

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

The impact of synchronizing variable frequency routes in public transport

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Mestrado em Engenharia Informática e Computação

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Resumo

Este trabalho aborda a otimização da sincronização de rotas de transporte público no contexto da rede ferroviária urbana do Porto. A rede é composta por quatro rotas que ligam o Porto às cidades circundantes: Aveiro, Marco de Canaveses, Guimarães e Braga. Estas rotas apresentam uma variabilidade significativa em termos de características operacionais, incluindo frequência, horários de operação, tempos de viagem e percursos de serviço, refletindo tanto dinâmicas urbanas quanto rurais dentro de um raio de 60 quilómetros do Porto. O objetivo principal é avançar no sentido de viagens sem interrupções, minimizando os tempos de transferência e melhorando a conectividade em toda a rede. Isso exige uma abordagem meticulosa no planeamento e otimização do transporte público, adaptada aos desafios únicos impostos pelos serviços de frequência variável. A metodologia integra uma revisão contínua da literatura visando utilizar metodologias de planeamento de transporte de última geração e um rigoroso processo de análise de dados para garantir a fiabilidade dos dados reais apurados da rede ferroviária urbana do Porto. As principais etapas incluem o desenvolvimento de um modelo de otimização de programação linear projetado para acomodar a complexidade da rede e a variabilidade nas frequências de serviço. A análise de sensibilidade, utilizando uma abordagem de planeamento experimental, aspirando à melhora na robustez do modelo proposto. Os resultados são analisados para obter percepções sobre a eficácia das estratégias de sincronização e o seu impacto na eficiência operacional e na experiência dos passageiros. Esta dissertação contribui para o avanço das metodologias de otimização do transporte público, particularmente em redes de frequência variável, e fornece recomendações práticas para melhorar a fiabilidade e a eficiência do serviço de transporte público em ambientes urbanos e rurais diversificados.

Palavras-chave: Transporte Público, Sincronização, Horários, Otimização, Viagem Sem Interrupções

Abstract

This dissertation addresses the optimization of Public Transport (PT) route synchronization in the context of Porto's urban train network. The network comprises four routes connecting Porto with surrounding cities: Aveiro, Marco de Canaveses, Guimarães, and Braga. These routes exhibit significant variability in terms of operational characteristics, including frequency, operational times, travel times, and service paths, reflecting both urban and rural dynamics within a 60 kilometer radius of Porto. The primary objective is to move towards seamless travel by minimizing transfer times and improving connectivity across the network. This necessitates a meticulous approach to PT planning and optimization, tailored to the unique challenges posed by variable frequency services. The methodology integrates a continuous literature review to leverage state-of-the-art transport planning methodologies and a rigorous data analysis process to ensure the reliability of real-world data collected from the Porto urban train network. Key stages include the development of a linear programming optimization model designed to accommodate network complexities and variability in service demands. Sensitivity analysis, using a design of experiments approach, further enhances the robustness of the proposed model. Results are analyzed to derive insights into the effectiveness of synchronization strategies and their impact on operational efficiency and passenger experience. This dissertation contributes to advancing PT optimization methodologies, particularly in variable frequency networks, and provides practical recommendations for enhancing PT service reliability and efficiency in diverse urban and rural settings.

Keywords: Public Transport, Synchronization, Timetabling, Optimization, Seamless Travel

Contents

Abbreviations and Symbols	ix
1 Introduction	1
1.1 Context	1
1.2 Motivation	2
1.3 Methodology	2
1.4 Dissertation Overview	3
2 Literature Review	5
2.1 Standards in Transport Planning	5
2.2 Optimizing Route Synchronization	6
2.3 Summary	9
3 Problem Statement	10
3.1 Network Characteristics	10
3.1.1 Aveiro	12
3.1.2 Marco de Canaveses	13
3.1.3 Guimarães	13
3.1.4 Braga	13
3.2 Operational Characteristics	14
3.2.1 Aveiro	14
3.2.2 Marco de Canaveses	16
3.2.3 Guimarães	17
3.2.4 Braga	18
3.3 Synchronization Characteristics	19
3.4 Real-World Data and Collection Process	20
3.4.1 Schedules	22
3.4.2 Headway	23
3.4.3 Travel Times	23
3.4.4 Schedule Deviations	23
3.4.5 Population-Based Synchronization Weights	24
3.5 Summary	26
4 Mathematical Formulation	28
4.1 Notation	29
4.2 Objective Function	29
4.3 Constraints	31
4.4 Domain	32

4.5	Performance Metrics	33
4.6	Summary	34
5	Results and Discussion	35
5.1	Design of Experiments	35
5.2	Solver Configuration Parameters	36
5.3	Benchmark Scenario	37
5.4	Sensitivity Analysis Results	41
5.5	Summary	44
6	Conclusions	46
6.1	Research Objectives and Achieved Results	46
6.2	Contributions	47
6.3	Limitations	47
6.4	Future Work	48
6.5	Summary	48
	References	50
A	Schedules	52
B	Headway	59
C	Travel Times	66
D	Deviations	79

List of Figures

2.1	The three decision-making levels and related planning/control tasks of PT planning and operations, retrieved from Liu et al. (2021).	6
2.2	Example of synchronization, retrieved from Elbaz et al. (2018).	7
3.1	Schematic Representation of the Public Transport Network.	10
3.2	Detailed Representation of the Public Transport Network, retrieved from MIH (2022).	11
5.1	Benchmark space-time diagram.	40

List of Tables

3.1	Aveiro Route Lines.	12
3.2	Marco de Canaveses Route Lines.	13
3.3	Guimarães Route Lines.	13
3.4	Braga Route Lines.	14
3.5	Aveiro-Porto Schedule Overview Excerpt (Line 1).	14
3.6	Porto-Aveiro Schedule Overview Excerpt (Line 2).	15
3.7	Aveiro-Porto Headway Overview Excerpt (Line 1).	15
3.8	Porto-Aveiro Headway Overview Excerpt (Line 2).	15
3.9	Marco de Canaveses-Porto Schedule Overview Excerpt (Line 3).	16
3.10	Porto-Marco de Canaveses Schedule Overview Excerpt (Line 4).	16
3.11	Marco de Canaveses-Porto Headway Overview Excerpt (Line 3).	16
3.12	Porto-Marco de Canaveses Headway Overview Excerpt (Line 4).	17
3.13	Guimarães-Porto Schedule Overview Excerpt (Line 5).	17
3.14	Porto-Guimarães Schedule Overview Excerpt (Line 6).	17
3.15	Guimarães-Porto Headway Overview Excerpt (Line 5).	18
3.16	Porto-Guimarães Headway Overview Excerpt (Line 6).	18
3.17	Braga-Porto Schedule Overview Excerpt (Line 7).	18
3.18	Porto-Braga Schedule Overview Excerpt (Line 8).	18
3.19	Braga-Porto Headway Overview Excerpt (Line 7).	19
3.20	Porto-Braga Headway Overview Excerpt (Line 8).	19
3.21	Pairs of lines that can be synchronized and in which nodes.	20
3.22	Aveiro-Porto Schedule Overview Excerpt.	22
3.23	Population Using Trains for Work and Study by Municipality.	25
3.24	Synchronization Weights by Synchronization Paths.	25
4.1	Summary of Model Notation	30
5.1	Definition of the range variation for sensitivity analysis parameters.	36
5.2	Benchmark results.	41
5.3	Headway offset variation results.	42
5.4	Earliest and latest start offset variation results.	44
5.5	Mixed parameter variation results.	44
A.1	Aveiro-Porto Schedule Overview.	52
A.2	Porto-Aveiro Schedule Overview	53
A.3	Marco de Canaveses-Porto Schedule Overview	54
A.4	Porto-Marco de Canaveses Schedule Overview	55
A.5	Guimarães-Porto Schedule Overview	56
A.6	Porto-Guimarães Schedule Overview	56

A.7	Braga-Porto Schedule Overview	57
A.8	Porto-Braga Schedule Overview	57
B.1	Aveiro-Porto Headway Overview	59
B.2	Porto-Aveiro Headway Overview	60
B.3	Marco de Canaveses-Porto Headway Overview	61
B.4	Porto-Marco de Canaveses Headway Overview	62
B.5	Guimarães-Porto Headway Overview.	63
B.6	Porto-Guimarães Headway Overview.	63
B.7	Braga-Porto Headway Overview.	64
B.8	Porto-Braga Headway Overview.	64
C.1	Aveiro-Porto Travel Time to Porto-Campanhã Synchronization Location	66
C.2	Porto-Aveiro Travel Time to Porto-Campanhã Synchronization Location	67
C.3	Marco de Canaveses-Porto Travel Time to Porto-Campanhã Synchronization Location	68
C.4	Marco de Canaveses-Porto Travel Time to Ermesinde Synchronization Location	69
C.5	Porto-Marco de Canaveses Travel Time to Porto-Campanhã Synchronization Location	70
C.6	Porto-Marco de Canaveses Travel Time to Ermesinde Synchronization Location	71
C.7	Guimarães-Porto Travel Time to Porto-Campanhã Synchronization Location	72
C.8	Guimarães-Porto Travel Time to Ermesinde Synchronization Location	72
C.9	Guimarães-Porto Travel Time to Lousado Synchronization Location	73
C.10	Porto-Guimarães Travel Time to Porto-Campanhã Synchronization Location	73
C.11	Porto-Guimarães Travel Time to Ermesinde Synchronization Location	73
C.12	Porto-Guimarães Travel Time to Lousado Synchronization Location	74
C.13	Braga-Porto Travel Time to Porto-Campanhã Synchronization Location	74
C.14	Braga-Porto Travel Time to Ermesinde Synchronization Location	75
C.15	Braga-Porto Travel Time to Lousado Synchronization Location	76
C.16	Porto-Braga Travel Time to Porto-Campanhã Synchronization Location	76
C.17	Porto-Braga Travel Time to Ermesinde Synchronization Location	77
C.18	Porto-Braga Travel Time to Lousado Synchronization Location	77
D.1	Aveiro-Porto Time Deviations to Porto-Campanhã Synchronization Location	79
D.2	Porto-Aveiro Time Deviations to Porto-Campanhã Synchronization Location	80
D.3	Marco de Canaveses-Porto Time Deviations to Porto-Campanhã Synchronization Location.	81
D.4	Marco de Canaveses-Porto Time Deviations to Ermesinde Synchronization Location.	82
D.5	Porto-Marco de Canaveses Time Deviations to Porto-Campanhã Synchronization Location.	83
D.6	Porto-Marco de Canaveses Time Deviations to Ermesinde Synchronization Location.	84
D.7	Guimarães-Porto Time Deviations to Porto-Campanhã Synchronization Location.	85
D.8	Guimarães-Porto Time Deviations to Ermesinde Synchronization Location.	85
D.9	Guimarães-Porto Time Deviations to Lousado Synchronization Location	86
D.10	Porto-Guimarães Time Deviations to Porto-Campanhã Synchronization Location.	86
D.11	Porto-Guimarães Time Deviations to Ermesinde Synchronization Location.	86
D.12	Porto-Guimarães Time Deviations to Lousado Synchronization Location.	87
D.13	Braga-Porto Time Deviations to Porto-Campanhã Synchronization Location.	87
D.14	Braga-Porto Time Deviations to Ermesinde Synchronization Location.	88

D.15 Braga-Porto Time Deviations to Lousado Synchronization Location.	89
D.16 Porto-Braga Time Deviations to Porto-Campanhã Synchronization Location. . . .	89
D.17 Porto-Braga Time Deviations to Ermesinde Synchronization Location	90
D.18 Porto-Braga Time Deviations to Lousado Synchronization Location.	90

Abbreviations and Symbols

API Application Programming Interface.

CP Comboios Portugal.

ID Identifier.

PDF Portable Document Format.

PT Public Transport.

SQL Structured Query Language.

TID1 Train Identifier 1.

TID2 Train Identifier 2.

TT Travel Time.

Chapter 1

Introduction

As cities continue to grow, urban mobility becomes a significant priority. Currently, approximately 4 billion people live in urban areas, and this number is expected to rise to 6 billion by 2050. This rapid urbanization brings challenges such as congestion, air pollution, accessibility, and affordability, exacerbated by limited capital investment in infrastructure. To address these challenges, new transportation technologies like ride-hailing, trip planning, micro-mobility, and micro-transit have emerged. While these solutions have made strides in tackling urban mobility issues, they often focus on a single mode or journey and are managed separately, limiting their overall effectiveness. According to the WEF (2020), a Seamless Integrated Mobility System is essential, aiming to coordinate different transportation modes and orchestrate the complex web of stakeholders involved in urban mobility, creating a more efficient and cohesive transportation network.

1.1 Context

Porto's urban trains present a unique set of challenges due to the extensive variability across routes. These routes span a radius of up to 60 kilometers from Porto, encompassing both urban and rural areas. This geographical diversity necessitates balancing the needs of densely populated urban centers with those of less populated rural regions.

Addressing this variability is a substantial undertaking. Each line has different operational characteristics, including the number of daily runs, headway times, starting and ending operational times, travel times, and paths. These factors contribute to a complex network requiring adaptive and flexible scheduling approaches. Enhancing the connectivity of PT in such a network, with its variable frequencies, is crucial for improving passenger experience and system efficiency.

The ultimate objective is to move toward seamless travel, minimizing transfer times and ensuring smooth connections between different services. This goal demands meticulous planning and coordination to manage the diverse elements effectively. By focusing on seamless travel, we aim to enhance the overall connectivity and reliability of Porto's urban train network, ultimately benefiting both urban and rural passengers.

1.2 Motivation

The planning and scheduling of Porto's urban trains is complex due to the many variables involved. In this work, the term route refers to the operation conducted on a physical railway. Conversely, the term line pertains to the operation in each direction along a particular railway route.

The system connects Porto - São Bento, the main hub, with four routes: Aveiro, Marco de Canaveses, Guimarães, and Braga. Each route has its own characteristics, making the planning process particularly intricate.

Firstly, each line has a different number of daily runs, reflecting the differing passenger demands across regions. Some lines experience high frequencies with trains every few minutes, while others may have less frequent services.

Secondly, headway times, or the intervals between consecutive runs, differ not only between lines but also within the same line across different times of the day. This variability impacts passenger waiting times and requires precise management.

Thirdly, the starting and ending operational times are not uniform. Each line has distinct schedules, with some starting earlier in the day and others extending late into the night, complicating the synchronization process.

Fourthly, travel times for each run are unique due to the varying stations served by different lines. Some trains make more stops than others, resulting in longer or shorter travel duration.

Additionally, each line may have multiple paths, further adding to the complexity of creating cohesive schedules. These variations necessitate a flexible and adaptive approach to planning.

The challenge lies in how to address such variability and enhance connectivity in a network with variable frequencies. Moving towards seamless travel in this context means creating schedules that accommodate the complexities of different lines while ensuring that passengers experience minimal disruption. This research seeks to explore strategies and methodologies to optimize scheduling, improve transfer coordination, and provide a more efficient and user-friendly PT system for the Porto metropolitan area.

1.3 Methodology

The methodology of this dissertation comprises several key steps, ensuring a comprehensive approach to addressing the challenges in optimizing the synchronization of PT routes in the Porto urban train network.

The first step involves conducting a continuous literature review throughout the research process. This ongoing review is essential for identifying existing solutions and methodologies in transport planning and optimization. It helps to inform the search for effective strategies to address the specific challenges encountered in optimizing PT route synchronization in the Porto urban train network. This ensures that the research remains grounded in the current state of knowledge and builds upon established theories and practices in the field.

The second step is the selection of the case study, specifically focusing on the Porto urban trains. This choice provides a practical and relevant context for applying and testing the developed methodologies.

Next, an in-depth analysis of the particularities of the network is conducted. This involves understanding the unique characteristics and operational dynamics of the four main routes: Aveiro, Marco de Canaveses, Guimarães, and Braga; and their interactions within the broader network.

Following this, real data collection and validation is carried out. This step is crucial for grounding the research in actual operational conditions. The data includes schedules, headway times, travel times, and schedule deviations, among other relevant parameters.

With the collected data, a linear programming optimization model is created. This model is tailored to address the specific variability and needs of the Porto urban train network, focusing on minimizing transfer times and enhancing line synchronization.

Subsequently, a sensitivity analysis was conducted to examine the impact of varying different inputs on the model. This analysis evaluates the robustness and effectiveness of the optimization model under various scenarios and conditions, offering insights into its practical applicability and limitations.

Finally, conclusions are formulated based on the analysis of the results. These conclusions summarize the findings, highlight the contributions of the research, discuss any limitations encountered, and suggest potential areas for future work.

This structured methodology ensures a thorough and systematic approach to optimizing PT route synchronization in Porto, aiming to enhance the overall efficiency and passenger experience of the urban train network.

1.4 Dissertation Overview

This dissertation is structured to address the complexities and challenges in optimizing the synchronization of PT routes in the Porto urban train network.

Chapter 2 provides a comprehensive review of the existing literature and standards in transport planning, focusing on methodologies for optimizing route synchronization. It concludes with a summary of the key points from the literature review.

In Chapter 3, the problem statement is outlined, detailing the specific characteristics of the Porto urban train network. This includes in-depth descriptions of the four main routes: Aveiro, Marco de Canaveses, Guimarães, and Braga; and their respective network and operational characteristics. This chapter also covers synchronization characteristics and the real-world data collection process, such as schedules, headway times, travel times, and schedule deviations. Population-based synchronization weights are discussed, and the chapter concludes with a summary.

Chapter 4 presents the mathematical formulation of the problem. It includes the notation used, the objective function, constraints, and domain. The chapter also details the performance metrics that will be used to evaluate the results and ends with a summary of the main points.

In Chapter 5, the results and discussion are provided. This chapter describes the design of experiments and the solver configuration parameters. It presents a benchmark scenario and its performance results, followed by sensitivity analysis results. The chapter concludes with a summary of the findings.

The final chapter, Chapter 6, summarizes the research objectives and the results achieved. It highlights the contributions of the dissertation, discusses limitations, and suggests directions for future work. The chapter concludes with a summary of the dissertation's key points.

Chapter 2

Literature Review

This review addresses established standards in transport planning and explores methods for effective route synchronization. It also examines key approaches to improving service reliability and user satisfaction by reducing transfer times and optimizing PT synchronization.

2.1 Standards in Transport Planning

The concept of seamless travel has been highlighted by the OECD as essential for 21st century transport systems, emphasizing the need for connectivity between rural and urban areas (OECD, 2012). Seamless transport focuses on minimizing transfer times and providing high-quality, door-to-door mobility, which can significantly reduce travel costs. Integrated transport systems not only compete with private transport but are also environmentally friendly, emitting less carbon per passenger or tonne moved. Achieving seamlessness relies on several types of connections: infrastructure connections to minimize transport times between modes, management connections to reduce waiting times, tariff connections to enable multiple transport modes with a single ticket, and technology connections leveraging advanced wireless technology. Real-time information on transport activities can enhance operations and promote efficient time management.

Based on Ceder (2021), the need to transfer between routes significantly contributes to passenger discomfort. Enhancing PT connectivity is crucial for maintaining user satisfaction and ensuring consistent transit usage. Poor connections can lead to passengers abandoning the transit service. By synchronizing PT timetables, passengers can experience seamless, direct transfers, thereby improving the overall service level of PT systems.

According to Liu et al. (2021), the objective of providing well-connected and seamless door-to-door PT services can be achieved by incorporating transfer considerations into each of the three levels of PT planning: strategic, tactical, and operational, as illustrated in 2.1. At the strategic level, long-term decisions regarding infrastructure planning and network design are made. PT agencies can reduce the number of transfers in the network, optimize the layout of transfer centers to facilitate transfers, and integrate payment methods to enhance inter-route or inter-modal

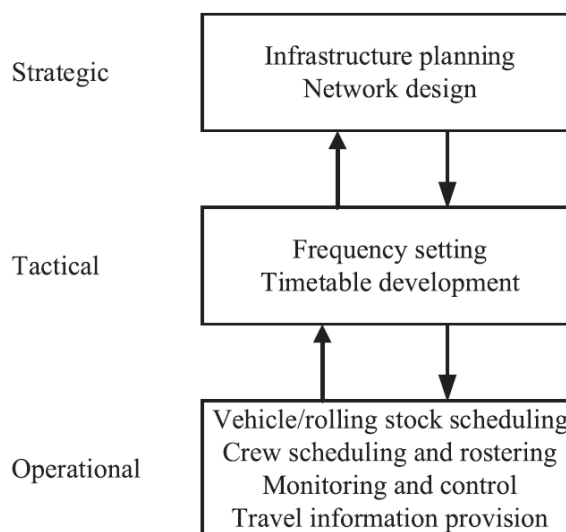


Figure 2.1: The three decision-making levels and related planning/control tasks of PT planning and operations, retrieved from Liu et al. (2021).

service connectivity. At the tactical level, optimizing service frequencies and timetables can minimize passenger transfer waiting times. At the operational level, improved vehicle and rolling stock scheduling, along with real-time monitoring and control measures, such as vehicle holding, stop-skipping, and rescheduling of vehicles, alongside online travel information provision, can be employed to increase the actual occurrences of synchronized transfers.

Transfer coordination design primarily aims to enhance the connectivity, synchronization, reliability, and accessibility of PT services, thereby making them more appealing to passengers (Liu et al., 2021). Implemented at the tactical decision-making level, focuses on developing a timetable that synchronizes the arrival and departure times of PT vehicles at transfer stations. This ensures minimal transfer waiting time or reliable transfer connections for passengers transitioning from one route to another (Castelli et al., 2004; Ceder, 2016; Vuchic, 2005).

Effective transfer coordination can boost PT patronage and potentially encourage a shift from private car use to PT (Chowdhury & Ceder, 2013; Chowdhury et al., 2015). For instance, a survey conducted among commuters in the Brussels Capital Region revealed that 25% of private car users would be willing to switch to PT if improvements were made in transfer connections, service speed, availability, timetables, and frequency (De Witte et al., 2008).

2.2 Optimizing Route Synchronization

Synchronization in the context of PT refers to the coordination of various elements within the transit system to ensure smooth and efficient transfers for passengers. Synchronization aims to align the schedules of different transit services, minimizing transfer waiting times and ensuring timely connections between routes. This involves creating well-coordinated timetables that allow for direct and seamless transfers.

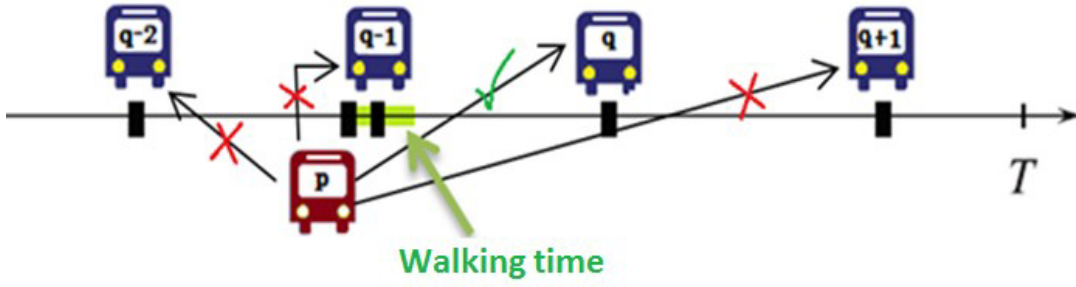


Figure 2.2: Example of synchronization, retrieved from Elbaz et al. (2018).

Elbaz et al. (2018) defines synchronization in public transport as the coordination of arrival times between buses on different lines to minimize passenger waiting times during transfers. According to this perspective, a bus from line i synchronizes with a bus from another line j if the arrival time of the bus from line j at the transfer station occurs after the arrival time of the bus from line i , accounting for the walking time required between stops. Additionally, there should be no other bus arriving between these two buses that satisfies the same timing condition. Figure 2.2 visually depicts this concept of synchronization.

To assess the feasibility of successful transfers at transfer stations in PT systems, synchronization is defined using binary synchronization variables widely adopted in the literature (Cao et al., 2019; Ceder et al., 2001; Fouilhoux et al., 2016; O. J. Ibarra-Rojas & Rios-Solis, 2012; Wu et al., 2015).

These variables are governed by the following equations:

$$(x_{ip} + t_{ipn}) - (x_{jq} + t_{jqn}) \geq w_n - M(1 - y_{ipjqn}) \quad (2.1)$$

$$(x_{ip} + t_{ipn}) - (x_{jq} + t_{jqn}) \leq W_n - M(1 - y_{ipjqn}) \quad (2.2)$$

The first equation (2.1) determines the lower bound for synchronization, where x_{ip} and x_{jq} are the departure times of vehicles p and q from routes i and j respectively, t_{ipn} and t_{jqn} are the travel times from their departure terminals to transfer station n , w_n is the minimal transfer time required, M is a large positive constant, and y_{ipjqn} is a binary variable indicating synchronization success.

The second equation sets the upper bound, where W_n represents the maximal transfer time permissible.

These equations collectively determine whether a transfer from vehicle p of route i to vehicle q of route j at transfer station n is feasible based on the specified time windows. This synchronization approach is critical for optimizing public transport networks by minimizing transfer waiting times and improving passenger travel efficiency.

Another set of equations commonly utilized (2.3, 2.4), as presented by O. J. Ibarra-Rojas and Rios-Solis (2012), enforces constraints that ensure the first trip of each line departs at the beginning of the planning period T , and the last trip departs before T . These constraints are crucial

for optimizing scheduling in public transport, ensuring systematic regulation of transit operations throughout the planning horizon.

$$X_1^i \leq H^i \quad (2.3)$$

$$T - H^i \leq X_{f_i}^i \leq T \quad (2.4)$$

The condition (2.3) dictates that the departure time X_1^i of the first trip on line i occurs no later than H^i , where H^i represents the maximum headway for line i . Essentially, this constraint ensures that the first trip starts within a reasonable time frame from the beginning of the planning period T .

The constraint (2.4) mandates that the departure time $X_{f_i}^i$ of the last trip on line i occurs no earlier than $T - H^i$ and no later than T . Here, T represents the end of the planning period. This constraint ensures that the last trip ends within a reasonable time frame from the end of the planning period T .

Collectively, these constraints ensure that the first and last trips of each line are appropriately timed relative to the planning period T . This systematic approach is crucial for optimizing the operational efficiency and reliability of public transport services.

The inequality (2.5) is a pivotal constraint in public transport scheduling models, extensively discussed in the literature (Elbaz et al., 2018; O. J. Ibarra-Rojas & Rios-Solis, 2012). It serves to regulate the timing between consecutive runs p and $p+1$ on the same line i . Here, h^i represents the minimum allowable headway, ensuring there is a sufficient time gap between the departure of trip p and trip $p+1$ to maintain operational reliability and passenger satisfaction. Conversely, H^i sets the maximum allowable headway, defining the upper limit for the time interval between these trips, thereby ensuring service remains predictable and efficient. By enforcing these constraints, public transport planners optimize service frequencies and enhance overall system reliability, aligning operational schedules with passenger demand while improving the overall quality of service delivery.

$$h^i \leq X_{p+1}^i - X_p^i \leq H^i \quad (2.5)$$

The objective function (2.6) is commonly used in public transport scheduling models to maximize the number of synchronizations between different lines i and j within a network, a concept extensively discussed by O. Ibarra-Rojas et al. (2015) and O. J. Ibarra-Rojas and Rios-Solis (2012). Here, Y_{ijpqb} is a binary synchronization variable indicating whether run p of line i synchronizes with run q of line j at node b . The function maximizes the total number of these synchronizations across all pairs of lines i and j , ensuring that the scheduling decisions enhance the coordination and connectivity of public transport services.

$$\max \sum_i \sum_j \sum_b \sum_p \sum_q Y_{ijpqb} \quad (2.6)$$

2.3 Summary

The literature review covers the critical aspects of seamless travel and its importance for 21st century transport systems. It discusses how integrated transport systems can reduce travel costs and emissions while enhancing user satisfaction through improved connectivity. The review emphasizes the need for synchronization of PT timetables to minimize transfer times and enhance service reliability. It explores the strategic, tactical, and operational planning levels necessary for achieving well connected PT services. Various synchronization methods, constraints, and objective functions are discussed to optimize PT networks, ultimately aiming to increase PT usage and reduce dependence on private transport.

Chapter 3

Problem Statement

This chapter outlines the problem statement, focusing on the intricacies of the train network serving the Porto metropolitan area and surrounding sub-regional cities. It delves into various characteristics of the network, including its physical and operational aspects, synchronization attributes, and the methodology for collecting real-world data essential for the optimization model.

3.1 Network Characteristics

This study explores the synchronization of a complex train network featuring four distinct routes: Aveiro, Marco de Canaveses, Guimarães, and Braga. Each route operates in two directions, which are considered independently in this analysis, resulting in eight distinct lines.

The focus is on three key synchronization nodes: Porto - Campanhã, Ermesinde, and Lousado. For a visual representation of the network, refer to Figure 3.1.

The network under investigation is situated in Portugal and forms an integral part of the Porto Urban Trains system. It encompasses 82 stations within a 60 kilometer radius around Porto, serving as a crucial transportation backbone for the region.

This study specifically focuses on two types of railway services within this network:

- **Urban Trains:** Operating within the Porto metropolitan area.
- **Suburban Trains:** Serving nearby sub-regional cities.

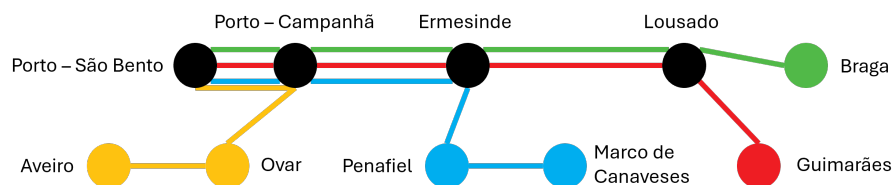


Figure 3.1: Schematic Representation of the Public Transport Network.

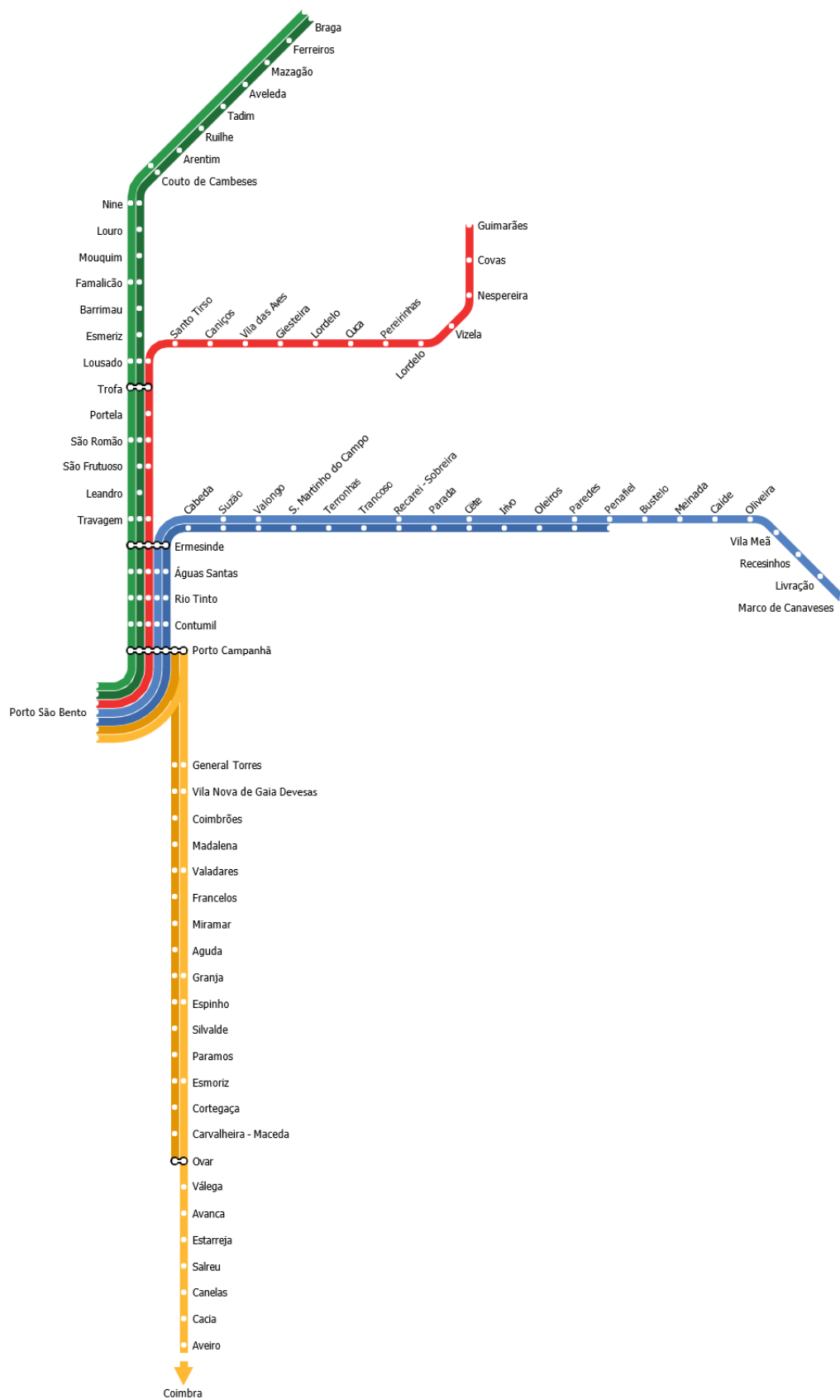


Figure 3.2: Detailed Representation of the Public Transport Network, retrieved from MIH (2022).

Furthermore, the Porto Urban Trains facilitate connections to other services, including International, Alfa Pendular, Intercidades, InterRegional, and Regional trains. However, these services fall outside the scope of this study.

It is also noteworthy that this network integrates with many intermodal connections at key hubs like Ermesinde, Porto Campanhã, and Porto São Bento. Despite these connections, intermodal transportation is not within the scope of this work.

Figure 3.2 depicts the detailed rail network in and around Porto, highlighting the routes to Aveiro, Marco de Canaveses, Guimarães, and Braga. The network converges at key junctions in Porto, specifically at Porto São Bento and Porto Campanhã stations. The route to Aveiro is represented in yellow, with trains taking two different paths, offering various stops onward until reaching Aveiro or Ovar, and vice versa. The Marco de Canaveses route, shown in blue, also has two distinct paths, terminating at Marco de Canaveses or earlier at Penafiel, serving different stations along the way, and vice versa. The Guimarães route, depicted in red, connects Porto to Guimarães, while the Braga route, shown in green, links Porto with Braga. Figure 3.2 provides a comprehensive view of the main rail routes and their significant stops, demonstrating the connectivity and flexibility within the Porto rail system.

3.1.1 Aveiro

The Aveiro route extends 65.9 kilometers, serving 25 stations and traversing six municipalities: Porto, Vila Nova de Gaia, Espinho, Ovar, Estarreja, and Aveiro.

Several trains use Ovar station as both their starting and ending points, forming a shorter sub route. Based on this setup, Table 3.1 outlines the distinct lines operating on the Aveiro route. The two lines on this route are as follows: Line 1 operates in the Aveiro - Porto direction, while Line 2 runs in the Porto - Aveiro direction.

Table 3.1: Aveiro Route Lines.

Line	Main Path	Sub-Path
Line 1	Begins at Aveiro station Ends in Porto	Begins at Ovar station Ends in Porto
Line 2	Begins at Porto Ends in Aveiro station	Begins at Porto Ends in Ovar station

When analyzing train services along the Aveiro route lines (Table 3.1), it is crucial to understand the context of Porto origination and termination as they refer to specific stations. Some trains originate or terminate their journeys at Porto - São Bento, while others commence or conclude at Porto - Campanhã, as shown in the Schedules Appendix A. Additionally, trains passing through Porto - Campanhã must reverse direction, observable in Figure 3.2. This operation involves not only changing the train's direction but also requires the train driver to move to the opposite cabin, restart, and test the train systems. This entire process typically lasts approximately five minutes.

3.1.2 Marco de Canaveses

The Marco de Canaveses route stretches 62.6 kilometers, encompassing 27 stations and passing through nine municipalities: Porto, Gondomar, Maia, Valongo, Paredes, Penafiel, Lousada, Amarante, and Marco de Canaveses.

Some trains start and end at Penafiel station, creating a sub route within the Marco de Canaveses route. Table 3.2 provides details on the specific lines operating along this route. Line 3 serves the Marco - Porto direction, while Line 4 covers the Porto - Marco direction.

Table 3.2: Marco de Canaveses Route Lines.

Line	Main Path	Sub-Path
Line 3	Begins at Marco de Canaveses station Ends at Porto - São Bento station	Begins at Penafiel station Ends at Porto - São Bento station
Line 4	Begins at Porto - São Bento station Ends at Marco de Canaveses station	Begins at Porto - São Bento station Ends at Penafiel station

3.1.3 Guimarães

The Guimarães route spans 58.3 kilometers, linking 24 stations and covering nine municipalities: Porto, Gondomar, Maia, Valongo, Trofa, Famalicão, Santo Tirso, Vizela, and Guimarães.

Table 3.3 presents the starting and ending stations for the lines that operate on the Guimarães route. Line 5 operates in the Guimarães - Porto direction, while Line 6 runs in the Porto - Guimarães direction.

Table 3.3: Guimarães Route Lines.

Line	Path
Line 5	Begins at Guimarães station Ends in Porto - São Bento station
Line 6	Begins at Porto - São Bento station Ends in Guimarães station

3.1.4 Braga

The Braga route covers 56.5 kilometers, connecting 27 stations and passing through eight municipalities: Porto, Gondomar, Maia, Valongo, Trofa, Famalicão, Barcelos, and Braga.

Table 3.4 details the initial and final stations for the lines running on the Braga route. Line 7 serves the Braga - Porto direction, while Line 8 covers the Porto - Braga direction.

Table 3.4: Braga Route Lines.

Line	Path
Line 7	Begins at Braga station Ends in Porto - São Bento station
Line 8	Begins at Porto - São Bento station Ends in Braga station

3.2 Operational Characteristics

This section delves into the operational characteristics of each train route, offering an overview of their schedules, number of daily runs, and specific operational details. For each line in the Aveiro, Marco de Canaveses, Guimarães, and Braga routes, the operational schedule is analyzed to outline the first departure time and the last arrival time, providing a clear understanding of the operational time frame for each line.

Additionally, the number of runs conducted daily on each line is discussed, highlighting the level of service provided. It is important to note that travel times are not uniform across all runs, as certain trains do not stop at every station, leading to variations in travel duration.

Furthermore, variations in headway throughout the operational day, influenced by changes in demand, are assessed. Both the minimum and maximum headway for each line on each route are presented.

This study focuses specifically on weekday operations, excluding weekends. Addressing these operational characteristics provides a comprehensive picture of the dynamics and complexity of the train network.

3.2.1 Aveiro

The Aveiro route operates from 04:31AM to 01:08AM the following day, resulting in a total operational span of 20 hours and 37 minutes. Within this time frame, there are 52 distinct runs on both Line 1 and Line 2.

These runs exhibit significant variations in Travel Time (TT) due to the specific combinations of stations they serve. This variation is evidenced in Table 3.5 and Table 3.6, respectively for Line 1 and Line 2, which present excerpts of the data found in the Schedules Appendix A.

Table 3.5: Aveiro-Porto Schedule Overview Excerpt (Line 1).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
AVEIRO	PORTO-SÃO BENTO	04:31	06:00	89	15601	15600	1
AVEIRO	PORTO-CAMPANHÃ	05:16	06:34	78	15603	15603	2
AVEIRO	PORTO-SÃO BENTO	06:18	07:35	77	15605	15604	3
OVAR	PORTO-CAMPANHÃ	06:48	07:39	51	15801	15801	4

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
AVEIRO	PORTO-CAMPANHÃ	06:46	07:57	71	15607	15607	5
OVAR	PORTO-CAMPANHÃ	07:31	08:23	52	15803	15803	6

Table 3.6: Porto-Aveiro Schedule Overview Excerpt (Line 2).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	AVEIRO	04:35	06:00	85	15703	15702	1
PORTO-SÃO BENTO	AVEIRO	05:40	06:57	77	15707	15706	2
PORTO-SÃO BENTO	OVAR	05:55	06:56	61	15901	15900	3
PORTO-CAMPANHÃ	AVEIRO	06:40	07:43	63	15708	15708	4
PORTO-CAMPANHÃ	OVAR	06:45	07:36	51	15902	15902	5
PORTO-SÃO BENTO	AVEIRO	06:50	08:07	77	15711	15710	6

An examination of train operations along the Aveiro route reveals significant fluctuations in train frequency throughout the day, Line 1 with headway times ranging from a minimum of 5 minutes to a maximum of 62 minutes, while Line 2 operates with headway times between 5 and 65 minutes. These variations stem from shifts in passenger demand, resulting in diverse headway times between consecutive runs. Detailed information on these variations can be found in the Headway Appendix B, with Table 3.7 and Table 3.8 providing excerpts for Line 1 and Line 2, respectively.

Table 3.7: Aveiro-Porto Headway Overview Excerpt (Line 1).

Origin	Departure	Headway	TID1	TID2	Run
OVAR	05:41	44	15603	15603	2
OVAR	06:43	62	15605	15604	3
OVAR	06:48	5	15801	15801	4
OVAR	07:09	21	15607	15607	5
OVAR	07:31	22	15803	15803	6
OVAR	07:48	17	15609	15608	7

Table 3.8: Porto-Aveiro Headway Overview Excerpt (Line 2).

Origin	Departure	Headway	TID1	TID2	Run
PORTO-CAMPANHÃ	05:50	65	15707	15706	2
PORTO-CAMPANHÃ	06:05	15	15901	15900	3
PORTO-CAMPANHÃ	06:40	35	15708	15708	4
PORTO-CAMPANHÃ	06:45	5	15902	15902	5
PORTO-CAMPANHÃ	07:00	15	15711	15710	6
PORTO-CAMPANHÃ	07:05	5	15905	15904	7

Notably, not all train runs share the same starting and ending stations. For the purpose of determining headway times, the first stations common to every run are considered (frequency measurement locations): Ovar for Line 1 and Porto - Campanhã for Line 2, as demonstrated in Table 3.7 and Table 3.8, independently for each of these lines.

3.2.2 Marco de Canaveses

The operational activities on the Marco de Canaveses route commence at 04:18AM and conclude at 01:51AM the subsequent day, spanning 21 hours and 33 minutes. Both Line 3 and Line 4 operate with distinct schedules comprising 36 and 37 runs, respectively.

These schedules exhibit notable variations in TT due to the specific station combinations served by each run. Detailed schedule excerpts for Line 3 and Line 4 can be found in Table 3.9 and Table 3.10 from Schedules Appendix A.

Table 3.9: Marco de Canaveses-Porto Schedule Overview Excerpt (Line 3).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	PORTO-SÃO BENTO	04:18	05:40	82	15500	15500	1
MARCO	PORTO-SÃO BENTO	05:08	06:30	82	15502	15502	2
PENAFIEL	PORTO-SÃO BENTO	05:57	06:50	53	15400	15400	3
MARCO	PORTO-SÃO BENTO	06:00	07:10	70	15504	15504	4
MARCO	PORTO-SÃO BENTO	06:13	07:30	77	15506	15506	5
PENAFIEL	PORTO-SÃO BENTO	07:07	08:00	53	15402	15402	6

Table 3.10: Porto-Marco de Canaveses Schedule Overview Excerpt (Line 4).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	MARCO	05:30	06:40	70	15503	15503	1
PORTO-SÃO BENTO	MARCO	06:30	07:39	69	15505	15505	2
PORTO-SÃO BENTO	PENAFIEL	07:00	07:53	53	15401	15401	3
PORTO-SÃO BENTO	MARCO	07:30	08:43	73	15507	15507	4
PORTO-SÃO BENTO	PENAFIEL	08:00	08:53	53	15403	15403	5
PORTO-SÃO BENTO	MARCO	08:30	09:39	69	15511	15511	6

Throughout the operational day, train frequency fluctuates significantly along Lines 3 and 4. In Line 3, the headway varies from a minimum of 3 minutes to a maximum of 60 minutes, whereas in Line 4, it varies between 5 and 120 minutes. Appendix B details the headway in Lines 3 and 4 throughout a workday, while Tables 3.11 and 3.12 provide an excerpt of that list.

Table 3.11: Marco de Canaveses-Porto Headway Overview Excerpt (Line 3).

Origin	Departure	Headway	TID1	TID2	Run
PENAFIEL	18:48	41	15544	15544	31
PENAFIEL	19:07	19	15426	15426	32
PENAFIEL	19:44	37	15546	15546	33
PENAFIEL	20:38	54	15548	15548	34
PENAFIEL	21:36	58	15550	15550	35
PENAFIEL	22:36	60	15552	15552	36

Table 3.12: Porto-Marco de Canaveses Headway Overview Excerpt (Line 4).

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	19:30	30	15545	15545	31
PORTO-SÃO BENTO	19:40	10	15431	15431	32
PORTO-SÃO BENTO	20:00	20	15433	15433	33
PORTO-SÃO BENTO	20:30	30	15549	15549	34
PORTO-SÃO BENTO	21:30	60	15551	15551	35
PORTO-SÃO BENTO	23:30	120	15553	15553	36

Importantly, not all runs start at the same station on Line 3. To calculate the headway on this line, the departures from Penafiel station are used, since it is the first common station for all runs on Line 3, the frequency measurement location. This is illustrated in Table 3.11.

3.2.3 Guimarães

The operational timeline for the Guimarães route spans from 05:53AM to 00:32AM the following day, totaling 18 hours and 39 minutes of service. Line 5 and Line 6 each operate with 16 distinct runs, showcasing varied travel times depending on the stations served. Specific schedule details for Line 5 and Line 6 are available in Table 3.13 and Table 3.14 from Appendix A.

Table 3.13: Guimarães-Porto Schedule Overview Excerpt (Line 5).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
GUIMARÃES	PORTO-SÃO BENTO	05:53	07:05	72	15150	15150	1
GUIMARÃES	PORTO-SÃO BENTO	07:02	08:05	63	15154	15154	2
GUIMARÃES	PORTO-SÃO BENTO	07:21	08:50	89	15156	15156	3
GUIMARÃES	PORTO-SÃO BENTO	08:02	09:05	63	15158	15158	4
GUIMARÃES	PORTO-SÃO BENTO	08:53	10:05	72	15160	15160	5
GUIMARÃES	PORTO-SÃO BENTO	09:53	11:10	77	15162	15162	6

Table 3.14: Porto-Guimarães Schedule Overview Excerpt (Line 6).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	GUIMARÃES	06:20	07:42	82	15151	15151	1
PORTO-SÃO BENTO	GUIMARÃES	07:25	08:37	72	15153	15153	2
PORTO-SÃO BENTO	GUIMARÃES	08:25	09:41	76	15155	15155	3
PORTO-SÃO BENTO	GUIMARÃES	09:25	10:27	62	15157	15157	4
PORTO-SÃO BENTO	GUIMARÃES	10:25	11:38	73	15159	15159	5
PORTO-SÃO BENTO	GUIMARÃES	11:25	12:41	76	15161	15161	6

Fluctuations in train frequency throughout the day are notable on the Guimarães route, reflecting shifts in passenger demand. Line 5 operates with headway times from a minimum of 19 minutes to a maximum of 120 minutes, and Line 6 features headway times between 15 and 125 minutes. Detailed headway information, highlighting these variations, is provided in Table 3.15 and Table 3.16, selections from the Headway Appendix B, for Line 5 and Line 6, respectively.

Table 3.15: Guimarães-Porto Headway Overview Excerpt (Line 5).

Origin	Departure	Headway	TID1	TID2	Run
GUIMARÃES	13:53	60	15168	15168	9
GUIMARÃES	15:53	120	15170	15170	10
GUIMARÃES	17:07	74	15172	15172	11
GUIMARÃES	18:13	66	15176	15176	12
GUIMARÃES	19:21	68	15178	15178	13
GUIMARÃES	20:20	59	15182	15182	14

Table 3.16: Porto-Guimarães Headway Overview Excerpt (Line 6).

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	16:20	120	15167	15167	9
PORTO-SÃO BENTO	17:25	65	15169	15169	10
PORTO-SÃO BENTO	18:25	60	15171	15171	11
PORTO-SÃO BENTO	19:10	45	15173	15173	12
PORTO-SÃO BENTO	19:25	15	15175	15175	13
PORTO-SÃO BENTO	20:20	55	15177	15177	14

3.2.4 Braga

The Braga route operates between 04:34AM and 01:53AM the following day, offering service for 21 hours and 19 minutes each operational day. Line 7 and Line 8 operate with 25 and 26 distinct runs, respectively, exhibiting varied travel times depending on the stations served. Detailed schedules for Line 7 and Line 8 are presented in Table 3.17 and Table 3.18 from Appendix A

Table 3.17: Braga-Porto Schedule Overview Excerpt (Line 7).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	PORTO-SÃO BENTO	04:34	05:45	71	15200	15200	1
BRAGA	PORTO-SÃO BENTO	05:29	06:45	76	15202	15202	2
BRAGA	PORTO-SÃO BENTO	06:21	07:15	54	15204	15204	3
BRAGA	PORTO-SÃO BENTO	06:29	07:45	76	15206	15206	4
BRAGA	PORTO-SÃO BENTO	07:21	08:15	54	15208	15208	5
BRAGA	PORTO-SÃO BENTO	07:45	08:35	50	15212	15212	6

Table 3.18: Porto-Braga Schedule Overview Excerpt (Line 8).

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	BRAGA	06:15	07:09	54	15203	15203	1
PORTO-SÃO BENTO	BRAGA	06:45	07:56	71	15205	15205	2
PORTO-SÃO BENTO	BRAGA	07:15	08:17	62	15207	15207	3
PORTO-SÃO BENTO	BRAGA	07:45	08:56	71	15209	15209	4
PORTO-SÃO BENTO	BRAGA	08:15	09:09	54	15211	15211	5
PORTO-SÃO BENTO	BRAGA	08:45	09:56	71	15213	15213	6

Throughout the operational day, there are notable fluctuations in train frequency along the Braga route due to varying passenger demand. Line 7 with headway times ranging from a minimum of 8 minutes to a maximum of 120 minutes, and Line 8 operates with headway times between 25 and 105 minutes. The Headway Appendix B provides detailed information on these variations, part of it are Table 3.19 and Table 3.20 for Line 7 and Line 8, respectively.

Table 3.19: Braga-Porto Headway Overview Excerpt (Line 7).

Origin	Departure	Headway	TID1	TID2	Run
BRAGA	08:34	30	15218	15218	8
BRAGA	09:37	63	15220	15220	9
BRAGA	10:39	62	15222	15222	10
BRAGA	11:34	55	15224	15224	11
BRAGA	12:29	55	15226	15226	12
BRAGA	13:21	52	15228	15228	13

Table 3.20: Porto-Braga Headway Overview Excerpt (Line 8).

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	10:45	45	15217	15217	8
PORTO-SÃO BENTO	11:45	60	15219	15219	9
PORTO-SÃO BENTO	12:15	30	15221	15221	10
PORTO-SÃO BENTO	12:40	25	15223	15223	11
PORTO-SÃO BENTO	13:45	65	15225	15225	12
PORTO-SÃO BENTO	14:55	70	15227	15227	13

3.3 Synchronization Characteristics

The synchronization characteristics of the train network are crucial for efficient passenger transfers and cohesive timetables. Table 3.21 details which lines can synchronize, the nodes where these synchronizations take place, and the directional flow of passengers.

The first column of Table 3.21 represents the starting lines, while the first row indicates the lines that these starting lines can transfer to upon synchronization. Synchronization occurs at three key nodes: Porto - Campanhã (1), Ermesinde (2), and Lousado (3). The synchronization node elected is the first common node in the line path for both synchronizing lines.

No lines from the same route can synchronize with each other, and lines with the same origin do not synchronize with each other, as lines starting from the main hub, Porto - São Bento, which already dispatches trains to every destination, making synchronization to another line unnecessary.

Synchronization is only possible from peripheral nodes to other peripheral nodes:

- From Aveiro (Line 1), synchronization is possible with lines coming from the main hub to Marco de Canaveses (Line 4, at Porto - Campanhã node), Guimarães (Line 6, at Porto - Campanhã node), or Braga (Line 8, at Porto - Campanhã node).

Table 3.21: Pairs of lines that can be synchronized and in which nodes.

Lines	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8
Line 1				1		1		1
Line 2								
Line 3		1				2		2
Line 4								
Line 5		1		2				3
Line 6								
Line 7		1		2		3		
Line 8								

- From Marco de Canaveses (Line 3), synchronization is possible with lines coming from the main hub to Aveiro (Line 2, at Porto - Campanhã node), Guimarães (Line 6, at Ermesinde node), or Braga (Line 8, at Ermesinde node).
- From Guimarães (Line 5), synchronization is possible with lines coming from the main hub to Aveiro (Line 2, at Porto - Campanhã node), Marco de Canaveses (Line 4, at Ermesinde node), and Braga (Line 8, at Lousado node).
- From Braga (Line 7), synchronization is possible with lines coming from the main hub to Aveiro (Line 2, at Porto - Campanhã node), Marco de Canaveses (Line 4, at Ermesinde node), and Guimarães (Line 6, at Lousado node).

The optimization model will exclusively focus on synchronizing the specified pairs of lines at each designated node, as outlined in Table 3.21. By concentrating on these pairs and nodes, the model aims to create a cohesive and efficient timetable that enhances passenger transfers at key junctions. This targeted approach ensures that the synchronization efforts are directed towards maximizing the usability of the train network, providing seamless connections between peripheral routes and the central hub. This strategy is essential for achieving optimal operational performance and passenger satisfaction within the constraints of the existing infrastructure.

3.4 Real-World Data and Collection Process

The effective analysis and synthesis of transportation systems depend critically on the availability and quality of data. This section outlines the methodologies and sources employed to gather essential datasets for the study, encompassing schedules, headway, travel times, schedule deviations, and population-based synchronization weights.

The primary source of information was the Comboios Portugal (CP) website¹, which serves as the official repository for train schedules. This website provided comprehensive data for each route and was particularly useful for verifying the consistency and accuracy of the collected data.

¹<https://www.cp.pt>

To streamline the data collection process and avoid the time-consuming and error-prone task of analyzing extensive schedule Portable Document Format (PDF) files, a public Application Programming Interface (API) endpoint was utilized. This endpoint allowed querying for runs information using specific parameters such as station Identifier (ID), start and end times for the analysis, and service type. Depending on the time interval queried, the API response would contain no information for past intervals, real-time data for current intervals, or scheduled train runs for future intervals. The endpoint provided information for both departures and arrivals, albeit in a format that required significant post processing.

The relevant data extracted from the API included several key details for each retrieved run:

- Boolean indicating whether the train had already passed
- Origin station ID
- Destination station ID
- Origin station name
- Destination station name
- Departure or arrival time at the queried station
- Train identifier (primary)
- Train identifier (secondary, for trains changing direction; each direction uses a distinct identifier)
- Real-time delay of the train
- Service type (international, high-speed, intercity, inter regional, regional, urban/suburban, special, freight, or service)
- Service operator

The data was cleaned and processed using different Python and Structured Query Language (SQL) scripts to build the datasets for schedules, headway, travel times, and deviations. Subsequently, the processed data was stored in an SQLite database for further analysis and retrieval.

For the population-based synchronization weights, data was gathered from trustworthy statistical providers. This demographic data was crucial in quantifying synchronization weights by aggregating passenger populations across municipalities served by the rail network, aiding in optimizing transit schedules to align with commuter needs and travel patterns.

3.4.1 Schedules

The accurate collection and verification of train schedules are foundational to the effective analysis of transportation systems. The initial data collection for train schedules was conducted using a public API. A Python script was utilized to query the API for a future time interval, retrieving the scheduled runs. The API provided various details about each run, including departure and arrival times, origin and destination stations, train identifiers, and more. This data was then processed and stored in an SQLite database for further analysis.

To ensure consistency and accuracy, the retrieved data underwent several processing steps. The runs were ordered based on the sequence of departures from the location where the frequency is measured. This method was necessary because, in some cases, such as Lines 1, 2, and 3, the runs start from different stations. Simply using the departure time of each run would result in inconsistencies. This approach mirrors the methodology used in the official schedules from the CP website².

An SQL script was employed to calculate the travel time for each run. This script computed the difference between the arrival and departure times, filling the travel time column with these values, in each database table respectively related to each of the routes lines.

The processed schedule data was subsequently confirmed against the official schedules available on the CP website. This verification step ensured that the data used in the study was accurate and reliable.

The schedules for all routes and lines are detailed in Schedule Appendix A. This appendix includes crucial information such as origin and destination stations, departure and arrival times, travel times, primary and secondary train identifiers (Train Identifier 1 (TID1) and Train Identifier 2 (TID2)), and run numbers.

In most cases, the TID1 and TID2 train identifiers are equal. However, they differ when trains are in service on routes that change direction, such as the Aveiro route when crossing Porto - Campanhã station. In these instances, the TID1 represents the train's identifier during operation in the first direction, while the TID2 is used for the opposite direction. This differentiation aids in internal organization and is consistent with the identifiers assigned to each run in the CP schedules. Table 3.22 highlights runs from the Aveiro route that have equal or different identifiers.

Table 3.22: Aveiro-Porto Schedule Overview Excerpt.

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
AVEIRO	PORTO-SÃO BENTO	04:31	06:00	89	15601	15600	1
AVEIRO	PORTO-CAMPANHÃ	05:16	06:34	78	15603	15603	2
AVEIRO	PORTO-SÃO BENTO	06:18	07:35	77	15605	15604	3
OVAR	PORTO-CAMPANHÃ	06:48	07:39	51	15801	15801	4

Besides the primary columns mentioned above available on Schedule Appendix A, the database tables also contain additional columns for comprehensive data analysis. These include origin station ID, destination station ID, service type (always urban and suburban, as these are the focus of

²<https://www.cp.pt>

this study), and operator (always CP Porto, since the study concentrates on the Porto urban trains operated by CP).

By meticulously collecting, processing, and verifying the schedule data, this study ensures a robust foundation for subsequent analysis and optimization of train synchronization within the network.

3.4.2 Headway

The headway for all routes, lines, and respective runs can be found in Headway Appendix B. Calculation of headway times relied on the data collected from the schedules (3.4.1), which served as the foundation for this analysis. Using an SQL script, headway times for each run of every line and route were determined by measuring the time interval between successive departures.

Special considerations were necessary for certain lines, such as Lines 1, 2, and 3, where runs originate from different stations. In these cases, headway times were calculated starting from the first common station on their respective paths: Line 1 from Ovar, Line 2 from Porto - Campanhã, and Line 3 from Penafiel.

It's important to note that direct access to frequency data was not available; instead, frequencies were inferred from the timetables obtained from the current CP schedules. This approach ensured consistent and accurate measurement of headway times for each line and route. Additionally, it was not possible to identify clear uniform demand periods, so the analysis focused on frequency upon each run.

3.4.3 Travel Times

The calculation of travel times relied on the data previously gathered from the schedules (3.4.1).

The travel times used as inputs for the synchronization model represent the duration in minutes for runs to reach specific synchronization nodes. This data is pivotal for optimizing synchronization across the network.

Additional schedule details were accessed from the CP online schedules repository to determine the arrival times of each train at synchronization stations.

Utilizing departure times extracted from the schedules and, where applicable, the corresponding arrival times at each synchronization node, an SQL script computed the time differences to determine the travel time to each specific synchronization node. It should be noted that not every train run passes through all synchronization nodes.

All travel times for every route, line, run, and to every node crossed can be found in Travel Time Appendix C.

3.4.4 Schedule Deviations

To analyze schedule deviations, a virtual machine was set up to host a Python cron job. This job executed every five minutes on weekdays, querying the public API to retrieve real-time train data. Among the fields retrieved was the delay, which allowed for the detection and storage of late

trains data in an SQLite database. The script ran continuously for 15 days, and the mean schedule deviations for each run, calculated over this period, are presented in Deviations Appendix D.

By querying all trains from the beginning of the day, it was possible to record cases where trains had delays even before starting their operation. On some days, such as during strikes, records showed trains with delays close to 24 hours, indicating suppression. These suppression cases were ignored when calculating the mean schedule deviations for each run.

The data collection process involved two scripts. The first script queried the API and stored all run data. The second script, executed locally, calculated the mean schedule deviations, preparing the data for use in the optimization model.

Like travel times, these deviations serve as inputs for the model, focusing on the deviations for each run until reaching the synchronization nodes. Although delays at terminal stations were recorded, they are not within the scope of this study.

3.4.5 Population-Based Synchronization Weights

To accurately model the synchronization of train runs within the network, it is crucial to determine the weights that reflect the population served by each synchronization. These weights were derived using population data from multiple sources.

Firstly, data was collected from the “População segundo os Censos: total e por meio de transporte utilizado, Ano 2021, Indicador Comboios” (FFMS, 2024), which provided the total number of people per municipality who use trains to commute to work and to study. This data covers all municipalities intersected by the train lines under consideration (3.23).

This study retrieved information from the *Inquérito à Mobilidade nas Áreas Metropolitanas do Porto e de Lisboa 2017* (INE, 2018) to validate the approximation used in calculating these weights. This document indicates the proportion of inter municipal trips in the Porto metropolitan area, showing that 39.7% of these trips are for work and 24.7% are for study, totaling 64.4%. This correlation supports the accuracy of the approximation applied in our calculations.

The next step involved summing the number of citizens served by each potential synchronization. This sum provided the weights for the synchronization, reflecting the total population that would benefit from optimized train schedules at each synchronization point.

The tables below illustrate the data collected and the subsequent calculations. The first table presents the population using trains for work and study by municipality (3.23). The second table shows the synchronization paths, including the corresponding set of municipalities and population count, which directly represents the weight for each synchronization (3.24).

Table 3.23: Population Using Trains for Work and Study by Municipality.

Municipality	Population Using Train (Work & Study)
Amarante	376
Aveiro	996
Barcelos	863
Braga	1275
Espinho	1075
Estarreja	555
Famalicão	1850
Gaia	3191
Gondomar	972
Guimarães	577
Lousada	850
Maia	1035
Marco	623
Ovar	1645
Paredes	2467
Penafiel	1766
Porto	892
Santo Tirso	725
Trofa	822
Valongo	3354
Vizela	173

Table 3.24: Synchronization Weights by Synchronization Paths.

Starting Line	Ending Line	Set of Municipalities	Population Count (Weight)
Line 1	Line 4	Aveiro, Estarreja, Ovar, Espinho, Gaia, Porto, Gondomar, Maia, Valongo, Paredes, Penafiel, Lousada, Amarante, Marco	19797
Line 1	Line 6	Aveiro, Estarreja, Ovar, Espinho, Gaia, Porto, Gondomar, Maia, Valongo, Trofa, Famalicão, Santo Tirso, Vizela, Guimarães	17862
Line 1	Line 8	Aveiro, Estarreja, Ovar, Espinho, Gaia, Porto, Gondomar, Maia, Valongo, Trofa, Famalicão, Barcelos, Braga	18525
Line 3	Line 2	Marco, Amarante, Lousada, Penafiel, Paredes, Valongo, Maia, Gondomar, Porto, Gaia, Espinho, Ovar, Estarreja, Aveiro	19797
Line 3	Line 6	Marco, Amarante, Lousada, Penafiel, Paredes, Valongo, Trofa, Famalicão, Santo Tirso, Vizela, Guimarães	13583
Line 3	Line 8	Marco, Amarante, Lousada, Penafiel, Paredes, Valongo, Trofa, Famalicão, Barcelos, Braga	14246
Line 5	Line 2	Guimarães, Vizela, Santo Tirso, Famalicão, Trofa, Valongo, Maia, Gondomar, Porto, Gaia, Espinho, Ovar, Estarreja, Aveiro	17862

Continued on next page

Starting Line	Ending Line	Set of Municipalities	Population Count (Weight)
Line 5	Line 4	Guimarães, Vizela, Santo Tirso, Famalicão, Trofa, Valongo, Paredes, Penafiel, Lousada, Amarante, Marco	13583
Line 5	Line 8	Guimarães, Vizela, Santo Tirso, Famalicão, Barcelos, Braga	5463
Line 7	Line 2	Braga, Barcelos, Famalicão, Trofa, Valongo, Maia, Gondomar, Porto, Gaia, Espinho, Ovar, Estarreja, Aveiro	18525
Line 7	Line 4	Braga, Barcelos, Famalicão, Trofa, Valongo, Paredes, Penafiel, Lousada, Amarante, Marco	14246
Line 7	Line 6	Braga, Barcelos, Famalicão, Santo Tirso, Vizela, Guimarães	5463

These weights are used in the optimization model to reflect the importance of each synchronization point, ensuring that the model prioritizes synchronizations serving the largest number of commuters. This approach forms a robust basis for enhancing train schedule efficiency across the network, thereby reducing total waiting times and improving service for the population.

3.5 Summary

This chapter begins with a comprehensive overview of the network characteristics, describing each route's unique features and the physical infrastructure. The network serves as a critical transportation backbone for the region, connecting key urban and suburban areas. The specific routes under examination include the Aveiro, Marco de Canaveses, Guimarães, and Braga routes, each with distinct attributes that influence the overall network dynamics.

Next, the operational characteristics of these routes are discussed. This includes the scheduling patterns, frequency of service, and other operational details that impact the daily functioning of the train network. Understanding these characteristics is vital for identifying areas where optimization can enhance efficiency and service quality.

Synchronization characteristics are then explored, highlighting how different routes interact and synchronize with one another. This aspect is crucial for ensuring smooth transitions and minimal wait times for passengers transferring between routes, thereby improving the overall network efficiency.

The final part of the chapter focuses on the real-world data collection process. It explains how data is gathered from various sources, including the online schedule repository of CP³ and a public API that provides real-time and scheduled train data. The collected data includes schedules, headway, travel times, schedule deviations, and population-based synchronization weights, all of which are inputs for the optimization model. Special attention is given to the automated script developed to track schedule deviations by querying the public API and storing the data for subsequent analysis.

³<https://www.cp.pt>

By comprehensively examining these topics, this chapter sets the stage for understanding the complexities of the current train network and the need for an optimization model to enhance its performance.

Chapter 4

Mathematical Formulation

This chapter presents the mathematical formulation of a linear programming model designed to produce synchronized timetables of a train network. It then proceeds by detailing key performance measures suitable for evaluating the quality of its solutions.

The main inputs of this model include network information regarding its lines, the operational start and end times, the expected travel times, and operation frequencies. The model returns timetables, with the departure time of each line run as the primary decision variable. The objective function maximizes the number of synchronized opportunities in the system, weighted by a measure of importance also developed in this work.

The importance of each connection is determined by the potential number of passengers who can utilize it. By optimizing the model's objective function, the total waiting time for passengers at synchronization points is minimized, ultimately enhancing the overall service quality of the train network.

The chapter is organized as follows: it begins with an introduction to the notation used throughout the model, providing a clear and consistent framework for representing the various components of the optimization problem. Following the notation, the objective function is detailed, encapsulating the goal of maximizing synchronized runs. Subsequently, the constraints that must be satisfied for the model to be realistic and applicable to actual train network operations are described. These constraints reflect real-world limitations including the number of runs, train frequency, operational start and end schedules, walking time, and maximum waiting time to consider a synchronized transfer. The domain of the model is then defined, specifying the permissible values for the parameters and decision variables involved. Then, the performance metrics used to evaluate the optimization model are presented, ensuring a comprehensive assessment of its effectiveness.

By the end of the chapter, a comprehensive understanding of the mathematical structure of the optimization model and its application to the challenge of maximizing synchronized train runs is provided. This formulation serves as a robust foundation for the subsequent analysis and solution of the problem, supporting the study's results and conclusions.

4.1 Notation

The notation section introduces the symbols and terms used throughout the mathematical formulation of the optimization model. This standardized notation provides a clear and consistent framework for representing the various elements of the model, facilitating a precise and unambiguous understanding of the optimization problem. The table 4.1 summarizes the notation used, including sets, parameters, and decision variables, along with their respective definitions.

The parameter N_{ijs} reflects the total commuters served by the synchronization of runs between line i and line j at location s . The specifics of index N_{ijs} are explored in 3.4.5, with real-world data used for this input as presented in Table 3.23, and the resulting index values shown in Table 3.24. Additionally, a schematic of this calculation can be seen in 4.1.

$$\begin{aligned} N_{ijs} = & \text{Commuters residing in municipalities crossed by line } i \text{ up to location } s \\ & + \text{Commuters residing in the subsequent section of line } j \end{aligned} \quad (4.1)$$

The variable D_{isp} represents the mean schedule deviation experienced on line i upon reaching location s for run p . This input was calculated using collected real-world data as explained in 3.4.4.

4.2 Objective Function

The objective function of this optimization model (4.2) maximizes the synchronization of runs across the network, weighted by the index N_{ijs} . This index N_{ijs} quantifies the importance of synchronizing line i with line j at station s , taking into account the commuter distribution along these lines. By maximizing $N_{ijs} \cdot Y_{ijspq}$ across all pairs of lines i and j , location s , and runs p and q , the objective function aims to achieve optimal synchronization patterns that effectively serve the population along the train network.

This formulation ensures that the optimization process prioritizes synchronizations that benefit areas with higher population density, aligning the scheduling of runs to minimize waiting times and improve overall network efficiency.

$$\max \sum_i \sum_j \sum_s \sum_p \sum_q N_{ijs} \cdot Y_{ijspq} \quad (4.2)$$

Table 4.1: Summary of Model Notation

Notation	Description
Sets	
$\mathbf{I}$	Set of lines in the train network
Parameters	
N_{ijs}	Numerical value quantifying the importance of synchronizing line i with line j at location s
$E_i^{\min}$	Minimum earliest minute that line i can start a run
$E_i^{\max}$	Maximum earliest minute that line i can start a run
$L_i^{\min}$	Minimum latest minute that line i can start a run
$L_i^{\max}$	Maximum latest minute that line i can start a run
$H_{ip}^{\min}$	Minimum headway for line i between its runs p and $p+1$
$H_{ip}^{\max}$	Maximum headway for line i between its runs p and $p+1$
Δ_{ip}	Travel time from the beginning of run p on line i until it reaches the frequency measurement location, the first station that is common to all different paths on the same line
T_{isp}	Travel time from the beginning of run p on line i until it reaches location s
D_{isp}	Average historical deviation from the planned schedule for run p on line i at location s
I_i	Number of lines that can synchronize with line i , $\forall i \in \mathbf{I}$
B_{ik}	Set of lines that synchronize with line i , $k \in \{1, \dots, I_i\}$
S_{ij}	Synchronization location for each pair of lines (i, j) , $j \in B_{ik}$
F_i	Number of runs for each line i
Decision Variables	
Y_{ijspq}	Binary variable that equals 1 if run p on line i synchronizes with run q on line j at location s , and 0 otherwise
X_{ip}	Departure time for run p on line i

4.3 Constraints

$$X_{i1} \geq E_i^{\min} \quad (4.3)$$

$$X_{i1} \leq E_i^{\max} \quad (4.4)$$

$$X_{iF_i} \geq L_i^{\min} \quad (4.5)$$

$$X_{iF_i} \leq L_i^{\max} \quad (4.6)$$

$$(X_{ip+1} + \Delta_{ip+1}) - (X_{ip} + \Delta_{ip}) \geq H_{ip}^{\min} \quad (4.7)$$

$$(X_{ip+1} + \Delta_{ip+1}) - (X_{ip} + \Delta_{ip}) \leq H_{ip}^{\max} \quad (4.8)$$

$$(X_{jq} + T_{jsq} + D_{jsq}) - (X_{ip} + T_{isp} + D_{isp}) \geq w - M(1 - Y_{ijspq}) \quad (4.9)$$

$$(X_{jq} + T_{jsq} + D_{jsq}) - (X_{ip} + T_{isp} + D_{isp}) \leq W + M(1 - Y_{ijspq}) \quad (4.10)$$

Constraints 4.3 and 4.4 enforce that the earliest departure time X_{i1} for each line i adheres to the designated time frame $[E_i^{\min}, E_i^{\max}]$. These constraints govern the initiation of the first run on each line.

Constraints 4.5 and 4.6 ensure that the departure time of the last run of each line X_{iF_i} falls within the defined time range $[L_i^{\min}, L_i^{\max}]$. These constraints dictate the beginning of the last run on each line.

Constraints 4.7 and 4.8 ensure that for each line i , the time interval between consecutive departures from the frequency measurement location, of any two runs p and $p+1$ lies within the specified bounds $[H_{ip}^{\min}, H_{ip}^{\max}]$. These constraints regulate the minimum and maximum headway, maintaining a balanced and efficient schedule by preventing runs from departing too close together or too far apart.

Therefore, these six constraints (4.3, 4.4, 4.5, 4.6, 4.7 and 4.8) collectively ensure a well distributed schedule of departures across the entire time horizon for each line. By defining the earliest and latest allowable departure times for both the first and last runs, and by regulating the headway intervals between consecutive runs, the constraints prevent situations where all runs might be concentrated in one segment of the time horizon while leaving other parts under served.

Constraints 4.9 and 4.10 ensure proper synchronization between runs p on line i and q on line j at location s . These constraints are inspired by models such as those proposed by O. J. Ibarra-Rojas and Rios-Solis (2012), which determine synchronization by activating a binary variable when two runs meet specific timing criteria.

Specifically, these constraints activate the binary variable Y_{ijspq} when the time difference between the arrivals of runs p and q at location s falls within a specified time window. Constraint 4.9 ensures that the time difference is at least w , the maximum walking time. Constraint 4.10 ensures that this time difference does not exceed W , the sum of the maximum walking time and the maximum transfer waiting time.

In this model, the constraints include additional factors: the travel time to reach the synchronization location T_{isp} , which may vary on each run due to different combinations of stations being

crossed, and the schedule deviation D_{isp} , which increases the schedule robustness by absorbing delays. The large constant M renders the constraints redundant when Y_{ijspq} is zero, ensuring they only take effect when synchronization is intended.

In summary, these synchronization constraints ensure that Y_{ijspq} is one only if the arrival times of runs p and q at location s fall within the allowable time window $[w, W]$, accounting for travel times and schedule deviations. If Y_{ijspq} is zero, the constraints are bypassed due to the large value of M .

4.4 Domain

The domain constraints specify the admissible values for the decision variables in the model. They ensure that the variables are defined within the appropriate sets and ranges, which is crucial for maintaining the model's integrity and ensuring valid solutions.

The domain constraints are as follows:

$$\begin{aligned} \forall i \in \mathbf{I}, k \in \{1, \dots, I_i\}, j \in B_{ik}, s \in S_{ij}, p \in \{1, \dots, F_i\}, q \in \{1, \dots, F_j\} \\ Y_{ijspq} \in \{0, 1\} \\ X_{ip} \in \mathbb{N}^+ \end{aligned}$$

- $\forall i \in \mathbf{I}$: This specifies that the constraints apply to all lines i in the set of lines $\mathbf{I}$.
- $k \in \{1, \dots, I_i\}$: This specifies that k ranges over the number of lines that can synchronize with line i .
- $j \in B_{ik}$: This indicates that j is a line in the set B_{ik} , which represents the lines that can synchronize with line i according to the index k .
- $s \in S_{ij}$: This specifies that s is a synchronization location between lines i and j .
- $p \in \{1, \dots, F_i\}$: This denotes that p is a run on line i , ranging from the first run to the last run F_i .
- $q \in \{1, \dots, F_j\}$: This indicates that q is a run on line j , ranging from the first run to the last run F_j .
- $Y_{ijspq} \in \{0, 1\}$: This binary variable indicates whether run p on line i and run q on line j are synchronized at location s (1 if they are synchronized, 0 otherwise).
- $X_{ip} \in \mathbb{N}^+$: This variable represents the departure time of run p on line i in minutes and must be a positive integer.

These domain constraints are crucial for ensuring that all variables operate within their intended limits, maintaining the model's consistency and feasibility.

4.5 Performance Metrics

In evaluating the optimization model's effectiveness, several key performance metrics are used. These metrics provide a comprehensive view of how well the model performs in various scenarios and are crucial for comparing different optimization outcomes. The performance metrics considered are:

- **Total Count of Synchronizations in the Network (Synchs):** This metric counts the number of successful synchronizations achieved across the entire network. Synchronization refers to the coordination of train schedules to minimize passenger transfer times between connecting services. A higher count indicates a more efficiently synchronized network, enhancing passenger convenience and reducing wait times.
- **Total Score of the Network for Population-Weighted Synchronizations (Score):** This metric evaluates the network's performance by weighting the synchronizations based on the population served by municipality. It reflects the model's effectiveness in prioritizing synchronizations that benefit the largest number of passengers. A higher score indicates better optimization in aligning train schedules with the needs of densely populated areas, thereby improving overall passenger satisfaction. When disabled, the score metric is marked as N/A, indicating non-assessment of optimization with this weights.
- **Gap to Reach the Perfect Solution (Gap(%)):** The gap metric measures the difference between the current solution and the theoretically perfect solution. Expressed as a percentage, this metric indicates how close the model's output is to the optimal scenario. A lower gap percentage signifies a more efficient and effective optimization, as it reflects the model's ability to approach the ideal solution.
- **Processing Time (Time):** This metric tracks the time taken to run the optimization model and produce results. Given the complexity of the optimization problem, a lower processing time is desirable. However, to ensure practical applicability, a maximum processing time of 30 minutes is enforced in further results collection (Section 5), to ensure practical applicability. Efficient models that provide solutions within this time frame are preferred, as they demonstrate a balance between computational efficiency and solution quality.

These metrics collectively offer a robust framework for assessing the optimization model's performance. They help in identifying strengths and weaknesses across different scenarios, guiding improvements and adjustments to enhance the overall efficiency and effectiveness of the transportation network.

4.6 Summary

This chapter presented the mathematical formulation for optimizing the synchronization of train runs within a network. The objective function aims to maximize the number of synchronized runs, weighted by an index that reflects the population served by the synchronization.

The constraints are divided into three main categories: departure time constraints, headway constraints, and synchronization constraints. Departure time constraints ensure that the first and last departures for each line occur within specified time windows. Headway constraints regulate the time intervals between consecutive departures on the same line, ensuring they remain within the minimum and maximum headway limits.

Synchronization constraints ensure that runs from different lines can synchronize at specified locations within acceptable time windows. These constraints are modeled to account for travel times to synchronization locations and schedule deviations.

Additionally, domain constraints define the suitable values for the decision variables, ensuring they operate within their intended limits.

To evaluate the effectiveness of the optimization model, performance metrics such as the synchronization score, number of synchronizations achieved, gap, and computational time are employed. These metrics provide a comprehensive assessment of how well the model maximizes synchronized runs and its practical applicability in real-world scenarios.

Together, these components form a comprehensive linear programming optimization model designed to enhance the efficiency of train networks by strategically synchronizing runs to minimize total waiting time at synchronization stations.

Chapter 5

Results and Discussion

This chapter is dedicated to presenting and analyzing the outcomes derived from the optimization model detailed in Chapter 4. Utilizing the data collected and processed as described in Chapter 3, this chapter aims to evaluate the model's performance across various scenarios and parameters, providing a comprehensive understanding of its efficacy and implications for transportation planning.

5.1 Design of Experiments

This section outlines the approach for conducting a sensitivity analysis by identifying key parameters, defining their range of variation, and discussing the intent behind systematically varying these parameters. By performing a sensitivity analysis we seek for information regarding on how is the sensitivity of the solution to certain changes in the data inputs (Jansen et al., 1997).

The key parameters selected for the sensitivity analysis include:

1. **Headway Offset:** The allowable variation in the interval between consecutive run departures.
2. **Earliest/Latest Start Offset:** The allowable variation in the start times of the first and last runs on each line.
3. **Maximum Walking Time:** The maximum allowable walking time for passengers to transfer between lines at a synchronization location.
4. **Maximum Waiting Time:** The maximum allowable waiting time for passengers at transfer points.
5. **Weighted Synchronizations:** Whether synchronization scoring incorporates weights based on the total population benefiting from train services.
6. **Time Deviations:** Whether schedule time deviations are considered.

Table 5.1: Definition of the range variation for sensitivity analysis parameters.

Parameter	Range of Variation
$H_{i,p}(\pm)$: Headway Offset	± 1 minute, ± 2 minutes, ± 3 minutes
$E^i/F^i(\pm)$: Earliest/Latest Start Offset	± 5 minutes, ± 10 minutes, ± 15 minutes
w^{max} : Maximum Walking Time	2 minutes, 3 minutes, 4 minutes
$(W - w)^{max}$: Maximum Waiting Time	10 minutes, 15 minutes, 20 minutes
$N_{i,j,s}$: Weighted Synchronizations	Enabled (yes), Disabled (no)
$D_{i,j,s}$: Time Deviations	Considered (yes), Not Considered (no)

The ranges for the key parameters are defined as follows:

The sensitivity analysis is conducted by systematically varying these parameters as defined in Table 5.1:

1. $H_{i,p}(\pm)$: The headway offset is varied from ± 1 minute to ± 3 minutes incrementally, assessing the impact of train regularity.
2. $E^i/F^i(\pm)$: The first and last train start times are varied by ± 5 minutes initially, then by ± 10 and ± 15 minutes. The effect of operational schedules is evaluated.
3. w^{max} : The maximum walking time for passengers to make connections is tested at 2, 3, and 4 minutes to understand the influence of passenger convenience in synchronization feasibility.
4. $(W - w)^{max}$: The maximum waiting time at transfer points is varied from 10 to 20 minutes, analyzing the impact of passenger waiting experience in overall synchronization quality.
5. $N_{i,j,s}$: The effect of enabling and disabling weighted synchronizations is examined to determine the influence of commuters' distribution throughout the territory on synchronization scores.
6. $D_{i,j,s}$: The consideration of schedule time deviations is tested to observe the impact of increase in robustness and the flexibility of the schedule.

By following this structured methodology, the sensitivity analysis provides detailed insights into how variations in these key parameters affect the optimization model's outcomes. This enables a comprehensive understanding of the model's behavior under different scenarios, helping to identify the most influential parameters and their optimal settings.

5.2 Solver Configuration Parameters

To effectively utilize IBM CPLEX Optimization Studio for solving the optimization problem, specific parameters were selected to control various aspects of the solver's behavior. These settings are crucial for balancing performance and resource usage. Below is an explanation of each parameter chosen:

Time Limits and Termination

- `cplex.tilim = 1800`: This parameter sets the time limit for the optimization process to 1800 seconds (30 minutes). It ensures that the solver terminates if it exceeds this time limit, providing a balance between computational effort and practical usability.

Memory Management

- `cplex.workmem = 12288`: This parameter allocates 12288 MB (12 GB) of memory for the solver's working memory. Adequate memory allocation helps in handling large problem instances efficiently by reducing the need for disk I/O.
- `cplex.nodefileind = 0`: This setting specifies that no node files are used. Node files are employed when the working memory limit is exceeded by the size of the search tree. By setting this to 0, the solver will terminate if the tree exceeds the available working memory, avoiding the performance overhead of managing node files.

Parallelism and Threads

- `cplex.threads = 14`: This parameter sets the number of threads to 14. Utilizing multiple threads enables parallel processing, which can significantly speed up the solution process by leveraging multi-core processors.
- `cplex.auxrootthreads = 6`: This parameter defines the number of threads dedicated to auxiliary root tasks. Allocating 6 threads helps in managing auxiliary computations efficiently, further enhancing the solver's performance.
- `cplex.parallelmode = 1`: This parameter sets the parallel mode to deterministic parallel. It ensures that multiple runs of the solver on the same problem with the same parameter settings will produce the same solution path, thereby making the results reproducible and reliable.

These parameters are tailored to optimize the solver's performance by leveraging available computational resources efficiently, ensuring timely and reliable results for the given optimization problem. The rest of the parameters were left as default, maintaining the remaining standard behavior of the solver.

5.3 Benchmark Scenario

The benchmark scenario is designed to precisely mirror the real-world operation of the transportation network. This scenario serves as a reference point for evaluating the performance of the optimization model by providing a direct comparison with the actual current schedule.

To create this benchmark scenario, several key elements from the real-world network were replicated exactly:

- **Departure Times:** The departure times for the runs on each line were maintained as they are in the actual schedule. By fixing these run departure times, we also inherently fix the headway between runs. This ensures that the timing of each train's departure and the intervals between consecutive trains in the benchmark scenario match that of the real-world scenario.
- **Travel Times:** The travel times for runs on each line were also kept identical to those in the real-world scenario. This preserves the integrity of the travel duration's across the network, ensuring a faithful representation of the actual schedule. These travel times remain constant across all the testing scenarios shown across the sensitivity analysis.

By aligning these aspects, the benchmark scenario effectively results in a schedule that is indistinguishable to the currently operating real-world network.

This precise alignment was accomplished by setting several specific offsets to zero, thus enforcing key operational constraints:

- **Earliest Start Offset:** By setting the first run start offset on each line to zero, the initial departure times match exactly with the real schedule. This ensures that E_i^{min} and E_i^{max} are now equal to the earliest departure time on each line i .
- **Latest Start Offset:** Similarly, setting the last run start offset on each line to zero, ensures that the final departure times align perfectly with the actual schedule, preserving the operational end times. This guarantees that L_i^{min} and L_i^{max} are set to match the latest departure time on each line i .
- **Headway Offset:** Setting the headway offset to zero ensures that the intervals between run departures on each line are distributed evenly throughout the operational time limits, as they are in the real-world schedule. This maintains the regularity and frequency of train services, ensuring that $H_{i,p}^{min}$ and $H_{i,p}^{max}$ reflect the actual headway observed in practice between every two runs p and $p + 1$ on each line i .

By meticulously adjusting these offsets, the benchmark scenario achieves an exact replication of the real-world transportation network schedule. This scenario provides a vital baseline against which the optimization model's performance can be measured and evaluated.

5.3.0.1 Benchmark Scenario Performance Results

A space-time diagram is a graphical representation that shows the movement and timing of entities, such as train runs, across different locations over time. The Diagram 5.1 represents the train schedule for the benchmark scenario with multiple routes and stops.

Axes

- **Vertical Axis (Space):** This axis lists different locations or stations along the routes. In this diagram, the stations are Aveiro, Ovar, Porto - São Bento, Porto - Campanhã, Ermesinde,

Penafiel, Lousado, Braga, Guimarães, and Marco de Canaveses, with some being terminals and others intermediate stations in certain routes.

- **Horizontal Axis (Time):** This axis represents time in minutes, progressing from left to right. The x-axis starts at 0, representing midnight of the starting operation day, and ends after the following midnight (minute 1440) of that same day. The entire operation of these four routes spans 1295 minutes (21 hours and 35 minutes).

Key Points

- **Earliest Departure:** The leftmost point on the diagram is at $x = 258$, corresponding to the first departure from Marco de Canaveses at 4:18AM.
- **Latest Arrival:** The rightmost point on the diagram is at $x = 1553$, corresponding to the latest arrival to Braga at 1:53AM the following day.

Routes and Runs

The diagram lines show the progression of each route run through different stations over time. When lines intersect on the diagram and represent trains using the same physical track (explored in Section 3.1), it indicates that the trains pass each other at that precise time. Each colored line represents a different run from the following routes:

- Yellow: Aveiro Route
- Blue: Marco de Canaveses Route
- Red: Guimarães Route
- Green: Braga Route

Points and Events

Each dot represents a significant event, such as a departure or arrival at a station. The position of the dot along the time axis indicates the exact time of the event.

Synchronization

Dots that are close together at the same station may indicate synchronization if the time interval between the arrival of that runs respect the considered synchronization time window. The specific synchronization characteristics of the network are detailed in Section 3.3.

The space-time diagram is a valuable tool for visualizing and analyzing the temporal and spatial relationships within a train network. In short, by examining the space-time diagram, it is possible to interpret:

- The timing and location of each train's journey.
- Intersections of lines, which indicate points where trains pass each other on the same physical line.

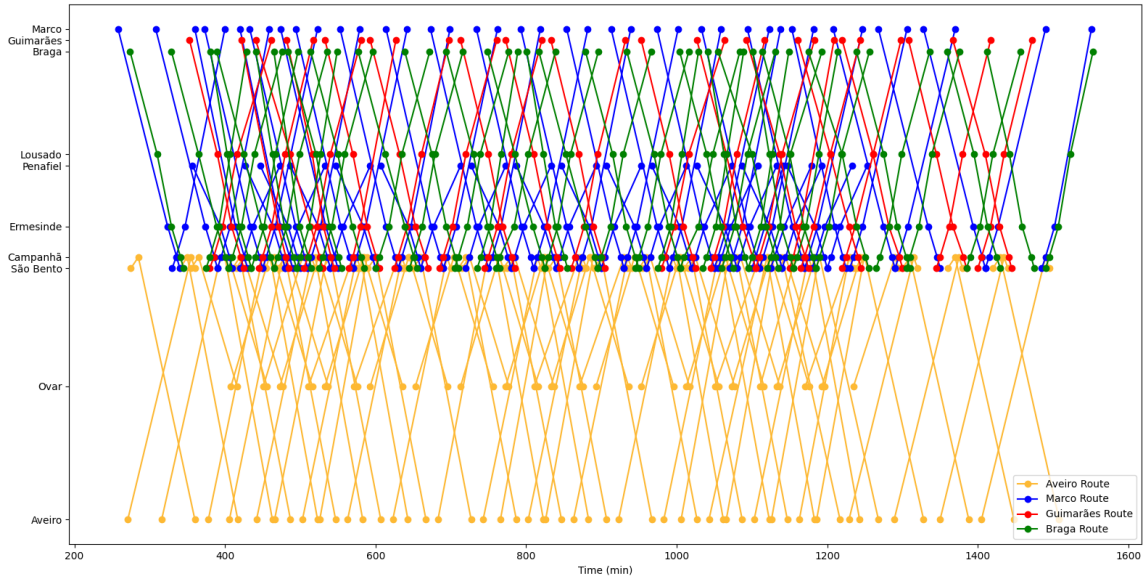


Figure 5.1: Benchmark space-time diagram.

- Proximity of dots at the same location, which can indicate potential synchronization opportunities.
- The density of intersections around certain stations (Porto - São Bento, Porto - Campanhã and Ermesinde) suggests these are major hubs in the network.

The Table 5.2 presents the results of a benchmark analysis, examining how different parameters affect the performance of real-world train schedules. The table provides various combinations of key parameters (Section 5.1) and their resulting performance metrics (Section 4.5).

By analysing Table 5.2, it is possible to interpret the following:

- **Maximizing synchronization without weighted scoring and time deviations (Rows 1-3):** When weighted synchronizations and time deviations are disabled, the synchronization count increases as the maximum walking and waiting times increase.
- **Maximizing synchronization with weighted scoring (Rows 4-6):** The weight score increases with higher maximum walking and waiting times, indicating a positive correlation between these parameters and the effectiveness of synchronization, that remains equal to the previous cases.
- **Synchronization with Time Deviations (Rows 7-9):** Considering time deviations while disabling weighted synchronizations results in a similar trend as seen in rows 1-3. The synchronization count is slightly negatively affected by time deviations.
- **Synchronization with Both Weighted Scoring and Time Deviations (Rows 10-12):** Enabling both weighted synchronizations and time deviations yields the highest synchronization scores comparing row 10 with row 4, although less synchronization count is achieved.

The scores and synchronization counts both increase with greater maximum walking and waiting times, but decrease in comparison with rows 5 and 6.

- **Gap** The optimal solution gap remains at 0.00% across all scenarios, indicating that the solutions obtained are optimal.
- **Execution Time:** The execution time is consistently 0.00 minutes for all scenarios, suggesting the computations were performed efficiently within a negligible time frame.

This Table 5.2 provides a comprehensive view of how varying key parameters affect train synchronization performance in the benchmark scenario. It highlights the impact of different strategies, such as enabling weighted synchronizations, considering time deviations, varying synchronization window (W) and its impact on synchronization count, score, gap and execution time. These insights are valuable for optimizing train schedules to enhance overall service efficiency and passenger convenience.

Table 5.2: Benchmark results.

#	$H_{i,p}(-+)$	$E^i/F^i(-+)$	w^{max}	$(W-w)^{max}$	$N_{i,j,s}$	$D_{i,j,s}$	Score	Synchs	Gap(%)	Time
1	0	0	2	10	no	no	N/A	93	0,00	0,00
2	0	0	3	15	no	no	N/A	178	0,00	0,00
3	0	0	4	20	no	no	N/A	239	0,00	0,00
4	0	0	2	10	yes	no	1641884	93	0,00	0,00
5	0	0	3	15	yes	no	2920414	178	0,00	0,00
6	0	0	4	20	yes	no	4060828	239	0,00	0,00
7	0	0	2	10	no	yes	N/A	92	0,00	0,00
8	0	0	3	15	no	yes	N/A	169	0,00	0,00
9	0	0	4	20	no	yes	N/A	221	0,00	0,00
10	0	0	2	10	yes	yes	1652081	92	0,00	0,00
11	0	0	3	15	yes	yes	2807860	169	0,00	0,00
12	0	0	4	20	yes	yes	3691157	221	0,00	0,00

5.4 Sensitivity Analysis Results

The Table 5.3 presents the sensitivity analysis results for varying headway offsets in the schedules. The key parameter analyzed here is the headway offset, $H_{i,p}(\pm)$, which is varied while keeping other parameters constant.

Table 5.3 below details the outcomes of this analysis, highlighting the impact on synchronization scores, the number of synchronizations, the gap, and computational time. By appraising it, it is possible to interpret the following insights from the results of headway offset variations:

1. **No Weighted Synchronizations and No Time Deviations (Rows 1-3):** As the $H_{i,p}(\pm)$ increases from ± 1 to ± 3 minutes, the number of synchronizations increases from 273 to 331. However, this increase also leads to a higher gap and a longer computational time.

2. **Weighted Synchronizations (Rows 4-6):** With weighted synchronizations enabled, the synchronization score improves significantly. The number of synchronizations also increases from 271 to 344, indicating better synchronization performance. However, the gap widens, and the computational time increases slightly.
3. **Time Deviations Considered (Rows 7-9):** When only time deviations are considered, the number of synchronizations increases from 263 to 330. Similar to other scenarios, the gap and computational time increase with larger $H_{i,p}(\pm)$.
4. **Both Weighted Synchronizations and Time Deviations (Rows 10-12):** Enabling both weighted synchronizations and time deviations yields the lower synchronization scores, comparing to Rows 4-6. The number of synchronizations increases from 263 to 331, and the synchronization score also grows with higher headway offsets. However, the gap and computational time are at their highest.
5. **Gap:** The gap remains 0.00% for ± 1 minute headway offset in all scenarios. As the headway offset increases, the gap widens, indicating a greater distance from the optimal solution.
6. **Computational Time:** The computational time is relatively low for ± 1 minute headway offset but increases significantly for ± 2 and ± 3 minutes headway offsets. This increase is consistent across all scenarios, reflecting the additional computational complexity introduced by larger headway variations.

The sensitivity analysis of headway offset variations reveals that increasing the headway offset generally improves synchronization performance, as indicated by higher synchronization counts and scores. However, this improvement comes at the cost of a higher gap and increased computational time. Enabling weighted synchronizations enhance synchronization performance but also contribute to a sub optimal and complex solution. On the other hand, upon considering time deviations, the performance seems to decrease when comparing to cases where this component is not active.

Table 5.3: Headway offset variation results.

#	$H_{i,p}(\pm)$	$E^i/F^i(\pm)$	w^{max}	$(W - w)^{max}$	$N_{i,j,s}$	$D_{i,j,s}$	Score	Synchs	Gap(%)	Time
1	1	0	3	15	no	no	N/A	273	0,00	1,45
2	2	0	3	15	no	no	N/A	314	9,88	30,04
3	3	0	3	15	no	no	N/A	331	38,16	30,04
4	1	0	3	15	yes	no	4610554	271	0,00	1,32
5	2	0	3	15	yes	no	5416614	317	11,78	30,04
6	3	0	3	15	yes	no	5832295	344	33,74	30,03
7	1	0	3	15	no	yes	N/A	263	0,00	2,66
8	2	0	3	15	no	yes	N/A	299	13,72	30,05
9	3	0	3	15	no	yes	N/A	330	35,67	30,04
10	1	0	3	15	yes	yes	4461799	263	0,00	3,47
11	2	0	3	15	yes	yes	5104653	301	21,86	30,08

Continued on next page

#	$H_{i,p}(\pm)$	$E^i/F^i(\pm)$	w^{max}	$(W - w)^{max}$	$N_{i,j,s}$	$D_{i,j,s}$	Score	Synchs	Gap(%)	Time
12	3	0	3	15	yes	yes	5681407	331	32,14	30,04

The Table 5.4 evaluates the earliest/latest start offset. The key parameter analyzed here is the earliest/latest start offset, $E^i/F^i(\pm)$, which is varied while keeping other parameters constant.

The Table 5.4 below details the outcomes of this analysis, highlighting the impact on synchronization scores, the number of synchronizations, the gap, and computational time. By examining it, it is possible to interpret the following insights from the sensitivity analysis of earliest/latest start offset variations:

1. **No Weighted Synchronizations and No Time Deviations (Rows 1-3):** As the $E^i/F^i(\pm)$ increases from ± 5 to ± 15 minutes, the number of synchronizations increases from 251 to 296. The gap remains at 0.00%, and computational time slightly increases from 0.00 to 0.03.
2. **Weighted Synchronizations (Rows 4-6):** With weighted synchronizations enabled, the number of synchronizations is the same as the last three rows, increasing from 251 to 296, indicating same synchronization performance without any change in the gap. Computational time remains consistent. The score also increases, following the $E^i/F^i(\pm)$ trajectory.
3. **Time Deviations Considered (Rows 7-9):** When only time deviations are considered, the number of synchronizations increases from 224 to 262. Similar to other scenarios, the gap remains 0.00%, and the computational time increases more noticeably from 0.00 to 0.16. In this testing set it is observable the lowest synchronization counts comparing to the previous two sets of rows.
4. **Both Weighted Synchronizations and Time Deviations (Rows 10-12):** Enabling both weighted synchronizations and time deviations yields lower synchronization scores. As the previous set, the number of synchronizations only increases from 224 to 262. The gap stays at 0.00%, and computational time shows a slight increase from 0.00 to 0.09.
5. **Gap:** The gap remains at 0.00% across all scenarios and variations of earliest/latest start offset, indicating that the solutions are optimal within the defined range.
6. **Computational Time:** The computational time is minimal for all scenarios, with slight increases observed as the earliest/latest start offset increases. The maximum time recorded is 0.16 minutes, indicating efficient computation even with higher offsets.

The sensitivity analysis of earliest/latest start offset variations reveals that increasing the offset generally improves synchronization performance, as indicated by higher synchronization counts. The gap remains consistently at 0.00%, showing that the solutions are optimal across all variations. Computational time increases slightly with larger offsets but remains relatively low, ensuring efficient schedule computation. Analyzing the results further reveals that while weighted synchronizations maintain the count of synchronizations across different offset variations, time deviations tend to slightly lower the number of synchronizations achieved.

Table 5.4: Earliest and latest start offset variation results.

#	$H_{i,p}(\pm)$	$E^i/F^i(\pm)$	w^{max}	$(W - w)^{max}$	$N_{i,j,s}$	$D_{i,j,s}$	Score	Synchs	Gap(%)	Time
1	0	5	3	15	no	no	N/A	251	0,00	0,00
2	0	10	3	15	no	no	N/A	277	0,00	0,01
3	0	15	3	15	no	no	N/A	296	0,00	0,03
4	0	5	3	15	yes	no	4244462	251	0,00	0,00
5	0	10	3	15	yes	no	4685848	277	0,00	0,01
6	0	15	3	15	yes	no	5034428	296	0,00	0,03
7	0	5	3	15	no	yes	N/A	224	0,00	0,00
8	0	10	3	15	no	yes	N/A	244	0,00	0,06
9	0	15	3	15	no	yes	N/A	262	0,00	0,16
10	0	5	3	15	yes	yes	3679989	224	0,00	0,00
11	0	10	3	15	yes	yes	4114426	242	0,00	0,05
12	0	15	3	15	yes	yes	4453314	262	0,00	0,09

Table 5.5: Mixed parameter variation results.

#	$H_{i,p}(\pm)$	$E^i/F^i(\pm)$	w^{max}	$(W - w)^{max}$	$N_{i,j,s}$	$D_{i,j,s}$	Score	Synchs	Gap(%)	Time
1	1	5	3	15	yes	no	5101012	301	2,57	30,03
2	1	5	3	15	yes	yes	4991764	294	3,11	30,06
3	1	10	3	15	yes	no	5225466	309	12,45	30,04
4	1	10	3	15	yes	yes	4952028	293	26,80	30,07
5	1	15	3	15	yes	no	5259598	308	26,36	30,10
6	1	15	3	15	yes	yes	5162163	305	31,41	30,04
7	2	5	3	15	yes	no	5381582	315	39,30	30,00
8	2	5	3	15	yes	yes	5299962	312	27,16	30,11
9	2	10	3	15	yes	no	5582992	329	38,36	30,03
10	2	10	3	15	yes	yes	5528571	328	32,33	30,00
11	2	15	3	15	yes	no	5448395	322	63,08	30,08
12	2	15	3	15	yes	yes	5550913	327	55,28	30,00
13	3	5	3	15	yes	no	6046014	352	49,09	30,03
14	3	5	3	15	yes	yes	5721549	339	51,17	30,03
15	3	10	3	15	yes	no	5403083	321	76,72	30,03
16	3	10	3	15	yes	yes	5885098	344	63,40	30,03
17	3	15	3	15	yes	no	6186140	362	70,16	30,00
18	3	15	3	15	yes	yes	5914845	348	77,32	30,04

5.5 Summary

The chapter opens with a detailed overview of the sensitivity analysis parameters. This part explains the methodology for conducting a sensitivity analysis, highlighting the key parameters under consideration, the range over which these parameters are varied, and the rationale behind these systematic variations.

Next, the chapter discusses the selected solver configuration parameters used in the IBM CPLEX Optimization Studio. This section provides an in-depth look at the solver settings and

configurations applied during the optimization process, explaining how these settings impact the model's performance and efficiency.

Moving forward, the benchmark scenario is introduced, serving as a baseline for comparison against other scenarios. The performance results of this benchmark scenario are then presented, providing a reference point for subsequent analyses.

Following this, the outcomes of the sensitivity analysis are explored, examining the impact of different factors on synchronization, population-weighted synchronization, and schedule deviations. The chapter delves into how changes in the parameters influence the synchronization of train schedules, the importance of demographic factors in optimizing schedules, and the effect of schedule deviations on overall performance, providing insights into the model's resilience to real-world disruptions.

Through these discussions, the chapter aims to provide a thorough examination of the optimization model's performance, offering valuable insights and practical implications for transportation planning and decision-making.

Chapter 6

Conclusions

The planning and scheduling of Porto's urban trains involve significant challenges due to the variability in route characteristics and the geographical diversity encompassing both urban and rural areas. This study aimed to tackle these challenges by developing adaptive and flexible scheduling approaches to improve PT connectivity, ultimately achieving seamless travel and enhancing overall network reliability and efficiency.

The conclusions drawn from this research address the complexities of different routes and the methodologies used to optimize scheduling and transfer coordination. The findings offer solutions to minimize transfer times, improve passenger experience, and ensure smooth connections across the diverse elements of Porto's urban train network. Through meticulous planning and innovative strategies, the existing PT system is improved to be more efficient and user-friendly, meeting the needs of both urban and rural passengers.

6.1 Research Objectives and Achieved Results

This study focused on addressing the variability inherent in Porto's urban train network, aiming to optimize scheduling and enhance connectivity across its diverse routes. Key challenges included managing variability in the number of daily runs, headway times, starting and ending operational times, travel times, and multiple line paths.

The model maintained the current number of daily runs for each line to meet passenger needs throughout the day. For headway times, the model kept existing headway as the baseline and optimized them within a predefined range to enhance network performance. Similarly, the operational start and end times were based on current schedules but allowed for variation to achieve better results. Travel times were kept consistent with the current data to respect the stations served by each run. The model incorporated constraints aligned with correct input data, enabling the processing of multiple line paths effectively.

To analyze synchronization, a time window was applied that took into account maximum walking and waiting times during transfers. The use of deterministic time deviations aimed to

increase the robustness of the model against delays, and population-weighted synchronization was tested to prioritize paths serving more commuters.

Results indicated that widening the synchronization window increased the number of synchronizations, as did increasing the headway offset and extending the earliest/latest start offset. Synchronization weights tended to maintain the synchronization count, suggesting that current timetables already effectively prioritize synchronization. Conversely, the deterministic use of time deviations reduced the synchronization count, indicating that such deviations can disrupt the original scheduling intentions.

Overall, the research developed a model that effectively addresses variability challenges in Porto's urban train network, offering solutions to improve connectivity, minimize transfer times, and enhance the passenger experience, thereby approaching seamless travel.

6.2 Contributions

The main contributions attained with this work are:

Firstly, the study employs an optimization model capable of managing variable frequency routes, specifically tailored to the complexities of Porto's urban train system. This approach was tested using real-world data from the network, demonstrating its applicability and effectiveness in optimizing scheduling throughout all operational day, amidst varying operational conditions.

Secondly, the comprehensive collection and utilization of real-world data. This dataset includes detailed information on schedules, headway times, travel times, and time deviations. By integrating this real data into the optimization model, the study ensures that the proposed solutions are grounded in the realities of Porto's urban train operations, thereby increasing the practical relevance of the findings.

Lastly, it introduces an innovative visualization method using space-time diagrams. These diagrams offer a dynamic tool that allows zooming and facilitates the visualization of large numbers of lines, thereby aiding in the analysis of scheduling within Porto's urban train network and enabling the visualization and analysis of complex solutions, capturing both temporal and spatial aspects of train movements.

6.3 Limitations

During the study's development, limitations were encountered in two primary areas:

Solver and hardware constraints posed challenges due to the complexity of the problem, leading to extended processing times and occasionally leaving significant gaps in computation results despite efforts over 30 minute processing periods.

Data constraints were notable, particularly in specific aspects like transfer data, where reliance was primarily on publicly available schedules, limiting access to more detailed information.

6.4 Future Work

Future research could explore expanding the network with new lines or extensions to enhance connectivity and service coverage across Porto and its surrounding areas. This expansion would aim to accommodate growing demand and improve accessibility to currently under served areas.

Additionally, measuring demand more comprehensively would optimize headway times and frequency adjustments, ensuring they better meet passenger needs. This could involve deploying advanced data analytics and passenger counting technologies to capture real-time demand patterns and adjust service frequencies dynamically.

Quantifying passenger transfers at route junctions more accurately could refine synchronization strategies based on actual commuter volumes. This approach would prioritize synchronization paths that serve a larger number of commuters, thereby enhancing overall network efficiency and passenger experience.

Enhancing inter modality at key hubs like Porto - São Bento, Porto - Campanhã, and Ermesinde would integrate the network with other transportation modes, improving overall mobility options. This integration could involve seamless transfer facilities, coordinated timetables, and shared ticketing systems to facilitate convenient multi modal travel.

Introducing additional types of train services tailored to varying commuter needs and travel patterns could further enhance service flexibility. This might include express services, off-peak services, or specialized services catering to specific demographics or travel purposes.

Optimizing resource management, including train availability, crew scheduling, and operational logistics, would improve service reliability and efficiency. This optimization could involve predictive maintenance systems, crew management algorithms, and enhanced operational planning tools to minimize disruptions and optimize resource utilization.

Detailed assessments of physical infrastructure along routes, such as platform capacities and line constraints, would optimize scheduling and operations. Understanding these physical constraints would enable better alignment of schedules with infrastructure capabilities, ensuring smooth operations and minimizing delays.

These future directions aim to build upon the findings and methodologies developed in this study, contributing to a more robust and responsive urban train network in Porto.

6.5 Summary

This study addresses the intricate challenges of planning and scheduling Porto's urban trains, encompassing diverse route characteristics and geographic complexities. By developing adaptive scheduling strategies, the research aimed to enhance PT connectivity, achieve seamless travel, and improve overall network reliability and efficiency.

Key findings underscore the importance of optimizing scheduling variables such as daily runs, headway times, operational hours, travel duration, and route paths to meet passenger demands

effectively. Through innovative methodologies and empirical validation, the study proposes solutions to minimize transfer times, enhance passenger experience, and ensure smooth connections within Porto's urban train network.

Contributions to the field include the introduction of space-time diagrams for visualizing scheduling dynamics, a novel approach to managing variable frequency routes, and the comprehensive utilization of real-world data to ground optimization strategies in practical realities. Despite limitations in computational resources and data availability, the study provides actionable insights for future research and practical applications.

Moving forward, expanding the network, measuring demand more accurately, enhancing inter modality, and optimizing resource management emerge as critical avenues for improving Porto's urban train system. These directions aim to build upon the study's foundations, fostering a more robust and responsive public transportation network tailored to meet evolving commuter needs and mobility challenges.

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Appendix A

Schedules

Table A.1: Aveiro-Porto Schedule Overview.

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
AVEIRO	PORTO-SÃO BENTO	04:31	06:00	89	15601	15600	1
AVEIRO	PORTO-CAMPANHÃ	05:16	06:34	78	15603	15603	2
AVEIRO	PORTO-SÃO BENTO	06:18	07:35	77	15605	15604	3
OVAR	PORTO-CAMPANHÃ	06:48	07:39	51	15801	15801	4
AVEIRO	PORTO-CAMPANHÃ	06:46	07:57	71	15607	15607	5
OVAR	PORTO-CAMPANHÃ	07:31	08:23	52	15803	15803	6
AVEIRO	PORTO-SÃO BENTO	07:22	08:40	78	15609	15608	7
OVAR	PORTO-CAMPANHÃ	07:53	08:44	51	15805	15805	8
AVEIRO	PORTO-CAMPANHÃ	07:46	08:55	69	15611	15611	9
OVAR	PORTO-SÃO BENTO	08:31	09:35	64	15807	15806	10
AVEIRO	PORTO-SÃO BENTO	08:23	09:40	77	15613	15612	11
OVAR	PORTO-CAMPANHÃ	08:53	09:44	51	15809	15809	12
AVEIRO	PORTO-CAMPANHÃ	08:46	09:49	63	15615	15615	13
OVAR	PORTO-SÃO BENTO	09:31	10:35	64	15811	15810	14
AVEIRO	PORTO-SÃO BENTO	09:23	10:40	77	15617	15616	15
OVAR	PORTO-CAMPANHÃ	09:53	10:44	51	15813	15813	16
AVEIRO	PORTO-SÃO BENTO	10:23	11:40	77	15621	15620	17
OVAR	PORTO-CAMPANHÃ	10:53	11:44	51	15815	15815	18
AVEIRO	PORTO-CAMPANHÃ	11:23	12:29	66	15623	15623	19
OVAR	PORTO-CAMPANHÃ	11:53	12:44	51	15817	15817	20
AVEIRO	PORTO-SÃO BENTO	12:23	13:40	77	15625	15624	21
OVAR	PORTO-CAMPANHÃ	12:53	13:44	51	15819	15819	22
AVEIRO	PORTO-CAMPANHÃ	12:46	13:49	63	15627	15627	23
OVAR	PORTO-SÃO BENTO	13:31	14:35	64	15821	15820	24
AVEIRO	PORTO-SÃO BENTO	13:23	14:40	77	15629	15628	25
OVAR	PORTO-CAMPANHÃ	13:53	14:44	51	15823	15823	26
AVEIRO	PORTO-CAMPANHÃ	13:46	14:49	63	15631	15631	27
OVAR	PORTO-SÃO BENTO	14:31	15:35	64	15825	15824	28
AVEIRO	PORTO-SÃO BENTO	14:23	15:40	77	15633	15632	29
OVAR	PORTO-CAMPANHÃ	14:53	15:44	51	15827	15827	30
AVEIRO	PORTO-SÃO BENTO	15:23	16:40	77	15635	15634	31

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
OVAR	PORTO-CAMPANHÃ	15:53	16:44	51	15829	15829	32
AVEIRO	PORTO-SÃO BENTO	16:23	17:40	77	15637	15636	33
OVAR	PORTO-CAMPANHÃ	16:53	17:44	51	15831	15831	34
AVEIRO	PORTO-CAMPANHÃ	16:46	17:49	63	15639	15639	35
OVAR	PORTO-SÃO BENTO	17:31	18:35	64	15833	15832	36
AVEIRO	PORTO-SÃO BENTO	17:23	18:45	82	15641	15640	37
OVAR	PORTO-CAMPANHÃ	17:53	18:44	51	15835	15835	38
AVEIRO	PORTO-CAMPANHÃ	17:46	18:48	62	15643	15643	39
OVAR	PORTO-CAMPANHÃ	18:31	19:18	47	15837	15837	40
AVEIRO	PORTO-SÃO BENTO	18:23	19:40	77	15645	15644	41
OVAR	PORTO-CAMPANHÃ	18:53	19:44	51	15839	15839	42
AVEIRO	PORTO-CAMPANHÃ	18:46	19:49	63	15647	15647	43
OVAR	PORTO-SÃO BENTO	19:31	20:35	64	15841	15840	44
AVEIRO	PORTO-CAMPANHÃ	19:23	20:29	66	15649	15649	45
OVAR	PORTO-CAMPANHÃ	19:53	20:44	51	15843	15843	46
AVEIRO	PORTO-CAMPANHÃ	19:46	20:49	63	15651	15651	47
OVAR	PORTO-SÃO BENTO	20:35	21:35	60	15845	15844	48
AVEIRO	PORTO-SÃO BENTO	20:29	22:00	91	15653	15652	49
AVEIRO	PORTO-SÃO BENTO	21:29	23:00	91	15655	15654	50
AVEIRO	PORTO-SÃO BENTO	22:30	00:00	90	15657	15656	51
AVEIRO	PORTO-SÃO BENTO	23:25	00:55	90	15659	15658	52

Table A.2: Porto-Aveiro Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	AVEIRO	04:35	06:00	85	15703	15702	1
PORTO-SÃO BENTO	AVEIRO	05:40	06:57	77	15707	15706	2
PORTO-SÃO BENTO	OVAR	05:55	06:56	61	15901	15900	3
PORTO-CAMPANHÃ	AVEIRO	06:40	07:43	63	15708	15708	4
PORTO-CAMPANHÃ	OVAR	06:45	07:36	51	15902	15902	5
PORTO-SÃO BENTO	AVEIRO	06:50	08:07	77	15711	15710	6
PORTO-SÃO BENTO	OVAR	06:55	07:57	62	15905	15904	7
PORTO-CAMPANHÃ	AVEIRO	07:40	08:43	63	15712	15712	8
PORTO-CAMPANHÃ	OVAR	07:45	08:36	51	15906	15906	9
PORTO-SÃO BENTO	AVEIRO	07:50	09:07	77	15715	15714	10
PORTO-SÃO BENTO	OVAR	07:55	08:57	62	15909	15908	11
PORTO-CAMPANHÃ	AVEIRO	08:40	09:43	63	15716	15716	12
PORTO-CAMPANHÃ	OVAR	08:45	09:36	51	15910	15910	13
PORTO-SÃO BENTO	AVEIRO	08:50	10:07	77	15719	15718	14
PORTO-CAMPANHÃ	AVEIRO	09:40	10:43	63	15720	15720	15
PORTO-CAMPANHÃ	OVAR	09:45	10:36	51	15912	15912	16
PORTO-SÃO BENTO	AVEIRO	09:50	11:07	77	15723	15722	17
PORTO-CAMPANHÃ	OVAR	10:45	11:36	51	15914	15914	18
PORTO-SÃO BENTO	AVEIRO	10:50	12:07	77	15725	15724	19
PORTO-CAMPANHÃ	OVAR	11:45	12:36	51	15916	15916	20
PORTO-SÃO BENTO	AVEIRO	11:50	13:07	77	15727	15726	21
PORTO-SÃO BENTO	OVAR	11:55	12:57	62	15919	15918	22

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-CAMPANHÃ	AVEIRO	12:40	13:43	63	15728	15728	23
PORTO-CAMPANHÃ	OVAR	12:45	13:36	51	15920	15920	24
PORTO-SÃO BENTO	AVEIRO	12:50	14:07	77	15731	15730	25
PORTO-SÃO BENTO	OVAR	12:55	13:57	62	15925	15924	26
PORTO-CAMPANHÃ	AVEIRO	13:40	14:43	63	15732	15732	27
PORTO-CAMPANHÃ	OVAR	13:45	14:36	51	15926	15926	28
PORTO-SÃO BENTO	AVEIRO	13:50	15:07	77	15735	15734	29
PORTO-CAMPANHÃ	OVAR	14:45	15:36	51	15928	15928	30
PORTO-SÃO BENTO	AVEIRO	14:50	16:07	77	15737	15736	31
PORTO-CAMPANHÃ	OVAR	15:45	16:36	51	15930	15930	32
PORTO-SÃO BENTO	AVEIRO	15:50	17:07	77	15739	15738	33
PORTO-SÃO BENTO	OVAR	15:55	16:57	62	15933	15932	34
PORTO-CAMPANHÃ	AVEIRO	16:40	17:42	62	15740	15740	35
PORTO-CAMPANHÃ	OVAR	16:45	17:36	51	15934	15934	36
PORTO-SÃO BENTO	AVEIRO	16:50	18:07	77	15743	15742	37
PORTO-SÃO BENTO	OVAR	16:55	17:57	62	15937	15936	38
PORTO-CAMPANHÃ	AVEIRO	17:40	18:43	63	15744	15744	39
PORTO-CAMPANHÃ	OVAR	17:45	18:36	51	15938	15938	40
PORTO-SÃO BENTO	AVEIRO	17:45	19:07	82	15747	15746	41
PORTO-SÃO BENTO	OVAR	17:55	18:57	62	15941	15940	42
PORTO-CAMPANHÃ	AVEIRO	18:40	19:43	63	15748	15748	43
PORTO-CAMPANHÃ	OVAR	18:45	19:36	51	15942	15942	44
PORTO-CAMPANHÃ	AVEIRO	19:00	20:07	77	15750	15750	45
PORTO-SÃO BENTO	OVAR	18:55	19:57	62	15945	15944	46
PORTO-CAMPANHÃ	AVEIRO	19:40	20:43	63	15752	15752	47
PORTO-CAMPANHÃ	AVEIRO	19:50	21:08	78	15754	15754	48
PORTO-SÃO BENTO	AVEIRO	20:40	22:08	88	15757	15756	49
PORTO-SÃO BENTO	AVEIRO	21:40	23:08	88	15759	15758	50
PORTO-SÃO BENTO	AVEIRO	22:40	00:08	88	15761	15760	51
PORTO-SÃO BENTO	AVEIRO	23:40	01:08	88	15763	15762	52

Table A.3: Marco de Canaveses-Porto Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	PORTO-SÃO BENTO	04:18	05:40	82	15500	15500	1
MARCO	PORTO-SÃO BENTO	05:08	06:30	82	15502	15502	2
PENAFIEL	PORTO-SÃO BENTO	05:57	06:50	53	15400	15400	3
MARCO	PORTO-SÃO BENTO	06:00	07:10	70	15504	15504	4
MARCO	PORTO-SÃO BENTO	06:13	07:30	77	15506	15506	5
PENAFIEL	PORTO-SÃO BENTO	07:07	08:00	53	15402	15402	6
MARCO	PORTO-SÃO BENTO	07:00	08:10	70	15508	15508	7
PENAFIEL	PORTO-SÃO BENTO	07:27	08:20	53	15404	15404	8
MARCO	PORTO-SÃO BENTO	07:13	08:30	77	15510	15510	9
PENAFIEL	PORTO-SÃO BENTO	08:07	09:00	53	15406	15406	10
MARCO	PORTO-SÃO BENTO	07:54	09:10	76	15512	15512	11
MARCO	PORTO-SÃO BENTO	08:14	09:30	76	15514	15514	12
PENAFIEL	PORTO-SÃO BENTO	09:07	10:00	53	15408	15408	13

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	PORTO-SÃO BENTO	09:13	10:30	77	15518	15518	14
PENAFIEL	PORTO-SÃO BENTO	10:07	11:00	53	15410	15410	15
MARCO	PORTO-SÃO BENTO	10:14	11:30	76	15520	15520	16
MARCO	PORTO-SÃO BENTO	11:13	12:30	77	15524	15524	17
PENAFIEL	PORTO-SÃO BENTO	12:07	13:00	53	15412	15412	18
MARCO	PORTO-SÃO BENTO	12:14	13:30	76	15526	15526	19
PENAFIEL	PORTO-SÃO BENTO	13:07	14:00	53	15414	15414	20
MARCO	PORTO-SÃO BENTO	13:13	14:30	77	15530	15530	21
PENAFIEL	PORTO-SÃO BENTO	14:07	15:00	53	15416	15416	22
MARCO	PORTO-SÃO BENTO	14:14	15:30	76	15532	15532	23
PENAFIEL	PORTO-SÃO BENTO	15:07	16:00	53	15418	15418	24
MARCO	PORTO-SÃO BENTO	15:13	16:30	77	15536	15536	25
PENAFIEL	PORTO-SÃO BENTO	16:07	17:00	53	15420	15420	26
MARCO	PORTO-SÃO BENTO	16:14	17:30	76	15538	15538	27
PENAFIEL	PORTO-SÃO BENTO	17:07	18:00	53	15422	15422	28
MARCO	PORTO-SÃO BENTO	17:13	18:30	77	15542	15542	29
PENAFIEL	PORTO-SÃO BENTO	18:07	19:00	53	15424	15424	30
MARCO	PORTO-SÃO BENTO	18:14	19:30	76	15544	15544	31
PENAFIEL	PORTO-SÃO BENTO	19:07	20:00	53	15426	15426	32
MARCO	PORTO-SÃO BENTO	19:13	20:25	72	15546	15546	33
MARCO	PORTO-SÃO BENTO	20:08	21:30	82	15548	15548	34
MARCO	PORTO-SÃO BENTO	21:08	22:30	82	15550	15550	35
MARCO	PORTO-SÃO BENTO	22:08	23:30	82	15552	15552	36

Table A.4: Porto-Marco de Canaveses Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	MARCO	05:30	06:40	70	15503	15503	1
PORTO-SÃO BENTO	MARCO	06:30	07:39	69	15505	15505	2
PORTO-SÃO BENTO	PENAFIEL	07:00	07:53	53	15401	15401	3
PORTO-SÃO BENTO	MARCO	07:30	08:43	73	15507	15507	4
PORTO-SÃO BENTO	PENAFIEL	08:00	08:53	53	15403	15403	5
PORTO-SÃO BENTO	MARCO	08:30	09:39	69	15511	15511	6
PORTO-SÃO BENTO	PENAFIEL	09:00	09:53	53	15405	15405	7
PORTO-SÃO BENTO	MARCO	09:30	10:42	72	15515	15515	8
PORTO-SÃO BENTO	MARCO	10:30	11:39	69	15517	15517	9
PORTO-SÃO BENTO	PENAFIEL	11:00	11:53	53	15407	15407	10
PORTO-SÃO BENTO	MARCO	11:30	12:42	72	15521	15521	11
PORTO-SÃO BENTO	PENAFIEL	12:00	12:53	53	15409	15409	12
PORTO-SÃO BENTO	MARCO	12:30	13:39	69	15523	15523	13
PORTO-SÃO BENTO	PENAFIEL	13:00	13:53	53	15411	15411	14
PORTO-SÃO BENTO	MARCO	13:30	14:42	72	15527	15527	15
PORTO-SÃO BENTO	PENAFIEL	14:00	14:53	53	15413	15413	16
PORTO-SÃO BENTO	MARCO	14:30	15:39	69	15529	15529	17
PORTO-SÃO BENTO	PENAFIEL	15:00	15:53	53	15415	15415	18
PORTO-SÃO BENTO	MARCO	15:30	16:42	72	15533	15533	19
PORTO-SÃO BENTO	PENAFIEL	16:00	16:53	53	15417	15417	20

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	MARCO	16:30	17:39	69	15535	15535	21
PORTO-SÃO BENTO	PENAFIEL	17:00	17:53	53	15419	15419	22
PORTO-SÃO BENTO	MARCO	17:30	18:43	73	15539	15539	23
PORTO-SÃO BENTO	PENAFIEL	17:35	18:28	53	15421	15421	24
PORTO-SÃO BENTO	MARCO	17:50	18:58	68	15541	15541	25
PORTO-SÃO BENTO	PENAFIEL	18:00	18:53	53	15423	15423	26
PORTO-SÃO BENTO	PENAFIEL	18:20	19:02	42	15425	15425	27
PORTO-SÃO BENTO	MARCO	18:30	19:42	72	15543	15543	28
PORTO-SÃO BENTO	PENAFIEL	18:45	19:39	54	15427	15427	29
PORTO-SÃO BENTO	PENAFIEL	19:00	19:53	53	15429	15429	30
PORTO-SÃO BENTO	MARCO	19:30	20:47	77	15545	15545	31
PORTO-SÃO BENTO	PENAFIEL	19:40	20:33	53	15431	15431	32
PORTO-SÃO BENTO	PENAFIEL	20:00	20:53	53	15433	15433	33
PORTO-SÃO BENTO	MARCO	20:30	21:46	76	15549	15549	34
PORTO-SÃO BENTO	MARCO	21:30	22:50	80	15551	15551	35
PORTO-SÃO BENTO	MARCO	23:30	00:50	80	15553	15553	36
PORTO-SÃO BENTO	MARCO	00:45	01:51	66	15501	15501	37

Table A.5: Guimarães-Porto Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
GUIMARÃES	PORTO-SÃO BENTO	05:53	07:05	72	15150	15150	1
GUIMARÃES	PORTO-SÃO BENTO	07:02	08:05	63	15154	15154	2
GUIMARÃES	PORTO-SÃO BENTO	07:21	08:50	89	15156	15156	3
GUIMARÃES	PORTO-SÃO BENTO	08:02	09:05	63	15158	15158	4
GUIMARÃES	PORTO-SÃO BENTO	08:53	10:05	72	15160	15160	5
GUIMARÃES	PORTO-SÃO BENTO	09:53	11:10	77	15162	15162	6
GUIMARÃES	PORTO-SÃO BENTO	11:53	13:05	72	15164	15164	7
GUIMARÃES	PORTO-SÃO BENTO	12:53	14:05	72	15166	15166	8
GUIMARÃES	PORTO-SÃO BENTO	13:53	15:05	72	15168	15168	9
GUIMARÃES	PORTO-SÃO BENTO	15:53	17:05	72	15170	15170	10
GUIMARÃES	PORTO-SÃO BENTO	17:07	18:25	78	15172	15172	11
GUIMARÃES	PORTO-SÃO BENTO	18:13	19:35	82	15176	15176	12
GUIMARÃES	PORTO-SÃO BENTO	19:21	20:45	84	15178	15178	13
GUIMARÃES	PORTO-SÃO BENTO	20:20	21:40	80	15182	15182	14
GUIMARÃES	PORTO-SÃO BENTO	21:48	23:05	77	15184	15184	15
GUIMARÃES	PORTO-SÃO BENTO	22:47	00:05	78	15186	15186	16

Table A.6: Porto-Guimarães Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	GUIMARÃES	06:20	07:42	82	15151	15151	1
PORTO-SÃO BENTO	GUIMARÃES	07:25	08:37	72	15153	15153	2
PORTO-SÃO BENTO	GUIMARÃES	08:25	09:41	76	15155	15155	3
PORTO-SÃO BENTO	GUIMARÃES	09:25	10:27	62	15157	15157	4
PORTO-SÃO BENTO	GUIMARÃES	10:25	11:38	73	15159	15159	5

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	GUIMARÃES	11:25	12:41	76	15161	15161	6
PORTO-SÃO BENTO	GUIMARÃES	12:25	13:41	76	15163	15163	7
PORTO-SÃO BENTO	GUIMARÃES	14:20	15:32	72	15165	15165	8
PORTO-SÃO BENTO	GUIMARÃES	16:20	17:44	84	15167	15167	9
PORTO-SÃO BENTO	GUIMARÃES	17:25	18:37	72	15169	15169	10
PORTO-SÃO BENTO	GUIMARÃES	18:25	19:43	78	15171	15171	11
PORTO-SÃO BENTO	GUIMARÃES	19:10	20:09	59	15173	15173	12
PORTO-SÃO BENTO	GUIMARÃES	19:25	20:44	79	15175	15175	13
PORTO-SÃO BENTO	GUIMARÃES	20:20	21:38	78	15177	15177	14
PORTO-SÃO BENTO	GUIMARÃES	22:25	23:37	72	15181	15181	15
PORTO-SÃO BENTO	GUIMARÃES	23:20	00:32	72	15183	15183	16

Table A.7: Braga-Porto Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	PORTO-SÃO BENTO	04:34	05:45	71	15200	15200	1
BRAGA	PORTO-SÃO BENTO	05:29	06:45	76	15202	15202	2
BRAGA	PORTO-SÃO BENTO	06:21	07:15	54	15204	15204	3
BRAGA	PORTO-SÃO BENTO	06:29	07:45	76	15206	15206	4
BRAGA	PORTO-SÃO BENTO	07:21	08:15	54	15208	15208	5
BRAGA	PORTO-SÃO BENTO	07:45	08:35	50	15212	15212	6
BRAGA	PORTO-SÃO BENTO	08:04	09:15	71	15214	15214	7
BRAGA	PORTO-SÃO BENTO	08:34	09:45	71	15218	15218	8
BRAGA	PORTO-SÃO BENTO	09:37	10:55	78	15220	15220	9
BRAGA	PORTO-SÃO BENTO	10:39	11:50	71	15222	15222	10
BRAGA	PORTO-SÃO BENTO	11:34	12:45	71	15224	15224	11
BRAGA	PORTO-SÃO BENTO	12:29	13:45	76	15226	15226	12
BRAGA	PORTO-SÃO BENTO	13:21	14:15	54	15228	15228	13
BRAGA	PORTO-SÃO BENTO	13:37	14:55	78	15230	15230	14
BRAGA	PORTO-SÃO BENTO	14:39	15:50	71	15232	15232	15
BRAGA	PORTO-SÃO BENTO	15:34	16:45	71	15234	15234	16
BRAGA	PORTO-SÃO BENTO	16:44	17:55	71	15236	15236	17
BRAGA	PORTO-SÃO BENTO	17:21	18:15	54	15238	15238	18
BRAGA	PORTO-SÃO BENTO	17:35	18:55	80	15240	15240	19
BRAGA	PORTO-SÃO BENTO	18:21	19:15	54	15242	15242	20
BRAGA	PORTO-SÃO BENTO	18:34	19:45	71	15244	15244	21
BRAGA	PORTO-SÃO BENTO	19:35	20:55	80	15246	15246	22
BRAGA	PORTO-SÃO BENTO	20:39	21:50	71	15248	15248	23
BRAGA	PORTO-SÃO BENTO	22:39	23:50	71	15252	15252	24
BRAGA	PORTO-SÃO BENTO	23:32	00:35	63	15254	15254	25

Table A.8: Porto-Braga Schedule Overview

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	BRAGA	06:15	07:09	54	15203	15203	1
PORTO-SÃO BENTO	BRAGA	06:45	07:56	71	15205	15205	2

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	BRAGA	07:15	08:17	62	15207	15207	3
PORTO-SÃO BENTO	BRAGA	07:45	08:56	71	15209	15209	4
PORTO-SÃO BENTO	BRAGA	08:15	09:09	54	15211	15211	5
PORTO-SÃO BENTO	BRAGA	08:45	09:56	71	15213	15213	6
PORTO-SÃO BENTO	BRAGA	10:00	11:12	72	15215	15215	7
PORTO-SÃO BENTO	BRAGA	10:45	11:56	71	15217	15217	8
PORTO-SÃO BENTO	BRAGA	11:45	12:57	72	15219	15219	9
PORTO-SÃO BENTO	BRAGA	12:15	13:09	54	15221	15221	10
PORTO-SÃO BENTO	BRAGA	12:40	13:59	79	15223	15223	11
PORTO-SÃO BENTO	BRAGA	13:45	14:56	71	15225	15225	12
PORTO-SÃO BENTO	BRAGA	14:55	16:06	71	15227	15227	13
PORTO-SÃO BENTO	BRAGA	15:45	16:56	71	15229	15229	14
PORTO-SÃO BENTO	BRAGA	16:15	17:09	54	15231	15231	15
PORTO-SÃO BENTO	BRAGA	16:45	18:04	79	15233	15233	16
PORTO-SÃO BENTO	BRAGA	17:15	18:09	54	15235	15235	17
PORTO-SÃO BENTO	BRAGA	17:40	18:51	71	15237	15237	18
PORTO-SÃO BENTO	BRAGA	18:15	19:09	54	15239	15239	19
PORTO-SÃO BENTO	BRAGA	18:40	19:53	73	15241	15241	20
PORTO-SÃO BENTO	BRAGA	19:15	20:14	59	15243	15243	21
PORTO-SÃO BENTO	BRAGA	19:45	20:56	71	15245	15245	22
PORTO-SÃO BENTO	BRAGA	21:05	22:16	71	15247	15247	23
PORTO-SÃO BENTO	BRAGA	21:45	22:56	71	15249	15249	24
PORTO-SÃO BENTO	BRAGA	23:05	00:17	72	15251	15251	25
PORTO-SÃO BENTO	BRAGA	00:50	01:53	63	15201	15201	26

Appendix B

Headway

Table B.1: Aveiro-Porto Headway Overview

Origin	Departure	Headway	TID1	TID2	Run
OVAR	04:57		15601	15600	1
OVAR	05:41	44	15603	15603	2
OVAR	06:43	62	15605	15604	3
OVAR	06:48	5	15801	15801	4
OVAR	07:09	21	15607	15607	5
OVAR	07:31	22	15803	15803	6
OVAR	07:48	17	15609	15608	7
OVAR	07:53	5	15805	15805	8
OVAR	08:09	16	15611	15611	9
OVAR	08:31	22	15807	15806	10
OVAR	08:48	17	15613	15612	11
OVAR	08:53	5	15809	15809	12
OVAR	09:09	16	15615	15615	13
OVAR	09:31	22	15811	15810	14
OVAR	09:48	17	15617	15616	15
OVAR	09:53	5	15813	15813	16
OVAR	10:48	55	15621	15620	17
OVAR	10:53	5	15815	15815	18
OVAR	11:48	55	15623	15623	19
OVAR	11:53	5	15817	15817	20
OVAR	12:48	55	15625	15624	21
OVAR	12:53	5	15819	15819	22
OVAR	13:09	16	15627	15627	23
OVAR	13:31	22	15821	15820	24
OVAR	13:48	17	15629	15628	25
OVAR	13:53	5	15823	15823	26
OVAR	14:09	16	15631	15631	27
OVAR	14:31	22	15825	15824	28
OVAR	14:48	17	15633	15632	29
OVAR	14:53	5	15827	15827	30

Continued on next page

Origin	Departure	Headway	TID1	TID2	Run
OVAR	15:48	55	15635	15634	31
OVAR	15:53	5	15829	15829	32
OVAR	16:48	55	15637	15636	33
OVAR	16:53	5	15831	15831	34
OVAR	17:09	16	15639	15639	35
OVAR	17:31	22	15833	15832	36
OVAR	17:48	17	15641	15640	37
OVAR	17:53	5	15835	15835	38
OVAR	18:09	16	15643	15643	39
OVAR	18:31	22	15837	15837	40
OVAR	18:48	17	15645	15644	41
OVAR	18:53	5	15839	15839	42
OVAR	19:09	16	15647	15647	43
OVAR	19:31	22	15841	15840	44
OVAR	19:48	17	15649	15649	45
OVAR	19:53	5	15843	15843	46
OVAR	20:09	16	15651	15651	47
OVAR	20:35	26	15845	15844	48
OVAR	20:55	20	15653	15652	49
OVAR	21:55	60	15655	15654	50
OVAR	22:56	61	15657	15656	51
OVAR	23:51	55	15659	15658	52

Table B.2: Porto-Aveiro Headway Overview

Origin	Departure	Headway	TID1	TID2	Run
PORTO-CAMPANHÃ	04:45		15703	15702	1
PORTO-CAMPANHÃ	05:50	65	15707	15706	2
PORTO-CAMPANHÃ	06:05	15	15901	15900	3
PORTO-CAMPANHÃ	06:40	35	15708	15708	4
PORTO-CAMPANHÃ	06:45	5	15902	15902	5
PORTO-CAMPANHÃ	07:00	15	15711	15710	6
PORTO-CAMPANHÃ	07:05	5	15905	15904	7
PORTO-CAMPANHÃ	07:40	35	15712	15712	8
PORTO-CAMPANHÃ	07:45	5	15906	15906	9
PORTO-CAMPANHÃ	08:00	15	15715	15714	10
PORTO-CAMPANHÃ	08:05	5	15909	15908	11
PORTO-CAMPANHÃ	08:40	35	15716	15716	12
PORTO-CAMPANHÃ	08:45	5	15910	15910	13
PORTO-CAMPANHÃ	09:00	15	15719	15718	14
PORTO-CAMPANHÃ	09:40	40	15720	15720	15
PORTO-CAMPANHÃ	09:45	5	15912	15912	16
PORTO-CAMPANHÃ	10:00	15	15723	15722	17
PORTO-CAMPANHÃ	10:45	45	15914	15914	18
PORTO-CAMPANHÃ	11:00	15	15725	15724	19
PORTO-CAMPANHÃ	11:45	45	15916	15916	20
PORTO-CAMPANHÃ	12:00	15	15727	15726	21

Continued on next page

Origin	Departure	Headway	TID1	TID2	Run
PORTO-CAMPANHÃ	12:05	5	15919	15918	22
PORTO-CAMPANHÃ	12:40	35	15728	15728	23
PORTO-CAMPANHÃ	12:45	5	15920	15920	24
PORTO-CAMPANHÃ	13:00	15	15731	15730	25
PORTO-CAMPANHÃ	13:05	5	15925	15924	26
PORTO-CAMPANHÃ	13:40	35	15732	15732	27
PORTO-CAMPANHÃ	13:45	5	15926	15926	28
PORTO-CAMPANHÃ	14:00	15	15735	15734	29
PORTO-CAMPANHÃ	14:45	45	15928	15928	30
PORTO-CAMPANHÃ	15:00	15	15737	15736	31
PORTO-CAMPANHÃ	15:45	45	15930	15930	32
PORTO-CAMPANHÃ	16:00	15	15739	15738	33
PORTO-CAMPANHÃ	16:05	5	15933	15932	34
PORTO-CAMPANHÃ	16:40	35	15740	15740	35
PORTO-CAMPANHÃ	16:45	5	15934	15934	36
PORTO-CAMPANHÃ	17:00	15	15743	15742	37
PORTO-CAMPANHÃ	17:05	5	15937	15936	38
PORTO-CAMPANHÃ	17:40	35	15744	15744	39
PORTO-CAMPANHÃ	17:45	5	15938	15938	40
PORTO-CAMPANHÃ	18:00	15	15747	15746	41
PORTO-CAMPANHÃ	18:05	5	15941	15940	42
PORTO-CAMPANHÃ	18:40	35	15748	15748	43
PORTO-CAMPANHÃ	18:45	5	15942	15942	44
PORTO-CAMPANHÃ	19:00	15	15750	15750	45
PORTO-CAMPANHÃ	19:05	5	15945	15944	46
PORTO-CAMPANHÃ	19:40	35	15752	15752	47
PORTO-CAMPANHÃ	19:50	10	15754	15754	48
PORTO-CAMPANHÃ	20:50	60	15757	15756	49
PORTO-CAMPANHÃ	21:50	60	15759	15758	50
PORTO-CAMPANHÃ	22:50	60	15761	15760	51
PORTO-CAMPANHÃ	23:50	60	15763	15762	52

Table B.3: Marco de Canaveses-Porto Headway Overview

Origin	Departure	Headway	TID1	TID2	Run
PENAFIEL	04:46		15500	15500	1
PENAFIEL	05:36	50	15502	15502	2
PENAFIEL	05:57	21	15400	15400	3
PENAFIEL	06:24	27	15504	15504	4
PENAFIEL	06:46	22	15506	15506	5
PENAFIEL	07:07	21	15402	15402	6
PENAFIEL	07:24	17	15508	15508	7
PENAFIEL	07:27	3	15404	15404	8
PENAFIEL	07:46	19	15510	15510	9
PENAFIEL	08:07	21	15406	15406	10
PENAFIEL	08:18	11	15512	15512	11
PENAFIEL	08:47	29	15514	15514	12

Continued on next page

Origin	Departure	Headway	TID1	TID2	Run
PENAFIEL	09:07	20	15408	15408	13
PENAFIEL	09:45	38	15518	15518	14
PENAFIEL	10:07	22	15410	15410	15
PENAFIEL	10:46	39	15520	15520	16
PENAFIEL	11:45	59	15524	15524	17
PENAFIEL	12:07	22	15412	15412	18
PENAFIEL	12:46	39	15526	15526	19
PENAFIEL	13:07	21	15414	15414	20
PENAFIEL	13:45	38	15530	15530	21
PENAFIEL	14:07	22	15416	15416	22
PENAFIEL	14:46	39	15532	15532	23
PENAFIEL	15:07	21	15418	15418	24
PENAFIEL	15:45	38	15536	15536	25
PENAFIEL	16:07	22	15420	15420	26
PENAFIEL	16:46	39	15538	15538	27
PENAFIEL	17:07	21	15422	15422	28
PENAFIEL	17:45	38	15542	15542	29
PENAFIEL	18:07	22	15424	15424	30
PENAFIEL	18:48	41	15544	15544	31
PENAFIEL	19:07	19	15426	15426	32
PENAFIEL	19:44	37	15546	15546	33
PENAFIEL	20:38	54	15548	15548	34
PENAFIEL	21:36	58	15550	15550	35
PENAFIEL	22:36	60	15552	15552	36

Table B.4: Porto-Marco de Canaveses Headway Overview

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	05:30		15503	15503	1
PORTO-SÃO BENTO	06:30	60	15505	15505	2
PORTO-SÃO BENTO	07:00	30	15401	15401	3
PORTO-SÃO BENTO	07:30	30	15507	15507	4
PORTO-SÃO BENTO	08:00	30	15403	15403	5
PORTO-SÃO BENTO	08:30	30	15511	15511	6
PORTO-SÃO BENTO	09:00	30	15405	15405	7
PORTO-SÃO BENTO	09:30	30	15515	15515	8
PORTO-SÃO BENTO	10:30	60	15517	15517	9
PORTO-SÃO BENTO	11:00	30	15407	15407	10
PORTO-SÃO BENTO	11:30	30	15521	15521	11
PORTO-SÃO BENTO	12:00	30	15409	15409	12
PORTO-SÃO BENTO	12:30	30	15523	15523	13
PORTO-SÃO BENTO	13:00	30	15411	15411	14
PORTO-SÃO BENTO	13:30	30	15527	15527	15
PORTO-SÃO BENTO	14:00	30	15413	15413	16
PORTO-SÃO BENTO	14:30	30	15529	15529	17
PORTO-SÃO BENTO	15:00	30	15415	15415	18
PORTO-SÃO BENTO	15:30	30	15533	15533	19

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Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	16:00	30	15417	15417	20
PORTO-SÃO BENTO	16:30	30	15535	15535	21
PORTO-SÃO BENTO	17:00	30	15419	15419	22
PORTO-SÃO BENTO	17:30	30	15539	15539	23
PORTO-SÃO BENTO	17:35	5	15421	15421	24
PORTO-SÃO BENTO	17:50	15	15541	15541	25
PORTO-SÃO BENTO	18:00	10	15423	15423	26
PORTO-SÃO BENTO	18:20	20	15425	15425	27
PORTO-SÃO BENTO	18:30	10	15543	15543	28
PORTO-SÃO BENTO	18:45	15	15427	15427	29
PORTO-SÃO BENTO	19:00	15	15429	15429	30
PORTO-SÃO BENTO	19:30	30	15545	15545	31
PORTO-SÃO BENTO	19:40	10	15431	15431	32
PORTO-SÃO BENTO	20:00	20	15433	15433	33
PORTO-SÃO BENTO	20:30	30	15549	15549	34
PORTO-SÃO BENTO	21:30	60	15551	15551	35
PORTO-SÃO BENTO	23:30	120	15553	15553	36
PORTO-SÃO BENTO	00:45	75	15501	15501	37

Table B.5: Guimarães-Porto Headway Overview.

Origin	Departure	Headway	TID1	TID2	Run
GUIMARÃES	05:53		15150	15150	1
GUIMARÃES	07:02	69	15154	15154	2
GUIMARÃES	07:21	19	15156	15156	3
GUIMARÃES	08:02	41	15158	15158	4
GUIMARÃES	08:53	51	15160	15160	5
GUIMARÃES	09:53	60	15162	15162	6
GUIMARÃES	11:53	120	15164	15164	7
GUIMARÃES	12:53	60	15166	15166	8
GUIMARÃES	13:53	60	15168	15168	9
GUIMARÃES	15:53	120	15170	15170	10
GUIMARÃES	17:07	74	15172	15172	11
GUIMARÃES	18:13	66	15176	15176	12
GUIMARÃES	19:21	68	15178	15178	13
GUIMARÃES	20:20	59	15182	15182	14
GUIMARÃES	21:48	88	15184	15184	15
GUIMARÃES	22:47	59	15186	15186	16

Table B.6: Porto-Guimarães Headway Overview.

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	06:20		15151	15151	1
PORTO-SÃO BENTO	07:25	65	15153	15153	2
PORTO-SÃO BENTO	08:25	60	15155	15155	3
PORTO-SÃO BENTO	09:25	60	15157	15157	4

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Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	10:25	60	15159	15159	5
PORTO-SÃO BENTO	11:25	60	15161	15161	6
PORTO-SÃO BENTO	12:25	60	15163	15163	7
PORTO-SÃO BENTO	14:20	115	15165	15165	8
PORTO-SÃO BENTO	16:20	120	15167	15167	9
PORTO-SÃO BENTO	17:25	65	15169	15169	10
PORTO-SÃO BENTO	18:25	60	15171	15171	11
PORTO-SÃO BENTO	19:10	45	15173	15173	12
PORTO-SÃO BENTO	19:25	15	15175	15175	13
PORTO-SÃO BENTO	20:20	55	15177	15177	14
PORTO-SÃO BENTO	22:25	125	15181	15181	15
PORTO-SÃO BENTO	23:20	55	15183	15183	16

Table B.7: Braga-Porto Headway Overview.

Origin	Departure	Headway	TID1	TID2	Run
BRAGA	04:34		15200	15200	1
BRAGA	05:29	55	15202	15202	2
BRAGA	06:21	52	15204	15204	3
BRAGA	06:29	8	15206	15206	4
BRAGA	07:21	52	15208	15208	5
BRAGA	07:45	24	15212	15212	6
BRAGA	08:04	19	15214	15214	7
BRAGA	08:34	30	15218	15218	8
BRAGA	09:37	63	15220	15220	9
BRAGA	10:39	62	15222	15222	10
BRAGA	11:34	55	15224	15224	11
BRAGA	12:29	55	15226	15226	12
BRAGA	13:21	52	15228	15228	13
BRAGA	13:37	16	15230	15230	14
BRAGA	14:39	62	15232	15232	15
BRAGA	15:34	55	15234	15234	16
BRAGA	16:44	70	15236	15236	17
BRAGA	17:21	37	15238	15238	18
BRAGA	17:35	14	15240	15240	19
BRAGA	18:21	46	15242	15242	20
BRAGA	18:34	13	15244	15244	21
BRAGA	19:35	61	15246	15246	22
BRAGA	20:39	64	15248	15248	23
BRAGA	22:39	120	15252	15252	24
BRAGA	23:32	53	15254	15254	25

Table B.8: Porto-Braga Headway Overview.

Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	06:15		15203	15203	1

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Origin	Departure	Headway	TID1	TID2	Run
PORTO-SÃO BENTO	06:45	30	15205	15205	2
PORTO-SÃO BENTO	07:15	30	15207	15207	3
PORTO-SÃO BENTO	07:45	30	15209	15209	4
PORTO-SÃO BENTO	08:15	30	15211	15211	5
PORTO-SÃO BENTO	08:45	30	15213	15213	6
PORTO-SÃO BENTO	10:00	75	15215	15215	7
PORTO-SÃO BENTO	10:45	45	15217	15217	8
PORTO-SÃO BENTO	11:45	60	15219	15219	9
PORTO-SÃO BENTO	12:15	30	15221	15221	10
PORTO-SÃO BENTO	12:40	25	15223	15223	11
PORTO-SÃO BENTO	13:45	65	15225	15225	12
PORTO-SÃO BENTO	14:55	70	15227	15227	13
PORTO-SÃO BENTO	15:45	50	15229	15229	14
PORTO-SÃO BENTO	16:15	30	15231	15231	15
PORTO-SÃO BENTO	16:45	30	15233	15233	16
PORTO-SÃO BENTO	17:15	30	15235	15235	17
PORTO-SÃO BENTO	17:40	25	15237	15237	18
PORTO-SÃO BENTO	18:15	35	15239	15239	19
PORTO-SÃO BENTO	18:40	25	15241	15241	20
PORTO-SÃO BENTO	19:15	35	15243	15243	21
PORTO-SÃO BENTO	19:45	30	15245	15245	22
PORTO-SÃO BENTO	21:05	80	15247	15247	23
PORTO-SÃO BENTO	21:45	40	15249	15249	24
PORTO-SÃO BENTO	23:05	80	15251	15251	25
PORTO-SÃO BENTO	00:50	105	15201	15201	26

Appendix C

Travel Times

Table C.1: Aveiro-Porto Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
AVEIRO	PORTO-CAMPANHÃ	04:31	05:55	84	15601	15600	1
AVEIRO	PORTO-CAMPANHÃ	05:16	06:34	78	15603	15603	2
AVEIRO	PORTO-CAMPANHÃ	06:18	07:30	72	15605	15604	3
OVAR	PORTO-CAMPANHÃ	06:48	07:39	51	15801	15801	4
AVEIRO	PORTO-CAMPANHÃ	06:46	07:57	71	15607	15607	5
OVAR	PORTO-CAMPANHÃ	07:31	08:23	52	15803	15803	6
AVEIRO	PORTO-CAMPANHÃ	07:22	08:35	73	15609	15608	7
OVAR	PORTO-CAMPANHÃ	07:53	08:44	51	15805	15805	8
AVEIRO	PORTO-CAMPANHÃ	07:46	08:55	69	15611	15611	9
OVAR	PORTO-CAMPANHÃ	08:31	09:30	59	15807	15806	10
AVEIRO	PORTO-CAMPANHÃ	08:23	09:35	72	15613	15612	11
OVAR	PORTO-CAMPANHÃ	08:53	09:44	51	15809	15809	12
AVEIRO	PORTO-CAMPANHÃ	08:46	09:49	63	15615	15615	13
OVAR	PORTO-CAMPANHÃ	09:31	10:30	59	15811	15810	14
AVEIRO	PORTO-CAMPANHÃ	09:23	10:35	72	15617	15616	15
OVAR	PORTO-CAMPANHÃ	09:53	10:44	51	15813	15813	16
AVEIRO	PORTO-CAMPANHÃ	10:23	11:35	72	15621	15620	17
OVAR	PORTO-CAMPANHÃ	10:53	11:44	51	15815	15815	18
AVEIRO	PORTO-CAMPANHÃ	11:23	12:29	66	15623	15623	19
OVAR	PORTO-CAMPANHÃ	11:53	12:44	51	15817	15817	20
AVEIRO	PORTO-CAMPANHÃ	12:23	13:35	72	15625	15624	21
OVAR	PORTO-CAMPANHÃ	12:53	13:44	51	15819	15819	22
AVEIRO	PORTO-CAMPANHÃ	12:46	13:49	63	15627	15627	23
OVAR	PORTO-CAMPANHÃ	13:31	14:30	59	15821	15820	24
AVEIRO	PORTO-CAMPANHÃ	13:23	14:35	72	15629	15628	25
OVAR	PORTO-CAMPANHÃ	13:53	14:44	51	15823	15823	26
AVEIRO	PORTO-CAMPANHÃ	13:46	14:49	63	15631	15631	27
OVAR	PORTO-CAMPANHÃ	14:31	15:30	59	15825	15824	28
AVEIRO	PORTO-CAMPANHÃ	14:23	15:35	72	15633	15632	29
OVAR	PORTO-CAMPANHÃ	14:53	15:44	51	15827	15827	30
AVEIRO	PORTO-CAMPANHÃ	15:23	16:35	72	15635	15634	31

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
OVAR	PORTO-CAMPANHÃ	15:53	16:44	51	15829	15829	32
AVEIRO	PORTO-CAMPANHÃ	16:23	17:35	72	15637	15636	33
OVAR	PORTO-CAMPANHÃ	16:53	17:44	51	15831	15831	34
AVEIRO	PORTO-CAMPANHÃ	16:46	17:49	63	15639	15639	35
OVAR	PORTO-CAMPANHÃ	17:31	18:30	59	15833	15832	36
AVEIRO	PORTO-CAMPANHÃ	17:23	18:40	77	15641	15640	37
OVAR	PORTO-CAMPANHÃ	17:53	18:44	51	15835	15835	38
AVEIRO	PORTO-CAMPANHÃ	17:46	18:48	62	15643	15643	39
OVAR	PORTO-CAMPANHÃ	18:31	19:18	47	15837	15837	40
AVEIRO	PORTO-CAMPANHÃ	18:23	19:35	72	15645	15644	41
OVAR	PORTO-CAMPANHÃ	18:53	19:44	51	15839	15839	42
AVEIRO	PORTO-CAMPANHÃ	18:46	19:49	63	15647	15647	43
OVAR	PORTO-CAMPANHÃ	19:31	20:30	59	15841	15840	44
AVEIRO	PORTO-CAMPANHÃ	19:23	20:29	66	15649	15649	45
OVAR	PORTO-CAMPANHÃ	19:53	20:44	51	15843	15843	46
AVEIRO	PORTO-CAMPANHÃ	19:46	20:49	63	15651	15651	47
OVAR	PORTO-CAMPANHÃ	20:35	21:30	55	15845	15844	48
AVEIRO	PORTO-CAMPANHÃ	20:29	21:55	86	15653	15652	49
AVEIRO	PORTO-CAMPANHÃ	21:29	22:55	86	15655	15654	50
AVEIRO	PORTO-CAMPANHÃ	22:30	23:55	85	15657	15656	51
AVEIRO	PORTO-CAMPANHÃ	23:25	00:50	85	15659	15658	52

Table C.2: Porto-Aveiro Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	04:35	04:45	10	15703	15702	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	05:40	05:50	10	15707	15706	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	05:55	06:05	10	15901	15900	3
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	06:40	06:40	0	15708	15708	4
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	06:45	06:45	0	15902	15902	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:50	07:00	10	15711	15710	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:55	07:05	10	15905	15904	7
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	07:40	07:40	0	15712	15712	8
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	07:45	07:45	0	15906	15906	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:50	08:00	10	15715	15714	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:55	08:05	10	15909	15908	11
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	08:40	08:40	0	15716	15716	12
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	08:45	08:45	0	15910	15910	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:50	09:00	10	15719	15718	14
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	09:40	09:40	0	15720	15720	15
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	09:45	09:45	0	15912	15912	16
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	09:50	10:00	10	15723	15722	17
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	10:45	10:45	0	15914	15914	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:50	11:00	10	15725	15724	19
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	11:45	11:45	0	15916	15916	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:50	12:00	10	15727	15726	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:55	12:05	10	15919	15918	22

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	12:40	12:40	0	15728	15728	23
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	12:45	12:45	0	15920	15920	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:50	13:00	10	15731	15730	25
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:55	13:05	10	15925	15924	26
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	13:40	13:40	0	15732	15732	27
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	13:45	13:45	0	15926	15926	28
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:50	14:00	10	15735	15734	29
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	14:45	14:45	0	15928	15928	30
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:50	15:00	10	15737	15736	31
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	15:45	15:45	0	15930	15930	32
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:50	16:00	10	15739	15738	33
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:55	16:05	10	15933	15932	34
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	16:40	16:40	0	15740	15740	35
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	16:45	16:45	0	15934	15934	36
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:50	17:00	10	15743	15742	37
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:55	17:05	10	15937	15936	38
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	17:40	17:40	0	15744	15744	39
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	17:45	17:45	0	15938	15938	40
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:45	18:00	15	15747	15746	41
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:55	18:05	10	15941	15940	42
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	18:40	18:40	0	15748	15748	43
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	18:45	18:45	0	15942	15942	44
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:00	19:00	0	15750	15750	45
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:55	19:05	10	15945	15944	46
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:40	19:40	0	15752	15752	47
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:50	19:50	0	15754	15754	48
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:40	20:50	10	15757	15756	49
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:40	21:50	10	15759	15758	50
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	22:40	22:50	10	15761	15760	51
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:40	23:50	10	15763	15762	52

Table C.3: Marco de Canaveses-Porto Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	PORTO-CAMPANHÃ	04:18	05:36	78	15500	15500	1
MARCO	PORTO-CAMPANHÃ	05:08	06:26	78	15502	15502	2
PENAFIEL	PORTO-CAMPANHÃ	05:57	06:46	49	15400	15400	3
MARCO	PORTO-CAMPANHÃ	06:00	07:06	66	15504	15504	4
MARCO	PORTO-CAMPANHÃ	06:13	07:26	73	15506	15506	5
PENAFIEL	PORTO-CAMPANHÃ	07:07	07:56	49	15402	15402	6
MARCO	PORTO-CAMPANHÃ	07:00	08:06	66	15508	15508	7
PENAFIEL	PORTO-CAMPANHÃ	07:27	08:16	49	15404	15404	8
MARCO	PORTO-CAMPANHÃ	07:13	08:26	73	15510	15510	9
PENAFIEL	PORTO-CAMPANHÃ	08:07	08:56	49	15406	15406	10
MARCO	PORTO-CAMPANHÃ	07:54	09:06	72	15512	15512	11
MARCO	PORTO-CAMPANHÃ	08:14	09:26	72	15514	15514	12
PENAFIEL	PORTO-CAMPANHÃ	09:07	09:56	49	15408	15408	13

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	PORTO-CAMPANHÃ	09:13	10:26	73	15518	15518	14
PENAFIEL	PORTO-CAMPANHÃ	10:07	10:56	49	15410	15410	15
MARCO	PORTO-CAMPANHÃ	10:14	11:26	72	15520	15520	16
MARCO	PORTO-CAMPANHÃ	11:13	12:26	73	15524	15524	17
PENAFIEL	PORTO-CAMPANHÃ	12:07	12:56	49	15412	15412	18
MARCO	PORTO-CAMPANHÃ	12:14	13:26	72	15526	15526	19
PENAFIEL	PORTO-CAMPANHÃ	13:07	13:56	49	15414	15414	20
MARCO	PORTO-CAMPANHÃ	13:13	14:26	73	15530	15530	21
PENAFIEL	PORTO-CAMPANHÃ	14:07	14:56	49	15416	15416	22
MARCO	PORTO-CAMPANHÃ	14:14	15:26	72	15532	15532	23
PENAFIEL	PORTO-CAMPANHÃ	15:07	15:56	49	15418	15418	24
MARCO	PORTO-CAMPANHÃ	15:13	16:26	73	15536	15536	25
PENAFIEL	PORTO-CAMPANHÃ	16:07	16:56	49	15420	15420	26
MARCO	PORTO-CAMPANHÃ	16:14	17:26	72	15538	15538	27
PENAFIEL	PORTO-CAMPANHÃ	17:07	17:56	49	15422	15422	28
MARCO	PORTO-CAMPANHÃ	17:13	18:26	73	15542	15542	29
PENAFIEL	PORTO-CAMPANHÃ	18:07	18:56	49	15424	15424	30
MARCO	PORTO-CAMPANHÃ	18:14	19:26	72	15544	15544	31
PENAFIEL	PORTO-CAMPANHÃ	19:07	19:56	49	15426	15426	32
MARCO	PORTO-CAMPANHÃ	19:13	20:21	68	15546	15546	33
MARCO	PORTO-CAMPANHÃ	20:08	21:26	78	15548	15548	34
MARCO	PORTO-CAMPANHÃ	21:08	22:26	78	15550	15550	35
MARCO	PORTO-CAMPANHÃ	22:08	23:26	78	15552	15552	36

Table C.4: Marco de Canaveses-Porto Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	ERMESINDE	04:18	05:24	66	15500	15500	1
MARCO	ERMESINDE	05:08	06:14	66	15502	15502	2
PENAFIEL	ERMESINDE	05:57	06:34	37	15400	15400	3
MARCO	ERMESINDE	06:00	06:54	54	15504	15504	4
MARCO	ERMESINDE	06:13	07:14	61	15506	15506	5
PENAFIEL	ERMESINDE	07:07	07:44	37	15402	15402	6
MARCO	ERMESINDE	07:00	07:54	54	15508	15508	7
PENAFIEL	ERMESINDE	07:27	08:04	37	15404	15404	8
MARCO	ERMESINDE	07:13	08:14	61	15510	15510	9
PENAFIEL	ERMESINDE	08:07	08:44	37	15406	15406	10
MARCO	ERMESINDE	07:54	08:54	60	15512	15512	11
MARCO	ERMESINDE	08:14	09:14	60	15514	15514	12
PENAFIEL	ERMESINDE	09:07	09:44	37	15408	15408	13
MARCO	ERMESINDE	09:13	10:14	61	15518	15518	14
PENAFIEL	ERMESINDE	10:07	10:44	37	15410	15410	15
MARCO	ERMESINDE	10:14	11:14	60	15520	15520	16
MARCO	ERMESINDE	11:13	12:14	61	15524	15524	17
PENAFIEL	ERMESINDE	12:07	12:44	37	15412	15412	18
MARCO	ERMESINDE	12:14	13:14	60	15526	15526	19
PENAFIEL	ERMESINDE	13:07	13:44	37	15414	15414	20

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
MARCO	ERMESINDE	13:13	14:14	61	15530	15530	21
PENAFIEL	ERMESINDE	14:07	14:44	37	15416	15416	22
MARCO	ERMESINDE	14:14	15:14	60	15532	15532	23
PENAFIEL	ERMESINDE	15:07	15:44	37	15418	15418	24
MARCO	ERMESINDE	15:13	16:14	61	15536	15536	25
PENAFIEL	ERMESINDE	16:07	16:44	37	15420	15420	26
MARCO	ERMESINDE	16:14	17:14	60	15538	15538	27
PENAFIEL	ERMESINDE	17:07	17:44	37	15422	15422	28
MARCO	ERMESINDE	17:13	18:14	61	15542	15542	29
PENAFIEL	ERMESINDE	18:07	18:44	37	15424	15424	30
MARCO	ERMESINDE	18:14	19:14	60	15544	15544	31
PENAFIEL	ERMESINDE	19:07	19:44	37	15426	15426	32
MARCO	ERMESINDE	19:13	20:10	57	15546	15546	33
MARCO	ERMESINDE	20:08	21:15	67	15548	15548	34
MARCO	ERMESINDE	21:08	22:14	66	15550	15550	35
MARCO	ERMESINDE	22:08	23:14	66	15552	15552	36

Table C.5: Porto-Marco de Canaveses Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	05:30	05:35	5	15503	15503	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:30	06:35	5	15505	15505	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:00	07:05	5	15401	15401	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:30	07:35	5	15507	15507	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:00	08:05	5	15403	15403	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:30	08:35	5	15511	15511	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	09:00	09:05	5	15405	15405	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	09:30	09:35	5	15515	15515	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:30	10:35	5	15517	15517	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:00	11:05	5	15407	15407	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:30	11:35	5	15521	15521	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:00	12:05	5	15409	15409	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:30	12:35	5	15523	15523	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:00	13:05	5	15411	15411	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:30	13:35	5	15527	15527	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:00	14:05	5	15413	15413	16
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:30	14:35	5	15529	15529	17
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:00	15:05	5	15415	15415	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:30	15:35	5	15533	15533	19
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:00	16:05	5	15417	15417	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:30	16:35	5	15535	15535	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:00	17:05	5	15419	15419	22
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:30	17:35	5	15539	15539	23
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:35	17:40	5	15421	15421	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:50	17:55	5	15541	15541	25
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:00	18:05	5	15423	15423	26
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:20	18:25	5	15425	15425	27

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:30	18:35	5	15543	15543	28
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:45	18:50	5	15427	15427	29
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:00	19:05	5	15429	15429	30
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:30	19:35	5	15545	15545	31
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:40	19:45	5	15431	15431	32
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:00	20:05	5	15433	15433	33
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:30	20:35	5	15549	15549	34
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:30	21:35	5	15551	15551	35
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:30	23:35	5	15553	15553	36
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	00:45	00:50	5	15501	15501	37

Table C.6: Porto-Marco de Canaveses Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	05:30	05:47	17	15503	15503	1
PORTO-SÃO BENTO	ERMESINDE	06:30	06:47	17	15505	15505	2
PORTO-SÃO BENTO	ERMESINDE	07:00	07:17	17	15401	15401	3
PORTO-SÃO BENTO	ERMESINDE	07:30	07:47	17	15507	15507	4
PORTO-SÃO BENTO	ERMESINDE	08:00	08:17	17	15403	15403	5
PORTO-SÃO BENTO	ERMESINDE	08:30	08:47	17	15511	15511	6
PORTO-SÃO BENTO	ERMESINDE	09:00	09:17	17	15405	15405	7
PORTO-SÃO BENTO	ERMESINDE	09:30	09:47	17	15515	15515	8
PORTO-SÃO BENTO	ERMESINDE	10:30	10:47	17	15517	15517	9
PORTO-SÃO BENTO	ERMESINDE	11:00	11:17	17	15407	15407	10
PORTO-SÃO BENTO	ERMESINDE	11:30	11:47	17	15521	15521	11
PORTO-SÃO BENTO	ERMESINDE	12:00	12:17	17	15409	15409	12
PORTO-SÃO BENTO	ERMESINDE	12:30	12:47	17	15523	15523	13
PORTO-SÃO BENTO	ERMESINDE	13:00	13:17	17	15411	15411	14
PORTO-SÃO BENTO	ERMESINDE	13:30	13:47	17	15527	15527	15
PORTO-SÃO BENTO	ERMESINDE	14:00	14:17	17	15413	15413	16
PORTO-SÃO BENTO	ERMESINDE	14:30	14:47	17	15529	15529	17
PORTO-SÃO BENTO	ERMESINDE	15:00	15:17	17	15415	15415	18
PORTO-SÃO BENTO	ERMESINDE	15:30	15:47	17	15533	15533	19
PORTO-SÃO BENTO	ERMESINDE	16:00	16:17	17	15417	15417	20
PORTO-SÃO BENTO	ERMESINDE	16:30	16:47	17	15535	15535	21
PORTO-SÃO BENTO	ERMESINDE	17:00	17:17	17	15419	15419	22
PORTO-SÃO BENTO	ERMESINDE	17:30	17:47	17	15539	15539	23
PORTO-SÃO BENTO	ERMESINDE	17:35	17:52	17	15421	15421	24
PORTO-SÃO BENTO	ERMESINDE	17:50	18:07	17	15541	15541	25
PORTO-SÃO BENTO	ERMESINDE	18:00	18:17	17	15423	15423	26
PORTO-SÃO BENTO	ERMESINDE	18:20	18:37	17	15425	15425	27
PORTO-SÃO BENTO	ERMESINDE	18:30	18:47	17	15543	15543	28
PORTO-SÃO BENTO	ERMESINDE	18:45	19:03	18	15427	15427	29
PORTO-SÃO BENTO	ERMESINDE	19:00	19:17	17	15429	15429	30
PORTO-SÃO BENTO	ERMESINDE	19:30	19:47	17	15545	15545	31
PORTO-SÃO BENTO	ERMESINDE	19:40	19:57	17	15431	15431	32
PORTO-SÃO BENTO	ERMESINDE	20:00	20:17	17	15433	15433	33

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	20:30	20:47	17	15549	15549	34
PORTO-SÃO BENTO	ERMESINDE	21:30	21:47	17	15551	15551	35
PORTO-SÃO BENTO	ERMESINDE	23:30	23:47	17	15553	15553	36
PORTO-SÃO BENTO	ERMESINDE	00:45	01:02	17	15501	15501	37

Table C.7: Guimarães-Porto Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
GUIMARÃES	PORTO-CAMPANHÃ	05:53	07:01	68	15150	15150	1
GUIMARÃES	PORTO-CAMPANHÃ	07:02	08:01	59	15154	15154	2
GUIMARÃES	PORTO-CAMPANHÃ	07:21	08:46	85	15156	15156	3
GUIMARÃES	PORTO-CAMPANHÃ	08:02	09:01	59	15158	15158	4
GUIMARÃES	PORTO-CAMPANHÃ	08:53	10:01	68	15160	15160	5
GUIMARÃES	PORTO-CAMPANHÃ	09:53	11:06	73	15162	15162	6
GUIMARÃES	PORTO-CAMPANHÃ	11:53	13:01	68	15164	15164	7
GUIMARÃES	PORTO-CAMPANHÃ	12:53	14:01	68	15166	15166	8
GUIMARÃES	PORTO-CAMPANHÃ	13:53	15:01	68	15168	15168	9
GUIMARÃES	PORTO-CAMPANHÃ	15:53	17:01	68	15170	15170	10
GUIMARÃES	PORTO-CAMPANHÃ	17:07	18:21	74	15172	15172	11
GUIMARÃES	PORTO-CAMPANHÃ	18:13	19:31	78	15176	15176	12
GUIMARÃES	PORTO-CAMPANHÃ	19:21	20:41	80	15178	15178	13
GUIMARÃES	PORTO-CAMPANHÃ	20:20	21:36	76	15182	15182	14
GUIMARÃES	PORTO-CAMPANHÃ	21:48	23:01	73	15184	15184	15
GUIMARÃES	PORTO-CAMPANHÃ	22:47	00:01	74	15186	15186	16

Table C.8: Guimarães-Porto Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
GUIMARÃES	ERMESINDE	05:53	06:49	56	15150	15150	1
GUIMARÃES	ERMESINDE	07:02	07:51	49	15154	15154	2
GUIMARÃES	ERMESINDE	07:21	08:34	73	15156	15156	3
GUIMARÃES	ERMESINDE	08:02	08:51	49	15158	15158	4
GUIMARÃES	ERMESINDE	08:53	09:49	56	15160	15160	5
GUIMARÃES	ERMESINDE	09:53	10:53	60	15162	15162	6
GUIMARÃES	ERMESINDE	11:53	12:49	56	15164	15164	7
GUIMARÃES	ERMESINDE	12:53	13:49	56	15166	15166	8
GUIMARÃES	ERMESINDE	13:53	14:49	56	15168	15168	9
GUIMARÃES	ERMESINDE	15:53	16:49	56	15170	15170	10
GUIMARÃES	ERMESINDE	17:07	18:08	61	15172	15172	11
GUIMARÃES	ERMESINDE	18:13	19:18	65	15176	15176	12
GUIMARÃES	ERMESINDE	19:21	20:29	68	15178	15178	13
GUIMARÃES	ERMESINDE	20:20	21:22	62	15182	15182	14
GUIMARÃES	ERMESINDE	21:48	22:47	59	15184	15184	15
GUIMARÃES	ERMESINDE	22:47	23:49	62	15186	15186	16

Table C.9: Guimarães-Porto Travel Time to Lousado Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
GUIMARÃES	LOUSADO	05:53	06:30	37	15150	15150	1
GUIMARÃES	LOUSADO	07:02			15154	15154	2
GUIMARÃES	LOUSADO	07:21	08:07	46	15156	15156	3
GUIMARÃES	LOUSADO	08:02	08:36	34	15158	15158	4
GUIMARÃES	LOUSADO	08:53	09:30	37	15160	15160	5
GUIMARÃES	LOUSADO	09:53	10:32	39	15162	15162	6
GUIMARÃES	LOUSADO	11:53	12:30	37	15164	15164	7
GUIMARÃES	LOUSADO	12:53	13:30	37	15166	15166	8
GUIMARÃES	LOUSADO	13:53	14:30	37	15168	15168	9
GUIMARÃES	LOUSADO	15:53	16:30	37	15170	15170	10
GUIMARÃES	LOUSADO	17:07	17:46	39	15172	15172	11
GUIMARÃES	LOUSADO	18:13	18:57	44	15176	15176	12
GUIMARÃES	LOUSADO	19:21	20:04	43	15178	15178	13
GUIMARÃES	LOUSADO	20:20	21:01	41	15182	15182	14
GUIMARÃES	LOUSADO	21:48	22:25	37	15184	15184	15
GUIMARÃES	LOUSADO	22:47	23:30	43	15186	15186	16

Table C.10: Porto-Guimarães Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:20	06:25	5	15151	15151	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:25	07:30	5	15153	15153	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:25	08:30	5	15155	15155	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	09:25	09:30	5	15157	15157	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:25	10:30	5	15159	15159	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:25	11:30	5	15161	15161	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:25	12:30	5	15163	15163	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:20	14:25	5	15165	15165	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:20	16:25	5	15167	15167	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:25	17:30	5	15169	15169	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:25	18:30	5	15171	15171	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:10	19:15	5	15173	15173	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:25	19:30	5	15175	15175	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:20	20:25	5	15177	15177	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	22:25	22:30	5	15181	15181	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:20	23:25	5	15183	15183	16

Table C.11: Porto-Guimarães Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	06:20	06:37	17	15151	15151	1
PORTO-SÃO BENTO	ERMESINDE	07:25	07:42	17	15153	15153	2
PORTO-SÃO BENTO	ERMESINDE	08:25	08:42	17	15155	15155	3
PORTO-SÃO BENTO	ERMESINDE	09:25	09:40	15	15157	15157	4

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	10:25	10:42	17	15159	15159	5
PORTO-SÃO BENTO	ERMESINDE	11:25	11:42	17	15161	15161	6
PORTO-SÃO BENTO	ERMESINDE	12:25	12:42	17	15163	15163	7
PORTO-SÃO BENTO	ERMESINDE	14:20	14:37	17	15165	15165	8
PORTO-SÃO BENTO	ERMESINDE	16:20	16:37	17	15167	15167	9
PORTO-SÃO BENTO	ERMESINDE	17:25	17:42	17	15169	15169	10
PORTO-SÃO BENTO	ERMESINDE	18:25	18:42	17	15171	15171	11
PORTO-SÃO BENTO	ERMESINDE	19:10	19:25	15	15173	15173	12
PORTO-SÃO BENTO	ERMESINDE	19:25	19:42	17	15175	15175	13
PORTO-SÃO BENTO	ERMESINDE	20:20	20:37	17	15177	15177	14
PORTO-SÃO BENTO	ERMESINDE	22:25	22:42	17	15181	15181	15
PORTO-SÃO BENTO	ERMESINDE	23:20	23:37	17	15183	15183	16

Table C.12: Porto-Guimarães Travel Time to Lousado Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	06:20	06:56	36	15151	15151	1
PORTO-SÃO BENTO	LOUSADO	07:25	08:00	35	15153	15153	2
PORTO-SÃO BENTO	LOUSADO	08:25	09:00	35	15155	15155	3
PORTO-SÃO BENTO	LOUSADO	09:25			15157	15157	4
PORTO-SÃO BENTO	LOUSADO	10:25	11:01	36	15159	15159	5
PORTO-SÃO BENTO	LOUSADO	11:25	12:00	35	15161	15161	6
PORTO-SÃO BENTO	LOUSADO	12:25	13:00	35	15163	15163	7
PORTO-SÃO BENTO	LOUSADO	14:20	14:55	35	15165	15165	8
PORTO-SÃO BENTO	LOUSADO	16:20	16:56	36	15167	15167	9
PORTO-SÃO BENTO	LOUSADO	17:25	18:00	35	15169	15169	10
PORTO-SÃO BENTO	LOUSADO	18:25	19:00	35	15171	15171	11
PORTO-SÃO BENTO	LOUSADO	19:10			15173	15173	12
PORTO-SÃO BENTO	LOUSADO	19:25	20:04	39	15175	15175	13
PORTO-SÃO BENTO	LOUSADO	20:20	21:01	41	15177	15177	14
PORTO-SÃO BENTO	LOUSADO	22:25	23:00	35	15181	15181	15
PORTO-SÃO BENTO	LOUSADO	23:20	23:55	35	15183	15183	16

Table C.13: Braga-Porto Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	PORTO-CAMPANHÃ	04:34	05:41	67	15200	15200	1
BRAGA	PORTO-CAMPANHÃ	05:29	06:41	72	15202	15202	2
BRAGA	PORTO-CAMPANHÃ	06:21	07:11	50	15204	15204	3
BRAGA	PORTO-CAMPANHÃ	06:29	07:41	72	15206	15206	4
BRAGA	PORTO-CAMPANHÃ	07:21	08:11	50	15208	15208	5
BRAGA	PORTO-CAMPANHÃ	07:45	08:31	46	15212	15212	6
BRAGA	PORTO-CAMPANHÃ	08:04	09:11	67	15214	15214	7
BRAGA	PORTO-CAMPANHÃ	08:34	09:41	67	15218	15218	8
BRAGA	PORTO-CAMPANHÃ	09:37	10:51	74	15220	15220	9
BRAGA	PORTO-CAMPANHÃ	10:39	11:46	67	15222	15222	10

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	PORTO-CAMPANHÃ	11:34	12:41	67	15224	15224	11
BRAGA	PORTO-CAMPANHÃ	12:29	13:41	72	15226	15226	12
BRAGA	PORTO-CAMPANHÃ	13:21	14:11	50	15228	15228	13
BRAGA	PORTO-CAMPANHÃ	13:37	14:51	74	15230	15230	14
BRAGA	PORTO-CAMPANHÃ	14:39	15:45	66	15232	15232	15
BRAGA	PORTO-CAMPANHÃ	15:34	16:41	67	15234	15234	16
BRAGA	PORTO-CAMPANHÃ	16:44	17:51	67	15236	15236	17
BRAGA	PORTO-CAMPANHÃ	17:21	18:11	50	15238	15238	18
BRAGA	PORTO-CAMPANHÃ	17:35	18:51	76	15240	15240	19
BRAGA	PORTO-CAMPANHÃ	18:21	19:11	50	15242	15242	20
BRAGA	PORTO-CAMPANHÃ	18:34	19:41	67	15244	15244	21
BRAGA	PORTO-CAMPANHÃ	19:35	20:51	76	15246	15246	22
BRAGA	PORTO-CAMPANHÃ	20:39	21:45	66	15248	15248	23
BRAGA	PORTO-CAMPANHÃ	22:39	23:45	66	15252	15252	24
BRAGA	PORTO-CAMPANHÃ	23:32	00:31	59	15254	15254	25

Table C.14: Braga-Porto Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	ERMESINDE	04:34	05:29	55	15200	15200	1
BRAGA	ERMESINDE	05:29	06:29	60	15202	15202	2
BRAGA	ERMESINDE	06:21	06:59	38	15204	15204	3
BRAGA	ERMESINDE	06:29	07:29	60	15206	15206	4
BRAGA	ERMESINDE	07:21	07:59	38	15208	15208	5
BRAGA	ERMESINDE	07:45	08:19	34	15212	15212	6
BRAGA	ERMESINDE	08:04	08:59	55	15214	15214	7
BRAGA	ERMESINDE	08:34	09:29	55	15218	15218	8
BRAGA	ERMESINDE	09:37	10:39	62	15220	15220	9
BRAGA	ERMESINDE	10:39	11:34	55	15222	15222	10
BRAGA	ERMESINDE	11:34	12:29	55	15224	15224	11
BRAGA	ERMESINDE	12:29	13:29	60	15226	15226	12
BRAGA	ERMESINDE	13:21	13:59	38	15228	15228	13
BRAGA	ERMESINDE	13:37	14:39	62	15230	15230	14
BRAGA	ERMESINDE	14:39	15:33	54	15232	15232	15
BRAGA	ERMESINDE	15:34	16:29	55	15234	15234	16
BRAGA	ERMESINDE	16:44	17:39	55	15236	15236	17
BRAGA	ERMESINDE	17:21	17:59	38	15238	15238	18
BRAGA	ERMESINDE	17:35	18:39	64	15240	15240	19
BRAGA	ERMESINDE	18:21	18:59	38	15242	15242	20
BRAGA	ERMESINDE	18:34	19:29	55	15244	15244	21
BRAGA	ERMESINDE	19:35	20:39	64	15246	15246	22
BRAGA	ERMESINDE	20:39	21:33	54	15248	15248	23
BRAGA	ERMESINDE	22:39	23:33	54	15252	15252	24
BRAGA	ERMESINDE	23:32	00:19	47	15254	15254	25

Table C.15: Braga-Porto Travel Time to Lousado Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
BRAGA	LOUSADO	04:34	05:10	36	15200	15200	1
BRAGA	LOUSADO	05:29	06:05	36	15202	15202	2
BRAGA	LOUSADO	06:21	06:43	22	15204	15204	3
BRAGA	LOUSADO	06:29	07:05	36	15206	15206	4
BRAGA	LOUSADO	07:21	07:43	22	15208	15208	5
BRAGA	LOUSADO	07:45			15212	15212	6
BRAGA	LOUSADO	08:04	08:41	37	15214	15214	7
BRAGA	LOUSADO	08:34	09:10	36	15218	15218	8
BRAGA	LOUSADO	09:37	10:13	36	15220	15220	9
BRAGA	LOUSADO	10:39	11:15	36	15222	15222	10
BRAGA	LOUSADO	11:34	12:10	36	15224	15224	11
BRAGA	LOUSADO	12:29	13:05	36	15226	15226	12
BRAGA	LOUSADO	13:21	13:43	22	15228	15228	13
BRAGA	LOUSADO	13:37	14:13	36	15230	15230	14
BRAGA	LOUSADO	14:39	15:15	36	15232	15232	15
BRAGA	LOUSADO	15:34	16:10	36	15234	15234	16
BRAGA	LOUSADO	16:44	17:20	36	15236	15236	17
BRAGA	LOUSADO	17:21	17:43	22	15238	15238	18
BRAGA	LOUSADO	17:35	18:20	45	15240	15240	19
BRAGA	LOUSADO	18:21	18:43	22	15242	15242	20
BRAGA	LOUSADO	18:34	19:10	36	15244	15244	21
BRAGA	LOUSADO	19:35	20:20	45	15246	15246	22
BRAGA	LOUSADO	20:39	21:15	36	15248	15248	23
BRAGA	LOUSADO	22:39	23:15	36	15252	15252	24
BRAGA	LOUSADO	23:32	00:02	30	15254	15254	25

Table C.16: Porto-Braga Travel Time to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:15	06:20	5	15203	15203	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	06:45	06:50	5	15205	15205	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:15	07:20	5	15207	15207	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	07:45	07:50	5	15209	15209	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:15	08:20	5	15211	15211	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	08:45	08:50	5	15213	15213	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:00	10:05	5	15215	15215	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:45	10:50	5	15217	15217	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:45	11:50	5	15219	15219	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:15	12:20	5	15221	15221	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:40	12:45	5	15223	15223	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:45	13:50	5	15225	15225	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:55	15:00	5	15227	15227	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:45	15:50	5	15229	15229	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:15	16:20	5	15231	15231	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:45	16:50	5	15233	15233	16

Continued on next page

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:15	17:20	5	15235	15235	17
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:40	17:45	5	15237	15237	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:15	18:20	5	15239	15239	19
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:40	18:45	5	15241	15241	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:15	19:20	5	15243	15243	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:45	19:50	5	15245	15245	22
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:05	21:10	5	15247	15247	23
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:45	21:50	5	15249	15249	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:05	23:10	5	15251	15251	25
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	00:50	00:55	5	15201	15201	26

Table C.17: Porto-Braga Travel Time to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	06:15	06:32	17	15203	15203	1
PORTO-SÃO BENTO	ERMESINDE	06:45	07:02	17	15205	15205	2
PORTO-SÃO BENTO	ERMESINDE	07:15	07:32	17	15207	15207	3
PORTO-SÃO BENTO	ERMESINDE	07:45	08:02	17	15209	15209	4
PORTO-SÃO BENTO	ERMESINDE	08:15	08:32	17	15211	15211	5
PORTO-SÃO BENTO	ERMESINDE	08:45	09:02	17	15213	15213	6
PORTO-SÃO BENTO	ERMESINDE	10:00	10:18	18	15215	15215	7
PORTO-SÃO BENTO	ERMESINDE	10:45	11:02	17	15217	15217	8
PORTO-SÃO BENTO	ERMESINDE	11:45	12:02	17	15219	15219	9
PORTO-SÃO BENTO	ERMESINDE	12:15	12:32	17	15221	15221	10
PORTO-SÃO BENTO	ERMESINDE	12:40	13:04	24	15223	15223	11
PORTO-SÃO BENTO	ERMESINDE	13:45	14:02	17	15225	15225	12
PORTO-SÃO BENTO	ERMESINDE	14:55	15:12	17	15227	15227	13
PORTO-SÃO BENTO	ERMESINDE	15:45	16:02	17	15229	15229	14
PORTO-SÃO BENTO	ERMESINDE	16:15	16:32	17	15231	15231	15
PORTO-SÃO BENTO	ERMESINDE	16:45	17:09	24	15233	15233	16
PORTO-SÃO BENTO	ERMESINDE	17:15	17:32	17	15235	15235	17
PORTO-SÃO BENTO	ERMESINDE	17:40	17:57	17	15237	15237	18
PORTO-SÃO BENTO	ERMESINDE	18:15	18:32	17	15239	15239	19
PORTO-SÃO BENTO	ERMESINDE	18:40	18:57	17	15241	15241	20
PORTO-SÃO BENTO	ERMESINDE	19:15	19:32	17	15243	15243	21
PORTO-SÃO BENTO	ERMESINDE	19:45	20:02	17	15245	15245	22
PORTO-SÃO BENTO	ERMESINDE	21:05	21:22	17	15247	15247	23
PORTO-SÃO BENTO	ERMESINDE	21:45	22:02	17	15249	15249	24
PORTO-SÃO BENTO	ERMESINDE	23:05	23:23	18	15251	15251	25
PORTO-SÃO BENTO	ERMESINDE	00:50	01:07	17	15201	15201	26

Table C.18: Porto-Braga Travel Time to Lousado Synchronization Location

Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	06:15	06:47	32	15203	15203	1
PORTO-SÃO BENTO	LOUSADO	06:45	07:19	34	15205	15205	2

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Origin	Destination	Departure	Arrival	TT	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	07:15	07:47	32	15207	15207	3
PORTO-SÃO BENTO	LOUSADO	07:45	08:19	34	15209	15209	4
PORTO-SÃO BENTO	LOUSADO	08:15	08:47	32	15211	15211	5
PORTO-SÃO BENTO	LOUSADO	08:45	09:19	34	15213	15213	6
PORTO-SÃO BENTO	LOUSADO	10:00	10:35	35	15215	15215	7
PORTO-SÃO BENTO	LOUSADO	10:45	11:19	34	15217	15217	8
PORTO-SÃO BENTO	LOUSADO	11:45	12:19	34	15219	15219	9
PORTO-SÃO BENTO	LOUSADO	12:15	12:47	32	15221	15221	10
PORTO-SÃO BENTO	LOUSADO	12:40	13:23	43	15223	15223	11
PORTO-SÃO BENTO	LOUSADO	13:45	14:19	34	15225	15225	12
PORTO-SÃO BENTO	LOUSADO	14:55	15:29	34	15227	15227	13
PORTO-SÃO BENTO	LOUSADO	15:45	16:19	34	15229	15229	14
PORTO-SÃO BENTO	LOUSADO	16:15	16:47	32	15231	15231	15
PORTO-SÃO BENTO	LOUSADO	16:45	17:28	43	15233	15233	16
PORTO-SÃO BENTO	LOUSADO	17:15	17:47	32	15235	15235	17
PORTO-SÃO BENTO	LOUSADO	17:40	18:14	34	15237	15237	18
PORTO-SÃO BENTO	LOUSADO	18:15	18:47	32	15239	15239	19
PORTO-SÃO BENTO	LOUSADO	18:40	19:11	31	15241	15241	20
PORTO-SÃO BENTO	LOUSADO	19:15	19:49	34	15243	15243	21
PORTO-SÃO BENTO	LOUSADO	19:45	20:19	34	15245	15245	22
PORTO-SÃO BENTO	LOUSADO	21:05	21:39	34	15247	15247	23
PORTO-SÃO BENTO	LOUSADO	21:45	22:19	34	15249	15249	24
PORTO-SÃO BENTO	LOUSADO	23:05	23:40	35	15251	15251	25
PORTO-SÃO BENTO	LOUSADO	00:50	01:23	33	15201	15201	26

Appendix D

Deviations

Table D.1: Aveiro-Porto Time Deviations to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
AVEIRO	PORTO-CAMPANHÃ	4:31	5:55	0.786	15601	15600	1
AVEIRO	PORTO-CAMPANHÃ	5:16	6:34	0.000	15603	15603	2
AVEIRO	PORTO-CAMPANHÃ	6:18	7:30	0.643	15605	15604	3
OVAR	PORTO-CAMPANHÃ	6:48	7:39	3.133	15801	15801	4
AVEIRO	PORTO-CAMPANHÃ	6:46	7:57	0.000	15607	15607	5
OVAR	PORTO-CAMPANHÃ	7:31	8:23	0.000	15803	15803	6
AVEIRO	PORTO-CAMPANHÃ	7:22	8:35	0.333	15609	15608	7
OVAR	PORTO-CAMPANHÃ	7:53	8:44	0.000	15805	15805	8
AVEIRO	PORTO-CAMPANHÃ	7:46	8:55	1.667	15611	15611	9
OVAR	PORTO-CAMPANHÃ	8:31	9:30	0.000	15807	15806	10
AVEIRO	PORTO-CAMPANHÃ	8:23	9:35	0.333	15613	15612	11
OVAR	PORTO-CAMPANHÃ	8:53	9:44	0.000	15809	15809	12
AVEIRO	PORTO-CAMPANHÃ	8:46	9:49	2.533	15615	15615	13
OVAR	PORTO-CAMPANHÃ	9:31	10:30	0.667	15811	15810	14
AVEIRO	PORTO-CAMPANHÃ	9:23	10:35	0.933	15617	15616	15
OVAR	PORTO-CAMPANHÃ	9:53	10:44	0.333	15813	15813	16
AVEIRO	PORTO-CAMPANHÃ	10:23	11:35	3.667	15621	15620	17
OVAR	PORTO-CAMPANHÃ	10:53	11:44	0.733	15815	15815	18
AVEIRO	PORTO-CAMPANHÃ	11:23	12:29	4.000	15623	15623	19
OVAR	PORTO-CAMPANHÃ	11:53	12:44	1.533	15817	15817	20
AVEIRO	PORTO-CAMPANHÃ	12:23	13:35	3.333	15625	15624	21
OVAR	PORTO-CAMPANHÃ	12:53	13:44	0.800	15819	15819	22
AVEIRO	PORTO-CAMPANHÃ	12:46	13:49	9.133	15627	15627	23
OVAR	PORTO-CAMPANHÃ	13:31	14:30	0.000	15821	15820	24
AVEIRO	PORTO-CAMPANHÃ	13:23	14:35	2.533	15629	15628	25
OVAR	PORTO-CAMPANHÃ	13:53	14:44	1.133	15823	15823	26
AVEIRO	PORTO-CAMPANHÃ	13:46	14:49	2.133	15631	15631	27
OVAR	PORTO-CAMPANHÃ	14:31	15:30	2.400	15825	15824	28
AVEIRO	PORTO-CAMPANHÃ	14:23	15:35	1.200	15633	15632	29
OVAR	PORTO-CAMPANHÃ	14:53	15:44	1.933	15827	15827	30
AVEIRO	PORTO-CAMPANHÃ	15:23	16:35	1.467	15635	15634	31

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
OVAR	PORTO-CAMPANHÃ	15:53	16:44	0.000	15829	15829	32
AVEIRO	PORTO-CAMPANHÃ	16:23	17:35	4.533	15637	15636	33
OVAR	PORTO-CAMPANHÃ	16:53	17:44	1.533	15831	15831	34
AVEIRO	PORTO-CAMPANHÃ	16:46	17:49	4.600	15639	15639	35
OVAR	PORTO-CAMPANHÃ	17:31	18:30	0.000	15833	15832	36
AVEIRO	PORTO-CAMPANHÃ	17:23	18:40	0.867	15641	15640	37
OVAR	PORTO-CAMPANHÃ	17:53	18:44	0.000	15835	15835	38
AVEIRO	PORTO-CAMPANHÃ	17:46	18:48	0.000	15643	15643	39
OVAR	PORTO-CAMPANHÃ	18:31	19:18	1.067	15837	15837	40
AVEIRO	PORTO-CAMPANHÃ	18:23	19:35	0.933	15645	15644	41
OVAR	PORTO-CAMPANHÃ	18:53	19:44	0.000	15839	15839	42
AVEIRO	PORTO-CAMPANHÃ	18:46	19:49	1.800	15647	15647	43
OVAR	PORTO-CAMPANHÃ	19:31	20:30	1.867	15841	15840	44
AVEIRO	PORTO-CAMPANHÃ	19:23	20:29	0.800	15649	15649	45
OVAR	PORTO-CAMPANHÃ	19:53	20:44	0.000	15843	15843	46
AVEIRO	PORTO-CAMPANHÃ	19:46	20:49	2.267	15651	15651	47
OVAR	PORTO-CAMPANHÃ	20:35	21:30	0.000	15845	15844	48
AVEIRO	PORTO-CAMPANHÃ	20:29	21:55	0.467	15653	15652	49
AVEIRO	PORTO-CAMPANHÃ	21:29	22:55	1.467	15655	15654	50
AVEIRO	PORTO-CAMPANHÃ	22:30	23:55	0.933	15657	15656	51
AVEIRO	PORTO-CAMPANHÃ	23:25	0:50	0.000	15659	15658	52

Table D.2: Porto-Aveiro Time Deviations to Porto-Campanhã Synchronization Location

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	4:35	4:45	1.333	15703	15702	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	5:40	5:50	1.333	15707	15706	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	5:55	6:05	0.667	15901	15900	3
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	6:40	6:40	0.000	15708	15708	4
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	6:45	6:45	0.000	15902	15902	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:50	7:00	0.667	15711	15710	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:55	7:05	0.667	15905	15904	7
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	7:40	7:40	0.000	15712	15712	8
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	7:45	7:45	0.000	15906	15906	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:50	8:00	0.000	15715	15714	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:55	8:05	0.000	15909	15908	11
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	8:40	8:40	0.000	15716	15716	12
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	8:45	8:45	0.000	15910	15910	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:50	9:00	0.000	15719	15718	14
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	9:40	9:40	0.000	15720	15720	15
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	9:45	9:45	0.000	15912	15912	16
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	9:50	10:00	0.000	15723	15722	17
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	10:45	10:45	0.000	15914	15914	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:50	11:00	0.000	15725	15724	19
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	11:45	11:45	0.000	15916	15916	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:50	12:00	0.000	15727	15726	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:55	12:05	0.000	15919	15918	22

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	12:40	12:40	0.000	15728	15728	23
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	12:45	12:45	0.000	15920	15920	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:50	13:00	0.467	15731	15730	25
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:55	13:05	0.467	15925	15924	26
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	13:40	13:40	0.000	15732	15732	27
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	13:45	13:45	0.000	15926	15926	28
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:50	14:00	1.333	15735	15734	29
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	14:45	14:45	0.000	15928	15928	30
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:50	15:00	0.000	15737	15736	31
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	15:45	15:45	0.000	15930	15930	32
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:50	16:00	0.000	15739	15738	33
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:55	16:05	0.000	15933	15932	34
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	16:40	16:40	0.000	15740	15740	35
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	16:45	16:45	0.000	15934	15934	36
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:50	17:00	0.000	15743	15742	37
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:55	17:05	0.667	15937	15936	38
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	17:40	17:40	0.000	15744	15744	39
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	17:45	17:45	0.000	15938	15938	40
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:45	18:00	0.000	15747	15746	41
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:55	18:05	0.000	15941	15940	42
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	18:40	18:40	0.000	15748	15748	43
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	18:45	18:45	0.000	15942	15942	44
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:00	19:00	0.000	15750	15750	45
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:55	19:05	0.000	15945	15944	46
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:40	19:40	0.000	15752	15752	47
PORTO-CAMPANHÃ	PORTO-CAMPANHÃ	19:50	19:50	0.000	15754	15754	48
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:40	20:50	0.000	15757	15756	49
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:40	21:50	0.000	15759	15758	50
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	22:40	22:50	0.000	15761	15760	51
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:40	23:50	0.000	15763	15762	52

Table D.3: Marco de Canaveses-Porto Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
MARCO	PORTO-CAMPANHÃ	4:18	5:36	0.000	15500	15500	1
MARCO	PORTO-CAMPANHÃ	5:08	6:26	0.000	15502	15502	2
PENAFIEL	PORTO-CAMPANHÃ	5:57	6:46	3.200	15400	15400	3
MARCO	PORTO-CAMPANHÃ	6:00	7:06	0.000	15504	15504	4
MARCO	PORTO-CAMPANHÃ	6:13	7:26	0.000	15506	15506	5
PENAFIEL	PORTO-CAMPANHÃ	7:07	7:56	0.000	15402	15402	6
MARCO	PORTO-CAMPANHÃ	7:00	8:06	2.333	15508	15508	7
PENAFIEL	PORTO-CAMPANHÃ	7:27	8:16	4.067	15404	15404	8
MARCO	PORTO-CAMPANHÃ	7:13	8:26	1.067	15510	15510	9
PENAFIEL	PORTO-CAMPANHÃ	8:07	8:56	1.667	15406	15406	10
MARCO	PORTO-CAMPANHÃ	7:54	9:06	1.133	15512	15512	11
MARCO	PORTO-CAMPANHÃ	8:14	9:26	0.733	15514	15514	12

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PENAFIEL	PORTO-CAMPANHÃ	9:07	9:56	0.400	15408	15408	13
MARCO	PORTO-CAMPANHÃ	9:13	10:26	0.400	15518	15518	14
PENAFIEL	PORTO-CAMPANHÃ	10:07	10:56	0.333	15410	15410	15
MARCO	PORTO-CAMPANHÃ	10:14	11:26	1.467	15520	15520	16
MARCO	PORTO-CAMPANHÃ	11:13	12:26	0.000	15524	15524	17
PENAFIEL	PORTO-CAMPANHÃ	12:07	12:56	1.333	15412	15412	18
MARCO	PORTO-CAMPANHÃ	12:14	13:26	0.000	15526	15526	19
PENAFIEL	PORTO-CAMPANHÃ	13:07	13:56	0.000	15414	15414	20
MARCO	PORTO-CAMPANHÃ	13:13	14:26	0.000	15530	15530	21
PENAFIEL	PORTO-CAMPANHÃ	14:07	14:56	3.400	15416	15416	22
MARCO	PORTO-CAMPANHÃ	14:14	15:26	1.133	15532	15532	23
PENAFIEL	PORTO-CAMPANHÃ	15:07	15:56	0.333	15418	15418	24
MARCO	PORTO-CAMPANHÃ	15:13	16:26	0.333	15536	15536	25
PENAFIEL	PORTO-CAMPANHÃ	16:07	16:56	0.400	15420	15420	26
MARCO	PORTO-CAMPANHÃ	16:14	17:26	0.867	15538	15538	27
PENAFIEL	PORTO-CAMPANHÃ	17:07	17:56	0.000	15422	15422	28
MARCO	PORTO-CAMPANHÃ	17:13	18:26	0.000	15542	15542	29
PENAFIEL	PORTO-CAMPANHÃ	18:07	18:56	0.333	15424	15424	30
MARCO	PORTO-CAMPANHÃ	18:14	19:26	7.067	15544	15544	31
PENAFIEL	PORTO-CAMPANHÃ	19:07	19:56	0.000	15426	15426	32
MARCO	PORTO-CAMPANHÃ	19:13	20:21	2.400	15546	15546	33
MARCO	PORTO-CAMPANHÃ	20:08	21:26	1.200	15548	15548	34
MARCO	PORTO-CAMPANHÃ	21:08	22:26	0.400	15550	15550	35
MARCO	PORTO-CAMPANHÃ	22:08	23:26	0.000	15552	15552	36

Table D.4: Marco de Canaveses-Porto Time Deviations to Ermesinde Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
MARCO	ERMESINDE	4:18	5:24	0.000	15500	15500	1
MARCO	ERMESINDE	5:08	6:14	0.000	15502	15502	2
PENAFIEL	ERMESINDE	5:57	6:34	2.200	15400	15400	3
MARCO	ERMESINDE	6:00	6:54	3.333	15504	15504	4
MARCO	ERMESINDE	6:13	7:14	3.800	15506	15506	5
PENAFIEL	ERMESINDE	7:07	7:44	0.000	15402	15402	6
MARCO	ERMESINDE	7:00	7:54	2.067	15508	15508	7
PENAFIEL	ERMESINDE	7:27	8:04	3.400	15404	15404	8
MARCO	ERMESINDE	7:13	8:14	0.867	15510	15510	9
PENAFIEL	ERMESINDE	8:07	8:44	1.600	15406	15406	10
MARCO	ERMESINDE	7:54	8:54	0.000	15512	15512	11
MARCO	ERMESINDE	8:14	9:14	0.400	15514	15514	12
PENAFIEL	ERMESINDE	9:07	9:44	0.467	15408	15408	13
MARCO	ERMESINDE	9:13	10:14	0.000	15518	15518	14
PENAFIEL	ERMESINDE	10:07	10:44	0.000	15410	15410	15
MARCO	ERMESINDE	10:14	11:14	2.067	15520	15520	16
MARCO	ERMESINDE	11:13	12:14	0.000	15524	15524	17
PENAFIEL	ERMESINDE	12:07	12:44	1.800	15412	15412	18
MARCO	ERMESINDE	12:14	13:14	0.000	15526	15526	19

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PENAFIEL	ERMESINDE	13:07	13:44	0.000	15414	15414	20
MARCO	ERMESINDE	13:13	14:14	0.000	15530	15530	21
PENAFIEL	ERMESINDE	14:07	14:44	2.267	15416	15416	22
MARCO	ERMESINDE	14:14	15:14	1.733	15532	15532	23
PENAFIEL	ERMESINDE	15:07	15:44	0.000	15418	15418	24
MARCO	ERMESINDE	15:13	16:14	0.000	15536	15536	25
PENAFIEL	ERMESINDE	16:07	16:44	0.400	15420	15420	26
MARCO	ERMESINDE	16:14	17:14	0.800	15538	15538	27
PENAFIEL	ERMESINDE	17:07	17:44	0.000	15422	15422	28
MARCO	ERMESINDE	17:13	18:14	0.000	15542	15542	29
PENAFIEL	ERMESINDE	18:07	18:44	0.000	15424	15424	30
MARCO	ERMESINDE	18:14	19:14	6.933	15544	15544	31
PENAFIEL	ERMESINDE	19:07	19:44	0.333	15426	15426	32
MARCO	ERMESINDE	19:13	20:10	2.000	15546	15546	33
MARCO	ERMESINDE	20:08	21:15	1.200	15548	15548	34
MARCO	ERMESINDE	21:08	22:14	0.533	15550	15550	35
MARCO	ERMESINDE	22:08	23:14	0.000	15552	15552	36

Table D.5: Porto-Marco de Canaveses Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	5:30	5:35	0.333	15503	15503	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:30	6:35	0.333	15505	15505	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:00	7:05	0.333	15401	15401	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:30	7:35	0.333	15507	15507	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:00	8:05	0.667	15403	15403	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:30	8:35	0.667	15511	15511	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	9:00	9:05	0.000	15405	15405	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	9:30	9:35	0.333	15515	15515	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:30	10:35	0.333	15517	15517	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:00	11:05	0.000	15407	15407	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:30	11:35	0.333	15521	15521	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:00	12:05	0.000	15409	15409	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:30	12:35	0.333	15523	15523	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:00	13:05	0.667	15411	15411	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:30	13:35	0.333	15527	15527	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:00	14:05	0.333	15413	15413	16
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:30	14:35	0.000	15529	15529	17
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:00	15:05	0.333	15415	15415	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:30	15:35	0.333	15533	15533	19
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:00	16:05	0.000	15417	15417	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:30	16:35	0.000	15535	15535	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:00	17:05	0.000	15419	15419	22
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:30	17:35	0.000	15539	15539	23
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:35	17:40	0.333	15421	15421	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:50	17:55	0.000	15541	15541	25

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:00	18:05	0.333	15423	15423	26
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:20	18:25	0.000	15425	15425	27
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:30	18:35	0.000	15543	15543	28
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:45	18:50	0.000	15427	15427	29
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:00	19:05	0.000	15429	15429	30
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:30	19:35	0.333	15545	15545	31
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:40	19:45	2.333	15431	15431	32
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:00	20:05	0.000	15433	15433	33
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:30	20:35	0.000	15549	15549	34
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:30	21:35	0.000	15551	15551	35
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:30	23:35	0.000	15553	15553	36
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	0:45	0:50	0.000	15501	15501	37

Table D.6: Porto-Marco de Canaveses Time Deviations to Ermesinde Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	5:30	5:47	1.000	15503	15503	1
PORTO-SÃO BENTO	ERMESINDE	6:30	6:47	1.000	15505	15505	2
PORTO-SÃO BENTO	ERMESINDE	7:00	7:17	1.000	15401	15401	3
PORTO-SÃO BENTO	ERMESINDE	7:30	7:47	0.000	15507	15507	4
PORTO-SÃO BENTO	ERMESINDE	8:00	8:17	1.000	15403	15403	5
PORTO-SÃO BENTO	ERMESINDE	8:30	8:47	1.067	15511	15511	6
PORTO-SÃO BENTO	ERMESINDE	9:00	9:17	0.000	15405	15405	7
PORTO-SÃO BENTO	ERMESINDE	9:30	9:47	0.800	15515	15515	8
PORTO-SÃO BENTO	ERMESINDE	10:30	10:47	0.000	15517	15517	9
PORTO-SÃO BENTO	ERMESINDE	11:00	11:17	0.000	15407	15407	10
PORTO-SÃO BENTO	ERMESINDE	11:30	11:47	0.000	15521	15521	11
PORTO-SÃO BENTO	ERMESINDE	12:00	12:17	0.000	15409	15409	12
PORTO-SÃO BENTO	ERMESINDE	12:30	12:47	0.000	15523	15523	13
PORTO-SÃO BENTO	ERMESINDE	13:00	13:17	1.667	15411	15411	14
PORTO-SÃO BENTO	ERMESINDE	13:30	13:47	1.133	15527	15527	15
PORTO-SÃO BENTO	ERMESINDE	14:00	14:17	0.600	15413	15413	16
PORTO-SÃO BENTO	ERMESINDE	14:30	14:47	0.000	15529	15529	17
PORTO-SÃO BENTO	ERMESINDE	15:00	15:17	0.800	15415	15415	18
PORTO-SÃO BENTO	ERMESINDE	15:30	15:47	0.000	15533	15533	19
PORTO-SÃO BENTO	ERMESINDE	16:00	16:17	0.000	15417	15417	20
PORTO-SÃO BENTO	ERMESINDE	16:30	16:47	0.000	15535	15535	21
PORTO-SÃO BENTO	ERMESINDE	17:00	17:17	0.400	15419	15419	22
PORTO-SÃO BENTO	ERMESINDE	17:30	17:47	0.000	15539	15539	23
PORTO-SÃO BENTO	ERMESINDE	17:35	17:52	0.600	15421	15421	24
PORTO-SÃO BENTO	ERMESINDE	17:50	18:07	0.000	15541	15541	25
PORTO-SÃO BENTO	ERMESINDE	18:00	18:17	0.333	15423	15423	26
PORTO-SÃO BENTO	ERMESINDE	18:20	18:37	0.000	15425	15425	27
PORTO-SÃO BENTO	ERMESINDE	18:30	18:47	0.000	15543	15543	28
PORTO-SÃO BENTO	ERMESINDE	18:45	19:03	0.000	15427	15427	29
PORTO-SÃO BENTO	ERMESINDE	19:00	19:17	0.400	15429	15429	30
PORTO-SÃO BENTO	ERMESINDE	19:30	19:47	0.000	15545	15545	31

Continued on next page

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	19:40	19:57	2.667	15431	15431	32
PORTO-SÃO BENTO	ERMESINDE	20:00	20:17	0.000	15433	15433	33
PORTO-SÃO BENTO	ERMESINDE	20:30	20:47	0.000	15549	15549	34
PORTO-SÃO BENTO	ERMESINDE	21:30	21:47	0.000	15551	15551	35
PORTO-SÃO BENTO	ERMESINDE	23:30	23:47	0.000	15553	15553	36
PORTO-SÃO BENTO	ERMESINDE	0:45	1:02	0.000	15501	15501	37

Table D.7: Guimarães-Porto Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
GUIMARÃES	PORTO-CAMPANHÃ	5:53	7:01	0.000	15150	15150	1
GUIMARÃES	PORTO-CAMPANHÃ	7:02	8:01	0.667	15154	15154	2
GUIMARÃES	PORTO-CAMPANHÃ	7:21	8:46	0.333	15156	15156	3
GUIMARÃES	PORTO-CAMPANHÃ	8:02	9:01	0.000	15158	15158	4
GUIMARÃES	PORTO-CAMPANHÃ	8:53	10:01	0.333	15160	15160	5
GUIMARÃES	PORTO-CAMPANHÃ	9:53	11:06	0.533	15162	15162	6
GUIMARÃES	PORTO-CAMPANHÃ	11:53	13:01	0.667	15164	15164	7
GUIMARÃES	PORTO-CAMPANHÃ	12:53	14:01	0.000	15166	15166	8
GUIMARÃES	PORTO-CAMPANHÃ	13:53	15:01	3.267	15168	15168	9
GUIMARÃES	PORTO-CAMPANHÃ	15:53	17:01	4.067	15170	15170	10
GUIMARÃES	PORTO-CAMPANHÃ	17:07	18:21	0.400	15172	15172	11
GUIMARÃES	PORTO-CAMPANHÃ	18:13	19:31	0.400	15176	15176	12
GUIMARÃES	PORTO-CAMPANHÃ	19:21	20:41	2.600	15178	15178	13
GUIMARÃES	PORTO-CAMPANHÃ	20:20	21:36	1.200	15182	15182	14
GUIMARÃES	PORTO-CAMPANHÃ	21:48	23:01	0.000	15184	15184	15
GUIMARÃES	PORTO-CAMPANHÃ	22:47	0:01	0.000	15186	15186	16

Table D.8: Guimarães-Porto Time Deviations to Ermesinde Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
GUIMARÃES	ERMESINDE	5:53	6:49	3.467	15150	15150	1
GUIMARÃES	ERMESINDE	7:02	7:51	0.000	15154	15154	2
GUIMARÃES	ERMESINDE	7:21	8:34	0.000	15156	15156	3
GUIMARÃES	ERMESINDE	8:02	8:51	0.000	15158	15158	4
GUIMARÃES	ERMESINDE	8:53	9:49	0.400	15160	15160	5
GUIMARÃES	ERMESINDE	9:53	10:53	0.467	15162	15162	6
GUIMARÃES	ERMESINDE	11:53	12:49	0.000	15164	15164	7
GUIMARÃES	ERMESINDE	12:53	13:49	0.000	15166	15166	8
GUIMARÃES	ERMESINDE	13:53	14:49	0.800	15168	15168	9
GUIMARÃES	ERMESINDE	15:53	16:49	4.200	15170	15170	10
GUIMARÃES	ERMESINDE	17:07	18:08	0.800	15172	15172	11
GUIMARÃES	ERMESINDE	18:13	19:18	0.667	15176	15176	12
GUIMARÃES	ERMESINDE	19:21	20:29	0.733	15178	15178	13
GUIMARÃES	ERMESINDE	20:20	21:22	1.133	15182	15182	14
GUIMARÃES	ERMESINDE	21:48	22:47	0.000	15184	15184	15
GUIMARÃES	ERMESINDE	22:47	23:49	0.000	15186	15186	16

Table D.9: Guimarães-Porto Time Deviations to Lousado Synchronization Location

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
GUIMARÃES	LOUSADO	5:53	6:30	2.467	15150	15150	1
GUIMARÃES	LOUSADO	7:02			15154	15154	2
GUIMARÃES	LOUSADO	7:21	8:07	0.000	15156	15156	3
GUIMARÃES	LOUSADO	8:02	8:36	0.333	15158	15158	4
GUIMARÃES	LOUSADO	8:53	9:30	0.333	15160	15160	5
GUIMARÃES	LOUSADO	9:53	10:32	0.467	15162	15162	6
GUIMARÃES	LOUSADO	11:53	12:30	0.333	15164	15164	7
GUIMARÃES	LOUSADO	12:53	13:30	0.000	15166	15166	8
GUIMARÃES	LOUSADO	13:53	14:30	0.333	15168	15168	9
GUIMARÃES	LOUSADO	15:53	16:30	2.800	15170	15170	10
GUIMARÃES	LOUSADO	17:07	17:46	1.000	15172	15172	11
GUIMARÃES	LOUSADO	18:13	18:57	1.000	15176	15176	12
GUIMARÃES	LOUSADO	19:21	20:04	0.733	15178	15178	13
GUIMARÃES	LOUSADO	20:20	21:01	0.800	15182	15182	14
GUIMARÃES	LOUSADO	21:48	22:25	0.000	15184	15184	15
GUIMARÃES	LOUSADO	22:47	23:30	0.000	15186	15186	16

Table D.10: Porto-Guimarães Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:20	6:25	0.333	15151	15151	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:25	7:30	0.333	15153	15153	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:25	8:30	0.333	15155	15155	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	9:25	9:30	0.000	15157	15157	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:25	10:30	0.000	15159	15159	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:25	11:30	0.333	15161	15161	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:25	12:30	0.000	15163	15163	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:20	14:25	0.000	15165	15165	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:20	16:25	0.000	15167	15167	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:25	17:30	0.000	15169	15169	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:25	18:30	0.000	15171	15171	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:10	19:15	0.667	15173	15173	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:25	19:30	0.333	15175	15175	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	20:20	20:25	0.000	15177	15177	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	22:25	22:30	0.000	15181	15181	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:20	23:25	0.000	15183	15183	16

Table D.11: Porto-Guimarães Time Deviations to Ermesinde Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	6:20	6:37	1.000	15151	15151	1
PORTO-SÃO BENTO	ERMESINDE	7:25	7:42	1.000	15153	15153	2
PORTO-SÃO BENTO	ERMESINDE	8:25	8:42	0.533	15155	15155	3
PORTO-SÃO BENTO	ERMESINDE	9:25	9:40	0.933	15157	15157	4

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	10:25	10:42	0.000	15159	15159	5
PORTO-SÃO BENTO	ERMESINDE	11:25	11:42	0.333	15161	15161	6
PORTO-SÃO BENTO	ERMESINDE	12:25	12:42	0.000	15163	15163	7
PORTO-SÃO BENTO	ERMESINDE	14:20	14:37	0.000	15165	15165	8
PORTO-SÃO BENTO	ERMESINDE	16:20	16:37	0.000	15167	15167	9
PORTO-SÃO BENTO	ERMESINDE	17:25	17:42	0.000	15169	15169	10
PORTO-SÃO BENTO	ERMESINDE	18:25	18:42	0.000	15171	15171	11
PORTO-SÃO BENTO	ERMESINDE	19:10	19:25	0.800	15173	15173	12
PORTO-SÃO BENTO	ERMESINDE	19:25	19:42	1.000	15175	15175	13
PORTO-SÃO BENTO	ERMESINDE	20:20	20:37	0.333	15177	15177	14
PORTO-SÃO BENTO	ERMESINDE	22:25	22:42	0.000	15181	15181	15
PORTO-SÃO BENTO	ERMESINDE	23:20	23:37	0.333	15183	15183	16

Table D.12: Porto-Guimarães Time Deviations to Lousado Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	6:20	6:56	2.333	15151	15151	1
PORTO-SÃO BENTO	LOUSADO	7:25	8:00	0.000	15153	15153	2
PORTO-SÃO BENTO	LOUSADO	8:25	9:00	1.133	15155	15155	3
PORTO-SÃO BENTO	LOUSADO	9:25			15157	15157	4
PORTO-SÃO BENTO	LOUSADO	10:25	11:01	0.333	15159	15159	5
PORTO-SÃO BENTO	LOUSADO	11:25	12:00	0.400	15161	15161	6
PORTO-SÃO BENTO	LOUSADO	12:25	13:00	0.333	15163	15163	7
PORTO-SÃO BENTO	LOUSADO	14:20	14:55	0.400	15165	15165	8
PORTO-SÃO BENTO	LOUSADO	16:20	16:56	0.000	15167	15167	9
PORTO-SÃO BENTO	LOUSADO	17:25	18:00	0.800	15169	15169	10
PORTO-SÃO BENTO	LOUSADO	18:25	19:00	0.000	15171	15171	11
PORTO-SÃO BENTO	LOUSADO	19:10			15173	15173	12
PORTO-SÃO BENTO	LOUSADO	19:25	20:04	0.600	15175	15175	13
PORTO-SÃO BENTO	LOUSADO	20:20	21:01	0.733	15177	15177	14
PORTO-SÃO BENTO	LOUSADO	22:25	23:00	1.600	15181	15181	15
PORTO-SÃO BENTO	LOUSADO	23:20	23:55	2.600	15183	15183	16

Table D.13: Braga-Porto Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
BRAGA	PORTO-CAMPANHÃ	4:34	5:41	0.000	15200	15200	1
BRAGA	PORTO-CAMPANHÃ	5:29	6:41	0.000	15202	15202	2
BRAGA	PORTO-CAMPANHÃ	6:21	7:11	3.267	15204	15204	3
BRAGA	PORTO-CAMPANHÃ	6:29	7:41	0.667	15206	15206	4
BRAGA	PORTO-CAMPANHÃ	7:21	8:11	0.000	15208	15208	5
BRAGA	PORTO-CAMPANHÃ	7:45	8:31	1.000	15212	15212	6
BRAGA	PORTO-CAMPANHÃ	8:04	9:11	0.333	15214	15214	7
BRAGA	PORTO-CAMPANHÃ	8:34	9:41	0.933	15218	15218	8
BRAGA	PORTO-CAMPANHÃ	9:37	10:51	0.400	15220	15220	9
BRAGA	PORTO-CAMPANHÃ	10:39	11:46	0.733	15222	15222	10

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
BRAGA	PORTO-CAMPANHÃ	11:34	12:41	0.667	15224	15224	11
BRAGA	PORTO-CAMPANHÃ	12:29	13:41	1.000	15226	15226	12
BRAGA	PORTO-CAMPANHÃ	13:21	14:11	0.000	15228	15228	13
BRAGA	PORTO-CAMPANHÃ	13:37	14:51	0.400	15230	15230	14
BRAGA	PORTO-CAMPANHÃ	14:39	15:45	0.000	15232	15232	15
BRAGA	PORTO-CAMPANHÃ	15:34	16:41	0.000	15234	15234	16
BRAGA	PORTO-CAMPANHÃ	16:44	17:51	0.333	15236	15236	17
BRAGA	PORTO-CAMPANHÃ	17:21	18:11	0.000	15238	15238	18
BRAGA	PORTO-CAMPANHÃ	17:35	18:51	0.333	15240	15240	19
BRAGA	PORTO-CAMPANHÃ	18:21	19:11	0.000	15242	15242	20
BRAGA	PORTO-CAMPANHÃ	18:34	19:41	0.333	15244	15244	21
BRAGA	PORTO-CAMPANHÃ	19:35	20:51	2.000	15246	15246	22
BRAGA	PORTO-CAMPANHÃ	20:39	21:45	0.667	15248	15248	23
BRAGA	PORTO-CAMPANHÃ	22:39	23:45	0.333	15252	15252	24
BRAGA	PORTO-CAMPANHÃ	23:32	0:31	0.000	15254	15254	25

Table D.14: Braga-Porto Time Deviations to Ermesinde Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
BRAGA	ERMESINDE	4:34	5:29	3.733	15200	15200	1
BRAGA	ERMESINDE	5:29	6:29	3.733	15202	15202	2
BRAGA	ERMESINDE	6:21	6:59	2.267	15204	15204	3
BRAGA	ERMESINDE	6:29	7:29	3.733	15206	15206	4
BRAGA	ERMESINDE	7:21	7:59	0.000	15208	15208	5
BRAGA	ERMESINDE	7:45	8:19	0.000	15212	15212	6
BRAGA	ERMESINDE	8:04	8:59	0.000	15214	15214	7
BRAGA	ERMESINDE	8:34	9:29	0.933	15218	15218	8
BRAGA	ERMESINDE	9:37	10:39	0.933	15220	15220	9
BRAGA	ERMESINDE	10:39	11:34	1.133	15222	15222	10
BRAGA	ERMESINDE	11:34	12:29	0.000	15224	15224	11
BRAGA	ERMESINDE	12:29	13:29	1.333	15226	15226	12
BRAGA	ERMESINDE	13:21	13:59	0.000	15228	15228	13
BRAGA	ERMESINDE	13:37	14:39	0.000	15230	15230	14
BRAGA	ERMESINDE	14:39	15:33	0.000	15232	15232	15
BRAGA	ERMESINDE	15:34	16:29	0.467	15234	15234	16
BRAGA	ERMESINDE	16:44	17:39	0.000	15236	15236	17
BRAGA	ERMESINDE	17:21	17:59	0.000	15238	15238	18
BRAGA	ERMESINDE	17:35	18:39	1.133	15240	15240	19
BRAGA	ERMESINDE	18:21	18:59	0.000	15242	15242	20
BRAGA	ERMESINDE	18:34	19:29	0.400	15244	15244	21
BRAGA	ERMESINDE	19:35	20:39	3.133	15246	15246	22
BRAGA	ERMESINDE	20:39	21:33	0.333	15248	15248	23
BRAGA	ERMESINDE	22:39	23:33	0.400	15252	15252	24
BRAGA	ERMESINDE	23:32	0:19	0.000	15254	15254	25

Table D.15: Braga-Porto Time Deviations to Lousado Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
BRAGA	LOUSADO	4:34	5:10	2.400	15200	15200	1
BRAGA	LOUSADO	5:29	6:05	2.400	15202	15202	2
BRAGA	LOUSADO	6:21	6:43	1.267	15204	15204	3
BRAGA	LOUSADO	6:29	7:05	2.933	15206	15206	4
BRAGA	LOUSADO	7:21	7:43	0.000	15208	15208	5
BRAGA	LOUSADO	7:45			15212	15212	6
BRAGA	LOUSADO	8:04	8:41	0.000	15214	15214	7
BRAGA	LOUSADO	8:34	9:10	0.467	15218	15218	8
BRAGA	LOUSADO	9:37	10:13	0.000	15220	15220	9
BRAGA	LOUSADO	10:39	11:15	1.200	15222	15222	10
BRAGA	LOUSADO	11:34	12:10	0.000	15224	15224	11
BRAGA	LOUSADO	12:29	13:05	1.267	15226	15226	12
BRAGA	LOUSADO	13:21	13:43	0.000	15228	15228	13
BRAGA	LOUSADO	13:37	14:13	0.000	15230	15230	14
BRAGA	LOUSADO	14:39	15:15	0.000	15232	15232	15
BRAGA	LOUSADO	15:34	16:10	0.667	15234	15234	16
BRAGA	LOUSADO	16:44	17:20	0.000	15236	15236	17
BRAGA	LOUSADO	17:21	17:43	0.000	15238	15238	18
BRAGA	LOUSADO	17:35	18:20	0.533	15240	15240	19
BRAGA	LOUSADO	18:21	18:43	0.000	15242	15242	20
BRAGA	LOUSADO	18:34	19:10	0.400	15244	15244	21
BRAGA	LOUSADO	19:35	20:20	1.533	15246	15246	22
BRAGA	LOUSADO	20:39	21:15	0.400	15248	15248	23
BRAGA	LOUSADO	22:39	23:15	0.000	15252	15252	24
BRAGA	LOUSADO	23:32	0:02	0.000	15254	15254	25

Table D.16: Porto-Braga Time Deviations to Porto-Campanhã Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:15	6:20	0.333	15203	15203	1
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	6:45	6:50	0.333	15205	15205	2
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:15	7:20	0.333	15207	15207	3
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	7:45	7:50	0.333	15209	15209	4
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:15	8:20	0.000	15211	15211	5
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	8:45	8:50	0.000	15213	15213	6
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:00	10:05	0.333	15215	15215	7
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	10:45	10:50	0.000	15217	15217	8
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	11:45	11:50	0.000	15219	15219	9
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:15	12:20	0.000	15221	15221	10
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	12:40	12:45	0.000	15223	15223	11
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	13:45	13:50	0.667	15225	15225	12
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	14:55	15:00	0.000	15227	15227	13
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	15:45	15:50	0.000	15229	15229	14
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:15	16:20	0.000	15231	15231	15
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	16:45	16:50	0.000	15233	15233	16

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:15	17:20	0.000	15235	15235	17
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	17:40	17:45	0.000	15237	15237	18
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:15	18:20	0.000	15239	15239	19
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	18:40	18:45	0.000	15241	15241	20
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:15	19:20	0.333	15243	15243	21
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	19:45	19:50	1.333	15245	15245	22
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:05	21:10	0.000	15247	15247	23
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	21:45	21:50	0.000	15249	15249	24
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	23:05	23:10	0.000	15251	15251	25
PORTO-SÃO BENTO	PORTO-CAMPANHÃ	0:50	0:55	0.000	15201	15201	26

Table D.17: Porto-Braga Time Deviations to Ermesinde Synchronization Location

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	ERMESINDE	6:15	6:32	1.000	15203	15203	1
PORTO-SÃO BENTO	ERMESINDE	6:45	7:02	1.000	15205	15205	2
PORTO-SÃO BENTO	ERMESINDE	7:15	7:32	1.000	15207	15207	3
PORTO-SÃO BENTO	ERMESINDE	7:45	8:02	0.333	15209	15209	4
PORTO-SÃO BENTO	ERMESINDE	8:15	8:32	0.000	15211	15211	5
PORTO-SÃO BENTO	ERMESINDE	8:45	9:02	0.333	15213	15213	6
PORTO-SÃO BENTO	ERMESINDE	10:00	10:18	0.333	15215	15215	7
PORTO-SÃO BENTO	ERMESINDE	10:45	11:02	0.000	15217	15217	8
PORTO-SÃO BENTO	ERMESINDE	11:45	12:02	0.000	15219	15219	9
PORTO-SÃO BENTO	ERMESINDE	12:15	12:32	0.000	15221	15221	10
PORTO-SÃO BENTO	ERMESINDE	12:40	13:04	0.000	15223	15223	11
PORTO-SÃO BENTO	ERMESINDE	13:45	14:02	0.467	15225	15225	12
PORTO-SÃO BENTO	ERMESINDE	14:55	15:12	0.800	15227	15227	13
PORTO-SÃO BENTO	ERMESINDE	15:45	16:02	0.000	15229	15229	14
PORTO-SÃO BENTO	ERMESINDE	16:15	16:32	0.000	15231	15231	15
PORTO-SÃO BENTO	ERMESINDE	16:45	17:09	0.000	15233	15233	16
PORTO-SÃO BENTO	ERMESINDE	17:15	17:32	0.000	15235	15235	17
PORTO-SÃO BENTO	ERMESINDE	17:40	17:57	0.333	15237	15237	18
PORTO-SÃO BENTO	ERMESINDE	18:15	18:32	0.000	15239	15239	19
PORTO-SÃO BENTO	ERMESINDE	18:40	18:57	0.000	15241	15241	20
PORTO-SÃO BENTO	ERMESINDE	19:15	19:32	1.200	15243	15243	21
PORTO-SÃO BENTO	ERMESINDE	19:45	20:02	2.000	15245	15245	22
PORTO-SÃO BENTO	ERMESINDE	21:05	21:22	0.333	15247	15247	23
PORTO-SÃO BENTO	ERMESINDE	21:45	22:02	0.000	15249	15249	24
PORTO-SÃO BENTO	ERMESINDE	23:05	23:23	0.333	15251	15251	25
PORTO-SÃO BENTO	ERMESINDE	0:50	1:07	0.000	15201	15201	26

Table D.18: Porto-Braga Time Deviations to Lousado Synchronization Location.

Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	6:15	6:47	2.000	15203	15203	1
PORTO-SÃO BENTO	LOUSADO	6:45	7:19	2.000	15205	15205	2

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Origin	Destination	Departure	Arrival	Delay	TID1	TID2	Run
PORTO-SÃO BENTO	LOUSADO	7:15	7:47	0.000	15207	15207	3
PORTO-SÃO BENTO	LOUSADO	7:45	8:19	1.333	15209	15209	4
PORTO-SÃO BENTO	LOUSADO	8:15	8:47	0.333	15211	15211	5
PORTO-SÃO BENTO	LOUSADO	8:45	9:19	0.000	15213	15213	6
PORTO-SÃO BENTO	LOUSADO	10:00	10:35	2.133	15215	15215	7
PORTO-SÃO BENTO	LOUSADO	10:45	11:19	0.000	15217	15217	8
PORTO-SÃO BENTO	LOUSADO	11:45	12:19	0.000	15219	15219	9
PORTO-SÃO BENTO	LOUSADO	12:15	12:47	0.000	15221	15221	10
PORTO-SÃO BENTO	LOUSADO	12:40	13:23	0.333	15223	15223	11
PORTO-SÃO BENTO	LOUSADO	13:45	14:19	1.067	15225	15225	12
PORTO-SÃO BENTO	LOUSADO	14:55	15:29	2.200	15227	15227	13
PORTO-SÃO BENTO	LOUSADO	15:45	16:19	0.000	15229	15229	14
PORTO-SÃO BENTO	LOUSADO	16:15	16:47	0.333	15231	15231	15
PORTO-SÃO BENTO	LOUSADO	16:45	17:28	0.333	15233	15233	16
PORTO-SÃO BENTO	LOUSADO	17:15	17:47	0.600	15235	15235	17
PORTO-SÃO BENTO	LOUSADO	17:40	18:14	0.467	15237	15237	18
PORTO-SÃO BENTO	LOUSADO	18:15	18:47	0.333	15239	15239	19
PORTO-SÃO BENTO	LOUSADO	18:40	19:11	0.333	15241	15241	20
PORTO-SÃO BENTO	LOUSADO	19:15	19:49	3.600	15243	15243	21
PORTO-SÃO BENTO	LOUSADO	19:45	20:19	1.733	15245	15245	22
PORTO-SÃO BENTO	LOUSADO	21:05	21:39	3.467	15247	15247	23
PORTO-SÃO BENTO	LOUSADO	21:45	22:19	0.000	15249	15249	24
PORTO-SÃO BENTO	LOUSADO	23:05	23:40	3.533	15251	15251	25
PORTO-SÃO BENTO	LOUSADO	0:50	1:23	0.000	15201	15201	26