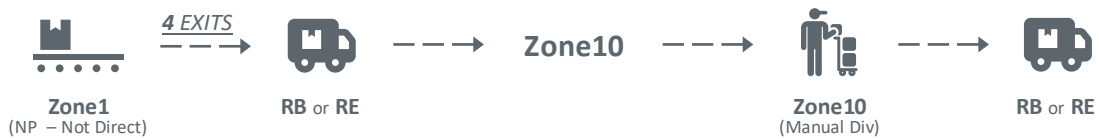


Figure 5.4 – Admissible routes from Zone1 to Zone10. Source: (svgrepo.com, n.d.) Adapted

Once the routes have been illustrated, it must be considered that there are three resources r (intermediate points) with limited capacities:

- $r1$ – Manual division capacity of **Zone9**;
- $r2$ – Manual division capacity of **Zone10**;
- $r3$ – Sorter capacity of **Zone1**.

The first steps in solving this problem were to formulate the problem and write its formulation in a Mathematical Programming System (MPS), one of the formats supported by the CPLEX solver. To do this, and based on knowledge from the IBM manual, the file was written in Python, using the panda's package (IBM, 2013).

The parameters and variables were defined, and some of the latter were randomly generated by Python code just for this simple example, because the necessary data had not yet been made available. That said, dataset $a(i, j, k)$ was already built (with some differences) and was used in this toy problem, containing all the possible routes of an object with origin i and destination j . The capacities of each resource, dataset $\beta(k, r)$ were also built. Only $c(i, j, k)$ and Y_R were randomly generated. Regarding dataset S_i , when the toy problem was developed, the formulation that had been considered did not yet have the maximum number of exits in each sorter as a restriction, so this set was not part of this small problem.

The parameters were mentioned above, the variables are the same as the one defined in the formulation of the main problem and the sets and formulation for the toy problem are as follows:

$$\begin{aligned} I &= \{1\} \\ J &= \{1, 2\} \\ K &= \{1, \dots, 9\} \\ R &= \{1, 2, 3\} \end{aligned}$$

γ_R, c_k^{ij} were randomly generated

$$\text{Minimize } \sum_i \sum_j \sum_k c_k^{ij} x_k^{ij} \quad (5.1)$$

$$\sum_k x_k^{ij} = 1 \quad (5.2)$$

$$\sum_i \sum_j \sum_k x_k^{ij} \beta(k, r) \leq \gamma_r \quad (5.3)$$

$$x_k^{ij} \in \{0, 1\} \quad (5.4)$$

Then, following the CPLEX tutorial on IBM's official manual, the MPS file was written, entered the solver and the result generated is shown in Table 5.2. The actual scenario is in Table 5.1.

Table 5.1 – Actual scenario of journeys

i/j	<i>Zone9 – RB</i>	<i>Zone9 – RE</i>	<i>Zone10 – RB</i>	<i>Zone10 – RE</i>
<i>Zone1</i>	2	8	13	18

Table 5.2 – LP solution details minimizing manual divisions

i/j	<i>Zone9 – RB</i>	<i>Zone9 – RE</i>	<i>Zone10 – RB</i>	<i>Zone10 – RE</i>
<i>Zone1</i>	3	7	13	14

Regarding the journeys that existed until now, manual division was present at some point in all of them.

With the results obtained from CPLEX, the following conclusions can be drawn about the k routes that have been allocated to each origin i and destination j , according to the objective function:

- From Zone1 to Zone9 - RB, route 3 was chosen, which passes through the Zone1 NP, with a direct division to the destination, falls on a carpet with two exits on the sorter and is transported to Zone9, where it will then continue to the corresponding CP4s;
- From Zone1 to Zone9 - RE, route 7 was chosen, which passes through the Zone1 NP, with a direct division to the destination, falls on a carpet with two exits on the sorter and is transported to Zone9, where it will then continue to the corresponding CP4s;
- From Zone1 to Zone10 - RB, route 13 has been chosen, which passes through the Zone1 NP, without direct division to the destination, falls on a carpet with four exits on the sorter and continues in transport to Zone10, where it will make manual division to the corresponding CP4s;
- From Zone1 to Zone10 - RE, route 14 has been chosen, which passes through the Zone1 NP, without direct division to the destination, falls on a carpet with six exits on the sorter and continues in transport to Zone10, where it will make manual division to the corresponding CP4s.

The conclusions that can be made from this toy problem are that the routes chosen by the model have only one of them with a manual division. It can thus be concluded that the formulation seems to be performing as expected and that it makes sense to move on to the main problem, which encompasses all CTT's COs and CDPs.

5.2. MAIN PROBLEM

The toy problem was very important at this stage to better understand whether the formulation is working well and generating the desired results. Moving on to the main problem, the restriction limiting the number of sorter exits for each CO has been included. This problem considers 7 COs with sorters as origins, 39 GEs as destinations and 41 intermediate points (with limited resources), which can be seen in Table 5.3 (all these components will be with Zones generic names). For each route k there will normally be two options, one for the RE and one for the RB, but there are exceptions, some destinations that are served by only one of these options.

Table 5.3 – List of origins, destinations and intermediate points

Origin (i)	Destination (j)	Intermediate points (r)
Zone2	Zone9 (RB and RE)	Div_Direta-N_Zone1
Zone3	Zone2 (RB and RE)	Post_Trat-N_Zone1
Zone4	Zone10 (RB and RE)	Div_Direta-R_Zone1
Zone7	Zone8 (RB only)	CD_Zone1
Zone6	Zone7 (RB and RE)	Div_Direta-N_Zone3
Zone1	Zone11 (RE only)	Post_Trat-N_Zone3
Zone5	Zone12 (RB only)	Div_Direta-R_Zone3
	Zone3 (RB and RE)	CD_Zone3
	Zone1_G1 (RB and RE)	Div_Direta-N_Zone2
	Zone13_R (RB only)	Post_Trat-N_Zone2
	Zone13_TR (RB only)	Div_Direta-R_Zone2
	Zone14 (RB and RE)	CD_Zone2
	Zone15 (RB only)	Div_Direta-N_Zone5
	Zone5 (RB and RE)	Post_Trat-N_Zone5
	Zone16_R (RB only)	Div_Direta-R_Zone5
	Zone16_TR (RB only)	CD_Zone5
	Zone4_[2xxx] (RB and RE)	Div_Direta-N_Zone7
	Zone4_[7xxx] (RB only)	Post_Trat-N_Zone7
	Zone17 (RE only)	Div_Direta-R_Zone7
	Zone18 (RB only)	CD_Zone7
	Zone19 (RB and RE)	Div_Direta-N_Zone6
	Zone20 (RB only)	Post_Trat-N_Zone6
	Zone21 (RB only)	Div_Direta-R_Zone6
	Zone22 (RB only)	CD_Zone6
	Zone23 (RB only)	Div_Direta-N_Zone4
	Zone1_G2 (RB and RE)	Post_Trat-N_Zone4
	Zone5_R (RB and RE)	Div_Direta-R_Zone4
		CD_Zone4
		DivM_Zone9
		DivM_Zone8
		DivM_Zone10
		DivM_Zone14
		DivM_Zone13
		DivM_Zone19
		DivM_Zone15
		DivM_Zone18
		DivM_Zone12
		DivM_Zone21
		DivM_Zone20
		DivM_Zone17
		DivM_Zone11

In the list of intermediate points, as there is some nomenclature that may not be very understandable, its meaning can be found below.

Div_Direta-N: when a parcel passes through the NP and is split at its destination, it does not undergo any further treatment.

Post_Trat-N: when a parcel passes through the NP but still needs to go through other treatments, whether it's a manual division or even the RP.

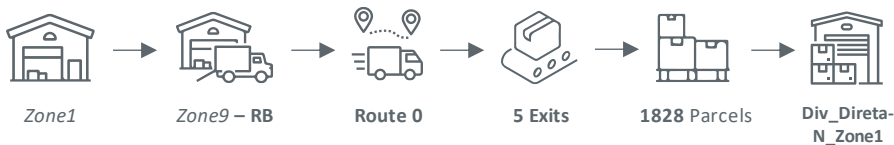
Div_Direta-R: when a parcel passes through the RP and is split at its destination.

CD: when a parcel passes through a certain intermediate point but does not undergo any treatment, it is just a cross-docking point.

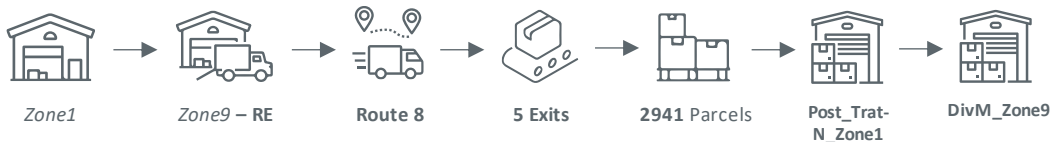
DivM: when a parcel passes through a manual division at that intermediate point.

Figure 5.5 and Figure 5.6 illustrates some of the routes that will be considered in the formulation of this model. But in the Appendix Chapter, there is an extract from dataset $a(i, j, k)$, exactly in the format that will be used by the model.

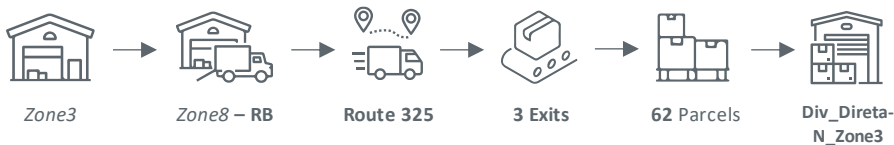
Route [1]



Route [2]



Route [3]



Route [4]

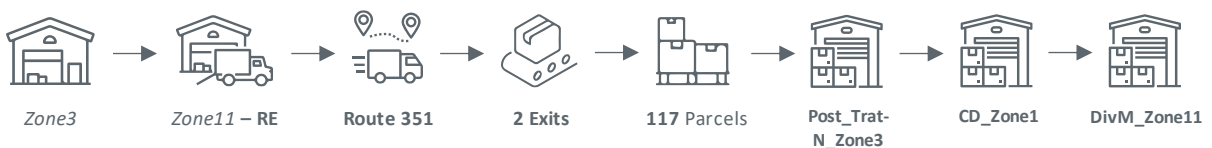
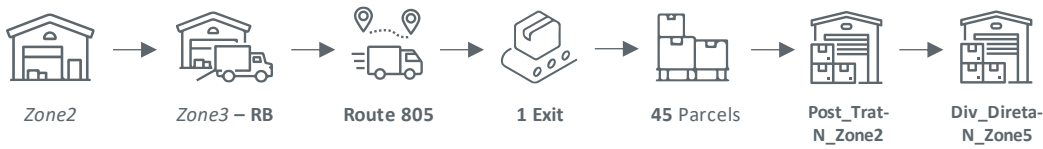
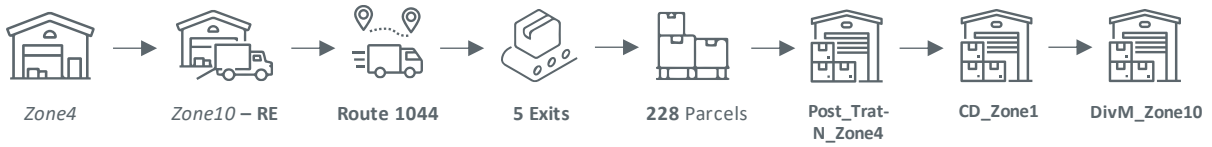


Figure 5.5 – Illustration of some of the dataset's routes $a(i, j, k)$. Source: (istockphoto.com, n.d.) Adapted

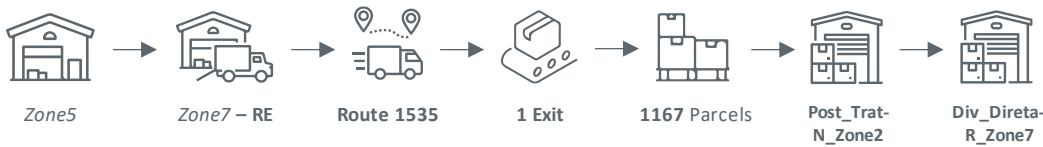
Route [5]



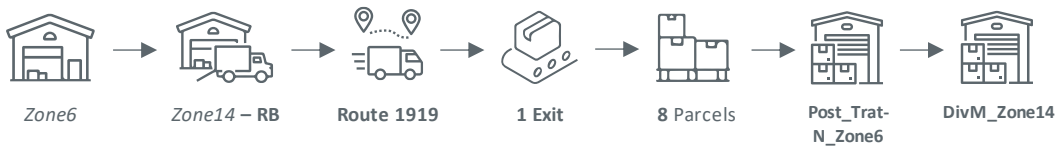
Route [6]



Route [7]



Route [8]



Route [9]

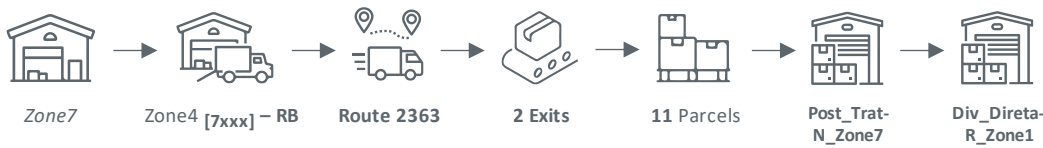


Figure 5.6 – Illustration of some of the dataset's routes $a(i,j,k)$. Source: (istockphoto.com, n.d.) Adapted

These illustrations represent only a small part of all the routes that will be introduced into the model. Once the mathematical formulation was done and all the datasets were ready to be consumed by CPLEX, the respective MPS file was generated, which can be consulted in the Appendix Chapter, the file and the respective Python code that generated it. The formulation of an MPS file has a particular way of being written in Python, so it was necessary to resort to some IBM documentation (IBM, 2013) to generate the code.

After fulfilling all the necessary requirements to use CPLEX, through a few commands in the CPLEX command control, the final solution was generated, that provides the routes chosen for each origin-destination pair. The solution generated by CPLEX can be found in the

appendixes as well as the corresponding routes in dataset $a(i, j, k)$. In Table 5.4 it is possible to see some chosen routes.

Table 5.4 – Illustration of some chosen routes

Origin	Destination	Route	Exits	Traffic	Intermediate Point 1	Intermediate Point 2	Intermediate Point 3
Zone1	Zone7-RB	53	5	2446	Div_Direta-N_Zone1	-	-
Zone1	Zone11-RE	66	1	2799	Post_Trat-N_Zone1	Div_Direta-R_Zone5	-
Zone1	Zone12-RB	78	3	1764	Div_Direta-N_Zone1	-	-
Zone1	Zone3-RB	85	3	508	Div_Direta-N_Zone1	-	-
Zone1	Zone4_[2xxx]-RB	184	1	1983	Post_Trat-N_Zone1	Div_Direta-R_Zone1	-
Zone3	Zone9-RE	302	2	123	Post_Trat-N_Zone3	Div_Direta-N_Zone1	-
Zone3	Zone3-RB	369	1	21	Post_Trat-N_Zone3	Div_Direta-R_Zone3	-
Zone3	Zone14-RB	418	1	16	Div_Direta-N_Zone3	CD_Zone1	-
Zone3	Zone1_G2-RB	663	0	206	Post_Trat-N_Zone3	Div_Direta-R_Zone1	-
Zone3	Zone1_G2-RE	671	0	252	Post_Trat-N_Zone3	Div_Direta-R_Zone1	-
Zone2	Zone8-RB	728	1	130	Post_Trat-N_Zone2	Div_Direta-R_Zone5	-
Zone2	Zone7-RB	744	1	216	Post_Trat-N_Zone2	Div_Direta-N_Zone5	-
Zone2	Zone7-RE	752	0	116	Post_Trat-N_Zone2	Div_Direta-N_Zone5	-
Zone2	Zone13_R-RB	831	1	224	Post_Trat-N_Zone2	Div_Direta-N_Zone5	-
Zone2	Zone17-RE	936	0	202	Post_Trat-N_Zone2	Div_Direta-R_Zone1	-
Zone4	Zone2-RB	1020	2	63	Post_Trat-N_Zone4	CD_Zone1	Div_Direta-R_Zone2
Zone4	Zone12-RB	1105	2	76	Post_Trat-N_Zone4	Div_Direta-N_Zone1	-
Zone4	Zone15-RB	1200	2	52	Post_Trat-N_Zone4	Div_Direta-N_Zone1	-
Zone4	Zone23-RB	1437	0	63	Div_Direta-N_Zone4	-	-
Zone4	Zone5_R-RE	1453	1	67	Post_Trat-N_Zone4	Div_Direta-N_Zone1	-
Zone5	Zone7-RB	1528	2	2179	Post_Trat-N_Zone5	Div_Direta-R_Zone7	-
Zone5	Zone11-RE	1541	2	2493	Post_Trat-N_Zone5	Div_Direta-R_Zone5	-
Zone5	Zone5-RB	1635	1	2239	Post_Trat-N_Zone5	Div_Direta-R_Zone5	-
Zone5	Zone4_[2xxx]-RE	1662	6	4217	Div_Direta-N_Zone5	-	-
Zone5	Zone1_G2-RB	1746	7	4387	Post_Trat-N_Zone5	Div_Direta-N_Zone1	-
Zone6	Zone9-RB	1772	2	36	Post_Trat-N_Zone6	DivM_Zone9	-
Zone6	Zone9-RE	1778	0	58	Post_Trat-N_Zone6	DivM_Zone9	-
Zone6	Zone16_R-RB	1959	1	31	Post_Trat-N_Zone6	Div_Direta-N_Zone5	-
Zone6	Zone19-RB	2016	1	41	Post_Trat-N_Zone6	DivM_Zone19	-
Zone6	Zone20-RB	2028	0	36	Post_Trat-N_Zone6	Div_Direta-N_Zone5	-
Zone7	Zone10-RB	2117	1	33	Post_Trat-N_Zone7	Div_Direta-N_Zone5	-
Zone7	Zone8-RB	2138	2	18	Div_Direta-N_Zone7	-	-
Zone7	Zone3-RB	2210	1	6	Post_Trat-N_Zone7	Div_Direta-N_Zone1	-
Zone7	Zone22-RB	2584	1	18	Div_Direta-N_Zone7	-	-
Zone7	Zone5_R-RE	2607	0	19	Post_Trat-N_Zone7	Div_Direta-N_Zone5	-

After analyzing the solution obtained and comparing it with what existed at the time in terms of the number of manual divisions in all routes per origin, Table 5.5 was constructed.

Table 5.5 – Comparison of results between what was and what happened after the optimization model, regarding manual divisions at destinations

Origin	Destinations with manual division	
	Before the solution	After the solution
Zone2	1	0
Zone3	1	0
Zone4	0	0
Zone7	6	0
Zone6	3	3
Zone1	5	0
Zone5	5	0
Total	21	3

Although the Table 5.5 shows the manual splits by origin, the number associated with each of them will be allocated to the respective destinations, because that's where the manual split will take place, in this analysis.

As can be seen, the number of manual divisions decreased by 18 and, with this result, some considerations can be considered. But first it is necessary to establish a context with what currently exists at CTT.

Through the data that was provided, it was possible to find out that, on average, one person divides 121 objects per hour in a manual division. Regarding the number of people assigned to manual splitting, CTT provided the number of people working at each intermediate point, but not all of them do manual splitting. Therefore, for this purpose, it was considered that 30% of the people at each intermediate point do manual division. These considerations are shown in Table 5.6.

Table 5.6 – Number of persons allocated to manual division at each destination

Intermediate Point	Total Persons	Persons in manual division
DivM_Zone9	41	13
DivM_Zone8	54	17
DivM_Zone10	45	14
DivM_Zone14	27	9
DivM_Zone13	195	59
DivM_Zone19	40	12
DivM_Zone15	27	9
DivM_Zone18	68	21
DivM_Zone12	49	15
DivM_Zone21	13	4
DivM_Zone20	10	3
DivM_Zone17	14	5
DivM_Zone11	34	11

The total capacity of objects per hour that can be processed into each sorter is also known, as can be seen in Table 5.7.

Table 5.7 – Capacity of the sorter of each origin, in objects per hour

Origin	Capacity (obj/h)
Zone2	5100
Zone3	5100
Zone4	5100
Zone7	3825
Zone6	3825
Zone1	8460
Zone5	6000

As already mentioned, when a package enters a sorter, it doesn't always leave divided at its destination, it may still have to go through some more processing. Table 5.8 shows the 43 routes that ceased manual division at the destination, those that now undergo division during their first pass through the sorter (at the origin) and the corresponding traffic, according to the obtained solution.

Table 5.8 – Number of routes, and the correspondent traffic, that have a direct division to the destination on the first pass through the sorter, at each origin

Origin	Sorter division in origin	Traffic
Zone2	0	0
Zone3	1	124
Zone4	0	0
Zone7	1	18
Zone6	0	0
Zone1	5	14988
Zone5	5	13351
Total	12	28481

From the Table 5.8 presented, of the 21 routes that no longer have manual splitting at destination, 12 of them split the parcels at their destination when they first pass through the sorter (at origin). To compare the time it would take to split all this traffic manually (at the destination) with the time spent in the sorter, Table 5.9 was constructed.

Table 5.9 – Time saved by dividing objects to destination directly at the sorter, instead of doing it manually

Origin	Time spent on the sorter (p/ h)	Time spent on manual division (p/ h)	Time Saved (p/ h)	
Zone2	0	0	0	
Zone3	0.024313725	0.104824246	-0.08051052	→ 5 minutes
Zone4	0	0	0	
Zone7	0.004705882	0.015216423	-0.01051054	→ 38 seconds
Zone6	0	0	0	
Zone1	1.771631206	12.67020803	-10.89857683	→ 10 hours 48 minutes
Zone5	2.225166667	11.28635892	-9.061192251	→ 9 hours 4 minutes

To calculate the time taken to split the sorter directly, the sorter's total capacity (in objects per hour) was divided by the traffic that had to be split, by origin. As for calculating the time taken to split all this traffic manually at the destination, a few more steps had to be considered. To clarify how this time was calculated, an example of Zone3 is shown in Table 5.10.

Table 5.10 – Time spent in manual division in origin Zone3

Origin - Zone3						
Intermediate Point	Total Persons	Persons in manual division	Capacity	Weight	Traffic	Time spent
DivM_Zone9	41	13	1573	0.121374463	15.05043341	0.009567981
DivM_Zone8	54	17	2057	0.037451028	4.643927465	0.002257622
DivM_Zone10	45	14	1694	0.201954781	25.04239281	0.014782995
DivM_Zone14	27	9	1089	0.123352961	15.29576714	0.0140457
DivM_Zone13	195	59	7139	0.083644359	10.37190052	0.001452851
DivM_Zone19	40	12	1452	0.067322867	8.348035501	0.005749336
DivM_Zone15	27	9	1089	0.030653341	3.801014303	0.003490371
DivM_Zone18	68	21	2541	0.063483565	7.871962039	0.003097978
DivM_Zone12	49	15	1815	0.044896029	5.567107541	0.003067277
DivM_Zone21	13	4	484	0.04907682	6.085525671	0.0125734
DivM_Zone20	10	3	363	0.047327468	5.868605993	0.016166959
DivM_Zone17	14	5	605	0.058237291	7.221424126	0.011936238
DivM_Zone11	34	11	1331	0.071225028	8.831903477	0.00663554
Total				1	124	0.104824246

The steps considered for these calculations are as follows:

1. First, it was necessary to identify the destinations that split manually, which can be seen in the "Intermediate Point" column;
2. In the "Total Persons" column is the number of people working at each of the intermediate points and, in the "Persons in manual division" column, it was considered that only 30% of these people do manual division, as had already been mentioned in Chapter 4.2.1;
3. The "Capacity" column was calculated by multiplying the number of people allocated to manual division by the number of objects that, on average, one person divides per hour (121 obj);
4. The "Weight" column had already been calculated to allocate traffic to each route in the dataset $a(i, j, k)$;
5. The traffic in the "Traffic" column was calculated by multiplying the weight of each intermediate point by the total traffic that existed for Zone3;
6. Finally, the total time spent in each manual division was calculated by dividing the hourly capacity of each destination (column "Capacity") by the traffic that needed to be divided (column "Traffic");
7. After this, to determine the total time spent per origin (in this case Zone3), it was necessary to sum all these times spent per destination.

As seen in Table 5.9, there is a total reduction of approximately 20 hours of work by transferring manual divisions from the destination to the sorter at the origin. It is important to note that despite traffic being divided directly at the origin sorter, there aren't enough machine exits to handle a CP4 for each of them, necessitating some manual division at the origin CO when parcels exit the sorter, as CP4s may occasionally be together through the same exit. So, it should be emphasized that this reduction of 20 hours of work does not fully reflect reality. However, due to the significantly greater resources available at origin COs, which are

larger facilities, this time would still be less than transporting traffic for manual division at the destination.

An analysis of these results shows that 20 hours of work reflects the working hours of 2 people (8 hours each, on average), plus 4 hours allocated to a third person. This means that, per day, CTT has these people free for other important tasks. This may seem like a small number, but it could mean 440 hours of work (working hours of 55 people) saved per month. This calculation was made considering only 22 days of the month because, although orders are handled at the weekend, traffic on those days can have a very different pattern.

6. CONCLUSIONS AND FUTURE WORKS

The aim of the work carried out in this research was to provide CTT with a solution that would allow for an optimized allocation of traffic to the machine exits at its postal processing centers, considering the minimization of manual intervention. Through the application of advanced linear programming techniques, the study provided useful information for improving CTT's logistics and processing processes, helping to increase overall efficiency and adapt to the growing demands of e-commerce.

At an early stage, the development of the toy problem was very important to understand whether the modulation of the linear programming problem was as intended. Since the complexity of the main problem is high, it would never have been possible to see if the modulation was correct without using a smaller example. After the results obtained from the toy problem and their discussion, it was possible to move on to the main problem with much more confidence.

In the main problem, the primary difficulties experienced were in mapping out the possible routes of a parcel once it has arrived at a treatment center. There are infinite possibilities for these routes, given the number of postal codes there are in the country and all the treatment centers that can serve them. In this way, the most challenging thing was to map these routes in the smallest possible number, only counting the ones that would make the most sense, so as not to make this number too high, which would be much more difficult to manage computationally.

Taking advantage of real-time traffic data in each center and the analysis carried out on the process used to date, the model made a significant contribution to improving the accuracy of traffic allocation to the various machine exits. The fact that there are fewer manual divisions at the destination and more divisions at the origin sorter means that parcels are processed more quickly and accurately. This can result in faster delivery times and a reduction in cases of misdirected parcels, since machines are much less likely to generate errors than humans, which can contribute to customer satisfaction and loyalty.

Consequently, with shorter processing times, it may be possible for CTT to handle more parcels in the same amount of time. This increase in performance means that CTT can process more parcels per hour/day, thereby improving overall productivity. Another point to keep in mind is that optimizing this treatment process allows for better use of existing resources, such as sorters and people. Machines work more efficiently, and staff can be redeployed to other tasks, maximizing the use of human and machine resources without additional investment. In conclusion, these overall improvements in efficiency and quality of service contribute to CTT's competitiveness and market position.

In this way, it was possible to help optimize the total processing time for each parcel in the respective operating center and thus reduce the use of resources and operational delays. Considering this, the research question presented in the beginning of this dissertation: "How can optimizing the destinations to be assigned to each machine output improve business performance at CTT and what are the potential economic impacts and challenges of this implementation?" has been addressed through the demonstration of the solutions and analysis mentioned in this chapter and the previous one.

Considering the significant potential of this project to improve the quality of service and reduce operational durations in parcel handling at CTT centers, it is crucial to move forward with research and development efforts. This ongoing effort will ensure sustained improvements and long-term benefits for the company's operational efficiency.

The results and implementation of this solution are aligned with CTT's strategic objectives, such as operational excellence, customer satisfaction and market competitiveness. This project provides the foundations for future innovations and continuous improvement in CTT's operations, thus contributing to sustained business growth and adaptability to market changes.

6.1. LIMITATIONS

Throughout the development of this problem there were several limitations, particularly in terms of obtaining and manipulating the data. Due to the lack of data, it was decided to estimate traffic by destination, the number of people allocated to the manual division at each destination, the capacity of each sorter per day at each origin, and the time taken for each manual division.

This is a highly complex problem and due to the time involved in developing this dissertation, some decisions had to be made, particularly regarding the objective function. As already mentioned, there were two options, and the hypothesis that aimed to minimize the total time a parcel spent in the processing process would be much more laborious in terms of data manipulation.

To calculate the time needed to make a complete route, it was necessary to know the time it takes, on average, to place a parcel in the sorter, the time it takes for a parcel to make its way through the machine and the time needed to remove the parcel from the sorter and place it in the right container. In addition, it was also necessary to consider how long a transport takes from each origin to each destination. Arranging all this data in such a way as to be able to have this total time was going to take a lot of time, so it was decided to use as objective function the minimization of manual divisions.

Another very important piece of information that could generate a different solution is the time windows in which each intermediate point operates. In other words, considering the

existing transportation schedules and the time it takes for an order to be processed at each of the intermediate points, these time windows would be constructed to make the route formulation more precise.

6.2. FUTURE WORK

As for future work, a few things can be considered. As a first step, change the objective function to minimize the total time it takes to process an order. To achieve this goal, it was necessary to know how long it takes each person, on average, to insert and remove an object from the machine. To define this time, it would be interesting to go to a CO and measure the time that some people take for these two processes and then take an average. As a second piece of information, it would be necessary to know how long a parcel takes on average, in the sorter. For this calculation, it would be wise to find out if CTT has this information.

A second step would be to incorporate time windows into the routes. CTT has the transport timetables, when they arrive and when they leave each CO of origin or intermediate point, so for this calculation it would be necessary to estimate the time an object needs to be in each CO or intermediate point during its processing process.

Another approach that could be considered is the refinement of the linear programming model. The model was constructed to address the main indications provided by CTT employees who contributed to this study. After implementing the solution, it is necessary to test it for a while and see if there is anything else to consider in the routes, for example, to enrich the model.

One other approach that could be considered is the development of alternative routes. There are many, and the ones considered in this formulation may have been the ones that seemed most appropriate at the time, but the landscape in postal services can change frequently, hence the need to test the model with other inputs.

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APPENDIXES

A. DATASETS USED IN THE MODEL

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone1	Zone9-RB	0	5	1,828	1	0	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	1	4	1,828	1	0	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	2	3	1,828	1	0	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	3	5	1,828	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	4	4	1,828	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	5	3	1,828	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RB	6	2	1,828	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	7	5	2,941	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	8	4	2,941	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	9	3	2,941	0	1	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	10	5	2,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	11	4	2,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone9-RE	12	3	2,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	13	5	1,475	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	14	4	1,475	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	15	3	1,475	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	16	2	1,475	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	17	3	1,475	0	1	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	18	2	1,475	0	1	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	19	1	1,475	0	1	0	0	0	0	0	0	0	0
Zone1	Zone2-RB	20	2	1,475	0	1	0	0	0	0	0	0	1	0
Zone1	Zone2-RB	21	1	1,475	0	1	0	0	0	0	0	0	1	0
Zone1	Zone2-RE	22	5	1,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RE	23	4	1,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RE	24	3	1,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RE	25	2	1,941	1	0	0	0	0	0	0	0	0	0
Zone1	Zone2-RE	26	3	1,941	0	1	0	0	0	0	0	0	0	0
Zone1	Zone2-RE	27	2	1,941	0	1	0	0	0	0	0	0	0	0

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone3	Zone9-RB	299	1	77	1	0	0	0	0	1	0	0	0	0
Zone3	Zone9-RB	300	3	77	0	0	0	1	0	1	0	0	0	0
Zone3	Zone9-RB	301	2	77	0	0	0	1	0	1	0	0	0	0
Zone3	Zone9-RE	302	2	123	1	0	0	0	0	1	0	0	0	0
Zone3	Zone9-RE	303	1	123	1	0	0	0	0	1	0	0	0	0
Zone3	Zone9-RE	304	3	123	0	0	0	1	0	1	0	0	0	0
Zone3	Zone9-RE	305	2	123	0	0	0	1	0	1	0	0	0	0
Zone3	Zone2-RB	306	2	62	0	0	0	1	0	1	0	0	0	0
Zone3	Zone2-RB	307	1	62	0	0	0	1	0	1	0	0	0	0
Zone3	Zone2-RB	308	1	62	1	0	0	0	0	1	0	0	0	0
Zone3	Zone2-RE	309	0	81	0	0	0	1	0	1	0	0	0	0
Zone3	Zone2-RE	310	0	81	1	0	0	0	0	1	0	0	0	0
Zone3	Zone10-RB	311	1	111	1	0	0	0	0	1	0	0	0	0
Zone3	Zone10-RB	312	4	111	0	0	0	1	0	1	0	0	0	0
Zone3	Zone10-RB	313	3	111	0	0	0	1	0	1	0	0	0	0
Zone3	Zone10-RB	314	7	111	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RB	315	6	111	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RB	316	5	111	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RE	317	7	222	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RE	318	6	222	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RE	319	5	222	0	0	0	1	1	0	0	0	0	0
Zone3	Zone10-RE	320	2	222	1	0	0	0	0	1	0	0	0	0
Zone3	Zone10-RE	321	1	222	1	0	0	0	0	1	0	0	0	0
Zone3	Zone10-RE	322	5	222	0	0	0	1	0	0	0	0	0	0
Zone3	Zone10-RE	323	4	222	0	0	0	1	0	1	0	0	0	0
Zone3	Zone10-RE	324	3	222	0	0	0	1	0	1	0	0	0	0
Zone3	Zone8-RB	325	3	62	0	0	0	1	1	0	0	0	0	0
Zone3	Zone8-RB	326	2	62	0	0	0	1	1	0	0	0	0	0

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone2	Zone9-RB	691	0	161	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RB	692	0	161	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RB	693	3	161	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RB	694	2	161	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RB	695	5	161	0	0	0	0	0	0	0	0	1	0
Zone2	Zone9-RB	696	4	161	0	0	0	0	0	0	0	0	1	0
Zone2	Zone9-RB	697	3	161	0	0	0	0	0	0	0	0	1	0
Zone2	Zone9-RE	698	2	260	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RE	699	1	260	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RE	700	3	260	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RE	701	2	260	0	0	0	0	0	0	0	0	0	1
Zone2	Zone9-RE	702	5	260	0	0	0	0	0	0	0	0	1	0
Zone2	Zone9-RE	703	4	260	0	0	0	0	0	0	0	0	1	0
Zone2	Zone9-RE	704	3	260	0	0	0	0	0	0	0	0	1	0
Zone2	Zone2-RB	705	2	130	0	0	0	0	0	0	0	0	0	1
Zone2	Zone2-RB	706	1	130	0	0	0	0	0	0	0	0	0	1
Zone2	Zone2-RE	707	0	171	0	0	0	0	0	0	0	0	0	1
Zone2	Zone2-RE	708	0	171	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	709	2	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	710	1	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	711	7	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	712	6	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	713	5	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	714	4	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	715	3	233	0	0	0	0	0	0	0	0	0	1
Zone2	Zone10-RB	716	7	233	0	0	0	0	0	0	0	0	1	0
Zone2	Zone10-RB	717	6	233	0	0	0	0	0	0	0	0	1	0
Zone2	Zone10-RB	718	5	233	0	0	0	0	0	0	0	0	1	0

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone4	Zone9-RB	1010	4	79	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RB	1011	3	79	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RB	1012	2	79	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RB	1013	2	79	1	0	0	0	0	0	0	0	0	0
Zone4	Zone9-RB	1014	1	79	1	0	0	0	0	0	0	0	0	0
Zone4	Zone9-RE	1015	4	126	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RE	1016	3	126	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RE	1017	2	126	0	0	0	1	0	0	0	0	0	0
Zone4	Zone9-RE	1018	2	126	1	0	0	0	0	0	0	0	0	0
Zone4	Zone9-RE	1019	1	126	1	0	0	0	0	0	0	0	0	0
Zone4	Zone2-RB	1020	2	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RB	1021	1	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RB	1022	2	63	1	0	0	0	0	0	0	0	0	0
Zone4	Zone2-RB	1023	1	63	1	0	0	0	0	0	0	0	0	0
Zone4	Zone2-RB	1024	5	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RB	1025	4	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RB	1026	3	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RB	1027	2	63	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1028	2	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1029	1	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1030	2	83	1	0	0	0	0	0	0	0	0	0
Zone4	Zone2-RE	1031	1	83	1	0	0	0	0	0	0	0	0	0
Zone4	Zone2-RE	1032	5	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1033	4	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1034	3	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone2-RE	1035	2	83	0	0	0	1	0	0	0	0	0	0
Zone4	Zone10-RB	1036	5	113	0	0	0	1	0	0	0	0	0	0
Zone4	Zone10-RB	1037	4	113	0	0	0	1	0	0	0	0	0	0

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone5	Zone9-RB	1454	6	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1455	5	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1456	4	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1457	3	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1458	4	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1459	3	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RB	1460	2	1,628	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1461	6	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1462	5	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1463	4	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1464	3	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1465	4	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1466	3	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone9-RE	1467	2	2,620	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1468	7	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1469	6	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1470	5	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1471	4	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1472	3	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1473	2	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1474	2	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RB	1475	1	1,314	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1476	7	1,729	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1477	6	1,729	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1478	5	1,729	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1479	4	1,729	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1480	3	1,729	0	0	0	0	0	0	0	0	0	0
Zone5	Zone2-RE	1481	2	1,729	0	0	0	0	0	0	0	0	0	0

origem	destino	Nº Percurso	Saida1	trafego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone6	Zone9-RB	1768	5	36	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RB	1769	4	36	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RB	1770	3	36	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RB	1771	3	36	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RB	1772	2	36	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1773	5	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1774	4	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1775	3	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1776	0	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1777	0	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone9-RE	1778	0	58	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RB	1779	2	29	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RB	1780	1	29	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RB	1781	4	29	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RB	1782	3	29	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RB	1783	2	29	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RE	1784	0	38	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RE	1785	0	38	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RE	1786	4	38	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RE	1787	3	38	0	0	0	0	0	0	0	0	0	0
Zone6	Zone2-RE	1788	2	38	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1789	2	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1790	1	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1791	7	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1792	6	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1793	5	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1794	6	52	0	0	0	0	0	0	0	0	0	0
Zone6	Zone10-RB	1795	5	52	0	0	0	0	0	0	0	0	0	0

origem	destino	Nº Percurso	Saida1	tráfego	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
Zone7	Zone9-RB	2078	3	23	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RB	2079	2	23	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RB	2080	2	23	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RB	2081	1	23	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RB	2082	5	23	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RB	2083	4	23	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RB	2084	3	23	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RE	2085	0	37	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RE	2086	0	37	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RE	2087	0	37	0	0	0	1	0	0	0	0	0	0
Zone7	Zone9-RE	2088	0	37	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2089	0	37	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2090	0	37	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2091	0	37	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2092	0	37	1	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2093	5	37	0	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2094	4	37	0	0	0	0	0	0	0	0	0	0
Zone7	Zone9-RE	2095	3	37	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2096	2	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2097	1	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2098	2	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2099	1	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2100	4	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2101	3	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RB	2102	2	18	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RE	2103	0	24	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RE	2104	0	24	0	0	0	0	0	0	0	0	0	0
Zone7	Zone2-RE	2105	0	24	0	0	0	0	0	0	0	0	0	0

origem	destino	Route	Manual Div
Zone1	Zone9-RB	0	0
Zone1	Zone9-RB	1	0
Zone1	Zone9-RB	2	0
Zone1	Zone9-RB	3	1
Zone1	Zone9-RB	4	1
Zone1	Zone9-RB	5	1
Zone1	Zone9-RB	6	1
Zone1	Zone9-RE	7	1
Zone1	Zone9-RE	8	1
Zone1	Zone9-RE	9	1
Zone1	Zone9-RE	10	0
Zone1	Zone9-RE	11	0
Zone1	Zone9-RE	12	0
Zone1	Zone2-RB	13	0

origem	destino	Route	Manual Div
Zone3	Zone9-RB	299	0
Zone3	Zone9-RB	300	1
Zone3	Zone9-RB	301	1
Zone3	Zone9-RE	302	0
Zone3	Zone9-RE	303	0
Zone3	Zone9-RE	304	1
Zone3	Zone9-RE	305	1
Zone3	Zone2-RB	306	0
Zone3	Zone2-RB	307	0
Zone3	Zone2-RB	308	0
Zone3	Zone2-RE	309	0
Zone3	Zone2-RE	310	0
Zone3	Zone10-RB	311	0
Zone3	Zone10-RB	312	1

origem	destino	Route	Manual Div
Zone2	Zone9-RB	691	0
Zone2	Zone9-RB	692	0
Zone2	Zone9-RB	693	1
Zone2	Zone9-RB	694	1
Zone2	Zone9-RB	695	0
Zone2	Zone9-RB	696	0
Zone2	Zone9-RB	697	0
Zone2	Zone9-RE	698	0
Zone2	Zone9-RE	699	0
Zone2	Zone9-RE	700	1
Zone2	Zone9-RE	701	1
Zone2	Zone9-RE	702	0
Zone2	Zone9-RE	703	0
Zone2	Zone9-RE	704	0

origem	destino	Route	Manual Div
Zone4	Zone9-RB	1010	1
Zone4	Zone9-RB	1011	1
Zone4	Zone9-RB	1012	1
Zone4	Zone9-RB	1013	0
Zone4	Zone9-RB	1014	0
Zone4	Zone9-RE	1015	1
Zone4	Zone9-RE	1016	1
Zone4	Zone9-RE	1017	1
Zone4	Zone9-RE	1018	0
Zone4	Zone9-RE	1019	0
Zone4	Zone2-RB	1020	0
Zone4	Zone2-RB	1021	0
Zone4	Zone2-RB	1022	0
Zone4	Zone2-RB	1023	0

origem	destino	Route	Manual Div
Zone5	Zone9-RB	1454	0
Zone5	Zone9-RB	1455	0
Zone5	Zone9-RB	1456	0
Zone5	Zone9-RB	1457	0
Zone5	Zone9-RB	1458	1
Zone5	Zone9-RB	1459	1
Zone5	Zone9-RB	1460	1
Zone5	Zone9-RE	1461	0
Zone5	Zone9-RE	1462	0
Zone5	Zone9-RE	1463	0
Zone5	Zone9-RE	1464	0
Zone5	Zone9-RE	1465	1
Zone5	Zone9-RE	1466	1
Zone5	Zone9-RE	1467	1

origem	destino	Route	Manual Div
Zone6	Zone9-RB	1768	0
Zone6	Zone9-RB	1769	0
Zone6	Zone9-RB	1770	0
Zone6	Zone9-RB	1771	1
Zone6	Zone9-RB	1772	1
Zone6	Zone9-RE	1773	0
Zone6	Zone9-RE	1774	0
Zone6	Zone9-RE	1775	0
Zone6	Zone9-RE	1776	1
Zone6	Zone9-RE	1777	1
Zone6	Zone9-RE	1778	1
Zone6	Zone2-RB	1779	0
Zone6	Zone2-RB	1780	0
Zone6	Zone2-RB	1781	0

origem	destino	Route	Manual Div
Zone7	Zone9-RB	2078	1
Zone7	Zone9-RB	2079	1
Zone7	Zone9-RB	2080	0
Zone7	Zone9-RB	2081	0
Zone7	Zone9-RB	2082	0
Zone7	Zone9-RB	2083	0
Zone7	Zone9-RB	2084	0
Zone7	Zone9-RE	2085	1
Zone7	Zone9-RE	2086	1
Zone7	Zone9-RE	2087	1
Zone7	Zone9-RE	2088	0
Zone7	Zone9-RE	2089	0
Zone7	Zone9-RE	2090	0
Zone7	Zone9-RE	2091	0

Route	N-Div_Direta_Zone1	N-Post_Trat_Zone1	R-Div_Direta_Zone1	CD_Zone1	Div_Direta-N_Zone3	Post_Trat-N_Zone3	Div_Direta-R_Zone3	CD_Zone3	Div_Direta-N_Zone2	Post_Trat-N_Zone2
0	1	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0
7	0	1	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0
13	1	0	0	0	0	0	0	0	0	0

Route	Div_Direta-R_Zone2	CD_Zone2	Div_Direta-N_Zone5	Post_Trat-N_Zone5	Div_Direta-R_Zone5	CD_Zone5	Div_Direta-N_Zone7	Post_Trat-N_Zone7	Div_Direta-R_Zone7	CD_Zone7
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	1	0	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0	0	0
19	1	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	1	0	0	0	0	0	0	0	0	0
27	1	0	0	0	0	0	0	0	0	0

Route	Div_Direta-N_Zone6	Post_Trat-N_Zone6	Div_Direta-R_Zone6	CD_Zone6	Div_Direta-N_Zone4	Post_Trat-N_Zone4	Div_Direta-R_Zone4	CD_Zone4	DivM_Zone9	DivM_Zone8
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0

Route	DivM_Zone10	DivM_Zone14	DivM_Zone13	DivM_Zone19	DivM_Zone15	DivM_Zone18	DivM_Zone12	DivM_Zone21	DivM_Zone20	DivM_Zone17	DivM_Zone11
42	1	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0

Origin	Exits
Zone2	23
Zone3	29
Zone4	59
Zone7	19
Zone6	19
Zone1	155
Zone5	124

R Resource	Total Capacity (obj)	R Resource	Total Capacity (obj)
N-Div_Direta_Zone1	131130	Div_Direta-N_Zone6	8606
N-Post_Trat_Zone1	131130	Post_Trat-N_Zone6	8606
R-Div_Direta_Zone1	44415	Div_Direta-R_Zone6	4781
CD_Zone1	100000000	CD_Zone6	100000000
Div_Direta-N_Zone3	7650	Div_Direta-N_Zone4	8925
Post_Trat-N_Zone3	7650	Post_Trat-N_Zone4	8925
Div_Direta-R_Zone3	5100	Div_Direta-R_Zone4	5100
CD_Zone3	100 000 000	CD_Zone4	100000000
Div_Direta-N_Zone2	12750	DivM_Zone9	11162
Post_Trat-N_Zone2	12750	DivM_Zone8	16335
Div_Direta-R_Zone2	5100	DivM_Zone10	12251
CD_Zone2	100000000	DivM_Zone14	9801
Div_Direta-N_Zone5	93000	DivM_Zone13	70785
Post_Trat-N_Zone5	93000	DivM_Zone19	14520
Div_Direta-R_Zone5	31500	DivM_Zone15	9801
CD_Zone5	100000000	DivM_Zone18	24684
Div_Direta-N_Zone7	7650	DivM_Zone12	17787
Post_Trat-N_Zone7	7650	DivM_Zone21	4719
Div_Direta-R_Zone7	3825	DivM_Zone20	3630
CD_Zone7	100000000	DivM_Zone17	5082
		DivM_Zone11	12342

origin-destination	trafego	origin-destination	trafego
Zone2 Zone9-RB	161	Zone3 Zone7-RB	102
Zone2 Zone9-RE	260	Zone3 Zone7-RE	55
Zone2 Zone2-RB	130	Zone3 Zone11-RB	0
Zone2 Zone2-RE	171	Zone3 Zone11-RE	117
Zone2 Zone10-RB	233	Zone3 Zone12-RB	74
Zone2 Zone10-RE	467	Zone3 Zone12-RE	0
Zone2 Zone8-RB	130	Zone3 Zone3-RB	21
Zone2 Zone8-RE	0	Zone3 Zone3-RE	72

origin-destination	trafego	origin-destination	trafego
Zone4 Zone1_G1-RB	53	Zone7 Zone15-RB	15
Zone4 Zone1_G1-RE	34	Zone7 Zone15-RE	0
Zone4 Zone13_R-RB	109	Zone7 Zone5-RB	31
Zone4 Zone13_R-RE	0	Zone7 Zone5-RE	65
Zone4 Zone13_TR-RB	32	Zone7 Zone16_R-RB	20
Zone4 Zone13_TR-RE	0	Zone7 Zone16_R-RE	0
Zone4 Zone14-RB	17	Zone7 Zone16_TR-RB	12
Zone4 Zone14-RE	191	Zone7 Zone16_TR-RE	0

origin-destination	trafego	origin-destination	trafego
Zone6 Zone4 [2xxx]-RB	39	Zone1 Zone19-RB	2118
Zone6 Zone4 [2xxx]-RE	93	Zone1 Zone19-RE	528
Zone6 Zone4 [7xxx]-RB	17	Zone1 Zone20-RB	1860
Zone6 Zone4 [7xxx]-RE	0	Zone1 Zone20-RE	0
Zone6 Zone17-RB	0	Zone1 Zone21-RB	1929
Zone6 Zone17-RE	45	Zone1 Zone21-RE	0
Zone6 Zone18-RB	49	Zone1 Zone22-RB	1472
Zone6 Zone18-RE	0	Zone1 Zone23-RB	1472

origin-destination	trafego
Zone5 Zone21-RB	1718
Zone5 Zone21-RE	0
Zone5 Zone22-RB	1311
Zone5 Zone23-RB	1311
Zone5 Zone1_G2-RB	4387
Zone5 Zone1_G2-RE	5347
Zone5 Zone5_R-RB	1232
Zone5 Zone5_R-RE	1380

B. PYTHON CODE THAT GENERATED THE MPS FILE

```
## MPS File
import pandas as pd

def write_mps_file(filename, a, custos, beta, gamma_r, saidas):
    """
    Write an MPS file for the optimization problem.
    """

    with open(filename, 'w') as file:
        # Write header section
        file.write("NAME          Otimização de Tráfego - Saídas de Máquina\n")
        file.write("ROWS\n")
        file.write("N COST\n")

        # Assignment constraints
        for (i, j), group in a.groupby(level=['origem', 'destino']):
            file.write(f" E ASSIGN_{i}_{j}\n")

        # Resource constraints
        for resource in gamma_r['Recurso R']:
            file.write(f" L RESOURCE_{resource}\n")

        # Exit constraints
        for origem in saidas['CO Origem']:
            file.write(f" E EXIT_{origem}\n")

        # COLUMNS section
        file.write("COLUMNS\n")
        for (i, j, k), row in a.iterrows():
            if row['trafego'] > 0:
                var_name = f"X_{i}_{j}_{k}"
                file.write(f" {var_name} ASSIGN_{i}_{j} 1\n")
                cost = custos.loc[(i, j, k), 'Div Manual']
                file.write(f" {var_name} COST {cost}\n")
            for resource in beta.columns:
                if beta.at[k, resource] > 0:
                    file.write(f" {var_name} RESOURCE_{resource} {row['trafego'] * beta.at[k, resource]}\n")

        # Write the exits constraints
        file.write(f" {var_name} EXIT_{i} {row['Saída1']}\n")
```

```

# RHS section
file.write("RHS\n")
for (i, j), group in a.groupby(level=['origem', 'destino']):
    file.write(f"    RHS1 ASSIGN_{i}_{j} 1\n")
for index, resource in gamma_r.iterrows():
    file.write(f"    RHS1 RESOURCE_{resource['Recurso R']} {resource['Capacidade Total (Obj)]}\n")
for index, row in saidas.iterrows():
    file.write(f"    RHS1 EXIT_{row['CO Origem']} {row['Nº Sidas']}\n")

# BOUNDS section
file.write("BOUNDS\n")
for (i, j, k), row in a.iterrows():
    if row['trafego'] > 0:
        var_name = f"X_{i}_{j}_{k}"
        file.write(f"    BV BND1 {var_name}\n")

# Write END section
file.write("ENDATA\n")

# Load the data
a = pd.read_excel('C:/Users/ /Tese/Construcao_Percursos_Certo.xlsx', sheet_name='a(i,
custos = pd.read_excel('C:/ /Tese/Construcao_Percursos_Certo.xlsx', sheet_name=
beta = pd.read_excel('C:/Users/ /Tese/Construcao_Percursos_Certo.xlsx', sheet_name='E
gamma_r = pd.read_excel('C:/Users/ /Tese/Construcao_Percursos_Certo.xlsx', sheet_name=
saidas = pd.read_excel('C:/Users/ /Tese/Construcao_Percursos_Certo.xlsx', sheet_name=
a = a[a['trafego'] != 0]

# Set indices
a.set_index(['origem', 'destino', 'Nº Percurso'], inplace=True)
custos.set_index(['origem', 'destino', 'Nº Percurso'], inplace=True)
beta.set_index(['Nº Percurso'], inplace=True)

if __name__ == "__main__":
    write_mps_file('C:/Users/ /Tese/MPS_File_teste.mps', a, custos, beta, gamma_r, saidas)

```

C. PART OF THE MPS FILE GENERATED TO USE IN CPLEX

```

NAME          Otimização de Tráfego - Saídas de Máquina
ROWS
N COST
E ASSIGN_ZONE2_ZONE20-RB
E ASSIGN_ZONE2_ZONE8-RB
E ASSIGN_ZONE2_ZONE12-RB
E ASSIGN_ZONE2_ZONE12-RE
E ASSIGN_ZONE2_ZONE21-RB
E ASSIGN_ZONE2_ZONE21R-RB
E ASSIGN_ZONE2_ZONE18-RB
E ASSIGN_ZONE2_ZONE9-RB
E ASSIGN_ZONE2_ZONE9-RE
E ASSIGN_ZONE2_ZONE2-RB
E ASSIGN_ZONE2_ZONE2-RE
E ASSIGN_ZONE2_ZONE10-RB
E ASSIGN_ZONE2_ZONE10-RE
E ASSIGN_ZONE2_ZONE7-RB
E ASSIGN_ZONE2_ZONE7-RE
E ASSIGN_ZONE2_ZONE11-RE
E ASSIGN_ZONE2_ZONE3-RB
E ASSIGN_ZONE2_ZONE3-RE
E ASSIGN_ZONE2_ZONE14-RB
E ASSIGN_ZONE2_ZONE14-RE
E ASSIGN_ZONE2_ZONE17-RE
E ASSIGN_ZONE2_ZONE19-RB
E ASSIGN_ZONE2_ZONE19-RE
E ASSIGN_ZONE2_ZONE22-RB
E ASSIGN_ZONE2_ZONE23-RB
E ASSIGN_ZONE2_ZONE1_G1-RB
E ASSIGN_ZONE2_ZONE1_G1-RE
E ASSIGN_ZONE2_ZONE1_G2-RB
E ASSIGN_ZONE2_ZONE1_G2-RE
E ASSIGN_ZONE2_Zone13_R-RB
E ASSIGN_ZONE2_Zone13_R-RE
E ASSIGN_ZONE2_Zone13_TR-RB
E ASSIGN_CO_PER_Zone4_[7xxx]-RE
E ASSIGN_CO_PER_ZONE5-RB
E ASSIGN_CO_PER_ZONE5-RE
E ASSIGN_CO_PER_ZONE5_R-RB
E ASSIGN_CO_PER_ZONE5_R-RE
E ASSIGN_CO_PER_Zone16_R-RB
E ASSIGN_CO_PER_ZONE16_TR-RB
L RESOURCE_N-Div_Direta_ZONE1
L RESOURCE_N-Post_Trat_ZONE1
L RESOURCE_R-Div_Direta_ZONE1
L RESOURCE_CD_ZONE1
L RESOURCE_Div_Direta-N_ZONE3
L RESOURCE_Post_Trat-N_ZONE3
L RESOURCE_Div_Direta-R_ZONE3
L RESOURCE_CD_ZONE3
L RESOURCE_Div_Direta-N_ZONE2
L RESOURCE_Post_Trat-N_ZONE2
L RESOURCE_Div_Direta-R_ZONE2
L RESOURCE_CD_ZONE2
L RESOURCE_Div_Direta-N_CO_PER
L RESOURCE_Post_Trat-N_CO_PER
L RESOURCE_Div_Direta-R_CO_PER
L RESOURCE_CD_CO_PER
L RESOURCE_Div_Direta-N_ZONE7
L RESOURCE_Post_Trat-N_ZONE7
L RESOURCE_Div_Direta-R_ZONE7
L RESOURCE_CD_ZONE7
L RESOURCE_Div_Direta-N_ZONE6
L RESOURCE_Post_Trat-N_ZONE6
L RESOURCE_Div_Direta-R_ZONE6
L RESOURCE_CD_ZONE6
L RESOURCE_Div_Direta-N_ZONE4
L RESOURCE_Post_Trat-N_ZONE4
L RESOURCE_Div_Direta-R_ZONE4
L RESOURCE_CD_ZONE4
L RESOURCE_DivM_ZONE9

```

```

X_ZONE1_ZONE9-RB_0 RESOURCE_N-Div_Direta_ZONE1 1828.0031994397539 65.6324241280445 X_ZONE3_ZONE16_R-RB_453 RESOURCE_Div_Direta-N_ZONE3
X_ZONE1_ZONE9-RB_0 EXIT_ZONE1 5.0 X_ZONE3_ZONE16_R-RB_453 EXIT_ZONE3 5.0
X_ZONE1_ZONE9-RB_1 ASSIGN_ZONE1_ZONE9-RB_1 X_ZONE3_ZONE16_R-RB_454 ASSIGN_ZONE3_ZONE16_R-RB_1
X_ZONE1_ZONE9-RB_1 COST 0 X_ZONE3_ZONE16_R-RB_454 COST 0
X_ZONE1_ZONE9-RB_1 RESOURCE_N-Div_Direta_ZONE1 1828.0031994397539 X_ZONE3_ZONE16_R-RB_454 RESOURCE_CD_ZONE1 65.6324241280445
X_ZONE1_ZONE9-RB_1 EXIT_ZONE1 4.0 X_ZONE3_ZONE16_R-RB_454 RESOURCE_Div_Direta-N_ZONE3
X_ZONE1_ZONE9-RB_2 ASSIGN_ZONE1_ZONE9-RB_1 65.6324241280445
X_ZONE1_ZONE9-RB_2 COST 0 X_ZONE3_ZONE16_R-RB_454 EXIT_ZONE3 4.0
X_ZONE1_ZONE9-RB_2 RESOURCE_N-Div_Direta_ZONE1 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_467 ASSIGN_ZONE3_ZONE16_TR-RB_1
X_ZONE1_ZONE9-RB_2 EXIT_ZONE1 3.0 X_ZONE3_ZONE16_TR-RB_467 COST 0
X_ZONE1_ZONE9-RB_3 ASSIGN_ZONE1_ZONE9-RB_1 X_ZONE3_ZONE16_TR-RB_467 RESOURCE_CD_ZONE1 38.8675716265723
X_ZONE1_ZONE9-RB_3 COST 1 X_ZONE3_ZONE16_TR-RB_467 RESOURCE_Post_Trat-N_ZONE3
X_ZONE1_ZONE9-RB_3 RESOURCE_N-Post_Trat_ZONE1 1828.0031994397539 38.8675716265723
X_ZONE1_ZONE9-RB_3 RESOURCE_DivM_ZONE9 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_467 RESOURCE_Div_Direta-R_ZONE6
X_ZONE1_ZONE9-RB_3 EXIT_ZONE1 5.0 38.8675716265723
X_ZONE1_ZONE9-RB_4 ASSIGN_ZONE1_ZONE9-RB_1 X_ZONE3_ZONE16_TR-RB_467 EXIT_ZONE3 2.0
X_ZONE1_ZONE9-RB_4 COST 1 X_ZONE3_ZONE16_TR-RB_468 ASSIGN_ZONE3_ZONE16_TR-RB_1
X_ZONE1_ZONE9-RB_4 RESOURCE_N-Post_Trat_ZONE1 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_468 COST 0
X_ZONE1_ZONE9-RB_4 RESOURCE_DivM_ZONE9 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_468 RESOURCE_CD_ZONE1 38.8675716265723
X_ZONE1_ZONE9-RB_4 EXIT_ZONE1 4.0 X_ZONE3_ZONE16_TR-RB_468 RESOURCE_Post_Trat-N_ZONE3
X_ZONE1_ZONE9-RB_5 ASSIGN_ZONE1_ZONE9-RB_1 38.8675716265723
X_ZONE1_ZONE9-RB_5 COST 1 X_ZONE3_ZONE16_TR-RB_468 RESOURCE_Div_Direta-R_ZONE6
X_ZONE1_ZONE9-RB_5 RESOURCE_N-Post_Trat_ZONE1 1828.0031994397539 38.8675716265723
X_ZONE1_ZONE9-RB_5 RESOURCE_DivM_ZONE9 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_468 EXIT_ZONE3 1.0
X_ZONE1_ZONE9-RB_5 EXIT_ZONE1 3.0 X_ZONE3_ZONE16_TR-RB_469 ASSIGN_ZONE3_ZONE16_TR-RB_1
X_ZONE1_ZONE9-RB_6 ASSIGN_ZONE1_ZONE9-RB_1 X_ZONE3_ZONE16_TR-RB_469 COST 0
X_ZONE1_ZONE9-RB_6 COST 1 X_ZONE3_ZONE16_TR-RB_469 RESOURCE_N-Div_Direta_ZONE1
X_ZONE1_ZONE9-RB_6 RESOURCE_N-Post_Trat_ZONE1 1828.0031994397539 38.8675716265723
X_ZONE1_ZONE9-RB_6 RESOURCE_DivM_ZONE9 1828.0031994397539 X_ZONE3_ZONE16_TR-RB_469 RESOURCE_Post_Trat-N_ZONE3
X_ZONE1_ZONE9-RB_6 EXIT_ZONE1 2.0 X_ZONE3_ZONE16_TR-RB_469 EXIT_ZONE3 1.0

RHS1 ASSIGN_ZONE5_ZONE7-RE 1 BV_BND1_X_ZONE2_ZONE12-RB_778
RHS1 ASSIGN_ZONE5_ZONE11-RE 1 BV_BND1_X_ZONE2_ZONE12-RB_779
RHS1 ASSIGN_ZONE5_ZONE3-RB 1 BV_BND1_X_ZONE2_ZONE12-RB_780
RHS1 ASSIGN_ZONE5_ZONE3-RE 1 BV_BND1_X_ZONE2_ZONE12-RB_781
RHS1 ASSIGN_ZONE5_ZONE14-RB 1 BV_BND1_X_ZONE2_ZONE12-RB_782
RHS1 ASSIGN_ZONE5_ZONE14-RE 1 BV_BND1_X_ZONE2_ZONE12-RB_783
RHS1 ASSIGN_ZONE5_ZONE17-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_784
RHS1 ASSIGN_ZONE5_ZONE19-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_785
RHS1 ASSIGN_ZONE5_ZONE19-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_786
RHS1 ASSIGN_ZONE5_ZONE22-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_787
RHS1 ASSIGN_ZONE5_ZONE23-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_788
RHS1 ASSIGN_ZONE5_ZONE1_G1-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_789
RHS1 ASSIGN_ZONE5_ZONE1_G1-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_790
RHS1 ASSIGN_ZONE5_ZONE1_G2-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_791
RHS1 ASSIGN_ZONE5_ZONE1_G2-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_792
RHS1 ASSIGN_ZONE5_ZONE13_R-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_793
RHS1 ASSIGN_ZONE5_ZONE13_R-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_794
RHS1 ASSIGN_ZONE5_ZONE13_TR-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_795
RHS1 ASSIGN_ZONE5_Zone4 [2xxx]-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_796
RHS1 ASSIGN_ZONE5_Zone4 [2xxx]-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_797
RHS1 ASSIGN_ZONE5_Zone4 [7xxx]-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_798
RHS1 ASSIGN_ZONE5_Zone4 [7xxx]-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_799
RHS1 ASSIGN_ZONE5_ZONE5-RB 1 BV_BND1_X_ZONE2_ZONE12-RE_800
RHS1 ASSIGN_ZONE5_ZONE5-RE 1 BV_BND1_X_ZONE2_ZONE12-RE_801
RHS1 ASSIGN_ZONE5_ZONE5_R-RB 1 BV_BND1_X_ZONE2_ZONE3-RB_802
RHS1 ASSIGN_ZONE5_ZONE5_R-RE 1 BV_BND1_X_ZONE2_ZONE3-RB_803
RHS1 ASSIGN_ZONE5_ZONE16_R-RB 1 BV_BND1_X_ZONE2_ZONE3-RB_804
RHS1 ASSIGN_ZONE5_ZONE16_TR-RB 1 BV_BND1_X_ZONE2_ZONE3-RB_805
RHS1 RESOURCE_N-Div_Direta_ZONE1 131130.0 BV_BND1_X_ZONE2_ZONE3-RB_806
RHS1 RESOURCE_N-Post_Trat_ZONE1 131130.0 BV_BND1_X_ZONE2_ZONE3-RB_807
RHS1 RESOURCE_R-Div_Direta_ZONE1 44415.0 BV_BND1_X_ZONE2_ZONE3-RE_808
RHS1 RESOURCE_CD_ZONE1 10000000.0 BV_BND1_X_ZONE2_ZONE3-RE_809
RHS1 RESOURCE_Div_Direta-N_ZONE3 7650.0 BV_BND1_X_ZONE2_ZONE3-RE_810
BV_BND1_X_ZONE2_ZONE3-RE_811

```

D. SOME ANALYSIS OF THE RESULTS

Origin - Zone2						
Intermediate Point	Total Persons	Persons in manual division	Capacity	Weight	Traffic	Time spent
DivM_Zone9	41	13	1573	0.121374	0	0
DivM_Zone8	54	17	2057	0.037451	0	0
DivM_Zone10	45	14	1694	0.201955	0	0
DivM_Zone14	27	9	1089	0.123353	0	0
DivM_Zone13	195	59	7139	0.083644	0	0
DivM_Zone19	40	12	1452	0.067323	0	0
DivM_Zone15	27	9	1089	0.030653	0	0
DivM_Zone18	68	21	2541	0.063484	0	0
DivM_Zone12	49	15	1815	0.044896	0	0
DivM_Zone21	13	4	484	0.049077	0	0
DivM_Zone20	10	3	363	0.047327	0	0
DivM_Zone17	14	5	605	0.058237	0	0
DivM_Zone11	34	11	1331	0.071225	0	0
Total				1	0	0

Origin - Zone3		Origin - Zone4	
Traffic	Time spent	Traffic	Time spent
15	0.009567981	0	0
5	0.002257622	0	0
25	0.014782995	0	0
15	0.0140457	0	0
10	0.001452851	0	0
8	0.005749336	0	0
4	0.003490371	0	0
8	0.003097978	0	0
6	0.003067277	0	0
6	0.0125734	0	0
6	0.016166959	0	0
7	0.011936238	0	0
9	0.00663554	0	0
124	0.104824246	0	0

Origin - Zone7		Origin - Zone1		Origin - Zone5	
Traffic	Time spent	Traffic	Time spent	Traffic	Time spent
2	0.0013889	1819	1.156491069	1620	1.030178294
1	0.000327719	561	0.272880898	500	0.243076652
4	0.002145919	3027	1.786834861	2696	1.591675489
2	0.002038892	1849	1.697717334	1647	1.512291441
2	0.000210898	1254	0.175607459	1117	0.156427488
1	0.000834581	1009	0.694927775	899	0.61902727
1	0.000506667	459	0.421884552	409	0.375806022
1	0.000449706	951	0.374455596	848	0.33355729
1	0.00044525	673	0.370744725	599	0.330251723
1	0.001825171	736	1.519759043	655	1.353769882
1	0.002346817	709	1.954115938	632	1.740686008
1	0.00173268	873	1.442744665	778	1.285167069
1	0.000963224	1068	0.802044117	951	0.71444429
18	0.015216423	14988	12.67020803	13351	11.28635892

