Redesigning and Improving the Efficiency of Bus Transit Networks Using Automatically Collected Data - The Case of Gipuzkoa, Spain

by

Carlos Gutiérrez de Quevedo Aguerrebere

B.Sc. in Engineering Physics, Universidad Iberoamericana Ciudad de México (2007)

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Author . . . .
Department of Civil and Environmental Engineering
May 10, 2012

Certified by . . . .
Mikel Murga
Lecturer and Research Associate of Civil and Environmental Engineering
Thesis Supervisor

Accepted by . . . .
Heidi M. Nepf
Chair, Department Committee for Graduate Students

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Abstract

Transit agencies around the world are adopting Automatically Data Collection Systems (ADCS) to carry out standard tasks in the management of their networks. Many of these agencies have taken further steps in the use of this data to support and enhance the performance of many other functions under their responsibility. One of these functions is service operations and planning or tactical planning where the use of ADCS will certainly improve their understanding on how the transportation system is performing and being used at almost no extra cost. This thesis focuses on the use of the ubiquitous information from two types of data sources: Automatic Vehicle Location (AVL) and Automatic Fare Collection (AFC) systems, to improve the efficiency of one of the main, although not as frequent, aspects of tactical planning: network design.

Since 2005, the Government of the Province of Gipuzkoa has worked to improve public transit's supply in the region. Over the last years, a progressive integration of the province's crosstown bus network has taken place starting with the creation of an umbrella public company Lurraldebus, the implementation of ADCS, and the further integration of the original operators by sector. These developments bring the unprecedented opportunity to render a more sustainable system and improve the levels of service offered to customers through a better understanding of their needs and the implementation of new processes not only for tactical planning but also for service control management, customer information and operations.

This thesis first explores the institutional, legal, and regulatory structures in which the system is circumscribed to ensure that the recommendations proposed will fall within appropriate boundaries. It also provides guidelines on how the use of ADCS could be adopted and systematized within these structures to obtain all its potential advantages. Then, this thesis proceeds to show how archived AFC and AVL data can be used in the context of Gipuzkoa to asses the overall efficiency of the network and to improve its performance by suggesting modifications to the network design based on the insights provided by a thorough analysis of the use of the available resources by the operator and the utilization of the system by their customers.

Thesis Supervisor: Mikel Murga
Title: Lecturer and Research Associate of Civil and Environmental Engineering

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To my family Jimena, Beatriz, and Carlos…

Living comfortably numb… is not an option.

- Roger Waters, David Jon Gilmour, and Diego Sanchez-Anguiano

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Chapter 1

Introduction

This thesis recommends ways to improve the management and planning methods of the interurban bus services in the province of Gipuzkoa, Spain. The results presented here are based on an evaluation of the state-of-practice and an analysis of the current state of the system using as the main source of information the automatically collected data systems on the bus network. The final goal of this work is to identify opportunities and suggest changes to improve the services' efficiency in the eastern part of the province as well as to lay out methods that can be reproduced when planning services in other sectors of the network. All these recommendations adhere to the contractual framework adopted by the Provincial Government to regulate the operators of the system.

1.1 Gipuzkoa and San Sebastián East

Gipuzkoa is one of the three provinces that forms part of the Autonomous Community of the Basque Country in the north of Spain. It is bordered at the northeast by the French province of Pyrénées-Atlantiques, at the east by the Spanish Autonomous Community of Navarre, and at the south and west by the provinces of Alava and of Biscay, having access to the Cantabrian Sea along the north.

According to the Basque Statistics Office (EUSTAT), in 2010 Gipuzkoa's population was approximately 700,300. More than 182,000 of these were concentrated in the provincial capital, Donostia-San Sebastián, and more than 160,000 lived between this city and the

French border. This area, hereafter San Sebastián East, has the most interurban trips in the province.

The province is governed by the entity known as the *Diputación Foral de Gipuzkoa* (DFG) and it is formed by nine counties, each with a principal town. Most of the trips in the province are made either within the counties or between the counties and San Sebastián. This thesis focuses on the interurban bus system connecting the province's capital with the towns and villages spanning all the way to the French border.

1.2 The Interurban Bus Network

After the ridership of the concessioned interurban bus network declined 25% between 1996 and 2005, DFG started studying methods to stimulate the demand and provide a competitive mobility option to balance the increasing auto mode share and renew the network's public image. At the time, there was little information to regulate the operators and public spending on interurban public transportation was limited to subsidizing fleet renewal. Fares and operations were left under the control of the incumbent operators serving legacy routes. All this left the government with limited space to intervene and limited capacity to systematically improve the provision of service in the network.

In an effort to change this situation and guarantee public mobility within the entire Territory, on November 22, 2005, DFG created Lurraldebus S.L. (Lurraldebus), a conglomeration under the same image of all the interurban bus concessionaires in the province. This structure enabled a series of service improvements culminating on September 12, 2006 with the approval of an operating subsidy by the provincial council (Laidig, D. A., 2010). The most important outcome of this effort was the creation of the Billete Único (single ticket), an automatic fare collection system using contact-less cards for all the services under the newly created Lurraldebus brand. On May 15, 2007, Billete Único was deployed by installing a distance-based fare system for all the concessions under provincial control (Diputación Foral de Gipuzkoa, 2011). Billete Único was also designed to be used in the local bus services of some towns within the province and accepted by the urban transit system of San Sebastián, called Donostiabus.

Throughout the process of creating Lurraldebus, negotiations with the concessionaires led into new contracts that included an annually reversible payment system designed to guarantee the economic equilibrium of the concessions. A clause in the new contracts guaranteed the total revenue of the concessionaires as long as they provided the same level of service. This clause generated problems when trying to coordinate services that belonged to different operators, demanding the establishment of procedures to integrate the different bus routes. In later negotiations with one of the concessionaires, this issue was addressed by implementing an audited cost per kilometer using the guaranteed income payment as basis. The modification of services in this new contract was enabled by the inclusion of a clause that exempts from negotiation a change of $\pm 12\%$ in the number of kilometers provided. A modified version of this principle still prevail in recent contracts.

An additional level of integration is gradually taking place by using demand-based criteria to group sets of routes in different sectors of the province and bidding them in single packages as the original round of concessions comes to an end. The DFG's main objectives in establishing integrated sets of routes are to: improve service management, reorganize service offers, and regulate the monitoring of existing services (Laidig, D. A., 2010). The first example of this took place in March 2010, when the DFG chose a series of routes previously served by four different operators in San Sebastián East and group them into a new set known as LUR-E-01 (Diputación Foral de Gipuzkoa, 2011).

Three of the four original operators in the area, AUIF (1993), Herribus (1990) and Interbus (1959), joined forces to form Ekialdebus; a larger company that would bid and eventually win the LUR-E-01. The original services served very similar alignments, most notable was the N-1 local route from Pasai Antxo to San Sebastián's Downtown as it was repeated in most of the services, creating constant bus bunching problems when entering and exiting the city (see Figure 1.1). Also, all services that entered the capital ended at the east part of the city inducing transfers for people that worked in Igara and Antiguo (a growing alternative Central Business District (CBD) and academic areas west from the city) creating congested traffic at the city center and reducing the efficiency of all services.

Figure 1.1: First sector of grouped routes between San Sebastián and the French border

To some extent these state of affaires still prevails in spite of the integrated services.

The reorganization of the network pursued the additional objectives of coordinating schedules, connecting the growing zones at the outskirts of San Sebastián East to south of the city, and taking advantage of the new highway infrastructure to produce a more competitive and attractive service. It also brought more uniformity to the system's operating hours.

With the economies of scale and density that came from coordinating routes, the DFG was able to reduce the operating costs of the sector. However, since the bid stipulated a fixed amount that had to be paid to the operators, the DFG used the surplus to increase the planned level of service offered before operations started on March 1^{st}, 2011. This thesis investigates the way to further improve the efficiency of these services considering the contractual constraints assumed by the provincial government.

1.3 Motivation

Large transit agencies in the world have migrated to automatically collected data (ACD) systems as their main source of information to take advantage of large and detailed data sets to identify performance problems in the provision of service, and as the main input in service planning. The Automatic Vehicle Location (AVL) and the Automatic Fare Collection (AFC) systems that were introduced with the implementation of the Billete Único provide a wealth of data that should be used for the benefit of the system. At the moment of writing this thesis, alternative ways in which this information can be systematically used by the DFG and Lurraldebus have not been fully explored; this study is the first to propose using this information systematically for other than its original purposes.

The use of this information could help DFG establish planning and management procedures that better meet the original goals by integrating the services by sector. The service integration of Ekialdebus provides an ideal setting to propose such procedures in a context where they could be implemented and tested. Additionally, the results of this thesis should encourage DFG to use the information from the ACD systems in the planning and preparation for the concession of future sectors.

1.4 Objectives

Establish a set of recommended measures to assess and improve the efficiency of Lurraldebus services taking into account the contractual restrictions agreed with the operator and the strategic goals set by the government.

Propose a new network design for the routes east of San Sebastián that provides the same or a better level of service using fewer resources and quantify the magnitude of these savings in economic and social terms, considering the current financial austerity plans of the public sector.

Chapter 2

Literature Review

2.1 Transit Planning

There are three levels of planning process: the strategic, the tactical, and the operational. On each of these levels there are legal, commercial, and technical decisions to be made for achieving the end product of transportation services. The strategic level takes place when the policy and transportation systems are first planned and created to serve the citizens mobility needs. Frameworks are constructed around these needs and furthermore, authorities retain the possibility to initiate later actions to fulfill them. The operational level is where transport service is produced and consumed. This task can also be performed directly by the authorities or subcontracted to a private entity, on either case authorities should keep enough regulating power over the system to protect the customers interests (Anreiter, 2007).

At the tactical level, the transportation system is defined and strategies are translated into actions that layout the structure and operational specifications of the system in coherence with the goals. At this level, the role of the authorities is still the heaviest, although other parties like the operator or specialized consulting firms may develop different aspects of the operation.

Normally, tactical planning has time horizons that can be measured in weeks, months, or years and it normally requires little or no capital investments. Tactical planning can be further understood as a sequential or hierarchical process constituted by: network design, frequency setting, timetable development, vehicle scheduling, and crew scheduling (Wilson,

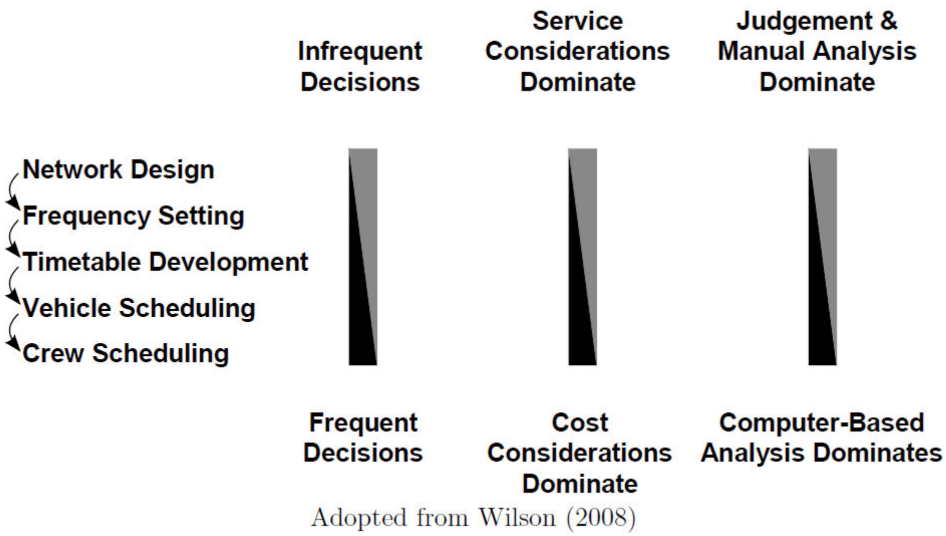


Figure 2.1: Conceptual diagram of tactical planning hierarchy

2011; Vuchic, 2005; Ceder, 2007). Figure 2.1 depicts these stages where network design is the first stage of the process. In this stage decisions are less frequent; service considerations, judgment, and manual analysis tend to dominate. Going down this list, the dependency or dominance of these factors change up to the point where crew scheduling decisions are constantly made using cost considerations as the main driver and where computer-based analysis dominates in the optimization of the system. The broad goal of this thesis is to demonstrate how existing automatic data collect systems can be used for the first two stages of this process, since they facilitate the analysis of the supply and demand, while allowing new network proposals.

2.1.1 Organizational Structure of Network Design

While the specification of what the system should achieve has to remain the responsibility of the authorities, and the production of service a responsibility of the operator; the network design is often a task that is being subcontracted to specialized consultants. The infrequent nature of this task allows to plan and allocate resources for the development of this specific task, leaving the authorities and the operator in charge of the daily tasks of running the system. However, decisions to extend or improve public transportation service are always considered a powerful tool to gain favor among voters and as a result, politicians like to keep that activity under their control. (European Commission et al., 1997)

2.1.2 Use of Automatically Data Collection Systems

Over the last years, the adoption of Automatically Data Collection Systems (ADCS) has become standard practice among all major transportation agencies over the world. In general, there are three different kinds of systems: Automatic Vehicle Location (AVL), Automatic Passenger Counting (APC), and Automatic Fare Collection (AFC). These are normally implemented with rather narrow purposes, by covering standard accountability aspects of the agency like monitoring the completion of the services by the operator, avoiding fare evasion, and collecting fares. In addition to these standard uses, there are many functions of the public transport agency that can be effectively supported by the use of ADCS. These functions are divided by Wilson et al. (2009) as: service and operation planning [1], service control and management, customer information, and performance measurement and operations. This contributes to a better understanding of how public transport systems are performing and being used.

The development of service and operations planning or tactical planning requires an outstanding amount of information covering all the inputs needed for travel demand forecasting, and for estimating the usage of the network and its performance (Wilson and Ceder, 1997). Automatically Data Collection Systems can most likely be effective in characterizing different aspects of these inputs including critical aspects needed for the scheduling of buses, like the distribution of run times for different segments and periods.

Automatic Vehicle Location and Tracking Systems include all systems that record in real time the vehicle position, enabling tracking of them inside the network. Bus systems' AVL is normally based on Global Positioning Systems (GPS) supplemented by a dead reckoning and/or fix detectors at various points in the network.

Automatic Fare Collection Systems register each transaction made by the customer when using the system. Usually validation is only required at the entrance of the system

[1] What is referred to here as service and operations planning" is also commonly referred to as "tactical planning".

(tap-in) except in distance based fare schemes where validations at the exit of the system is also required (tap-out). An early example of this is the Bay Area Rapid Transit network where a magnetic stripe system with unique identification required both validations. This enabled the estimation of a system-level origin and destination matrix. However, the development of origin and destination matrices is not exclusively linked with the availability of distance based fare systems, methodologies using tap-in only systems have been developed and proved to be accurate enough for all purposes of tactical planning (Wilson et al., 2009).

2.2 Demand Response to Changes in Level of Service

While there is an extensive bibliography about demand variations due to fare changes, findings on demand variations due to the level of service are scarce and the most detailed information on this topics is not very recent. However, new findings suggest that the relation between level of service changes and impacts on ridership remain stable over the years (Richard H. Pratt Consultant Inc. et al., 2000). For the purpose of this thesis, the response to three aspects of the level of service were investigated: in-vehicle travel time, transfers, and frequency of service. This section makes a review of previous findings on elasticities of demand due to changes in these three elements of the level of service with the purpose of identifying the most appropriate values to be used in the context of any given proposal.

2.2.1 In-Vehicle Travel Time

Full journey travel times are comprised of at least four elements: walk from the origin, wait for the vehicle, ride in vehicle, and walk to the final destination. In other cases, transfer and wait times should also be taken into account. In private modes of transportation, the in-vehicle travel time represents the most important part of the journey, whereas in public transportation it tends to be less as more time is allocated to the other stages. For local bus routes, the in-vehicle travel time typically accounts for 50% of the time. This means that an increment in speed that reduces in-vehicle travel time to half will only induce a reduction of 25% in the full journey.

Findings on in-vehicle travel times are very scarce as most of the studies are relevant to rail. In a recent compilation made by the Victoria Transport Institute (Litman., 2011) the author in fact makes reference to an earlier work by Small and Winston (1998), presenting a table that compares the elasticities from urban and interurban services from different modes. In this document, interurban is understood as long distance trips between cities. The case of San Sebastián East is closer to a suburban service, although it can even be considered as urban at the outskirts of the city. For this reason the most appropriate elasticity value in the case of a proposal in the Eastern section is of +0.60 for changes in travel time within an urban area.

In a low frequency service, savings in travel time can be achieved in other ways impacting the other three stages of the journey. For instance, in the case of waiting time, increased reliability could reduce the time that a customer allocates to its full journey. With a schedule based system, passengers will include in their journey time budget, a safety margin. This safety margin or buffer time can only be reduced when the reliability of the system increases. This was explored in detail by Uniman, D. L. (2009) and applied and presented by Laidig, D. A. (2010) for the case of Gipuzkoa.

2.2.2 Headways

In terms of demand changes in the response to variations in the frequency of services, several studies point out that elasticity values vary significantly, depending on the existing characteristics of the route, the hours of the day, and the level of service prior to the headway adjustments. Headway elasticities are reported with negative values because when the headway is reduced the quality of service increases, therefore demand also increases.

Cost effectiveness and service quality are the most common goals when changing the frequency of services. In systems with high ridership, the main goal of a frequency modification is to adjust the capacity to the demand, in order to comply with passenger loading standards and an adequate distribution of service. It also serves, in any case, to increase the utilization of vehicles and crew. Either for cost savings or service enhancement, the response of travelers to such changes is always a concern. Frequency changes affect directly the perceived waiting times, increase reliability of service, and improve the experience of transfers in both low and high frequency services. Increasing frequency is commonly used as a strategy to achieve the goals of providing a more attractive service, increasing ridership, and shifting travel out of low occupancy autos. (Richard H. Pratt Consultant Inc. et al., 2000)

The use of frequency elasticities to predict demand changes should be done, taking into consideration several aspects that might affect the effectiveness of the proposed strategy. For instance, when dealing with an "unlinked trip" system where counts are taken either at the beginning of a service or at a transfer point, the evaluation of elasticities is done directly. When dealing with systems that involve timed transfers this is not as simple. As it will be showed later, the first is the primary case of Lurraldebus given that there is a low level of transfer trips and no timed transfer are currently being scheduled. Additionally, the local conditions or concurrent actions may play a significant role on the effects produced by frequency changes, accounting for differences from one situation to another. There is no conclusive information on whether increasing or decreasing the service will have proportional impacts although the highest elasticity values have always been reported when service is improved. (Richard H. Pratt Consultant Inc. et al., 2000)

An aggregated value for headway elasticity of -0.47 $\pm$ 0.17 is presented by a compilation of demonstrations made by Lago et al. (1981). However, the paper also shows great variability depending on the hour of the day and the level of service offered. For instance, during the off-peak period, the elasticity values reported vary from -0.19 $\pm$ 0.09 under an existing high level of service (less than 10 minutes headway) to -0.71 $\pm$ 0.11 under a previous low level of service (more than 50 minutes headway). A less abrupt variation is reported during the peak period with a low boundary of -0.27 $\pm$ 0.14 for high service and -0.37 $\pm$ 0.19 for low service. The paper provides an aggregated elasticity for changes to services with low levels of service of -0.58 $\pm$ 0.19 which will be used in the development of the proposals. Income level is an additional factor that influences the changes in demand having more impact in places with lower income levels.

The Santa Clarita (1992/93 - 1997/98) and Charlottesville (1980 - 1981) examples show contrasting elasticity values for low level of service. The results of Santa Clarita represent primarily changes in headway from 60 to 30 minutes, but the modifications also included service hours enhancements. In this example, the elasticity found was +1.14 for all hours (with positive value because it is compared to the original service quality). On the Charlottesville, the frequency change was the same and the elasticity reported was +0.33. Additional results from the example of Santa Clarita and other studies show that on situations where the express services frequency between suburban residential areas and the CBD was enhanced, elasticities around -0.90 were found (Richard H. Pratt Consultant Inc. et al., 2000).

Several studies show that elasticities are considerably higher during the off-peak than during the peak. The Chesapeake/Northfolk demonstrations (1965-1967) and in the Detroit Grand River demonstration (1962) show that off-peak elasticity proves to be 50% higher than the mean of -0.57 and 100% higher than the mean of -0.13, respectively. Mullen (1975), found different conclusions during the Stevenage demonstrations. A recent analysis done over the data of the Massachusetts experiment also showed more sensitivity to frequency changes when the prior service was infrequent (Lago et al., 1981).

Travel response time lag is normal when making frequency changes in a network as riders need time to assess the new commuting possibilities and change their behavior. In the Massachusetts experiments of 1960, a first wave of new riders started utilizing the system within the first month of operation, which is mostly seen on urban bus services during off-peak hours. Suburban services stabilized the new ridership over the course of 9 to 12 months (Mass Transportation Commission, MA et al., 1964; Southeastern Pennsylvania Transportation Authority). However, in a more recent case in Portland, the stabilization of the ridership had an inverse effect as the urban area reached stable ridership over the course of 8 to 10 months, while in the suburban area, ridership time response ranged from 1 to 5 months (Kyte, M. et al., 1988). Further more, the Portland case shows that in the case of new routes, the demand may take two years to be completely stabilized (Lago et al., 1981).

2.2.3 Timed-Transfer Findings

In the summer of 1979 the redesign of the bus network at the western side suburbs of Portland, Oregon, was based on transfer centers where timed transfers took place. The goal of the new design was to increase the number of frequencies offered to users to improve the accessibility to the CBD. The service was further enhanced thanks to the high level of reliability that was possible to provide because of these transfer centers. In spite of these new transfers, an increase in the number of riders was measured, and by the spring of 1980, the demand was 40% larger (Kyte, M. et al.).

Improvements in the perception of riders were found after the implementation of a hub system involving transfers in the Tidewater region in Norfolk, Virginia, between 1989 and 1992. The system was put in place to reduce the subsidy required by introducing transfers for 40 to 45 percent of all trips. As a result, 71% thought that the travel times were decreased, 77% that the schedules had improved, and more than 60% that the service reliability was improved. The latter is an important factor when planning the implementation of timed transfers in low frequency services as it has a heavy impact on customers transfer waiting times. One of the explanations behind users improved perceptions is that contrary to the initial waiting time at the beginning of a trip, transfer waiting times cannot be controlled by the customer (Richard H. Pratt Consultant Inc. et al., 2000).

2.2.4 Network Restructuring

The adjustment, creation, or extension of bus routes may improve the efficiency, effectiveness, or catchment area of a transportation system. These changes may have a wide variety of purposes: improve access to merchants and employers, enhance accessibility by providing alternative mode choices while reducing auto dependency, and enhance mobility of the non-driving population. At the same time, the curtailment of transit routes and coverage can be a cost saving measure for the system that needs to be reconfigured to decrease negative impacts among least number of customers. Coverage can be defined as the proportion of a metropolitan area or population served by transit. In urban services, a known rule of thumb points to the presence or lack of services within a radius of 400 meters.

There are not many examples that describe with enough detail, the demand response to changes in coverage. However, in general, expansions of bus networks either on its own or with concurrent fare changes seem to have an elasticity range of +0.6 to +1.0. In cases where the previous level of service was lower than the average, it has been shown through different examples, that system-wide ridership response appears to be better in small cities, suburbs, and during the off-peak.

In terms of suburb to suburb trips, routes serving multiple functions tend to be more productive. Successful suburb to suburb services have led to transit centers located at major activity centers, services to major generators, and services to other rail or metro transit stations. (Richard H. Pratt Consultant Inc. et al., 2000)

Chapter 3

Legal and Regulatory Framework

The legal and regulatory framework helps determine the method in which transport services are designed, planned, and produced. Transparent rules should be well defined in order to allocate properly the responsibilities and to share the risks among the agents of the system; this is an essential tool for public transport management and planning. The actors must understand that different authorities, operators, and representatives from diverse legal entities have to coexist both in time and in space. Also, transport authorities as well as from other areas have to devise common strategic objectives for the same area or region if congestion relief and environmental protection is to be achieved (Anreiter, 2007). In this thesis, the regulatory framework ranges from legal to relevant contractual clauses.

The purpose of this chapter is to identify the legal and regulatory frame that governs the changes to Lurraldebus network as well as the existing guidelines and recommendations already in place in the European context. The first section of the chapter presents the legislation in transportation issued by different levels of government, i.e. the legal boundaries will be presented first within the European Union, then at the Country level, and finally at the regional level in order to comply with the regulations from the Basque Country. The second section of the chapter provides a description of the guidelines and goals pursuing the restructuring of the network. The third and last part describes the service contract signed by Diputación Foral de Gipuzkoa and Ekialdebus, and the constraints that limit the possibility of deeper changes in the design of the routes. An assessment about the current conditions and the range of changes to propose in the design, and planning of the routes will be described without trespassing the legal and contractual boundaries.

This chapter concludes that while there is no regulation limiting DFG to make decisions on the strategic, tactical, or operational planning, there are a wealth of guidelines within the European Union that should serve to frame the path towards a more efficient service.

3.1 Regulatory Framework

3.1.1 European Commission

The European Commission (EC) and its members have seen important changes in the legal and organizational frameworks of public transport during recent years. The objective of these changes is to improve the transparency, economic efficiency, and service quality. The EC promotes this through the establishment of an appropriate legal framework at the European level. It has turned out that whatever regulatory regime is adopted, its success strongly depends on the effectiveness of the relationship between authorities and operators. Thus, one of the main functional roles of each country authority is to induce operators to align their business interests with the strategic goals of the system. In this context, specific and complementary schemes of incentives and penalties are an indispensable tool. To achieve these strategic goals, the specification and creation of a public transportation system needs to rest in the local authorities. These guidelines are to be implemented considering the particular approach that each country decides to follow.

Public Service Obligation Regulation

On October 23, 2007, the European Parliament (EP) published the Regulation No 1370/2007; commonly referred in the literature as Public Service Obligation Regulation (PSOR) which applies to public passenger transport services by rail and by road, defining how “competent authorities may act in the field of public passenger transport to guarantee the provision of services of general interest which are among other things, more numerous, safer, of a higher quality or provided at lower cost than those that market forces alone would have allowed” (Anon., 2007). The provision of services through concessions is regulated by the Public

Service Obligation (PSO). The PSOR supervises the procurement of public transport contracts, and all contracts and tenders must follow its guidelines.

European Standard EN 13816

The EN 13816 was created as a concise framework to implement and operationalize the recommendations of the QUATTRO project (Quality approach for public transportation). A quality management strategy is required from service providers, involving the selection of a set of quality criteria, determination of acceptable levels of service, measurement, and determination of corrective action to be taken in case of non-compliance. This standard recommends the design of metrics which balance the customers viewpoint and its use as a management tool for reaching targeted quality standards (CEN Comite Europeen de Normalisation, 2002).

According to EN 13816, a quality management system begins with an overview of existing quality performance and from this, areas for potential improvement are identified. After the targets are set, a process of creating quality criteria from data is developed. This quality criteria contains 8 categories:

1. Availability: it refers to the scope of the service offered in terms of geography, time, frequency, and mode of transport;

2. Accessibility: access to the public passenger transport (PPT) system including transfers to other transport modes;

3. Information: systematic provision of knowledge about a PPT system to assist the planning and service supply;

4. Time: aspects relevant to the planning and service supply;

5. Customer care: service elements introduced to serve as a liaison between standard service and specific requirements of customers;

6. Comfort: service elements introduced for the purpose of making PPT trips more comfortable;

7. Safety and Security: sense of personal protection experienced by passengers, inferred from concrete measures implemented and from measures designed to ensure that passengers are conscious of aware of such measures; and

8. Environmental impact: affect on the environment resulting from the provision of a PPT service.

The selection and specification of these criteria is guided by the consideration of the number of passengers affected. For the purpose of this thesis, the criteria elements that have a direct and positive impact on the structural changes that will be proposed are selected to be the ones on Availability, Time, and Environmental Impact. These standards presents ways to measure aspects of this criteria, however, it does not state any thresholds or performance targets, leaving it to the transportation agency or national regulatory entity to define them. In the EN Standard, the specification of performance levels includes four topics:

- A plain-language statement of the service standard;
- Level of achievement, expressed, where appropriate, as a ratio or percentage of passengers affected;
- Thresholds of unacceptability; and
- Redress, in case of failure to meet the targeted threshold.

In case of non-attainment of performance targets, a policy for corrective action must be defined. This policy identifies the deficiencies in performance, describes methods to achieve the desired performance improvement, and finally, implements that corrective action. Once the customer perception of quality is assessed, action plans designed to reduce the difference between delivered and perceived quality are developed and acted upon. In terms of Availability and Time, a wide discussion of the recommended characteristics for the case of Gipuzkoa is presented by Julian Gomez Galvez (2010). In terms of Environmental Impact, the standard deals only with the efficiency of the technology used and not with the design of the services.

Intelligent Transport Systems

On July 2010, the EP adopted a legal framework for the deployment of Intelligent Transport Systems (ITS) in the field of road transport and its interfaces with other modes. The goal is to contribute to a cleaner, safer, and more efficient transport system; and to accelerate the implementation of these innovative transport technologies across Europe. Under this instruction, the EC has to adopt before 2017 new specifications (i.e. functional, technical, organizational or services provisions) to address the compatibility, interoperability, and coherence of ITS solutions across the EU.

The Commission already took a major step towards the deployment and use of ITS in road transport (and its interfaces with other transport modes) by adopting an Action Plan. The Action Plan suggested a number of targeted measures and included the proposal to create the momentum necessary to speed up market penetration of rather mature ITS applications and services in Europe. Priority actions include optimizing the use of road and traffic data, including information sharing. On the other hand, data used by ITS applications must be reliable, accurate, and continuously available. Other priorities are improving road traffic management on European transport corridors and in cities while promoting the compatibility of different ITS systems used in different types of vehicles (EP European Parliament, 2010).

The Action Plan also highlights the potential of ITS solutions for road-use and zone-based charging, as well as for journey planning, in-vehicle navigation, and eco-driving support. ITS regulations also enhance a more efficient transport use. For example, real-time traffic and travel information (RTTI) in some cases linked to satellite navigation, is now available from both public and private sources. And, in many parts of Europe, ITS technologies are already being used to improve transport management of operations and to facilitate interchange between modes, thus encouraging inter-modality.

Also, this norm includes a Clean Transport goal, which assumes that ITS applications will have a key role in making transport greener. The ITS Action Plan refers to the green transport corridors concept, where ITS technology for different modes of transport are integrated to enable a more a environmentally friendly transport. In this direction, the proposal presented in this thesis aims to lessen the environmental impact through a better use of ITS data to improve the resources of the network and the awareness of a wider mode transportation usage (inter-modality). Optimization is to be understood as the convergence of available built infrastructure, notably between road and rail, i.e. Euskotren, Renfe, D-Bus, and Irún Bus, among others.

3.1.2 Spanish Government

Ley de Ordenación de los Transportes Terrestres

In section 3.1.1 the PSOR was described, which is a European regulation. As a consequence and following these guidelines approved by the European Parliament, the Spanish Government published the "Ley de Ordenación de los Transportes Terrestres" (LOTT), which is the primary regulation that governs land-based transport in Spain. This law, for example, stipulates the maximum contract duration for PSO contracts as ten years for bus passenger transport.

This law indicates that interurban passenger transport services between Autonomous Communities are under the control of the Spanish Ministry of Development, while services within Autonomous Communities are ruled by the competent Local Authority within the respective Autonomous Community (Ministerio de Fomento del Gobierno de España, 2012). It is primarily for this reason that not all interurban routes that travel within Gipuzkoa operate under the Lurraldebus brand (Laidig, D. A., 2010). This also means that the guidelines and directives presented in 3.1.1 are managed by local governments enabling them to use and set the standards under their own discretion.

3.1.3 Basque Country and the Historic Territory of Gipuzkoa

Autonomy Statute of the Basque Autonomous Community

The Autonomy Statute of the Basque Autonomous Community, article 10.32, establishes that the country has exclusive competence over the rail and surface transportation systems constrained within the Basque Country. Additionally, article 12.32 establishes that the Basque government has competence over the execution of legislation on any PPT with origin and destination within the boundaries of the Basque Country, even when using infrastructure owned by the Spanish Government.

On July 18, 1981, the Royal Decree 1446/81 approved the transfer of the infrastructure and services related to the provision of PPT to the Administration of the General Council of the Basque Country, precursor of the current Autonomous Basque Government. Among other aspects, the document enables the Basque Country to:

- Authorize, create concessions, and operate public services within the Basque Country boundaries.
- Establish and deliver transportation cards and tickets within the Territory.
- Set and approve fares as long as they are within the general policy set by the National Government.

The law of Urban and Interurban Bus Transportation

The Basque Parliament approved this law on August 1, 2000, which enables DFG to mandate and control over the planing and operative aspects of the Territory's transportation system.

Transport Authorities

The Basque Government has also approved the creation of Transportation Authorities at different levels of government, being of relevance for this thesis, the creation of the Transport Authority of the Basque Country, leading in turn to the creation of a Territorial Transport Authority of Gipuzkoa (ATTG).

The Territorial Transport Authority of Gipuzkoa has as its main goal the coordination and improvement of the public transportation supply in the Historic Territory of Gipuzkoa. It is authorized to act over all kinds of public and private transportation within the Province, having the duty of protecting the Province's interests. Among others, it is within the responsibilities of this Authority, to plan and optimize the transportation supply services. However, in practice this is not yet the case given that this entity is still at the early stages of its development and has neither the legal autonomy nor the technical staff to do so. The Diputación Foral de Gipuzkoa retains the power to regulate all public passenger transportation matters in the province, but as the ATTG, it does not have the technical staff to generate new operating plans. In time, the ATTG is supposed to regulate on almost every aspect of the following areas:

- Infrastructure and service planning
- Mediation with operators
- Fare policy
- Communication, user information, and system evaluation
- Consultancy services to local entities
- Finance planning
- Management of the transportation services
- Future regulatory framework changes

3.2 Guidelines and Vision of the New Network

3.2.1 The Planned Reorganization of the Network

As explained in section 1.2, after 2003 several measures have been taken to improve the provision of public transportation service across the province of Gipuzkoa culminating in 2005 with the establishment of Lurraldebus, the development of a Sustainable Mobility Plan (SMP), and in 2011 with the integration of the routes in San Sebastián East with a single operator. A project proposal for the integration of these services was presented by DFG to address the SMP, with the main objective of upgrading the current transport services offered in the region by proposing changes to the original route structure.

The re-organization of operators and routes aimed to provide improved and more efficient services. The operation by a single operator who controls all the service within the original concessions, implied that the structure of the new company would result in a more efficient use of available resources and, at the same time, a wider service area. The goal was to establish a better service between the towns of Hondarribia, Irún, Oiartzun, Renteria, Lezo, Pasaia, and Donostia by improving its efficiency, and effectiveness of operation. The main objectives were summarized as follows:

- Improve service management,
- Re-organize the supply of services,
- Regulation of the current operations, and
- Increase of demand served.

The original proposal for changing the routes consisted of a rather complex service design integrated into two different service plans that would alternate throughout the day. During the peak hours, direct services would be provided to the different destinations, offering direct services to most of the destinations. During the off-peak hours, the plan was to establish a troncal service along the N-1 and a set feeder services, connecting the different destinations. However, the original idea was modified during the final negotiation with the operator Ekialdebus, who won the bid.

The reorganization of the routes responded to new criteria that fosters a more competitive service supply to compete with the use of private vehicles. The main criteria was to:

- Strengthen express routes among the main population centres.
- Establish routes through the areas where new developments are taking place.
- Establish effective links with other transport modes to facilitate effective transfers.
- Strengthen the routes linking different counties. As a result, the line Hondarribia-Irun-Renteria-Pasaia-Donostia continues to use N-1, along with the same itinerary and stops.
- Extended night and owl services on Fridays, Saturdays and during summer evenings .

- Retain the services that have proved effective in the past.
- Priority given to regular users of the system.
- Establish a competitive and efficient transport system from a service supply perspective.

The proposal also states that the idea of coordinating services increases frequencies, avoids overlaps, and enables a better way to commute. This requires to re-define and re-size service supply in order to enhance efficiency and effectiveness. There is a wide range of services, which have are not competitive in terms of time, price, and flexibility. (Diputación Foral de Gipuzkoa, 2008).

At the end of the bidding process, most of the new routes were created with a mix of DFG's goals to achieve some specific targets and the experience of operators who served those routes in the past. Additionally, Diputación had enough information to create origin destination matrices at the route and zone level for each of its routes, thanks to the information provided by their smart cards. They also could detail the OD matrices by time period. The planning process began in May 2010 and after a bidding process, Ekialdebus, a new company formed by three of the originals operator of the area was awarded the concession.

The project also proposes a cost model based on revenue per kilometer establishing a fix amount of kilometers that should be operated throughout the year. The model gathers all sorts of costs and divides them by the total amount of scheduled kilometers arriving to a per unit cost. This model has been used in past concessions proving to be convenient for its simplicity. However, the model was established in a time where Diputación did not had accurate information about the service hours needed to operate the bus networks which normally represent 50% of the total costs. Other costs are fuel consumption and maintenance of vehicles which amounts to 20-30% of the total costs, while fixed costs typically account for 15-20% of the expenses (Attanucci and Wilson, 2009). Costs can be better estimated with more elaborate cost models. Laidig, D. A. (2010) discusses in his masters thesis a more suitable option for the case of Lurraldebus, acknowledging the discrete nature of the costs of running a transportation system where capital costs per unit are high and prior agreements with the labor force contain several rules and limitations.

Such a simple approach to the cost model may lead to other issues depending on specific contractual agreements established. For instance, a lack of clear guidelines in the way networks are to be designed and operated, might lead to an unbalanced relationship between the operator and the Authorities. A cost model under such unrealistic conditions will induce the operator to promote the provision of services with high commercial speeds as they lead to higher profits, given that the cost model only acknowledges the distance and not the time.

3.3 Legal Opportunities for Improving the Efficiency of the Service

As described at the end of section 1.2 the bidding process followed by the integration of the routes in sector LUR-E-01 lead into the integration of the former operators into Ekialdebus. This section will discuss the legal agreements between Lurraldebus and Ekialdebus and its implications when trying to improve the efficiency of the network. The service contract was signed on February 28^{th} 2011 and it began operations on March 1^{st} 2011 for the next ten years after which the concession will expire. This contract could be renewed, at most, for half of the original period (5 years).

There are two main constraints for improving the efficiency of the network: the labor force and the establishment of a fixed number of kilometers to be operated and reimbursed. On labor, DFG agreed with Ekialdebus to retain all the staff from the original companies which led to no efficiencies of scale achieved by the integration. As mentioned before, this represents almost 50% of the total cost of operation, which in the absence of those constraints could have led to great savings. To the contrary, the contract signed with Ekialdebus, lists the people, type of work, and salaries from the original companies. However, it is important to note that it does not states any restriction to modify the role played by the employees (Diputación Foral de Gipuzkoa, 2011).

In the contract, the inclusion of new frequencies requires direct approval of DFG also the planning, definition, and control of the services is left to the complete control of this

Authority. In fact, it was during the negotiation of the contract that Ekialdebus suggested not only changes to the frequencies of services but also changes to the original structure of the routes proposed originally by DFG. Following these negotiations, the final contract was valuated at 73,588,133.88 € for the span of ten years.

This contract specifies an annual commitment of 3,650,650 kilometers for every 12 months of operation starting on March 2011. This includes 3,616,687 kilometers of paid services and 33,943 free of charge. The contract further agrees to a per kilometer cost of 2.4384 €/Km which means an annual cost of 8,818,952.00 €. These figures are different than the ones provided a year before by the four operators, (2,896,472 kilometers and 7,681,444.00 € with a unit price of 2.652 €/Km). The contract establishes that every month there is a reconciliation of the programmed kilometers against the performed kilometers, to estimate the payment due to the operator. The equation to be used is:

$$C = (Km_s\ P_{km} + Km_n\ P_{km}\ 0.8) - In \quad (3.1)$$

Where:

$C = Payment\ to\ operator$

$Km_s = Revenue\ kilometers$

$P_{km} = Cost\ per\ kilometer$

$Km_n = Kilometers\ not\ performed\ because\ of\ causes\ not\ related\ to\ the\ operator$

$In = Cash\ revenue\ received\ by\ the\ operator$

During the first year of operation, the amount of Scheduled Kilometers could not be modified, since this was established as a trial period in which the effectiveness of the routes and the price per kilometer would be tested and approved. After this first year, DFG reserved the right to modify all the services up to a limit of 10% in the number of kilometers without changing the price per kilometer. This means that Diputación could potentially modify the services to achieve a reduction of 361,668.70 Km which would result on maximum savings of 881,895 € (using 2.4384 €/Km as the unit price).

During the writing of this thesis, the first year of the contract expired and some adjustments to the network were done. The author had enough information to make an estimation of the new costs of operating this new network structure, assuming that the cost per kilometer remains unchanged. However, no access to data on the operation of this network was available to make further investigations. The results from this analysis are presented in Table 3.1 where it can be showed that between the March 2011 schedule and that planned for March 2012, there is an increment of 2.57% in the amount of scheduled kilometers. This means that DFG will pay 226,681 € for 92,963 additional kilometers. Of the added kilometers 83% will be used for regular services and 17% for night services.

Of the regular services, the highest percentage increment occurs on Sunday as they will provide 5.08% more service than in March 2011. In the case of night and owl services, a 99.06% increase on Friday frequencies will be applied. This last one is not excessive if it is considered that on March 2011 schedule there was barely no night service and no owl service on Fridays and that in March 2012 this is still half of what is provided on Saturdays.

The contract presents no other limitations for DFG or Lurraldebus to make modification on the tactical planning of the network. There are no performance goals on either the economic or the level of service provided. Moreover, the flexibility of 10% in the number of kilometers is set and fixed before a deeper analysis on the impacts of reductions are done. The contract specifies how to make corrections to the tariff and to the number of kilometers during the first year but it does not state or points out on what basis should the corrections be made. Additionally, it forces the operator to keep a high number of employees which represent most of the expenses of the operation. This entails risks to both the Authority which might end up paying excessive costs or an excessive provision of service, and to the operator which in case of reaching the lower bound of the number of kilometers provided, it might not be able to recover its costs, although it could become more efficient, if the system becomes indeed more efficient.

Table 3.1: Change in Scheduled Kilometers between March 2011 and 2012

Type of Service	**Annual Kilometers March 2011 Schedule**	**Annual Kilometers March 2012 Schedule**	**Service Kilometers Increase**	**Cost Increase (€)**	**% Change**	**Proportion of Total New Service Kilometers**
Regular Services	3,607,823	3,627,964	20,141	49112	0.56%	56%
Monday to Thursday	*2,330,662*	*2,324,118*	*-6,544*	*-15957*	*-0.28%*	*-18%*
Fridays	*582,150*	*582,231*	*80*	*196*	*0.01%*	*0%*
Saturdays	*414,861*	*427,223*	*12,362*	*30144*	*2.98%*	*34%*
Sundays	*280,150*	*294,393*	*14,243*	*34729*	*5.08%*	*40%*
Night and Owl Services	65,788	81,686	15,897	38764	24.16%	44%
Monday to Thursday	*0*	*0*	*0*	*0*	*0.00%*	*0%*
Fridays	*13,312*	*26,498*	*13,186*	*32153*	*99.06%*	*37%*
Saturdays	*52,477*	*55,188*	*2,711*	*6611*	*5.17%*	*8%*
Sundays	*0*	*0*	*0*	*0*	*0.00%*	*0%*
Total	**3,673,611**	**3,709,650**	**36,039**	**87877**	**0.98%**	**100%**
Cost per Kilometer used	*2.4384*					

Chapter 4

Analysis of the existing conditions

This chapter makes use of Lurraldebus' automatically collected data to analyze the conditions after the integrated provision of services started operations on March 1^{st} 2011; this data and the schedule used throughout this analysis belongs to the weekdays period between the 2^{nd} and 28^{th} of May 2011 [1]. In the section 4.1 of this chapter, a description of the routes is done to provide a clearer idea of the services being studied and the necessary context to understand the following sections.

Section 4.2 analyses the provision of service and the usage of resources given the operating conditions in the area. The first part of this section describes the data preparation process done to verify and validate the run time measurements obtained from AFC and AVL data. The second part describes the methodology used to estimate different aspects of the operating conditions and to compute the minimum resources needed to provide the service. The last part of this section makes an assessment of the conditions by comparing the number of resources needed and used in operation. The analysis found that the use of resources is reasonable in all cases. However, it was noted that in general the services linking San Sebastián with Oarsoaldea have tight run times, while the services linking it with Bidasoaldea have long layovers. This produces a sub-utilization of buses that makes possible to improve the operation by introducing interlining as part of the scheduling practices.

[1] Data prior to this date was excluded from the analysis because of changes to the schedule during the first months of operation and because of vacation periods on the last two weeks of April 2011.

Section 4.3 makes an analysis of the demand and the utilization of resources. The section is divided in three parts: the first one describes the data preparation process followed to verify and validate the AFC transactions used in estimating origin and destination matrices. The second part describes the methodology used to compute these origin and destination matrices for both departure and arriving times at every hour of the day. The last part evaluates how the system is being used by passengers and how the resources are being utilized.

The last section of this chapter makes an evaluation of the economic performance of the network as a whole and for each of its routes.

4.1 Overview of the Network

The services of the Lurraldebus Network in San Sebastián East can be classified by the two counties that they serve: Oarsoaldea (with routes between E01 and E09) and Bidasoaldea (or Bajo Bidasoa, with routes between E20 and E26). Oarsoaldea is closest to the capital city and encompasses the municipalities of Lezo (5,900 pop.), Oiartzun (9,700 pop.), Pasaia (16,300 pop.), and Errenteria (38,100 pop.). Bidasoaldea is located further away, between Oarsoaldea and the French border; and groups the municipalities of Hondarribia (16,500 pop.) and Irún (61,000 pop.). In this region the network provides both local (using the N-1 route) and express services (using the expressway A-8) connecting the counties to the capital city but also linking the municipalities within the counties. The city of San Sebastián and its surrounding area is also known as Donostialdea, and its straight distance to the central area of Oarsoaldea is of 6 kilometers while its distance to Bidasoaldea is of 16 kilometers.

Oarsoaldea

Nine regular services connect this county with different areas inside the capital city; five arrive to the city center, three to the Hospitals area, and one service loops the city passing through multiple areas inside it but with the zones of Igara and Antiguo as prime destinations. The city center receives local routes E01, E08, and E09, arriving from the neighborhoods of Lezo, Pasai Donibane, Pasai Antxo, Trintxerpe, and Pasai San Pedro in the municipalities of Lezo and Pasaia; the local route E05 from Errenteria; and the local route E02 from Oiartzun. The Hospitals area is connected to Pasai San Pedro and Trintx-

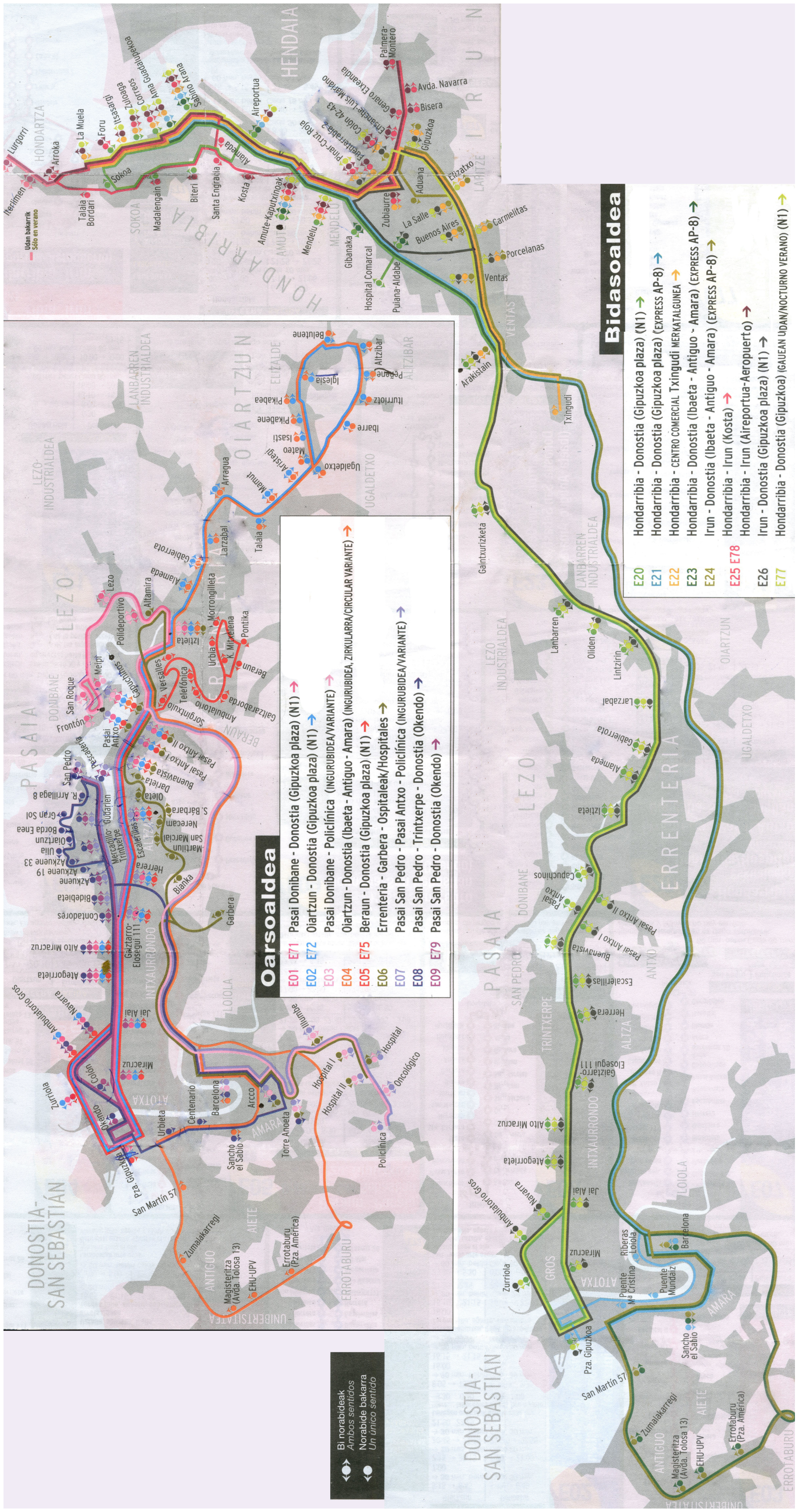


Figure 4.1: Map of routes serving in San Sebastián East

erpe with the express route E07, to Pasai Donibane and Lezo with the express route E03, and to Lezo, Errenteria, and Altza (a neighborhood of San Sebastián), with the express route E06. Routes E03 and E07 overlap between the intersection named Capuchinos and the Hospitals area, and run parallel to E06 in this same segment. In this county, the zones of Igara and Antiguo are only connected to the municipality of Oiartzun through the express route E04. However, more services connect them with the county of Bajo Bidasoa. Figure 4.1 shows the routes descriptions of this area.

Bidasoaldea

There are seven routes providing service to the county of Bidasoaldea. Five of them link the county with Oarsoaldea and with the provincial capital while the other two interconnect the municipalities of Irún and Hondarribia. The center of San Sebastián is served by local routes E20 and E26 coming from Irún's and Hondarribia's downtowns, and by the express route E21 coming from the Airport. The express routes E23 (Hondarriabia) and E24 (Irún) link the zones of Igara and Antiguo following the same loop as route E04 and overlapping between them from the intersection at Arakistain to San Sebastián and back. Also, the city centers of Irún and Hondarribia are interconnected by local routes E25 and E22 although this last one covers a larger path to reach a shopping mall at Txingudi. Figure 4.1 shows the routes descriptions of this area.

Following this organization, Table 4.1 presents additional characteristics of the routes that provide a general perspective of the services being deployed and their importance. In this table, routes are further organized by its daily demand in descendant order putting the demand in Oarsoaldea in first place with more than 15,000 customers per day which accounts for 72% of the total demand in San Sebastián East. Furthermore, the demand on the first four routes of this county represent 62% of the sector's demand while the summed demand of the remaining five is less than the demand of any of them individually. The Bidasoaldea routes connecting the municipalities of Irún and Hondarribia follow in order of importance with 15% of the total demand where route E25 is the main contributor. The Bidasoaldea routes linking the city of San Sebastián can be found at the last part of the table. The total demand of these routes is comparable to that of routes E09 or E25 individually. In this last set, routes E20 and E26 are responsible for moving 74% of the customers that potentially travel outside Bidasoaldea but they may also belong to Oarsoaldea. The rest of the routes in this area are express routes that represent 4% of the total demand in San Sebastián East.

Table 4.1 also shows other aggregated figures, e.g. the length of each route, the stop density, and the operational speed on an average weekday. The local routes present stops spacings that range from 200 to 800 meters and an average speed of 21 Km/hr - higher than in common urban areas (14 Km/hr). The express routes, on the other side, have stops spacings that range from 600 to 3,500 meters. The average speed for these routes is 32.1 Km/hr although there is a large difference in speed between the express routes of Oarsoaldea (27.3 Km/hr) and the express routes of Bidasoaldea (42.5 Km/hr).

The next to last column specifies the total scheduled kilometers per day. This figure was used to divide the daily ridership of each route and obtain an aggregated index that allows to compare the routes under the same terms: number of passengers served for every scheduled kilometer. The route with the highest index is E09 (4.12 Pax/Sch.Km) followed by E01, E05, and E02 (3.11 Pax/Sch.Km) - all local routes. At the other extreme, are the routes with indexes of less than 1 Pax/Sch.Km which coincide in all cases with the express services.

4.2 Supply Analysis and Use of Resources

Through this section run times are vastly used for the analysis, given that the number of resources required for a service is tied to the length of time required for its operation. In this thesis, run times are defined as the time between the departure of a bus at the first stop of a route in one direction and its arrival at the last stop on that same direction.

4.2.1 Data Preparation

Run times for every trip were estimated by crossing the information of different tables from the archived AVL and the AFC systems. Every time a bus approaches a stop by a predetermined radius of between 50 and 150 meters, Lurraldebus' database records the time and a service number that identifies each trip. With this information, the run time for every

Table 4.1: General characteristics of the routes in San Sebastián East

	Routes by County	Demand per Weekday (Pax)	Percentage of Total Demand	Frequency (Services/h)	Length (m)	Stop Density (m/stop)	Operational Speed (Km/h)	Scheduled Km. per Weekday	Demand per Scheduled Km. (Pax/Km)
Oarsoaldea - San Sebastian		***15,837***	***72%***		***23,718***			***6,447***	
E02	OIARTZUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3,932	18%	3	25,828	517	21.8	1,266	3.11
E05	BERAUN-PASAIA-DONOSTIA (N I)	3,485	16%	4	18,241	468	21.0	1,122	3.11
E01	DONIBANE-LEZO-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3,395	15%	3	20,650	607	22.1	1,001	3.39
E09	SAN PEDRO-DONOSTIA (N I)	2,887	13%	4	10,301	412	13.4	700	4.12
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES (AP-8)	776	4%	2	26,703	809	27.6	687	1.13
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	514	2%	1	37,173	1,093	28.6	520	0.99
E03	DONIBANE-ERRENTERIA-POLICLNICA (AP-8)	364	2%	1	29,046	1,210	30.0	436	0.84
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	269	1%	1	15,644	559	19.6	266	1.01
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	216	1%	1	29,876	807	30.9	448	0.48
Bidasoaldea		***3,383***	***15%***		***16,022***			***1,605***	
E25	HONDARRIBIA-IRUN	2,898	13%	5	13,393	209	20.1	1,334	2.17
E22	HONDARRIBIA-C.C. TXINGUDI	486	2%	1	18,650	622	22.8	270	1.80
Bidasoaldea - San Sebastian		***2,877***	***13%***		***44,549***			***3,143***	
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	1,133	5%	1	35,801	716	22.4	593	1.91
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	986	4%	1	44,224	804	25.0	730	1.35
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	409	2%	1	45,651	3,512	44.9	685	0.60
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	179	1%	1	46,404	2,730	40.9	427	0.42
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	170	1%	1	50,667	2,815	41.6	709	0.24
	Total	***22,097***					***Total***	***11,194***	***1.97***

trip can be estimated as the time difference between the last and first stops. With enough amount of measured trips it is possible to reliably determine the run times for each route and direction by doing an statistical analysis of the individual run times.

However, the fact that the recording of this information is only linked to proximity criteria and not to a specific event -e.g. the opening and closing of doors- raises a question about the accuracy of the resulting information. When buses spend a certain amount of time at a given stop, the system records the exact same data multiple times with subsequent timestamps. This means that even after choosing the last of these records for any given stop, it is not possible to determine whether the bus left or lingered before departing to the next stop. This effect happens with more frequency at precisely the first and last stops where buses have planned recovery times or drivers have their breaks. To reduce the effects of this, the data was cleaned by removing any trip with abnormal travel time between the first and second stop. Still, the run times may contain a degree of error since in very few cases it was difficult to identify whether the time elapsed between the two stops was within the norm or not. Cleaning data is not an unusual practice when it comes to ADC data given that it removes extreme or misleading values that are occasionally produced by errors in the system or by exceptional behavior in the operation. Nevertheless, what is being cleaned here occurs systematically, thus it is recommended to correct it by fixing the cause.

Another issue encountered was the low recording rate of the passes by stop data at some of the stops. In most of the cases the missing data belonged to the last stop of the itinerary and less often to the first one, reducing the sample size of the measured run times. For some routes -e.g. example route E20- this happened to the extent that a conclusive analysis of the run times was not feasible. This issue was approached by measuring the run time without the missing segment and inferring the run time for it based on the bus' speed at the adjacent segment.

Table 4.2 synthesizes the nature of the data used for each route and shows, for example, that the detection of first and last stop range from 3% in the case of route E07 outbound to 87% in the case of the E20 inbound.

Table 4.2: Measured and Inferred Stop Recordings

Route	Direction	Used	Infered	Measured	Discarded
E01	DONIBANE-DONOSTIA	**72%**	*19%*	*53%*	*28%*
E01	DONOSTIA-DONIBANE	**82%**	*57%*	*25%*	*18%*
E02	OIARTZUN-DONOSTIA	**70%**	*16%*	*54%*	*30%*
E02	OIARTZUN-DONOSTIA	**66%**	*38%*	*28%*	*34%*
E03	DONIBANE-DONOSTIA(POLIKLINIKA)	**63%**	*18%*	*45%*	*37%*
E03	DONOSTIA(POLIKLINIKA)-DONIBANE	**74%**	*60%*	*15%*	*26%*
E04	OIARTZUN-DONOSTIA-OIARTZUN(A8)	**12%**	*1%*	*11%*	*88%*
E05	BERAUN-DONOSTIA	**81%**	*24%*	*57%*	*19%*
E05	DONOSTIA-BERAUN	**88%**	*26%*	*62%*	*12%*
E06	ERRENTERIA-DONOSTIA (HOSPITALES)	**57%**	*54%*	*3%*	*43%*
E06	DONOSTIA (HOSPITALES)-ERRENTERIA	**88%**	*37%*	*51%*	*12%*
E07	TRINTXERPE-DONOSTIA (POLIKLINIKA)	**56%**	*19%*	*37%*	*44%*
E07	DONOSTIA(POLIKLINIKA)-TRINTXERPE	**45%**	*3%*	*41%*	*55%*
E08	PASAI SAN PEDRO-DONOSTIA	**95%**	*42%*	*53%*	*5%*
E08	DONOSTIA-PASAI SAN PEDRO	**77%**	*4%*	*73%*	*23%*
E09	PASAI SAN PEDRO-DONOSTIA	**71%**	*0%*	*71%*	*29%*
E09	DONOSTIA-PASAI SAN PEDRO	**81%**	*0%*	*81%*	*19%*
E20	HONDARRIBIA-DONOSTIA	**84%**	*50%*	*33%*	*16%*
E20	DONOSTIA-HONDARRIBIA	**78%**	*62%*	*16%*	*22%*
E21	HONDARRIBIA(AIREPORTUA)-DONOSTIA	**94%**	*7%*	*87%*	*6%*
E21	DONOSTIA-HONDARRIBIA(AIREPORTUA)	**81%**	*0%*	*81%*	*19%*
E22	HONDARRIBIA-CC TXINGUDI	**91%**	*36%*	*55%*	*9%*
E22	CC TXINGUDI-HONDARRIBIA	**81%**	*20%*	*61%*	*19%*
E24	IRUN-DONOSTIA(IBAETA)-IRUN(A8)	**100%**	*100%*	*0%*	*0%*

4.2.2 Run and Cycle Times Estimation

Run times are commonly affected by three main factors: congestion, dwell times, and scheduled run times. Congestion reduces the operating speed of the buses especially during peak hours. Dwell times can slow down the operation at stops where the bus is crowded and the boarding and alighting process takes longer than usual. Finally, scheduled run times must be set loose enough so the percentage of buses arriving on-time to start the next trip is high and at the same time, they have to be set tight enough so operators do not drive slower than necessary. The cleaned data was used to analyze and set the run and recovery times per direction and operating period for all services. This information was used to determine the cycle times and the total resources needed to reliably operate the schedule. These resources and cycle times are then compared to those used on the services provided during the period of analysis.

Some agencies set half-cycle times to the median of the observed run times while others plan some slack into the schedule and use holding strategies at time-points to increase the reliability of the operation (Furth et al, 2006). The latter “splits” the half-cycle time in two as the sum of the median observed run time and a recovery time; this recovery time can be estimated as the difference between a higher percentile value of the run times and the 50^{th} percentile so the defined half-cycle time is in fact the mark set by this higher percentile. Increasing this last percentile will increase the percentage of on-time trips proportionally, for example, if a half-cycle time is set to the 85^{th} percentile it means that 15% of the buses will be late to depart on the next scheduled trip (Shireman, M. T., 2011). The probability of having a late bus propagates and increases in subsequent trips. In the following paragraphs route E01 will be used as an example to explain the process followed to define the cycle times. The analysis made for the rest of the routes can be found on Appendix A for the Oarsoaldea routes and on Appendix B for the Bidasoaldea routes.

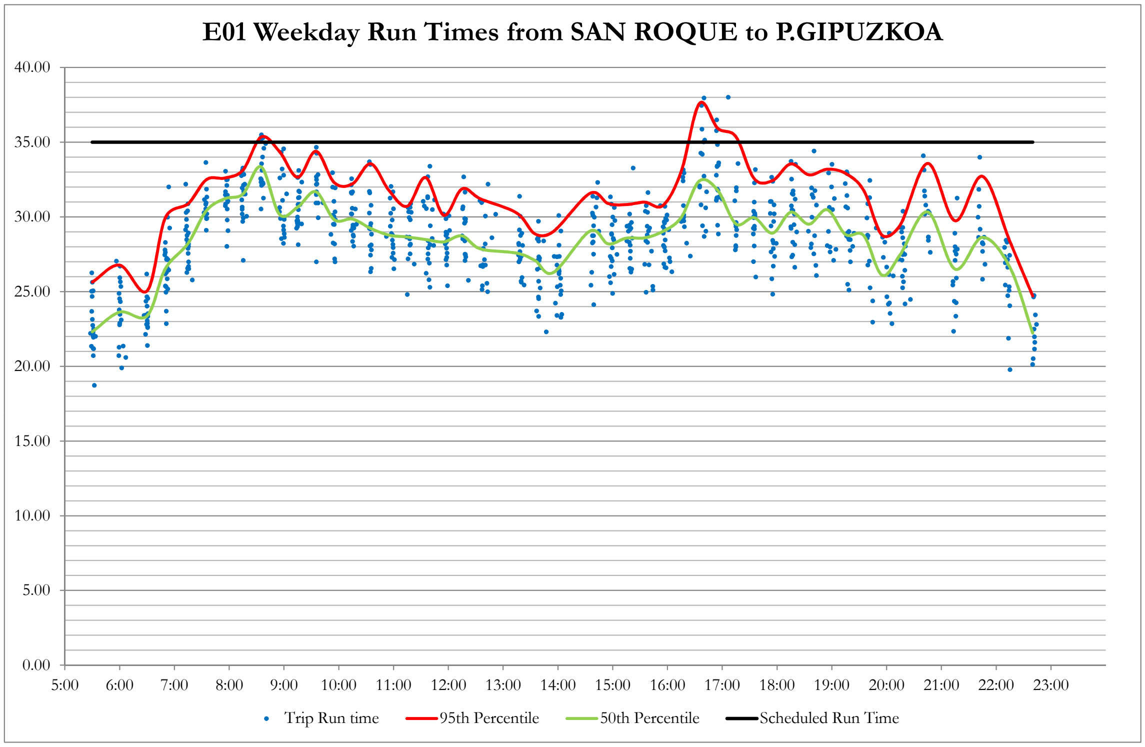
Figure 4.2a shows the analysis of the inbound run times for route E01 from San Roque to Plaza Gipuzkoa, while Figure 4.2b shows the analysis made for the outbound direction. The hours of the day are on the horizontal axes while on the vertical axes the time is measured in minutes; each blue dot represents a trip that started at the first stop in the hour specified on the horizontal axes and ended at the final stop lasting the time specified in the vertical axes. The green and red lines cover the 50^{th} and 95^{th} percentiles of the duration of every scheduled trip. Finally, the straight black line is the scheduled run time as found in the database's definition for this route.[2].

In the case of this route (E01) it can be seen that the inbound scheduled half-cycle time is set way above the 95^{th} percentile of most of the scheduled trips during the day and just to some morning and afternoon trips. On the outbound direction the scheduled run time is below the 50^{th} percentile of most of the trips. As discussed earlier, this would mean that more than 50% of the outbound trips arrive late to their final destination. Furthermore, the profile of the measured run times indicates that the scheduled half-cycle time could be broken down into more periods tailoring the times to better fit the observed data. As it will be showed later, the mentioned issues may not represent any concern when operat-

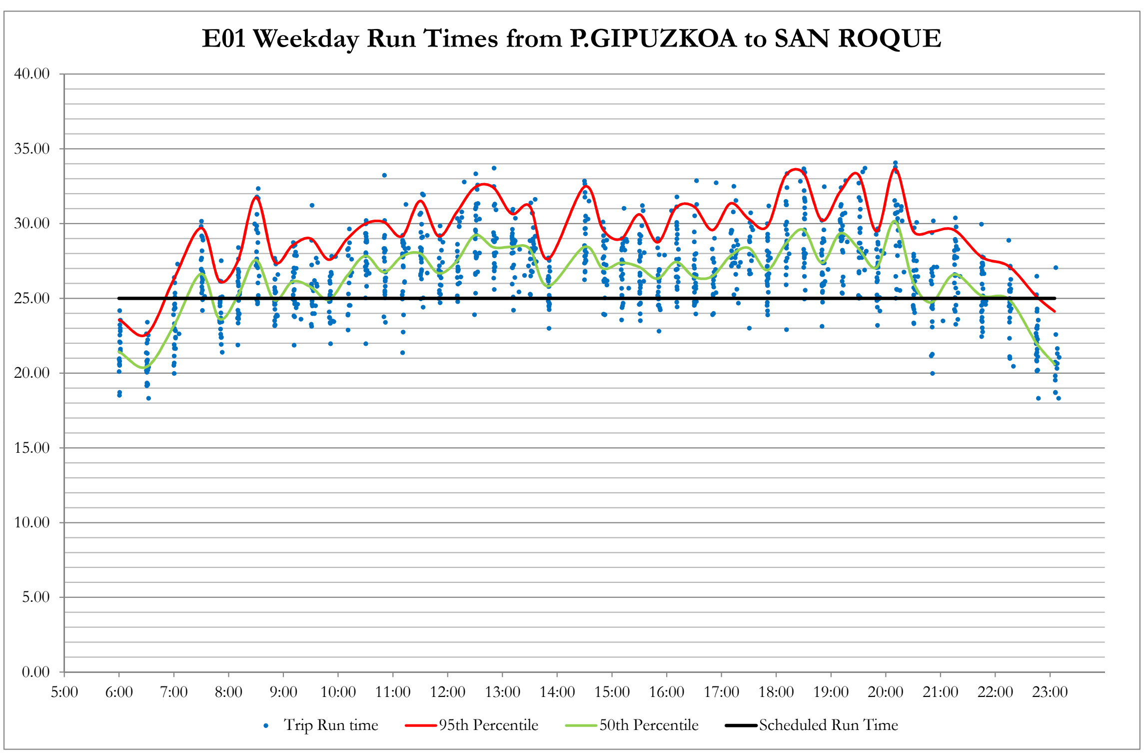
[2]The use of these run times served only to illustrate a part of the followed process and were not used on any of the computation towards the final results of this analysis. These run times were obtained directly from the route's description in the Lurraldebus' database and it was not possible to confirm with Ekialdebus whether they are actually used in planning the services or for a different purpose. However, their sum (60 minutes) coincides with the implied cycle-time of the route when considering the headway and the number of buses used for its operation. Additionally, it is known by phone interview with Javier Gil, responsible for route scheduling at Ekialdebus, that all routes except for route E22 use flat run times throughout the day.

Figure 4.2: Scatter plot and analysis of route E01 Donibane-Lezo-Errenteria-Pasaia-Donostia (N-I)

(a) Inbound



(b) Outbound



ing with full-cycle times given that the profiles of the run times may complement each other.

Operation periods were determined by jointly evaluating the inbound and outbound direction of each route and setting common segments of time in which the run times remained even. For instance, in Figure 4.2a it can be seen how for route E01 the 50^{th} percentile run times varies from 26 minutes at 07:00 hrs., up to 34 minutes before 09:00 hrs., returning down to 30 minutes just before 10:00 hrs.. On the other hand, Figure 4.2b shows no significant variation that would alter this definition of the period. A similar exercise can be made to find the P.M. peak between 16:00 and 20:00 hrs. Global periods for this part of the network were estimated by comparing those of each route and finding shared segments of time. Table 4.3 reports these global periods.

Table 4.3: Determined operating periods in the San Sebastián East routes

Early Morning	05:00	06:59
A.M. Peak	07:00	09:59
Midday	10:00	15:59
P.M. Peak	16:00	19:59
Evening	20:00	23:59

Given that the service provided in the Lurraldebus' network operates with low frequencies and that users plan their trips according to the schedule, it would be desirable to deliver a service with high reliability, thus it is recommended to set run times of all routes above the 90^{th} percentile mark within each period. This practice builds reliability into the schedule and sets the base for delivering a better adherence to it. For the sake of saving resources, run times may be set at lower marks at the expense of reducing the reliability of the arrival times and therefore the departure of the next trip. However, during this analysis all routes showed that in most cases only one or two additional minutes were required to reach the 95^{th} mark, thus in these cases, this last mark was set as the half-cycle time. Modifications to the definition of routes, the setting of on-time-performance measures, or external factors may alter the lengths of these times and they should be revisited to identify problems or to make adjustments to the operation.

The resulting inbound and outbound half-cycle times for each period were added to de-

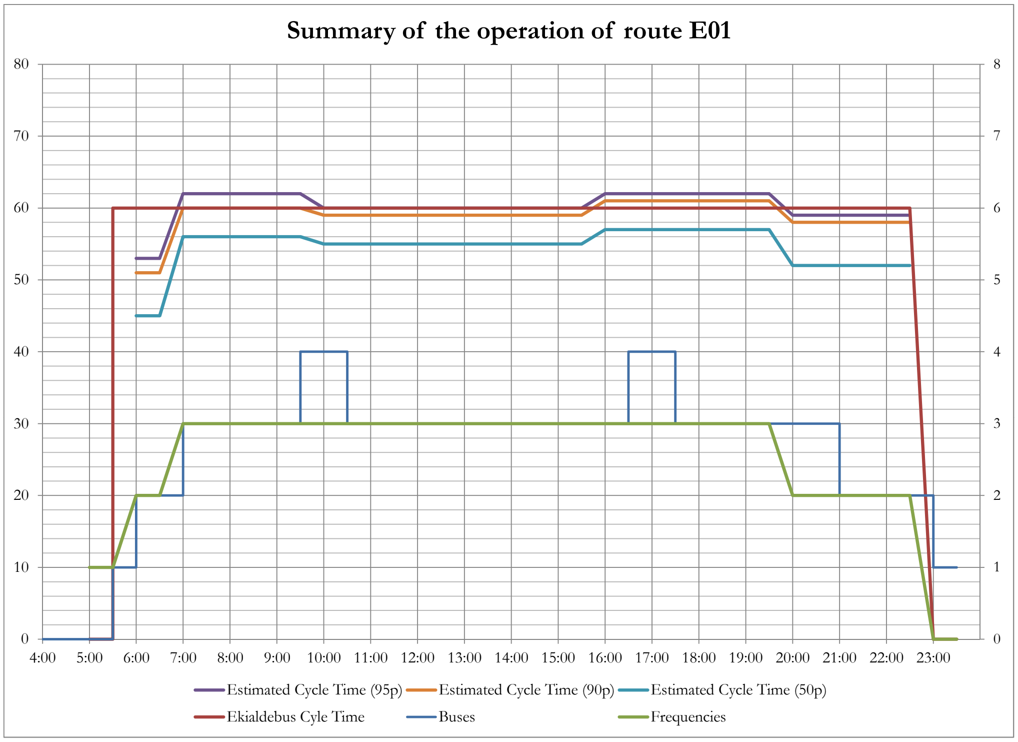


Figure 4.3: Comparison of estimated and scheduled cycle times in Route E01

termine full-cycle times. These were then compared to the scheduled cycle times to evaluate the use of the planned resources. Given that Ekialdebus makes no use of interlining on 13 of its 16 [3] regular routes, the scheduled cycle times were inferred with information on the headway and number of buses used in the operation. Graphs like the one presenting route E01 in Figure 4.3 were produced for all routes to visually asses this, (they can be consulted in Appendix A and B). This graph has the hours of the day on the horizontal axes, on the left vertical axes the time is measured in minutes, and on the right vertical axes natural numbers are shown to count either the number of buses (in dark blue) or the frequencies at different points of the day (in green). The red line represents the scheduled cycle time while the light blue, orange, and purple represents the 50^{th}, 90^{th}, and 95^{th} percentiles, respectively, of the estimated cycle time broken down into the defined periods; all these lines are referenced to the left side axes.

[3] Route E25 operates with a variant that in some cases will be considered as an additional route

4.2.3 Analysis of Service Supply

Figure 4.3 shows that the scheduled cycle time is set at 60 minutes and it is operated with a frequency of three services per hour until 21:00 hrs., when it changes to two services per hour. Three buses are mainly used to operate this route except for two moments on the day at 09:00 and at 16:00 hrs. when one additional bus is required. During the A.M. peak the scheduled cycle time coincides with the 90^{th} percentile with a recovery time of 4 minutes which means that during this period 10% of the trips will arrive late. The current scheduled cycle time seems not to be enough as the propagated tardiness generates the requirement of an additional bus, right when the period is coming to an end. Similar effects are observed at the P.M. peak although earlier in the period since the scheduled cycle time leaves even less recovery time. This systematic need for an additional bus is difficult to elude using dedicated fleets for specific routes and without the use of interlining strategies in the operation.

The summary information for the A.M. peak of this analysis is presented on Table 4.4 where the columns labeled Run Times, Cycle Times, and Recovery refer to the estimated values after the analysis. The estimated and the rounded up fleet for each route are in the following two columns; the cycle times, layover, and number of buses used by Ekialdebus are in columns labeled with the word Current. Ekialdebus' use of resources is reasonable in all cases although most of the routes operating in Oarsoaldea have higher recovery times than the used layover, which means that half-cycle times are tight and may produce unreliable services if correction measures are not taken. This is the case of route E01 where an extra bus in a punctual part of the operation is needed to maintain the schedule. In this case, if cycle times were set to be the 95^{th}, the number of buses required for the operation would be 4, resulting in layovers of 24 minutes. The opposite to this happens in the case of the Bidasoa routes where cycle times are too long to produce the service within the policy headway of 60 minutes.

A way around this would be to use interlining strategies to complement the spare and missing time between routes and this could also generate savings on the number of resources required for the operation. In the analysed schedule there are two ways to apply this method

Table 4.4: Operating times and use of resources by route

	Routes with no interlining	**Headway (min)**	**Run Times**	**Cycle Time**	**Recovery Time**	**Computed Buses**	**Roundup Buses**	**New Cycle Time**	**New Layover**	**Current Buses**	**Current Cycle Time**	**Current Layover**	**Change in Layover**
E01	DONIBANE-LEZO-ERRENTERIA-PASAIA-DONOSTIA (N-I)	20	56	62	6	3.1	4.0	80	24	3	60	4	76
E03	DONIBANE-ERRENTERIA-POLICLNICA	60	58	64	6	1.1	2.0	120	62	1	60	2	118
E05	BERAUN-PASAIA-DONOSTIA (N I)	15	52	59	7	3.9	4.0	60	8	4	60	8	52
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES	30	58	68	10	2.3	3.0	90	32	2	60	2	88
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	60	58	64	6	1.1	2.0	120	62	1	60	2	118
E08	SAN PEDRO-TRINTXERPE-DONOSTIA	60	48	55	7	0.9	1.0	60	12	1	60	12	48
E09	SAN PEDRO-DONOSTIA (N I)	15	46	55	9	3.7	4.0	60	14	3	45	-1	61
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA	60	106	116	10	1.9	2.0	120	14	2	120	14	106
E22	HONDARRIBIA-C.C. TXINGUDI	60	49	58	9	1.0	1.0	60	11	1	60	11	49
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	60	68	74	6	1.2	2.0	120	52	2	120	52	68
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	60	96	110	14	1.8	2.0	120	24	2	120	24	96

Table 4.4: Operating times and use of resources by route

	Routes with interlining	**Headway (min)**	**Run Times**	**Cycle Time**	**Recovery Time**	**Computed Buses**	**Roundup Buses**	**New Cycle Time**	**New Lay-over**	**Buses**	**Current Cycle Time**	**Current Lay-over**	**Change in Lay-over**
E02	OIARTZUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	20	71	79	8	4.0	4.0	80	9		N/A	N/A	N/A
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	60	78	83	5	1.4	2.0	120	42	6	N/A	N/A	N/A
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	60	61	70	9	1.2	2.0	120	59		N/A	N/A	N/A
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	60	73	81	8	1.4	2.0	120	47	3	N/A	N/A	N/A
E25	HONDARRIBIA-IRUN (KOSTA)	20	40	48	8	2.4	3.0	60	20		N/A	N/A	N/A
E25	HONDARRIBIA-IRUN (AIREPORTUA)	20	45	53	8	2.7	3.0	60	15	6	N/A	N/A	N/A
	TOTAL FLEET					**34.9**	**43**			**37**			

in routes E02 and E04, and in routes E21 and E23; shown at the bottom of the Table 4.4. With the first pair of routes, it is possible to provide a more reliable service but the number of buses required remains the same. On the second one, the planned service is more robust and the number of buses is lowered from 4 to 3.

4.3 Demand Analysis

This section makes an analysis of the passenger's use of the system two months after the integration of the LUR-E-01 routes. Origin and destination matrices (OD) are the main input for this analysis as they contain demand information about time and intention of the passengers' trips, and consequently provide insights on the travel patterns of the system.

The first part deals with the preparation of the AFC data used to compute OD matrices. The second part describes the methodology used to compute these matrices for the subsequent analysis and for proposing changes to the network. The third part compares the demand with the services provided and makes an assessment of the utilization of the network.

4.3.1 Data Preparation

Lurraldebus' automatic fare collection system contains accurate and complete descriptions of the trips done by the users of Billete Único. For each trip, passengers are required to tap their cards at the boarding of the bus and when they arrive to their final destination. Each of these transactions are translated into the data base system as information on the time, stop, and number of passengers involved on that trip [4]; and it also has the route taken for that trip. In the case when the transaction is done with cash, the system also registers all this information but only with the origin of the trip. The high use of the card in the system and the availability of this information over several days provides accurate and vast information to infer the destination of these cash transactions and describe the transportation needs of the system's users.

[4]Some affiliating cards allow to pay more than one trip with the same card

Prior to the estimation of the ODM, an analysis of the use of the card in San Sebastián East was done to evaluate the quality and quantity of the available data. The first conclusion drawn from this analysis was the variability of the card use across the days of the week. While on a regular weekday 86% of the trips are made using Billete Único, on Saturdays and Sundays its use goes down to 80% and 71%, respectively. This is expected as customers that use the service on a daily basis -for work or study- will tend to own a card and profit from its discounts while infrequent and more leisure-focused users might not care so much about obtaining its advantages.

The second conclusion from this analysis is about the recording of complete trips. Of the total transactions done with the card, 84% are recorded as complete tap-in&tap-out at the trip level while for 16% there is only tap-in information. This means that of all the trips in the system there is complete origin and destination information for 73% and the reminder 17% are both cash and tap-in-only card transactions (see Table 4.5). There is more than one reason behind the missing information; the most natural of them being that customers may forget about tapping-out when exiting the system at the end of their trips. Another source for this is that the information about the trips is linked to the fare-box making it susceptible to human error. When a bus arrives at the end of the route it requires the driver to manually end the service and start the following one on the fare-box. If the driver does not have enough time to change this before the new customers board the bus, they will be registered on the previous trip. This error is visible when trying to generate ODM with the raw data as for some routes, e.g. route E02, new passengers on the last stop can account 4% of the total demand on that direction. This problem was solved by identifying the routes that presented this issues and transferring those passenger counts to the same stop of the following trip.

After validating and cleaning the data, three different tables were produced: the first containing all the cash transactions, a second one with all the tap-in-only transactions, and the last one with tap-in&tap-out information. As discussed earlier in this section the data on this table not only contains the origin and destination, but also the route, direction, and hour at the beginning of each trip. In the following analysis the first two tables will be considered as one piece of information and gathered into an only origin table while the

Table 4.5: Percentage of tap-in&tap-out, tap-in only and cash transactions in San Sebastiaán East

	AVERAGE WEEKDAY		**SATURDAYS**		**SUNDAYS**	
	Transactions	**Proportion of Total Transactions**	**Transactions**	**Proportion of Total Transactions**	**Transactions**	**Proportion of Total Transactions**
Total Transactions	**21,207**	**100%**	**15,155**	**100%**	**10,540**	**100%**
Cash	*2,968*	*14%*	*3,061*	*20%*	*3,061*	*29%*
Only Tap-in	*2,846*	*13%*	*2,359*	*16%*	*1,373*	*13%*
Tap in and Tap out	*15,392*	*73%*	*9,736*	*64%*	*6,107*	*58%*
Total Card Transactions	**18,238**	**100%**	**12,095**	**100%**	**7,480**	**100%**
Only Tap-in	*2,846*	*16%*	*2,359*	*20%*	*1,373*	*18%*
Tap in and Tap out	*15,392*	*84%*	*9,736*	*80%*	*6,107*	*82%*

second will be considered as an origin and destination table.

4.3.2 Methodology for Origin and Destination Matrices Computation

The resulting tables from the validation and cleaning process of the last subsection are used here to estimate complete origin and destination matrices for all the services in San Sebastián East in two phases. On the first phase the table with origin and destination data is used as the base to infer the destinations of the only origin table within every hour. On the second phase, a different version of the origin and destination table, referencing the demand with the arrival time rather than with the departure of each trip, is used to infer an ODM with more realistic flows across the hours of the day. The following paragraphs describe these two phases and the assumptions made to infer complete origin and destination matrices.

For the first phase of this method, we define that on any hour h at the i^{th} origin of a specific route and direction with a set of origins S the total number of boardings $\hat{B}_i^h$ is the sum of both; the number of boardings B_i^h for which its destination is unknown and the boardings b_{ij}^h for which its different destinations $j, j+1, j+2, \ldots, j+n$ are known. So $\hat{B}_i^h$ may be written as:

$$\hat{B}_i^h = B_i^h + b_{ij}^h + b_{ij+1}^h + b_{ij+2}^h + \cdots + b_{ij+n}^h \;\; \forall \text{ i, j>i } \in (S) \tag{4.1}$$

Using the complete origin and destination data from the 20 weekdays of the analysis period it can be assumed that at every hour the customers B_i^h distribute on all the possible destinations keeping the same proportions as the customers b_{ij}^h, b_{ij+1}^h, b_{ij+2}^h, $\ldots$, b_{ij+n}^h boarding at the same station. By estimating the proportions of every b_{ij}^h of the sum of all customers boarding in i with known destinations, and multiplying these by the number of customers B_i^h it is possible to infer the destination of these last ones. Equation 4.2 shows the computation of the these proportions; RB_{ij}^h.

$$RB_{ij}^h = \frac{B_{ij}^h}{\sum_{j=0}^{n} b_{ij}^h} \forall i, j > i \in (S) \tag{4.2}$$

And the inferred demand for each origin and destination pair b'^{h}_{ij} is the multiplication of these proportions RB^{h}_{ij} by the number of customers B^{h}_{i} :

$$b'^{h}_{ij} = RB^{h}_{ij}\, B^{h}_{i} \tag{4.3}$$

Then the equation 4.1 can be written as the sum of known and unknown origin and destinations:

$$\hat{B}^{h}_{i} = \left(b'^{h}_{ij} + b^{h}_{ij}\right) + \left(b'^{h}_{ij+1} + b^{h}_{ij+1}\right) + \left(b'^{h}_{ij+2} + b^{h}_{ij+2}\right) + \cdots + \left(b'^{h}_{ij+n} + b^{h}_{ij+n}\right)$$

or more synthetically as:

$$\hat{B}^{h}_{i} = B'^{h}_{ij} + B'^{h}_{ij+1} + B'^{h}_{ij+2} + \cdots + B'^{h}_{ij+n} \tag{4.4}$$

where:

$$B'^{h}_{ij} = b'^{h}_{ij} + b^{h}_{ij} \tag{4.5}$$

By doing this for all the hours, routes, and directions, we can obtain origin and destination matrices for a complete day of service assuming that all the trips that departed in hour h arrived within that same hour. However, this would mean that a customer that departed at 09:58 will be considered to have arrived at some point after this time but before the hour ends. In the following paragraphs a second part of this method generates more realistic origin and destination matrices by taking into account the trips that are completed across different hours. For the next steps of the method it was necessary to include the same table with complete origins and destinations although the arrival time of the passengers is specified instead of the departure time.

With the demand information timed at both the departure and the arrival, it is possible to count the number of trips that started and ended at different but subsequent hours of the day. The destination of these boardings in the following hour can be inferred according to the proportions RB^{h}_{ij} at their starting time and counted as part of the alights of the next hour. This will allow to have better information about the loads of the routes at every hour of the day.

Similarly to equation 4.5, lets define that for any hour h, the total amount of passengers A'^{h}_{ij} alighting at the j^{th} destination of a specific route and direction is the sum of the number of alights for which its destination can be inferred a'^{h}_{ij} and the number of alights for which its destination is known a^{h}_{ij}. We also know that not all these alights come from trips that started in the same hour but that there is a portion that started at least the hour before. This means that a'^{h}_{ij} and a^{h}_{ij} are each equal to the sum of two different types of trips: the trips started and ended in this hour $h \to h$ and the trips that started in the previous hour and ended in this one $(h-1) \to h$. To take this as true, we need to assume that there are no trips that started in the previous hour $h-1$ that will end in the following $h+1$, which means that all trips last at the most one hour. This statement is very close to reality given that a trip longer than 59 minute is a very rare event; none of the 95^{th} percentiles half-cycle times estimated in section 4.2.2 is longer than this time and trips between the extremes of a route are infrequent. Equation 4.6 shows these relations in terms of the alights.

$$A'^{h}_{ij} = a'^{h}_{ij} + a^{h}_{ij} = (a^{(h-1)\to h}_{ij} + a^{h\to h}_{ij}) + (a'^{(h-1)\to h}_{ij} + a'^{h\to h}_{ij}) \tag{4.6}$$

With this consideration and acknowledging that at the beginning and end of the day the passenger load on every route and direction is zero; we can use the complete origin and destination data to account for the number of passengers $b^{h\to h+1}_{ij}$ that boarded and alighted in different though subsequent hours and the number $b^{h\to h}_{ij}$ of passengers that boarded and alighted within the same hour. Where the sum of this two is equal to the total boardings with known destinations:

$$b^{h}_{ij} = b^{h\to h+1}_{ij} + b^{h\to h}_{ij} \tag{4.7}$$

The number of passengers $b^{h\to h+1}_{ij}$ can be thought as a"temporal load" from one hour to the next and for each origin and destination pair. However, this is not possible to do in the case of the passengers B^{h}_{i} thus the known $b^{h\to h+1}_{ij}$ is divided by the total number of boardings at i with known destination j to compute a ratio α^{h}_{ij}. This ratio was then used to estimate the number of B^{h}_{i} that arrive in the next hour.

$$\alpha^{h}_{ij} = \frac{b^{h\to h+1}_{ij}}{b^{h}_{ij}}$$

Similarly, the amount $b^{h\to h}_{ij}$ is used to compute the complementary value β^{h}_{ij} as the percentage of the total trips boarding at h that started and ended within the same hour.

$$\beta_{ij}^{h} = \frac{b_{ij}^{h \to h}}{b_{ij}^{h}}$$

This means that Equation 4.7 can also be written in the following way:

$$b_{ij}^{h} = b_{ij}^{h \to h+1} + b_{ij}^{h \to h} = \alpha_{ij}^{h}\, b_{ij}^{h} + \beta_{ij}^{h}\, b_{ij}^{h} \tag{4.8}$$

Similarly, the boardings $b_{ij}^{\prime h}$ inferred in Equation 4.3 can be written as:

$$b_{ij}^{\prime h} = b_{ij}^{\prime h \to h+1} + b_{ij}^{\prime h \to h} = \alpha_{ij}^{h}\, b_{ij}^{\prime h} + \beta_{ij}^{h}\, b_{ij}^{\prime h} \tag{4.9}$$

And the total number of boardings with known and inferred destinations from Equation 4.5 can be written as follows:

$$B_{ij}^{\prime h} = b_{ij}^{h \to h+1} + b_{ij}^{h \to h} + \alpha_{ij}^{h}\, b_{ij}^{\prime h} + \beta_{ij}^{h}\, b_{ij}^{\prime h} \tag{4.10}$$

Finally, we know that the total number of boardings $b_{ij}^{(h) \to h+1}$ in hour h should be equal to the total number of the alights $a_{ij}^{(h-1) \to h}$ in hour $h+1$. This means that Equation 4.6 can be written as :

$$A_{ij}^{\prime h} = a_{ij}^{(h-1) \to h} + a_{ij}^{h \to h} + \alpha_{ij}^{(h-1)}\, b_{ij}^{\prime (h-1)} + \beta_{ij}^{h}\, b_{ij}^{\prime h} \tag{4.11}$$

This last equation provides a way to estimate complete origin and destination matrices at the arrival time of passengers, complementing the one computed with Equation 4.4 to estimate average loads at every hour of the day for every route and direction.

4.3.3 Analysis of the Demand for Service

This section makes use of the origin and destination matrices estimated before to analyze in more detail how is the system being used by the customers. The first part makes a review of the temporal variations of demand while the second one makes further investigations estimating their load profiles at utilization indexes at the peak periods. One general conclusion is that most of the routes are under-utilized because the amount of service provided is mainly limited by the policy frequencies and not by their capacity. This happens more often on the express routes either from Oarsoaldea or Bidasoaldea.

Overview of the demand

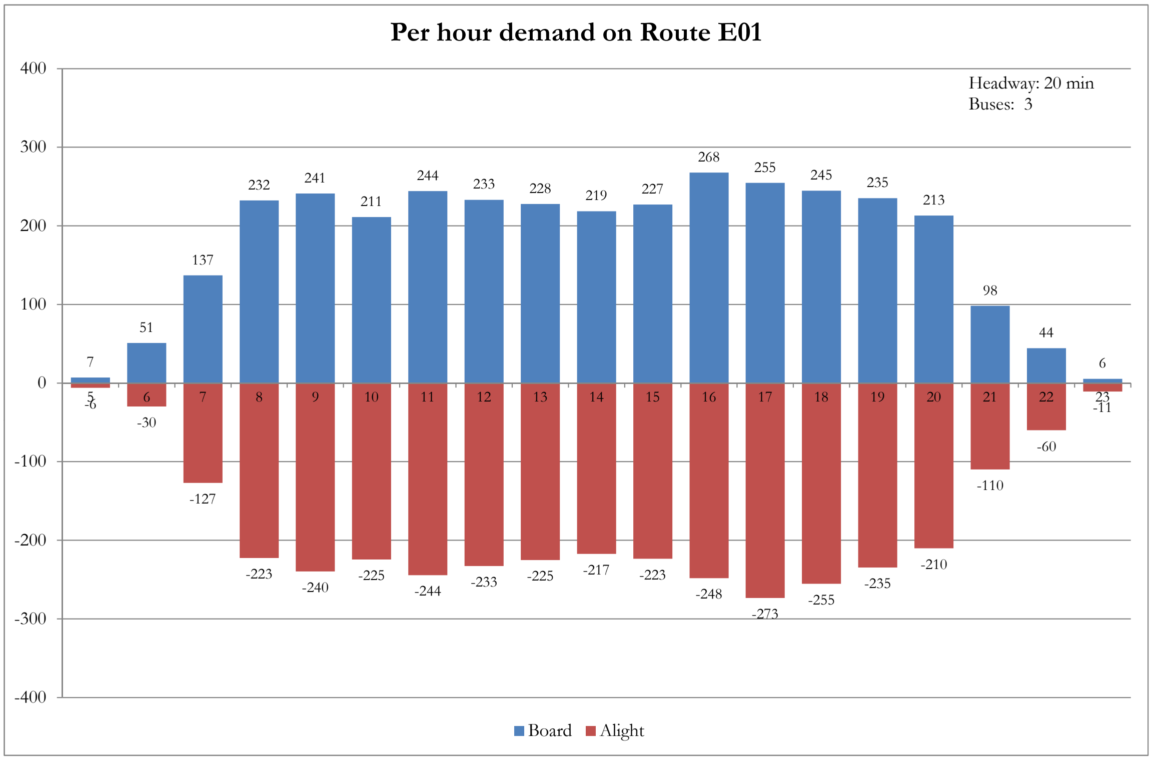
Route E01 from Donibane to San Sebastián's center is used to present an example of the analysis done to all the routes, as discussed in section 4.1, this is one of the best performing routes of the network. The reminder of the graphs are presented on Appendix A and B. As almost all routes in this area, the total demand of E01 varies little across the hours and only shifts direction at different times of the day. This is shown in Figure 4.4a, where at any hour of the day the demand on this route is above 210 and below 270 passengers. Other routes have a much lower demand, for example the express route E03 in Figure 4.4b -that shares origin with E01 from Donibane but has destination in Hostpitales- has a demand varying from 26 to 30 passengers. Its total demand is only 8% of E01 while the number of spaces per hour supplied is a third of what is provided in this last one. The limiting factor that generates the excess capacity in this route is the policy headway of 60 minutes; ten of the sixteen routes are in this same situation.

Similar graphs were produced to find the peak periods and peak hours on each direction. In general, there are two peak periods per direction: the A.M. peak inbound and the P.M. peak outbound; although for some routes like E05 the outbound peak was found at midday. In the case of route E01 inbound, the highest peak with 182 passengers was found between 08:00 and 09:59 hrs., and a secondary peak between 15:00 and 17:00 hrs. On the opposite direction 169 passengers were found on the highest peak between 18:00 and 20:59 hrs., and a secondary peak between 12:00 and 13:59 hrs. This is presented in Figures 4.5a and 4.5b. A global period from 07:00 to 09:59 hrs. encompassing the peak of all routes was chosen to generate average load profiles and compute load factors and utilization coefficients to evaluate each route.

Figure 4.6 shows the load profiles at the peak hours of route E01. The stops are presented on the horizontal axes while the vertical axes counts the number of customers that board and alight the service. The gray straight line represents the limit of seating spaces

Figure 4.4: Demand across hours in both directions on Routes E01 and E03

(a) Route E01



(b) Route E03

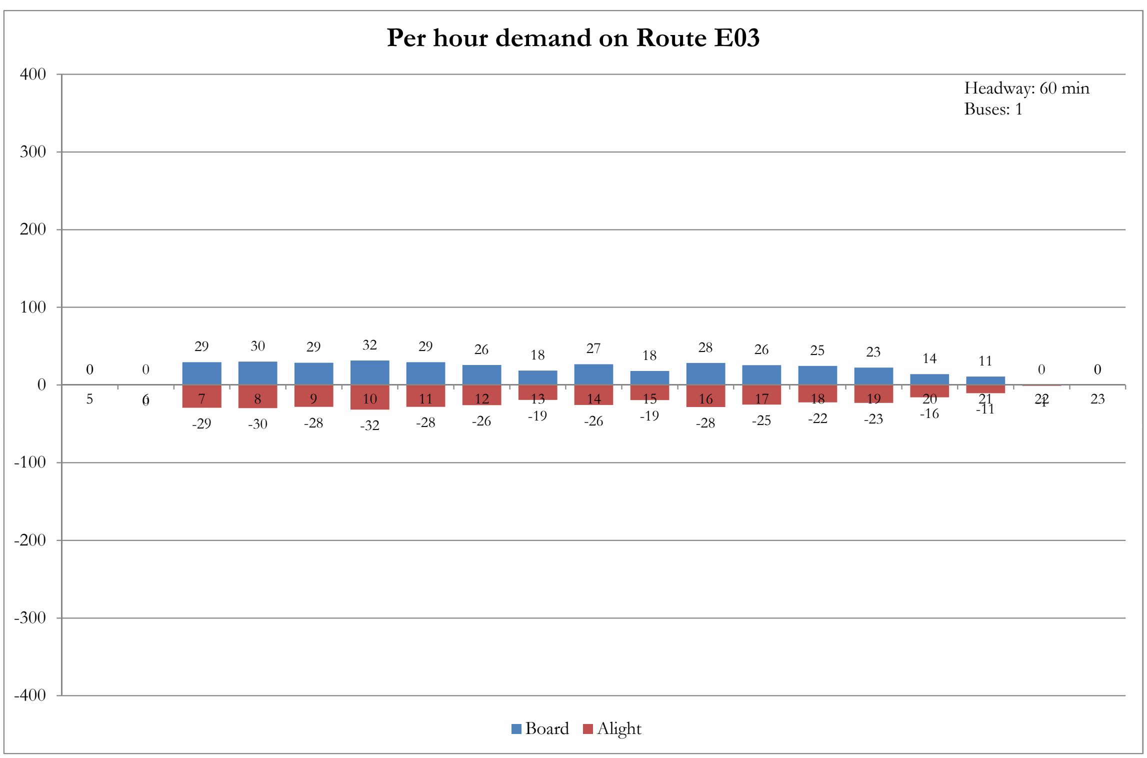
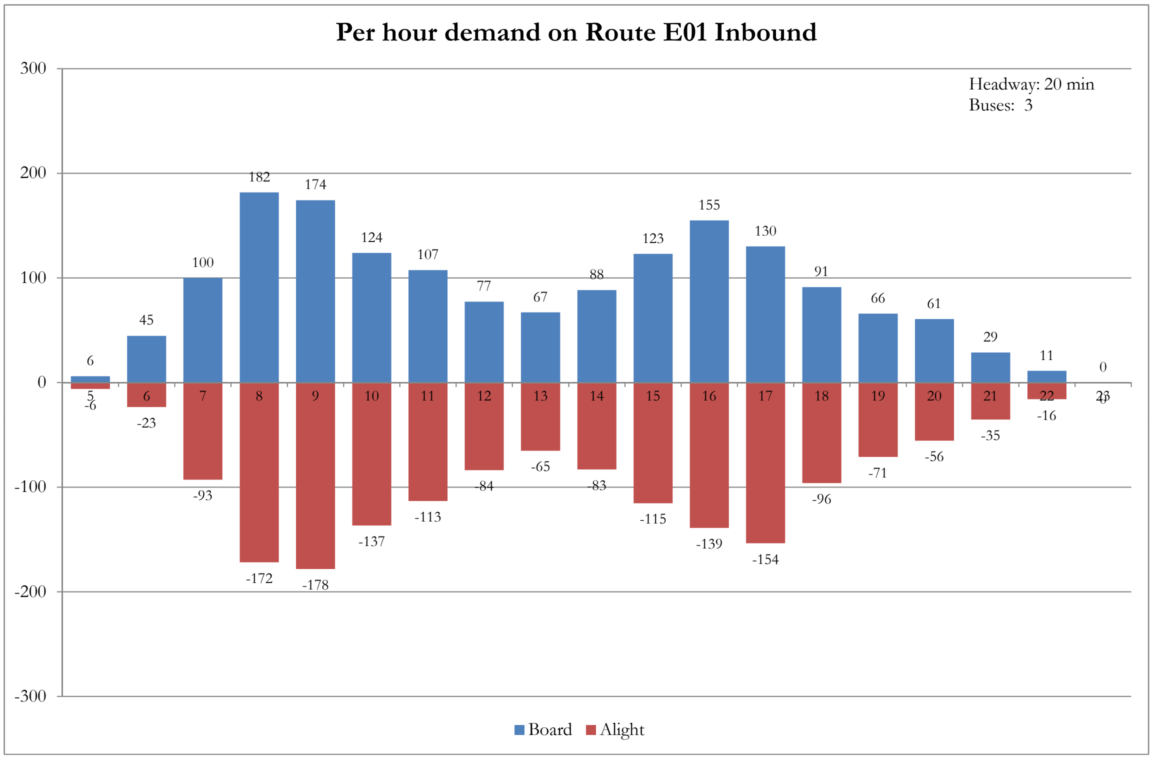
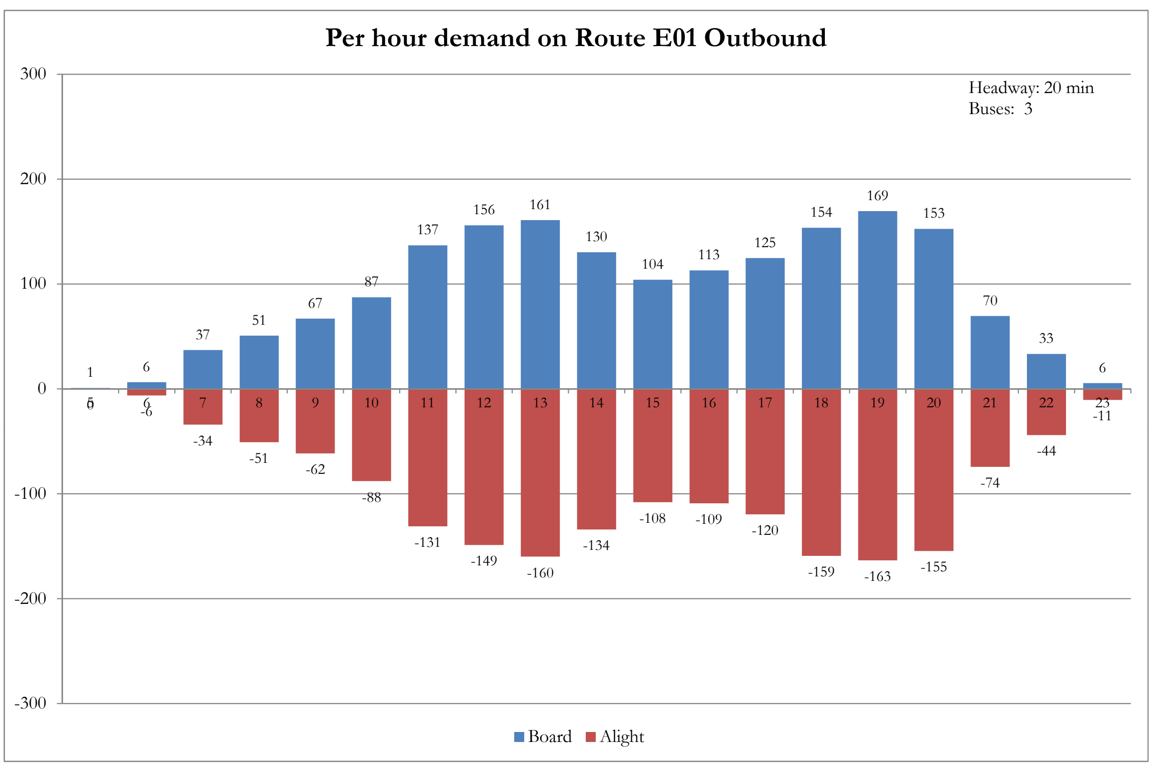


Figure 4.5: Demand across hours in each direction on Route E01

(a) Inbound



(b) Outbound



offered while the black line is the total offered capacity at 100% of occupancy. The curved black line represents the average load at any point of the route. The graph shows that on the inbound direction during the A.M. peak the demand for service exceeds slightly the number of offered seats while on the outbound direction customers traveling seated is the norm. The graph also shows that at these time of the day most of the demand for service comes from the stops in Lezo and Iztieta, this last station is very important for most of the routes including those serving the county of Bidasoaldea.

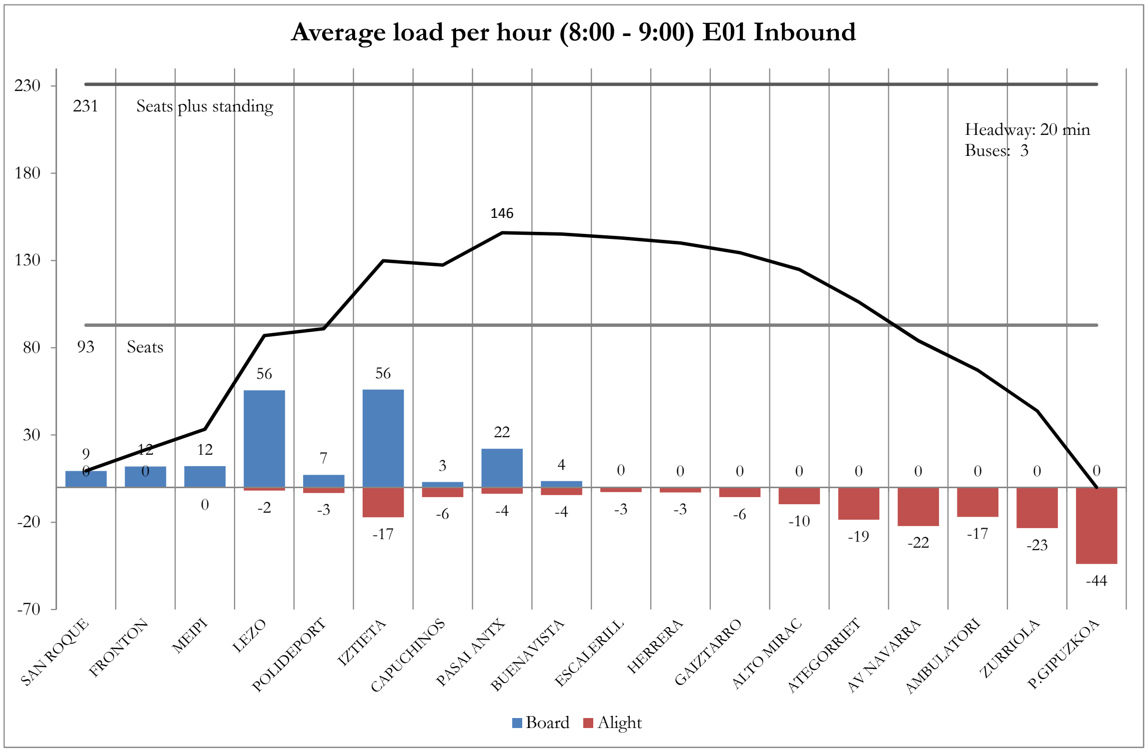
Information presented on these graphs along with other utilization computations for all the routes during the A.M. period (07:00 to 09:59 hrs.) inbound is presented in Table 4.6. The two main indexes are the load factors, estimated as the ratio of the passengers over the offered capacity in one hour, and the utilization coefficient which is the ratio of utilized work (Pax-Km) over the performed work (Vehicle-Km.). Here route E01 presents an average load factor over the period of 66% and of 79% during its peak hour and the utilization coefficient averages 0.37 on the period and marks 0.44 at the peak hour. These are fairly reasonable figures and benchmarks route E01 as the second more utilized after E05.

Assuming a maximum load factor of 85% only two routes operate at capacity and two more close to capacity during their peak hours; the rest of them have excess capacity that ranges from 21% to 65%. The local routes E02 and E05 are the busiest during their peaks with 87% and 85% followed by routes E01 and E26. However, in the case of this last one the average load factor during the peak is the lowest of the four at 68%. Of the reminder of the routes, the express E06 is among the four routes with lowest load factors. This is because it offers excess capacity by providing two services by the hour when it could be operated with only one and have similar indexes to those of route E04. Another example of low load factors is route E25 where the total demand is less than in route E01 but it operates with double of frequencies. This last case is somewhat special since this route operates half of its frequencies over a by-pass that is not as productive as the main route.

In terms of its utilization factors, almost all the express routes have coefficients below 0.3 and among local routes only E09 is below this mark. This route provides the same capacity as route E05; however, its demand is similar to route E01 meaning that it could be

Figure 4.6: Load by stop of route E01 at the A.M. and P.M. peak hours

(a) Inbound



(b) Outbound

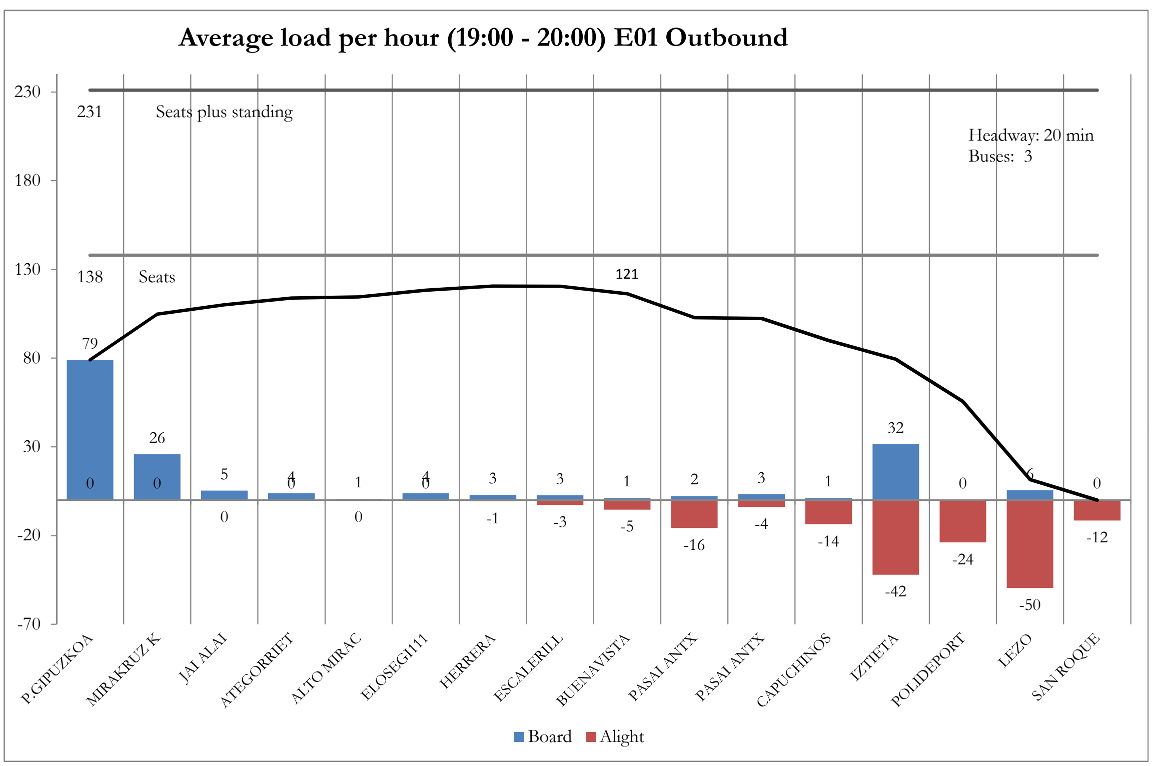


Table 4.6: Utilization indexes of all routes at the A.M. peak inbound

	Routes by County	**Frequency (Serv./h)**	**Offered capacity (Sp./hr.)**	**Avg. Passengers (Pax./hr.)**	**Passengers at Max. Load hour (Pax/hr.)**	**Avg. Load Factor (Pax/Sp.)**	**Max. Load Factor (Pax/Sp.)**	**Avg. Work Utilization Coeff. (Pax-Km/Sp.-Km)**	**Max. Work Utilization Coeff. (Pax-Km/Sp.-Km)**
Oarsoaldea - San Sebastian									
E02	OIARTZUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3	231	187	201	81%	87%	0.38	0.41
E05	BERAUN-PASAIA-DONOSTIA (N I)	4	308	216	263	70%	85%	0.41	0.50
E01	DONIBANE-LEZO-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3	231	152	182	66%	79%	0.37	0.44
E09	SAN PEDRO-DONOSTIA (N I)	4	308	170	191	55%	62%	0.29	0.29
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES (AP-8)	2	154	40	51	26%	33%	0.12	0.15
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	1	77	44	59	57%	76%	0.13	0.20
E03	DONIBANE-ERRENTERIA-POLICLNICA (AP-8)	1	77	27	29	35%	37%	0.20	0.24
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	1	77	17	21	22%	28%	0.11	0.13
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	1	77	12	13	15%	16%	0.10	0.11
Bidasoaldea									
E25	HONDARRIBIA-IRUN	5	385	54	77	25%	27%	0.12	0.12
E22	HONDARRIBIA-C.C. TXINGUDI	1	77	14	27	28%	36%	0.08	0.14
Bidasoaldea - San Sebastian									
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	1	77	53	62	68%	81%	0.28	0.29
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	1	77	39	54	50%	70%	0.17	0.24
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	1	77	29	32	38%	41%	0.30	0.33
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	1	77	19	24	25%	32%	0.11	0.14
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	1	77	17	30	22%	39%	0.09	0.16

operated with only 3 frequencies per hour and achieve a better utilization of the resources. On the other hand, it should be noted that in terms of used resources, the E09 is the most productive as it only requires 3 buses to operate its four frequencies.

Demand Analysis by Route

Following the analysis made on 4.3.3 a subset of routes was selected to be analyzed in more depth and identify areas where they could potentially be improved. In the case of Oarsoaldea all the routes with utilization indexes of 0.20 or below (Table 4.6) were selected; as for Bidasoaldea all the routes are submitted to the analysis described in the following paragraphs. In this analysis routes are individually evaluated in terms of demand and level of service that they provide.

The origin and destination matrices of each route were analyzed at two different periods, the peak and all day. For each route the three to four most demanded stops were selected to understand how the main attractors and generators of trips are distributed along the route. The demand on these stops was then computed as the proportion of the total demand during the analyses period to have a sense of the importance of the flows at these OD pairs. This analysis was then compared to the load profile of each route to have a visual confirmation on how the demand distributes along the route and makes additional considerations on the maximum load segment. The analysis presented in the following pages show the most relevant aspects of the demand on each route. When suited, tables are presented with different scopes of time and scale.

Route E03

The destinations of Iztieta, Anoeta, and Hospital attract more than 65% of the passengers during the peak. Likewise, the two main origins of the route, the stops of Lezo and Iztieta, are responsible for more than 40% of the demand, this is 35 of the 81 trips done during the peak period. The end to end travel time on the inbound direction is of 31 minutes and it provides one service per hour.

Table 4.7: Inbound demand distribution in route E03 during the A.M. Peak (07:00 - 09:59)

	A. M. Peak	*6 IZTIETA*	*8 ANOETA*	*10 HOSPITAL*	Totals	**Percentage of Total Demand**
	Totals	10	20	24	53	66%
1	*SAN ROQUE*		*1*		1	1%
2	*FRONTON*	*2*	*2*	*1*	6	7%
3	*MEIPI*	*2*	*2*	*1*	5	6%
4	*LEZO*	*4*	*6*	*7*	17	21%
5	*POLIDEPORT*		*1*		1	1%
6	*IZTIETA*		*5*	*13*	18	22%
7	*CAPUCHINOS*		*3*	*1*	4	5%
	TOTAL DEMAND				**81**	

Route E04

On table presented for route E04 the destinations for every stop were grouped by county as a way to differentiate the local trips with the ones that use the expressway. It was found that during the peak period 79% of the demand access the city using the express way and the remainder 21% use the route to make local trips. For the whole day, these proportions change to 54% and 48% respectively. Moreover, in both cases, more than 60% of the trips entering the city come from the area of Errenteria and not from Oiartuzun. The peak period moves a third of the route's total demand. This route has a frequency of one service per hour and a travel time from Iglesia to Errotaburu of 35 minutes and 48 on the way back.

Table 4.8: Inbound demand distribution in route E04 during the A.M. Peak (07:00 - 09:59)

	A. M. Peak	*Donostialdea*	**Percentage of Total Demand**	*Oarsoaldea*	**Percentage of Total Demand**	**Totals**
	Totals	72	79%	19	21%	91
1	*IGLESIA*	*4*	*4%*	*3*	*3%*	7
2	*BELUTENE*	*3*	*3%*	*3*	*3%*	5
3	ALTZIBAR	*4*	*4%*	*3*	*3%*	7
4	*PEENE*	*2*	*3%*	*1*	*1%*	3
5	*ITURRIOTZ*	*1*	*1%*	*2*	*2%*	3
7	*UGALDETXO*	*3*	*3%*	*2*	*2%*	5
8	ARISTEGI	*2*	*2%*	*1*	*1%*	3
9	*MAMUT*	*0*	*0%*		*0%*	1
10	*ARRAGUA*	*4*	*5%*	*4*	*4%*	8
11	*GABIERROTA*	*5*	*6%*		*0%*	5
12	*ALAMEDA E.*	*7*	*7%*		*0%*	7
13	IZTIETA	*28*	*31%*		*0%*	28
14	*CAPUCHINOS*	*9*	*10%*		*0%*	9

Route E06

In the case of route E06 the destinations of St. Barbara, Garbera, and again, Anoeta and Hospital attract more than 70% of the passengers during the peak period and when adding the total demand of the day. For these same periods the stop of Iztieta is the main origin of the route generating more than a third of the routes total demand while St. Barbara and Nerecan stops, that are right beside each other, produce more than 15% of the demand. The peak period moves almost a third of the total demand of the day. The total travel time of this route is 35 minutes departing from the stop of Altamira to the stop of Hospital. There are two services per hour. With a few exceptions, stops served in the area of Altza between stops Darieta and Garbera- are not very demanded even during the peak period.

Table 4.9: Inbound demand distribution in route E06 during the A.M. Peak (07:00 - 09:59)

	A. M. Peak	*8 ST BARBARA*	*13 GARBERA*	*14 ANOETA*	*16 HOSPITAL*	Totals	**Percentage of Total Demand**
	Totals	7	21	28	35	97	80%
1	*ALTAMIRA*			*1*	*2*	3	3%
2	*IZTIETA*	*5*	*11*	*5*	*22*	42	35%
3	*CAPUCHINOS*		*2*	*1*	*1*	4	3%
4	*PASAI ANTX*	*2*	*2*	*1*	*3*	8	7%
5	*BUENAVISTA*		*1*			1	1%
6	*DARIETA*			*1*		2	1%
7	*OLETA*			*1*	*1*	2	2%
8	*ST BARBARA*		*3*	*9*	*3*	16	13%
9	*NERECAN*		*1*	*6*	*3*	10	8%
10	*S. MARCIAL*				*1*	2	1%
11	*MARTILUM*			*1*	*1*	2	2%
12	*BIANKA*			*1*	*2*	4	3%
13	*GARBERA*						0%
14	*ANOETA*				*1*	1	1%
	TOTAL DEMAND					**121**	

Route E07

This is the least performing route in Oarsoaldea, as its revenue to cost index is of 0.16 and all the other performance indicators showed so far, are among the lowest of San Sebastián East. The total inbound demand during the whole day is 105 passengers -this is the equivalent to two buses with a load factor of less than 70%. Almost all the customers in this route board before Escalerill and more than 70% of them have as final destination the stops of Anoeta, Hospital, and Poliklinika. The service provided on the reminder of the stops is

Table 4.10: Inbound demand distribution in route E07 during the A.M. Peak (07:00 - 09:59)

	A. M. Peak	*14 ANOETA*	*16 HOSPITAL*	*19 POLIKLINIK*	Totals	**Percentage of Total Demand**
	Total	7	15	7	30	85%
1	*SAN PEDRO*	*2*	*2*		4	11%
2	*PESCADERIA*				0	1%
3	*GUDARI E.*	*2*	*2*	*1*	6	16%
4	*TRINTXERPE*	*1*	*2*	*1*	5	13%
5	*EUSKADI ET*	*1*	*5*	*2*	8	22%
6	*BIDEBIETA*				0	0%
7	*ELOSEGI111*				0	0%
8	*HERRERA*				0	0%
9	*ESCALERILL*			*1*	1	2%
10	*BUENAVISTA*				0	1%
11	*PASAI ANTX*		*1*		2	5%
12	*PASAI ANTX*		*1*	*1*	2	6%
13	*CAPUCHINOS*	*1*	*1*		1	4%
	TOTAL DEMAND				**36**	

redundant with that of routes routes E03 and E06. The end to end travel time of this route is of 35 minutes.

Route E08

Table 4.11: Outbound demand distribution in route E08 for all day

	All Day	*8 AZKUENE*	*9 MERCADILLO*	*10 GUDARI E.*	Totals	**Percentage of Total Demand**
	Totals	49	20	15	84	77%
1	*OKENDO*	*12*	*6*	*3*	21	19%
2	*C/ URBIETA*	*12*	*7*	*2*	21	20%
3	*PZA CENTEN*	*4*	*1*	*1*	5	5%
4	*SANCHO 26*	*10*	*2*	*3*	15	14%
5	*ANOETA*	*5*	*2*	*2*	9	8%
6	*ARCCO*	*3*	*1*	*2*	6	5%
7	BARCELO 28	*4*	*1*	*1*	6	6%
8	AZKUENE			*0*	0	0%
	TOTAL DEMAND				**109**	

The table above shows the demand of routes E08 for a complete day on the outbound direction. It was noted that in this direction the route does not cover the same path as on the inbound; the first part of the path returns to San Pedro using the express way and once there it uses the main road and not the original path to return to the final stop. In terms of demand, half of it comes from the area near the city center while the other half is gathered from the stop of Sancho in Amara and onward. The route has one service per hour and travel time on this direction is 26 minutes.

Route E20

The table for route E20 shows the grouped demand by county for a complete day on the inbound direction; the data is presented in both net figures and percentage of the total demand. It can be seen that this route is used by 65% of the customers to make commutes inside the county of Oarsoaldea or from Oarsoaldea to Donostialdea, 19% percent uses it move from Bidasoaldea to Oarsoaldea and only 8% of the demand uses it as a way to arrive to San Sebastián from Bidasoaldea.[5]. The route provides one service by the hour and has end to end travel time of 60 minutes.

Table 4.12: Inbound demand distribution in route E20 for all day

All Day	*Bidasoaldea*	*Oarsoaldea*	*Donostialdea*	Totals
Totals	42	185	284	511
Bidasoaldea	*42*	*99*	*40*	181
Oarsoaldea		*86*	*243*	330
Totals	8%	36%	56%	100%
Bidasoaldea	*8%*	*19%*	*8%*	35%
Oarsoaldea		*17%*	*48%*	65%

Route E21

Table 4.13: Inbound demand distribution in route E21 for all day

	A. M. Peak	*4 RIBERAS*	*5 MCRISTINA*	*6 P.GIPUZKOA*	Totals	**Percentage of Total Demand**
	Totals	13	25	49	87	99%
1	*AMA*	*11*	*20*	*36*	67	76%
2	*S. ARANA*	*1*	*4*	*8*	13	15%
3	*AMUTE*	*1*	*1*	*5*	7	8%
	TOTAL DEMAND				**88**	

This route connects the city to the airport located between Hondarribia and Irún. However, the table above shows that customers use this route as a direct link from Hondarribia to different areas inside the province's capital. 76% of the demand comes from Ama, the

[5]In all the cases, the limit between Oarsoaldea and Donostialdea was defined between the stops of Herrera and Gaiztarro-Elosegui 111

stop closest to Hondarribia's center, and the main destination inside San Sebastián is Plaza Gipuzkoa. Moreover, 42% of the inbound demand is concentrated in the peak period. There is one service per hour and the end to end travel time is of 35 minutes.

Route E22

Table 4.14: Inbound demand distribution in route E22 for all day

	All Day	*9 COLON 43*	*13 BENTAS*	*15 TXINGUDI*	Totals	**Percentage of Total Demand**
	Totals	24	21	133	178	71%
1	*LA MUELA*		*1*	*1*	2	1%
2	*ZULOAGA*	*6*	*1*	*1*	9	4%
3	*CORREOS*	*9*	*4*	*4*	17	7%
4	*S. ARANA*	*6*	*4*	*1*	10	4%
5	*AMUTE*	*1*	*1*	*1*	3	1%
6	*MENDELU*	*1*		*1*	2	1%
7	*CRUZ ROJA*	*1*	*1*	*8*	10	4%
8	*ZUBIAURRE*			*6*	6	2%
9	*COLON 43*		*2*	*30*	32	13%
10	*A.GIPUZKOA*		*4*	*58*	62	25%
11	*LA SALLE*		*2*	*11*	13	5%
12	*BUENOSAIRE*			*2*	2	1%
13	*BENTAS*			*8*	8	3%
14	*ARAKISTAIN*			*1*	1	0%
	TOTAL DEMAND				**252**	

About half of E22's demand has as final destination the commercial center at Txingudi but only 3% of the total demand comes from Hondarribia. This means that this route is mostly used for urban services between Irún's downtown and the mall. In fact, when evaluating the complete OD matrix, 140 of the route's 250 trips are made within this city. Services between Irun and Hondarribia are also supplied by route E25 which has 6 frequencies per hour as opposed to E22's one service per hour. The end to end travel time of this route is 30 minutes.

Route E23

There are 78 customers that use this line on the inbound direction in one day. Fifty-four of these passengers have as final destination the University on the west side of the city, and a similar amount distribute evenly in the surrounding stops. The rest of the demand use the route for small local trips. This route has a headway of 60 minutes and an end to end travel time of 30 on the way in and 40 on the way out.

Table 4.15: Inbound demand distribution in route E23 for all day

	All Day	*7 ERROTAB*	*8 UNIV.*	*10 ZUMALK*	*11 S MARTIN*	Totals	**Percentage of Total Demand**
	Totals	9	27	9	10	54	69%
1	*AMA*	*3*	*16*	*6*	*7*	33	42%
2	*S. ARANA*	*3*	*5*	*1*	*2*	11	15%
3	*AMUTE*		*1*			2	2%
4	*GIBENAKA*	*1*	*3*	*1*		6	7%
5	*PUIANA*		*1*			2	2%
	TOTAL DEMAND					**78**	

Route E24

Similarly to route E23, route E24 is an express route which in this case links the city of Irún with the east side of San Sebastián. The total daily inbound demand is of 92 customers of which 66% distribute almost evenly between the stops of Universidad y Zumalaka. The route has one service per hour and an estimated travel time of 30 minutes on the inbound direction and 40 on the outbound.

Table 4.16: Inbound demand distribution in route E24 for all day

	All Day	9 UNIVERSIDA	11 ZUMALAKA	Totals	**Percentage of Total Demand**
	Totals	37	24	61	66%
1	A.GIPUZKOA	*18*	*15*	33	36%
2	COLON 42	*1*		1	1%
3	ADUANA	*11*	*5*	16	17%
4	LA SALLE	*2*	*2*	5	5%
5	BUENOSAIRE			1	1%
6	BENTAS	*3*	*1*	4	4%
	TOTAL DEMAND			**92**	

Route E26

Route E26 is, in a similar situation as route E20, mostly used to commute between Oarsoaldea and between Oarsoaldea and Donostialdea (61% of the trips). An equal number of passengers (18%) commute from the city of Irún to either Donostialdea or Oarsoaldea. The service has a frequency of one service per hour and an end to end travel time of 55 minutes

Table 4.17: Inbound demand distribution in route E26 for all day

All Day	*Bidasoaldea*	*Oarsoaldea*	*Donostialdea*	Totals
Totals	19	185	357	561
Bidasoaldea	*19*	*99*	*99*	216
Oarsoaldea		*87*	*258*	345
Totals	3%	33%	64%	100%
Bidasoaldea	*3%*	*18%*	*18%*	39%
Oarsoaldea		*15%*	*46%*	61%

on the inbound direction.

Diagnostic

After this analysis, the stop of Iztieta was identified as the busiest of Oarsoaldea. Additionally, the stops that correspond to the Hospital Area of San Sebastián and to the Neighborhood of Altza were also noted by its higher demand. However, there is service redundancy at some of the routes, for example, routes E06 and E07 that share stops connecting at Pasai Antxo and Hospital. This last service is the longest and least productive in Oarsoaldea. There are also parallel services between routes E03 and E06 that share stops at the area of Iztieta-Lezo and Hospitales. In spite of this and providing an express service, route E03 carries half the demand than route E06 on the shared segments. This can be observed when comparing the correspondent origin and destination pairs from Tables 4.7 and 4.9. Furthermore, these services are not coordinated at Iztieta providing and uneven level of service at the common stops. Route E06 departs from Altamira every 30 minutes, on the hour and past half the hour, serving passengers at Iztieta four minutes later while route E03 departs five minutes past the hour from San Roque passing by Iztieta eight minutes after; only with nine minutes difference with route E06.

In some cases services seem to be tailored to specific sectors of the population while in others there are some discrepancies between the service provided and the way customers use it. In both cases these situations generate sub-utilization of the capacity provided. This is mostly seen on two types of services: the express liking San Sebastián East with the west side of the city (E04, E23, and E24), and the services connecting Bidasoaldea with Donostialdea (E20 and E26). On the first ones efforts are made to communicate the farthest towns with the western side of the city but this is only efficient for a few hours during the day on the peak period; the rest of the day the route serves mostly the same population that head back at different hours of the day. On the second type of service most of the capacity provided is being used in the same way as services that already exist in the area.

The demand from Hondarribia to Donostialdea is very low and the options are too many, which is not appropriate for the system, as it would be better to offer more consistent regular service to the city.

4.4 Economic Performance

The main economic criteria used to compare the routes is the revenue to cost ratio as it provides information on the share of the cost that is being covered by the customers, and therefore is a measure of the economic productivity of the system. For the purpose of this evaluation it is assumed that none of the customers obtain frequent users discounts. Therefore, the users of Billete Único (86%) pay a tariff of € 0.74 for trips within the same county and € 1.07 for trips between two counties while the reminder 14% of cash users are charged € 1.40 and € 1.95 respectively. The cost per kilometer used is of € 2.4384 as stipulated on the 2011 contract. Moreover, the proportions of the demand that pay either the ratio for one zone or two zones in routes connecting Bidasoaldea with Oarsoaldea and San Sebastián, was also considered. It was estimated from the OD matrices that in the case of the local routes E20 and E36, 30% of the demand travel for more than one zone, while for the express routes E21, E23, and E24 90% of the demand does such trips. The number of resources needed to operate the different scenarios is also considered although in the frame of this contractual agreement it does increment the cost of the service.

Table 4.18 shows that in general the revenue to cost ratio in Oarsoaldea is 0.84 although this is mainly due to the four best performing routes in the area; all of them are profitable under the fare assumptions made. The routes in Bidasoaldea come second and again, the worst performing routes coincide with the express ones. This is inherent to express routes when using a cost model such as Lurraldebus. In express routes the number of kilometers is consumed faster than service is provided; i.e. the number of kilometers per unit of time grows faster than the number of new customers on the route.

In the county of Oarsoaldea, route E06 comes after the profitable routes -although very far back- followed by with routes E08, E04, E03, and E07. The ratios of the two services inside Bidasoaldea have similar values with only a 0.13 difference. Such a small difference is striking given that route E25 has almost 6 times the demand of E22 and they are not very different in length. The services that connect Bidasoaldea with San Sebastián have joint revenue to cost ratio of 0.38. There are only two of these routes that are pulling up this ratio, route E26 and route E20.

Table 4.18: Economic Performance of the routes in San Sebastián East

	Routes by County	Demand per Weekday (Pax)	Revenue per route (€)	Length (m)	Scheduled Km. per Weekday	Cost Per Route (€)	Revenue to Cost Ratio
Oarsoaldea	***- San Sebastian***	***15,837***	***13,183***	***23,718***	***6,447***	***15,720***	***0.84***
E02	OIARTZUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3,932	3,273	25,828	1,266	3,086	1.06
E05	BERAUN-PASAIA-DONOSTIA (N I)	3,485	2,901	18,241	1,122	2,735	1.06
E01	DONIBANE-LEZO-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3,395	2,826	20,650	1,001	2,442	1.16
E09	SAN PEDRO-DONOSTIA (N I)	2,887	2,403	10,301	700	1,708	1.41
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES (AP-8)	776	646	26,703	687	1,676	0.39
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	514	428	37,173	520	1,269	0.34
E03	DONIBANE-ERRENTERIA-POLICLNICA (AP-8)	364	303	29,046	436	1,062	0.29
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	269	224	15,644	266	650	0.34
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	216	179	29,876	448	1,093	0.16
Bidasoaldea		***3,383***	***2,816***	***16,022***	***1,605***	***3,912***	***0.72***
E25	HONDARRIBIA-IRUN	2,898	2,412	13,393	1,334	3,253	0.74
E22	HONDARRIBIA-C.C. TXINGUDI	486	404	18,650	270	659	0.61
Bidasoaldea	***- San Sebastian***	***2,877***	***2,870***	***44,549***	***3,366***	***8,208***	***0.35***
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	1,133	1,066	35,801	593	1,445	0.74
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	986	928	44,224	730	1,780	0.52
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	409	473	45,651	685	1,670	0.28
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	179	207	46,404	650	1,584	0.13
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	170	197	50,667	709	1,730	0.11
	Total	***22,097***	***18,869***		***11,418***	***27,840***	***0.68***

Chapter 5

Proposed Changes to the Route Structure

This chapter proposes structural changes to the network with the aim of improving not only the overall performance indicators but also the economic productivity of the routes. The changes proposed build scenarios that make more emphasis on the routes that proved to have low levels of utilization or used capacity on Chapter 4. These scenarios constrained by the legal framework exposed on Chapter 3, look to improve the level of service offered, to obtain the benefits behind the integration of the routes, and to acknowledge and enhance those routes with good performance ratios.

The chapter is divided into three sections, the first one describes the methodology used to produce origin and destination matrices of complete trips by including transfers within Lurraldebus and with the urban system of Donostiabus. This matrix is used to identify the underlying flows in San Sebastián East and come out with ways in which they could be better served. A second section presents the assumptions made in the development of the scenarios, and the economic and level of service criteria used to evaluate them. The last section proposes different routes structures where the supplied capacity is synthesized or reduced without impacting the level of service but at the same time suggesting a more reasonable use of resources when considered appropriate.

5.1 Origin and Destination Matrix of San Sebastián East

The origin and destination matrix computed on section 4.3.2 is used as starting point for constructing the underlying OD matrix for the whole sector. The process is divided into two phases, the first one transforms the current matrix at the stop level into a more aggregated OD matrix. On the second phase, some assumptions are made to identify the trips that incurred in a transfer, either within Lurraldebus or to Donostiabus, so as to be included in the aggregated OD Matrix.

In the first phase of this process, the sector of San Sebastián East is divided into 26 different sub-areas using as main criteria the structure of Lurraldebus' network and the knowledge acquired during the analysis made on Chapter 4. The areas were selected by grouping stops along the different spurs on the network that had similar levels of demand. In some cases, like the stops of Garbera, the shopping center at Txingudi, and the Airport, a single stop is treated as an sub-area with the purpose of isolating its demand and assess its importance. Following this process, the county of Donostialdea was divided in eight different sub-areas, Oarsoaldea in twelve, and Bidasoaldea in six (a detailed table of this division can be seen on Appendix C). Each stop in the sector is assigned to one of these sub-areas, and its total demand per hour was added along with the demand of other stops in the same sub-area. The result of this process is a 26 by 26 OD matrix of unlinked trips for every hour of the day.

Transfers made within Lurraldebus and with Donostiabus were found by using the tap-in&tap-out information from "Billete Único" to link subsequent trips of the same card number and by defining a reasonable time threshold to allow for such transfers. In the case of transfers within Lurraldebus, this process enabled to find the final destination of each linked trip. In the case of transfers to Donostiabus only the transfer location and the route used to reach the final destination is known, therefore it was necessary to make some approximate assumptions to estimate the sub-area of the final destination. A similar approach was used by Gómez Gélvez, J. A. (2010) with the purpose of differentiate the demand of the two systems Lurraldebus and Donostiabus.

To find the transfers in the system, transactions for the same card numbers were linked according to subsequent tap-out and tap-in in different routes. Although it is possible to restrict these two transactions to the same location, this is not done for the sake of identifying transfers that involve different stops as tap-out and tap-in may occur in different places within the same journey. The time difference between the linked transactions is used as the real limiting factor to determine whether a linked trip is a transfer or not. These transfer durations were computed and plotted to see their distribution and select a reasonable threshold to identify transfers of the same journey. Figure 5.1 shows two different distributions of transfer times for the month of May 2011; the transfers within Lurraldebus are shown in blue and the transfers to Donostiabus in red. It can be seen that most of the transfers are made within 30 minutes after a tap-out. The different shapes of the curves can be explained by the differences in operating frequencies and network structure of each system; Donostiabus has headways of between 5 to 20 min and its average stop spacing is more urban-like while Lurraldebus' most frequent route has a 15 minutes headway and the stop spacing varies greatly across the different areas. In both cases a threshold of 30 minutes was set as the transfer threshold.

These computations showed that the number of daily transfers in the system is very low, In fact, the number of daily inbound transfers with Donostiabus, and the transfers within the Lurraldebus system are less than 200. In the case of transfers to Donostiabus, only the inbound trips are taken into account because identifying linked journeys will require further assumptions and more complex computations that are outside the scope of this thesis. Moreover, the volumes of the identified transfers are not significant enough to change radically the underlying structure of the OD matrix computed earlier.

The origin, transfer, and final destination locations of all the trips matching these criteria were associated to their corresponding sub-area described at the beginning of this section and the trips in the original OD matrix were re-distributed to allocate the linked trips. In the case of the linked trips within Lurraldebus, its demand was subtracted from the origin and transfer areas and added to the origin and final destination areas of the original OD matrix. With this approach, the trips with transfers were removed from the transfer locations and then added to the final destination. To allocate the linked trips with

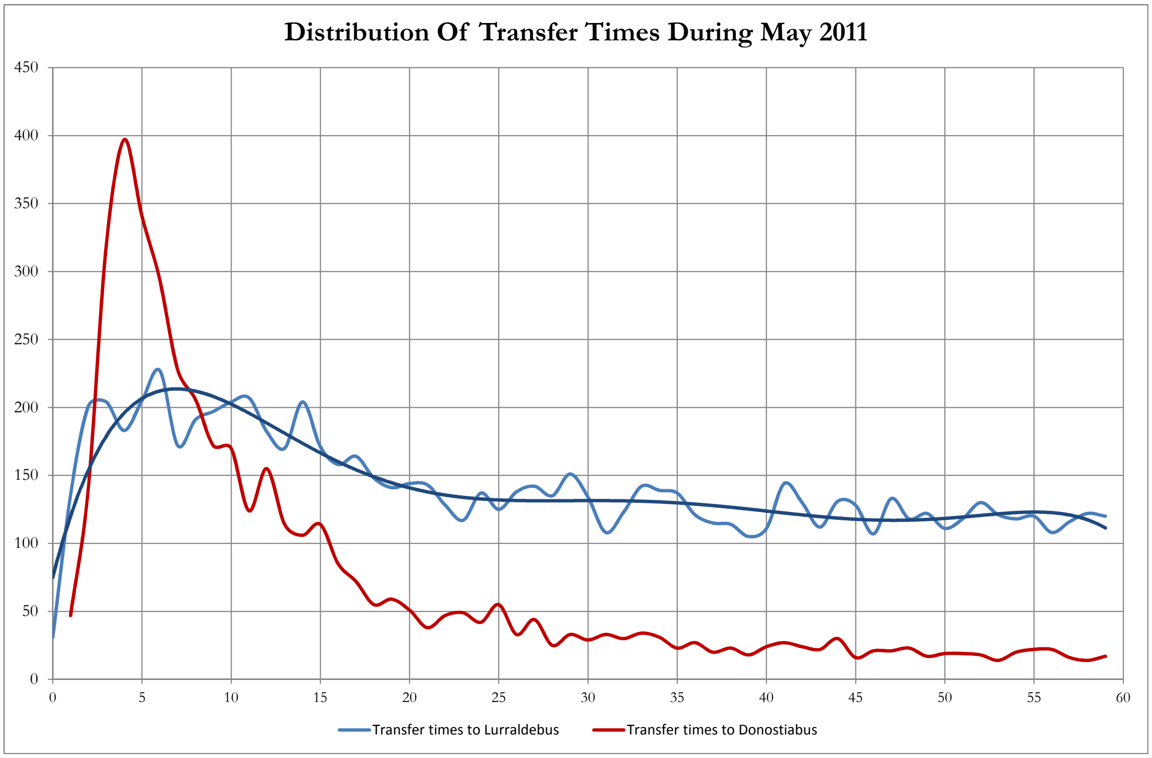


Figure 5.1: Distribution Of Transfer Times During May 2011

transfers to Donostiabus, the final destination was approximated by using the transfer route as a proxy for their direction. In this case, it was assumed that the demand distributes evenly along the route on the first and second sub-area after the transfer location, which in all cases covered the total length of the route.

5.2 Assumptions and Indicators Used in the Analysis

The scenarios are evaluated using the level of service and economic indicators . For the level of service side, the implications of changes to frequencies and additional travel time are discussed, and its impact on the demand is also considered. On the economic, side three parameters were computed: the net savings, the revenue to cost ratio, and the social cost due increments of travel time and waiting time. The intention of these indicators is to compare different aspects of the routes and the of service supply to evaluate and size the proposed changes.

For the purpose of comparing the level of service, the elements considered are the change in travel times and the change in frequency. For the original routes the travel times are considered to be equal to the run time estimated on the previous chapter. In the cases where the paths of the routes are modified and there is no information on the travel times in the new segments, the travel times from other routes covering the same path is used as a proxy. In these cases, the 50^{th} percentile for these segments is computed and added to the known times. The use of the run time as a proxy for the in-vehicle time is used in some cases due to changes that involve the elimination of bus service along the expressway. The evaluation of the frequency is discussed at both, the route level and the network level, acknowledging improvements achieved when linking services with a transfer that in most of the cases is recommended to be timed.

Before estimating the economic parameters, we adopted some assumptions needed to bracket changes in demand. The way that the original demand is distributed in the new routes is discussed case by case on each proposed scenario although in general the process follows two stages. First, the demand from the original routes and from the underlying OD matrix is used as the main input to establish the new demand under the specific assumptions made for every case. Second, the demand is adjusted using different elasticities for either changes in the in-vehicle travel time or in the frequency of a specific service. Values for both elasticities were chosen from the literature, using ranges representing similar situations as the ones presented in Gipuzkoa. Except when noted differently, an in-vehicle time elasticity of -0.6 (Litman., 2011) is applied to the fraction of the demand that experiences their travel times modified. Likewise, for changes in the level of services provided, an elasticity of 0.58 reported for variation of service with headway above 50 minutes is used (Richard H. Pratt Consultant Inc. et al., 2000).

A value of time equal to 15 € per hour is used to estimate the social cost induced when travel times are modified independently of the socio-economic level of the user. In the case of computations that require an estimate of the revenue, the assumptions used are the same ones described in section 4.4, where the maximum possible fare is considered when computing the performance indicators.

5.3 Proposed Scenarios and Analysis

The improvements suggested in this section pursue a better economic performance of the routes and a better utilization of the system, while maintaining or improving the level of service currently provided. Thus in the development of the scenarios, the goal is to identify and reduce the excess capacity provided in the form of overlapping or parallel services or excessive number of frequencies. At the same time the goal is to maintain or increase the different zonal accessibility in terms of origin and destinations, and maintain the travel times for the most important services. Given the nature of the cost model -that is linked to the number of scheduled kilometers and not to the level of service provided to users- it is also in the scope of this analysis to identify and reduce the number of scheduled kilometers and thus improve the economic efficiency of the network.

This section is divided into three parts, the first two describe the scenarios proposed for the counties of Oarsoaldea and Bidasoaldea while the third one gathers the results from different scenarios and presents a joint analysis plus the final recommendations.

5.3.1 Changes in the area of Oarsoaldea

Two scenarios are proposed for the county of Oarsoaldea, in both cases the objective is to find a better balance between the high quality service provided in some areas with low density and DFG's commitment to improve mobility throughout the province. As discussed earlier, there are nine routes serving this county. The two scenarios focus on routes E03, E06, E07, and E08. Route E04 is also among the least performing routes in Oarsoaldea but recommendations for modifying it, will be discussed later as part of the scenarios proposed for Bidasoaldea.

Scenario Oarsoaldea 1

Description

This scenario proposes to remove route E06 and modify the alignments of routes E03 and E07 to serve the service that was provided by E06. The route alignment of E07 is extended to form a loop passing by the stops of Altamira and Iztieta and then go back to Buenavista and follow the former alignment of route E06 all the way to Policlinica and back. Route E03 is modified to follow the current alignment of route E06 from Capuchinos to the Policlinica and back. Both routes keep their original frequency of one service per hour alternating their passing through the stop of Iztieta. Route E08 is kept with its original alignment except the final segments of the outbound direction where it is modified to enter San Pedro using the streets of Jaizkibel, Uliako, Francisco Andonaegui, Gran Sol, Daniel del Castelao, leading to the roundabout at Ingeniero Markina. Figure 5.2 shows these changes.

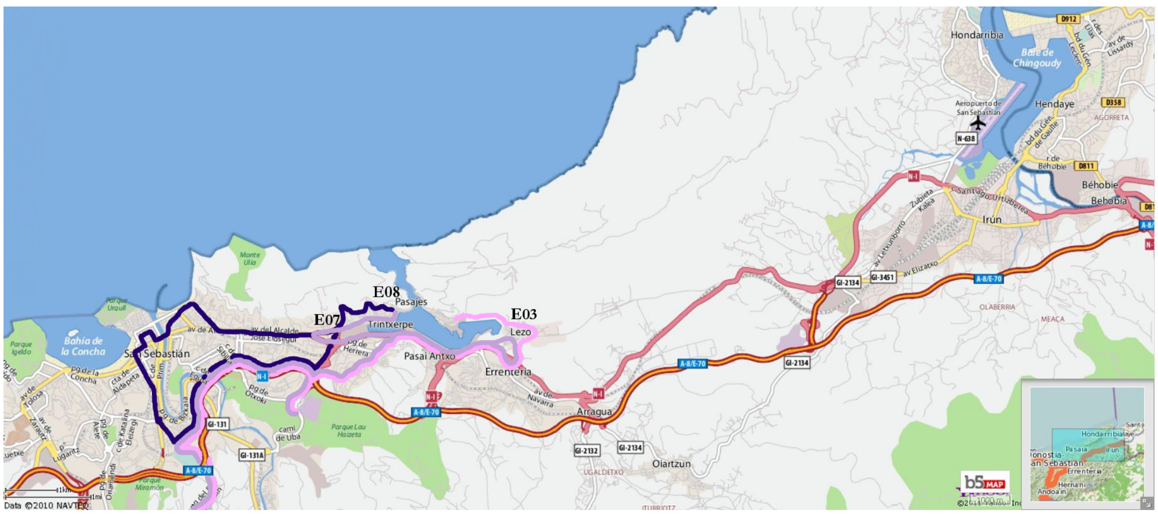


Figure 5.2: Scenario Oarsoaldea 1

Implications

The main objective of this scenario is to maintain the access to all the locations while eliminating the excess capacity offered by redundant services between Hospitals and Errenteria. The original joint frequency of the services between the origin and destination pairs remain almost the same except for the case of one less service per hour between the areas of Errenteria and Hospitals. The frequency variation is not expected to impact the demand as current routes E03 and E06 are very close in time offering a clear example of excess capacity. However, there is a potential loss of 20% (70 pax per day) of E03's original customers due to an increment in travel times due to the elimination of the expressway segment. Route E07 faces the same issue with a loss 40% (80 pax per day) of its original customers. However, the proposed structure offers better frequencies between the new origin and destination pairs, such as the new connections between San Juan and San Pedro to Altza and San Pedro to

Errenteria. These new connections may lead to a modest increment of the demand for both services as on the underlying OD matrix trips between these areas are already being served. Additionally, it is assumed that E06's demand remains constant as there is no variation on the service provided by its users. This demand is distributed evenly between E03 and E07.

The changes proposed lead to a increment of travel times for routes E03 and E07. On the inbound direction, the end to end travel time of route E03 increases from 32 to 45 minutes and on the outbound direction from 30 to 40 minutes. The travel times of E07 are increased from 33 to 55 minutes on the inbound direction and from 31 to 50 on the outbound direction. The extended in-vehicle times generate a decrement of 11% (150 pax.) of the total demand considered in the scenario.

The changes on route E08 improve the service by returning passengers through the same path followed by the route on the inbound direction, using the winding streets cutting through the top of the hills. As seen during the analysis of this route, the main outbound destination is the street of Azkuene; right at the bottom of the hills in the main access to the residential area. Other than this, there are no significant changes to route E08, however an increase on the demand derived from a more convenient service might be expected.

The overall revenue to cost ratio of these changes increases from 0.30 to 0.35 and the economic performance of E03 and E07 improve significantly. These new ratios imply daily net economic savings of more than 900 €; this is equivalent to 234,000 € per year. However, the social costs induced by the increment in travel times exceed the economic savings by 700 € per day. Table 5.1 summarizes these results by scenario and for each route.

Scenario Oarsoaldea 2

Description

This scenario proposes to reduce the frequency of route E06 by half, and modify the alignment of E03, E07, and E08. Route E03 is modified to follow E06s path from Capuchinos to Policlinica and back. The alignment of E07 is modified completely to take advantage of a faster and more direct connection to the area of Amara and the Hospitals at the south of the

Table 5.1: Economic Performances of the Scenarios 1 and 2 in Oarsoaldea

	Routes by Scenario	Demand per Weekday (Pax)	Revenue per route (€)	Length (m)	Scheduled Km. per Weekday	Cost Per Route (€)	Revenue to Cost Ratio	Monetary Savings (€)	Social Cost (€)
	Original Routes	***1,625***	***1,352***		***1,837***	***4,480***	***0.30***	***0***	***0***
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES	776	646	26,703	687	1,676	0.39	0	0
E03	DONIBANE-ERRENTERIA-POLICLNICA (AP-8)	364	303	29,046	436	1,062	0.29	0	0
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	216	179	29,876	448	1093	0.16	0	0
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	269	224	15,644	266	650	0.34	0	0
	Scenario Oarsoaldea 1	***1,470***	***1,224***		***1,416***	***3,453***	***0.35***	***899***	***1,639***
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES	0	0	26,703	0	0	0.00	1030	0
E03	DONIBANE - ALTZA - HOSPITALES	680	566	34,334	515	1256	0.45	70	774
E07	SAN PEDRO - ALTZA - HOSPITALES	521	433	42,309	635	1547	0.28	-201	864
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	269	224	15,644	266	650	0.34	0	0
	Scenario Oarsoaldea 2	***1,561***	***1,299***		***1,359***	***3,313***	***0.39***	***1,114***	***691***
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES	388	323	26,703	344	838	0.39	515	0
E03	DONIBANE-ALTZA-POLICLNICA	680	566	34,334	515	1256	0.45	70	774
E07	SAN PEDRO-PIO XII-POLICLNICA	224	186	19,175	288	701	0.27	398	-83
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	269	224	12,500	213	518	0.43	131	0

city. This service will use the expressway A-8 using the access before the stop of Bidebieta and approach the roundabout of Pio XII using the first exit into the city, with the return leg along the same alignment. This new connection to Amara allows to modify the outbound path of route E08 aligning it to its inbound path. As in the Scenario Oarsoaldea 1, the end of the E08 outbound path is modified to provide a more convenient service into the hills of San Pedro as shown in Figure 5.3.

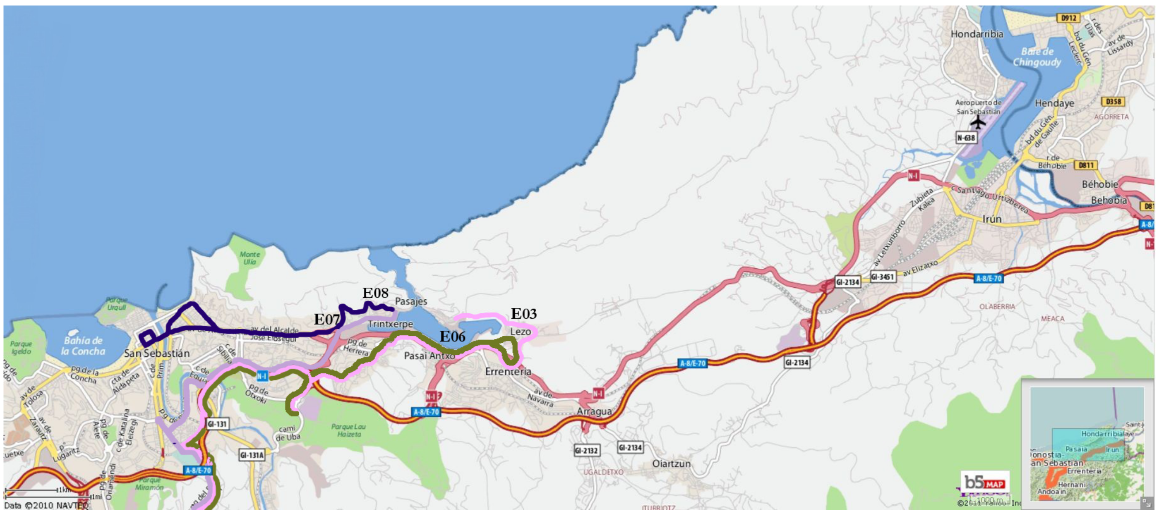


Figure 5.3: Scenario Oarsoaldea 2

Implications

This scenario proposes more substantial and more effective changes than the previous proposal for Scenario Oarsoaldea 1. The modification of route E07 allows a more comprehensive access to the city by extending its alignment through the area of Amara before reaching the Hospitals area while providing a faster alternative to reach the area of Amara at Pio XII without the need to make transfers -currently 10% of the transfers to Donostiabus come from San Pedro as they head to the Amara area. This is done with a modest economy of travel times between San Pedro and the area of Hospitales which leads to a small increase of the current ridership. Furthermore, Pio XII provides a wealth of free transfer options within the urban system that link virtually all corners of the city. The convenience of this transfer may in fact further attract riders heading to the University and to Antiguo given that the customer is provided with more commuting options. The change of this route means that a direct connection between San Pedro and Pasai Antxo will be lost. However, there are only 14 passengers doing this trip every day which could use instead the multiple services offered along that segment of the N-1. The new E07 also offers the opportunity to improve the utilization of E08 by changing its outbound path to be aligned with the inbound one. As seen on section 4.3.3, the stop of Sancho is the third with the largest demand of route E08 but it will be served by E07 providing the exact same service it offers today.

In the same way as in scenario 1, the changes to route E03 generate a potential loss of 20% of the route's customers but it interconnects the areas of San Juan with Lezo and Altza including the shopping center at Garbera. The travel time for route E03 is increased from 32 to 45 minutes on the inbound direction and from 30 to 40 minutes on the outbound, while the frequencies between Errenteria and Hospitals are adjusted to provide a more reasonable capacity. This route is to be synchronized with E06 at Altamira requiring one additional bus or the use of interlining with other routes.

The results of this scenario are more promising than the ones achieved with scenario 1, with an economic surplus when comparing the economic benefits to the social costs. The overall revenue to cost ratio of the area goes up from 0.30 to 0.39 and the individual performance of the routes is maintained or increased. The net economic savings are estimated to exceed 1,100 € per day or 286,000 € annually. The social costs generated by these changes are less than 700 € per day or 182,000 € annually making this a viable solution. While the last scenario reduces the total demand considered in the scenario by 10%, this one has an impact of only 3% (or 54 pax.) of the total demand. However, the improved connectivity with the south of San Sebastián and the higher convenience of the service provided by E08 will compensate this loss by increasing the overall ridership. Table 5.1 summarizes these results by scenario and for each route.

5.3.2 Changes in the area of Bidasoaldea

The changes presented in the case of Bidasoaldea, refer to the routes that interconnect this county with Oarsoaldea and Donostialdea. The intention is to improve the level of service for the customers of these routes and identify efficiencies on the current route structure. For this reason, the demand taken into consideration in the plotting and evaluation of these proposals refer only to the customers using these lines between OD pairs inside or connecting to Bidasoaldea. This was done by using a different base demand including only the customers being affected and computing the performance measures for the current and proposed services to compare them using equivalent figures. This implies that the values presented for the base case are lower than the ones reported in the Table 4.18, as the total costs of every route divided by a lower demand. This allows to assess only the total demand that is being affected.

Opportunities to improve the performance of the routes linking the towns of Irún and Hondarribia were identified after the analysis made on section 4.3.3, however, they are not considered in the scope of this proposals.

Scenario Bidasoaldea 1

Description

The local routes E20 and E26 are curtailed on their inbound end using the roundabout that is located before the stop of Ategorrieta as a turning point. Route E21 is modified at both ends to increase its catchment area: at the Hondaribia end, a loop is create replicating E20's shape, and on the side of San Sebastián, the alignment is changed to pass on its way to and from the city through the roundabout of Pio XII. Additionally its headway is lowered from 60 to 30 minutes. Two modifications are done to route E04: its alignment inside the province's capital is modified by using the boulevards of Paseo de Pio Baroja and Paseo de Izostegui for exiting the city, and the begining of this service from Oarsoaldea is curtailed at the stop of Larzabal to start the service in Errenteria. The frequency of this route is also doubled. Routes E23 and E24 were completely removed. Figure 5.4 presents these changes.

Implications

The scenario proposes changes to routes E20, E21, E23, E24, and E26 focusing on enhancing the services entering and exiting Bidasoaldea while improving service to the town of Hondarribia which does not have access to any of the two rail services in the sector. After analyzing the OD matrix, it was noted that even though Hondarribia has three times less population than Irún, the demand for service of the two towns is very similar. Moreover, in

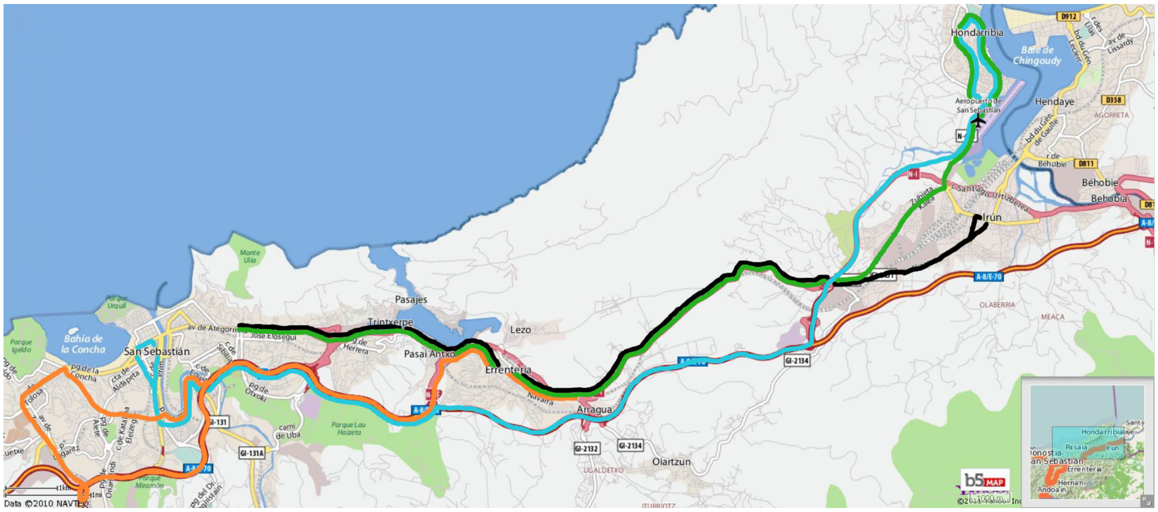


Figure 5.4: Scenario Bidasoaldea 1

the case of Irún, the connectivity provided by the rail services is considerably more frequent than the bus services and in some cases, redundant. Additionally it was taken into account that of all the OD pairs that are being served by these routes, include the ones linking Bidasoaldea with the west side of the city have the least demand. The following paragraphs describe the changes proposed in order to balance the provision of service in the area.

The curtailment of the local routes E20 and E26 are proposed as a way to tailor service for the targeted customers of Bidasoaldea. In the case of E20, this curtailment still serves 91% of the targeted customers, as it can be seen in the load graph for this route, most customers start their trips at the stop of Larzabal heading in the inbound direction to the city center. The demand will not be lost as these customers are already being served by the routes in Oarsoaldea, and by the multiple options that pass through Errenteria heading to the city center. For this change, it is recommended to move this stop to a location before the previous red light, right at the roundabout, to facilitate potential transfers of passengers reaching the end of the line. After the curtailment, route E26 will still provide service to 70% of its Bidasoa clients. Similar conclusions than in the case of route E20 can be drawn, although in this case there is a larger demand that will be affected. However, it is precisely in this area where the alignment of route N-1 and the RENFE service overlap. The frequencies of both E20 and E26 are kept as one per hour. The main results of these changes are presented on Table 5.2 where the revenue to cost ratio of the routes changes from 0.33 to 0.38 in the case of E20 and from 0.42 to 0.49 in the case of E26. These changes on the revenue to cost ration come from a better adjustment of the service to the demand in Bidasoaldea.

The alignment of route E21 is modified to increase its catchment area on its Hondarribia's end and to improve the connectivity with the urban system of Donostiabus on the San Sebastián end, and, the service frequency is doubled. These modifications are done with the idea of providing a higher level of service between the province's capital and Hondarribia and to make up for the lack of rail service by providing a fast and frequent connection between both ends. The passage of the route through the Pio XII roundabout enables convenient transfers to a vast number of Donostiabus routes heading to almost every destination inside the city. Routes 24 and 27 are of particular interest in providing a full range of services to Hondarribia as they both connect Pio XII with the growing CBD at the areas of Antiguo, the university, and Igara. The service of route E21 should be timed with these two routes on its way in and out the city, in this way the service formerly provided by route E23 can be completed once every 30 minutes instead of every hour by performing a free of charge transfer at Pio XII. This allows to take advantage of the capacity already being provided by Donostiabus, rendering a more integrated and sustainable solution for the provision of these services. It is expected that the increment in the number of frequencies will affect positively the ridership, adding 50% new riders to the route. However, the revenue to cost ratio drops from 0.29 to 0.22 mainly because of the additional scheduled kilometers.

Route E04 is curtailed at the stop of Larzabal and the direct link to the city of Oiartzun is suspended to allow for more frequent service between Errenteria and San Sebastián with a headway of 30 minutes while still providing service to most of the users. As it was shown on section 4.3.3, 20% of the customers using this route from Oiartzun are heading to Errenteria and 55% move between this last town and the western side of San Sebastián. This means that 25% of these routes users will have to transfer at Errenteria to go to the western side of the city. However, the area of Oiartzun is also served by E02, one of the most frequent services in Oarsoaldea offering multiple opportunities to transfer to route E04 and reach the final destination. Additionally, this route's new headway will double its services thus customers will have a more convenient connection with the western side of the city. The former users of routes E23 and E24 will also have the possibility to transfer to this line by using routes E20 and E26 to arrive to any of the transferring points on route E04. As discussed on section 4.3.3, the ridership of routes E23 and E24 are the lowest of all the system, moreover its demand is concentrated in the first hours of the day leaving an excess of capacity for most part of the daily operation. At the same time, E04's path inside the city is modified to reduce redundant services at the city center and to have a more direct and fast exit from the city. The revenue to cost ratio of this route has a higher increase by changing from 0.21 to 0.32.

As mentioned at the beginning of this section, a different demand base than the one taken into account to evaluate the complete route, was used to evaluate the solutions presented for Bidasoladea. The new demand is estimated by synthesizing the original demand with three assumptions. First, in the case where an area is no longer served by a route, but its demand can be covered by another one, the affected fraction of the demand is removed from the route but not from the total figures of the network. Second, in the case where customers have better options to reach their final destination, like route E26 on this scenario, the affected demand is assumed to be lost to that option. Third, in the cases where customers are forced to transfer and there is no other option for the commute, a penalty of 10 minutes is considered when applying the elasticities reported on section 5.2 to compute the resulting demand.

In an effort to have dedicated services for each of the main destinations, the current schedule provides three different options with a frequency of one service per hour each from the town of Hondarribia. Instead of providing a good level of service, this situation divides the demand in three and provides a low frequency to each fraction creating a perception of poor service. The joint services proposed in the area of Hondarribia are meant to change this perception by enabling customers to reach multiple destinations through one synchronized transfer or no transfers, and having as result a higher level of accessibility. Instead of one service per hour they would have three. This is reflected by an increment of 14% on Hondarribia's demand for routes E20 and E21. In the case of Irún, the situation is somewhat different. Given that this town is already being served by two rail lines, plus a municipal bus service, it was decided to only provide complementary services covering the

Table 5.2: Economic Performances of the Scenario Bidasoaldea 1

	Routes by Scenario	Demand per Weekday (Pax)	Revenue per route (€)	Length (m)	Scheduled Km. per Weekday	Cost Per Route (€)	Revenue to Cost Ratio	Monetary Savings (€)	Social Cost (€)
	Original Routes	***1,939***	***2,314***		***3,887***	***9,477***	***0.24***	***0***	***0***
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	409	488	45,651	685	1,670	0.29	0	0
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	509	608	35,801	593	1,445	0.42	0	0
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	488	582	44,224	730	1,780	0.33	0	0
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	221	263	37,173	520	1,269	0.21	0	0
E24	IRUN-DONOSTIA CIRCULAR EX-PRESS (AP-8)	164	195	46,404	650	1,584	0.12	0	0
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	149	178	50,667	709	1,730	0.10	0	0
	Scenario Bidasoaldea 1	***2,241***	***2,674***		***3,424***	***8,348***	***0.32***	***1,489***	***1,275***
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	620	740	45,651	1370	3,339	0.22	-1,417	0
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	631	680	33,400	568	1,385	0.49	133	0
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	574	633	40,000	680	1,658	0.38	173	0
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	417	621	28,800	806	1,966	0.32	-340	217
E24	IRUN-DONOSTIA CIRCULAR EX-PRESS (AP-8)	0	0	0	0	0	0.00	1,389	482
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	0	0	0	0	0	0.00	1,552	576

areas unserved by RENFE or Euskotren. The most important change is that the service connecting this town to the west side of San Sebastián was modified to rely on a timed transfer to route E04 at Errenteria.

The overall performance of this set of routes increases mainly because of the consolidation of the demand and the simplification of services. The revenue to cost ratio of the route set moved from 0.24 to 0.32 achieving monetary benefits of 1,490 € per day or an annual figure of 387,000 € . The social cost induced by this scenario is of 1,270 € per day or 331,575 € annually.

Scenario Bidasoaldea 2

Description
The local route of E20 is curtailed on their inbound end using the roundabout that is located right before the stop of Ategorrieta as a turning point. Route E26 is removed and a modified version of route E24 is set in its place covering its original alignment up to the stop of Capuchinos and then following E24's alignment on the city. On its way out of San Sebastián, the route uses the boulevards of Paseo de Pio Baroja and Paseo de Izostegui. Route E21 is modified at both ends to increase its catchment area: at the Hondarribia end a new loop is created replicating E20's shape, and on the side of San Sebastián, the alignment is changed to pass on its way in and out of the city through the roundabout of Pio XII. The frequency of both E21 and E24 is doubled, while route E23 is removed completely from the network. The changes proposed are presented in Figure 5.5.

Implications
As in Bidasoaldea 1, this scenario proposes changes to routes E20, E21, E23, E24, and E26 and makes emphasis on improving the connectivity of this area with the other two. It also tries to balance all the services provided in the sector by using the bus network to complement the existing services from the other modes.

Routes E21 and E20 are modified in the same fashion as in scenario 1. The curtailment of the local route E20 provides service to 91% of the targeted customers, users from the area of Oarsoaldea who will use other options to commute into the city. The resulting revenue to

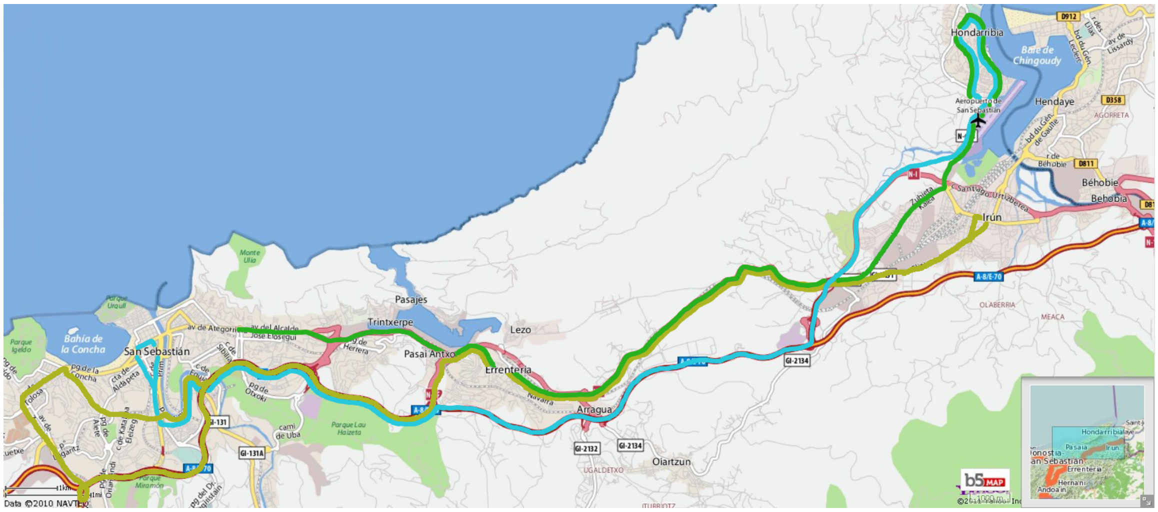


Figure 5.5: Scenario Bidasoaldea 2

cost ratio changes from 0.33 to 0.38. Route E21 achieves the same performance indicated before, with revenue to cost ratio dropping from 0.29 to 0.22 because of the increase in kilometers, although demand increases by 50%, and a faster and more frequent connection to the city is provided. As seen on section 4.3.3, the main destination outside Hondarribia is San Sebastián's center.

The new proposed E24 service can be considered similar to E26 but with a curtailment at the stop of Capuchinos. The purpose of this route is to keep providing a connection between Irún and Oarsoaldea with a service free of transfers to the west side of San Sebastián. The curtailment at Capuchinos will still offer a direct service to 60% of the targeted customers which means that 40% of them will need to transfer to reach their final destination. This means adding 200 transfers throughout the day. However, the frequency of this service is doubled and thus the accessibility to Oarsoaldea from Bidasoaldea improves. For this same reason, the route's demand is not only comprised by users of the former E24 and E26 but it also attracts new riders heading towards these two destinations. Additionally a timed transfer with routes E20 and E04 will serve the customers from Hondarribia and Oiartzun that have as main destination the western side of San Sebastián. In evaluating this route, a new base demand was used for the original E26 as the curtailment reduced the demand being served. Furthermore the new route was compared to the joint revenue to cost ratio of routes E24 and E26, resulting in a ratio from 0.20 to 0.27 of the proposed route.

In terms of connecting Hondarribia to different areas inside the city and Oarsoaldea, this proposal is as effective as the one proposed in scenario 1. Every half an hour there is a service that will take them to the city center in 30 minutes and every hour they will have the option to reach the western side of San Sebastián through timed transfers at either Pio XII or at Errenteria. In both scenarios, it is expected that the demand left unattended by the modified routes will be absorbed by other routes in the area of Bidasoaldea. However if need arrives, the frequency of route E02 could be increased by one bus per hour to provide more capacity in the area and further synchronize the services from Oiartzun with the ones connecting to the eastern side of city.

Table 5.3 summarizes the results of this scenario where the overall revenue to cost ratio moves from 0.22 to 0.28 which is less than the 0.32 estimated for scenario 2. Monetary daily savings of 1,400 € can be expected, which represents yearly savings of 355,000 € . The daily social cost is significantly lower than in the last scenario with a figure of 793 € or in annual terms 206,000 € . However, in this case the total demand of the targeted customers rises 10% as opposed to the 16% reported in the last scenario.

Comment on services within Bidasoaldea

The routes connecting Irún with Hondarribia are not considered within the scope of this thesis. However, after completing the analysis described in Chapter 4, was obvious that the service provided by route E25 could be reduced to 5 instead of the current 6 services per hour. This is a simple improvement that will not harm the demand as the headway will only vary from 10 minutes to 12.

5.3.3 Proposed Scenario

The scenarios presented for Oarsoaldea and Bidasoaldea give a set of alternatives that can be combined to define a new network structure with better performance levels than the ones present in the original one. In the case of Oarsoaldea, only the second scenario presented has a positive balance between the social costs and the monetary savings as the social costs

Table 5.3: Economic Performances of the Scenarios Bidasoaldea 2

	Routes by Scenario	Demand per Weekday (Pax)	Revenue per route (€)	Length (m)	Scheduled Km. per Weekday	Cost Per Route (€)	Revenue to Cost Ratio	Monetary Savings (€)	Social Cost (€)
	Original Routes	***1,785***	***2,130***		***3,887***	***9,477***	***0.22***	***0***	***0***
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	409	488	45,651	685	1,670	0.29	0	0
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	355	424	35,801	593	1,445	0.29	0	0
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	488	582	44,224	730	1,780	0.33	0	0
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	221	263	37,173	520	1,269	0.21	0	0
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	164	195	46,404	650	1,584	0.12	0	0
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	149	178	50,667	709	1,730	0.10	0	0
	Scenario Bidasoaldea 2	***1,947***	***2,283***		***3,368***	***8,213***	***0.28***	***1,417***	***793***
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	620	740	45,651	1,370	3339	0.22	-1417	0
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	0	0	0	0	0	0.00	1021	0
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	574	685	40,000	680	1658	0.41	224	0
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	0	0	0	0	0	0.00	1006	0
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	753	859	47,100	1,319	3216	0.27	-968	0
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	0	0	0	0	0	0.00	1552	793

represented 62% of the total savings. Moreover, the scenario shows improvements in terms of convenience and connectivity that may attract new ridership, improving further its performance. In the case of Bidasoaldea the first scenario has the best monetary return while the social costs are within this range, although still representing 85% of the total savings. On the other hand, the second scenario is almost as profitable but the induced social cost are only 58% of the total savings. Furthermore, the frequencies serving the area of Bidasoaldea are kept the same and the overall number of transfers required to reach the western side of San Sebastián is lower than in the first scenario. For these reasons the scenarios Oarsoaldea 2 and Bidasoaldea 2 are recommended for implementation in the new network. Table 5.4 shows the results of the combined scenarios.

There are many differences between the original network structure and the one being proposed denoting an overall improved performance of the system due to a better distribution of the passengers and the provision of a more customized service. For instance, when comparing Table 5.4 to Table 4.18, it is possible to see a different distribution of passengers across the routes in Oarsoaldea, with 350 more users per day in this county where most of them come originally from curtailed routes in Bidasoladea. This redistribution improves the utilization of the network in this area taking advantage of the capacity already being provided while the new services are better adjusted to the needs of the customers. Additionally, this part of the network requires 1,000 less scheduled kilometers per day lowering the operating costs from 15,700 € to 13,300 € daily. This difference does not come from a reduction in the number of services but from a different design that optimizes the length of the routes adjusting them to the demand for service. As a result, the average length of the routes in the area drops from 23,700 to 20,300 kilometers. The revenue to cost ratio in this area changes from the already high values 0.84 to 1.02, presumably just crossing the boundary of profitability. It is important to remember that the analysis assumed that the highest possible revenue was indeed possible for all situations thus relegating these figures to an indicative role of the differences between scenarios.

The changes in the routes connecting the area of Bidasoaldea with the other two counties are more qualitative than quantitative. The two tables show considerable differences in terms of demand and economic performance; the original network counted 2,900 users while the new one has just 1,900. However, on the original network only 30% (800 pax) of the demand were in fact traveling from Bidasoaldea to Oarsoaldea. The proposed network and frequencies change this proportion to 68% (1,350 pax) by providing a better service to the county. This is done at the expense of less revenue while the cost of operating the service remains the same, leading to a lower revenue to cost ratio than in the original network. However, these numbers do not consider the increase in targeted ridership thus the lower revenue to cost ratio means in fact a better economic adjustment of the service provided. This was illustrate with the revenue to cost ratios shown in Table 5.3.

There are important trade offs to consider when choosing to change the structure of the network. In one hand, the changes recommended are expected to transfer 2% of the ridership to other modes while increased travel times will lead to a social costs of 380,000 € per year. On the other hand, the revenue to cost ratio of the whole network improves from 0.68 to 0.73 leading to monetary savings of 640,000 € per year.

Table 5.4: Economic performance of the proposed scenario

	Routes by County	Demand per Weekday (Pax)	Revenue per route (€)	Length (m)	Scheduled Km. per Weekday	Cost Per Route (€)	Revenue to Cost Ratio
Oarsoaldea	***- San Sebastian***	***16,203***	***13,487***	***20,306***	***5,448***	***13,284***	***1.02***
E02	OIARTZUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	4,361	3,630	25,828	1,266	3,086	1.18
E05	BERAUN-PASAIA-DONOSTIA (N I)	3,570	2,971	18,241	1,122	2,735	1.09
E01	DONIBANE-LEZO-ERRENTERIA-PASAIA-DONOSTIA (N-I)	3,824	3,183	20,650	1,001	2,442	1.30
E09	SAN PEDRO-DONOSTIA (N I)	2,887	2,403	10,301	700	1,708	1.41
E06	ERRENTERIA-ALTZA-GARBERA-HOSPITALES (AP-8)	388	323	26,703	344	838	0.39
E04	OIARTZUN-ERRENTERIA-DONOSTIA CIRCULAR (AP-8)	0	0	0	0	-	0.00
E03	DONIBANE-ERRENTERIA-POLICLNICA (AP-8)	680	566	29,046	515	1,256	0.45
E08	SAN PEDRO-TRINTXERPE-DONOSTIA (N-1/AP-8)	248	207	12,500	213	518	0.40
E07	TRINTXERPE-P. ANTXO-POLICLNICA (AP-8)	245	204	19,175	288	701	0.29
Bidasoaldea		***3,383***	***2,816***	***16,022***	***1,605***	***3,912***	***0.72***
E25	HONDARRIBIA-IRUN	2,898	2,412	13,393	1,334	3,253	0.74
E22	HONDARRIBIA-C.C. TXINGUDI	486	404	18,650	270	659	0.61
Bidasoaldea	***- San Sebastian***	***1,947***	***2,232***	***44,250***	***3,368***	***8,213***	***0.27***
E26	IRUN-ERRENTERIA-PASAIA-DONOSTIA (N-I)	0	0	0	0	-	0.00
E20	HONDARRIBIA-HOSPITAL-ERRENTERIA-PASAIA-DONOSTIA (N-I)	574	633	40,000	680	1,658	0.38
E21	HONDARRIBIA-AEROPUERTO-DONOSTIA EXPRESS (AP-8)	620	740	45,651	1,370	3,339	0.22
E24	IRUN-DONOSTIA CIRCULAR EXPRESS (AP-8)	753	859	47,100	1,319	3,216	0.00
E23	HONDARRIBIA-IRUN OESTE-DONOSTIA CIRCULAR (AP-8)	0	0	0	0	-	0.00
	Total	***21,533***	***18,536***		***10,420***	***25,409***	***0.73***

Chapter 6

Conclusions

This chapter presents a summary of the results and the analysis performed throughout this thesis, and proposes suggestions for future research. Overall, this thesis demonstrates with a clear example how ADCS could and should be used in the assessment of the Lurraldebus' system and to propose strategic changes that will render it a more efficient and effective transportation network. Moreover, most of the estimations and computations done throughout can be easily systematized and reproduced to either revisit the state of the network in San Sebastián East or to analyze other sectors of the network. Section 6.2 proposes future opportunities for research identified through the development of this thesis, based on the potential of ADCS and DFG's vision of public transportation in the province.

6.1 Summary

The eastern part of San Sebastián has the greatest population concentration outside the province's capital and has a wide variety of economic activities creating a high demand for mobility. This situation represents a strategic opportunity to implement best practices in planning and modal integration. The readily available data from the ADSC contains all the information required to monitor and manage the services effectively as presented by Laidig, D. A. (2010) and also to design alternatives for the network and to assess the effectiveness of such alternatives.

The legal and regulatory constraints were reviewed to set the working framework for the development of this thesis. It was concluded that DFG and Lurraldebus have total flexibility to redefine and implement their preferred performance standards and metrics, and to make any modifications to the service and network structure as long as they are within the general guidelines established by the European Union adopted by the Spanish and Basque governments. This does not only mean that DFG and Lurraldebus have the right to set higher standards, but also that they are responsible for and should pursue them, to improve the transportation services and better meet customers needs. Specific economic and level of service criteria should be defined to set up goals and to manage all the tasks involving the provision of public transportation, including those related to network design. For this task, the government should strongly consider the possibility of contracting out these tasks to a specialized consultancy firm. Since there is no need for frequent modifications to the network, an in-house team could be devoted to monitor the quality of the service on a day-to-day basis using standards like the ones proposed by Laidig, D. A. (2010). Moreover, frequent changes to the route structure can be confusing for customers and may lead to a lower perception of the transportation services.

Information obtained from the automatic data collection systems was used to first evaluate the utilization of the resources by the operator, i.e. supply, and the demand of the network so as to propose changes to the network design in order to improve its efficiency. Through the development of these two analyses, it was showed that the ubiquitous information already available can provide an incredibly detailed insight on how the system is operated and used by customers. All the operating fleet has AVL systems and the penetration of Billete Único is 86%; these two facts allow a comprehensive picture of the system that should be taken advantage of. This is the first time, since these systems were set in place on 2007, that the available data is used in such detail for planning purposes.

The supply side analysis found that an adequate number of vehicles is used to operate the current services, although a reduction of the number of buses could be achieved by using computer aided scheduling tools to implement strategies, such as interlining and reeduction of the number of unproductive hours of services. After the characterization of the demand, the routes with lowest productivity indexes were identified and further analyzed to obtain more insights on their utilization and the reasons behind their low performance. In terms of demand, there are some routes, all of them within a range of 10 kilometers from the capital, that have an excellent performance and their use is well coupled to the customers needs. However, most of the remaining routes presented a high level of underutilization. Under the current cost model, the overall revenue to cost ratio of the routes in San Sebastián East was estimated to be 0.68, which means that there is a 32% subsidy for the operation of the network. For some routes this same index could be as low as 0.11 and while this may not represent an issue under the province's mobility policy, these routes also provided low frequencies to disperse destinations, resulting in a low level of service. Being the area with the highest travel demand in the province, it is expected to be the most productive when it comes to public transportation.

The current network design practice in Lurraldebus relies on the ADCS to obtain highly aggregated figures at the zones and route levels to make an initial assessment of the network, but final judgment and decisions are heavily determined by the operator's experience and his advice to the authorities. Furthermore, through the development of this thesis it was found that the layout of the routes was modified several times over their first year of operation giving the impression of a *trial and error amendment* process for optimizing the network. The last modifications applied on March 2012 included the duplication of routes' E20 and E26 frequencies. This was done in spite of the fact that both routes' demand remained stable over the course of the year (see Table D.1). In the assessment made on section 4.3.3, these same routes proved to be among the least performing ones and its curtailment was recommended. As showed in section 4.3.3, when evaluating the aggregated figures, these seem to be the most profitable of the routes interconnecting Bidasoaldea with Oarsoaldea and Donostialdea. However, when a closer analysis is made, it is evident that most of its ridership commutes between the counties of Oarsoaldea and Donostialdea, therefore duplicating the services will most probably lead to even less productivity for these routes.

Different scenarios per county were presented and a final recommendation was made in order to achieve better economic performance and better levels of service. Using the relationship of the demand response to level of service, it was possible to assess different alternatives of the current network design. On one hand, the recommendations reduced service redundancy, improved connectivity between areas, maintained the existing connections, rendered more frequent services, and increased the utilization of the supplied capacity.

On the other hand, the recommendations added transfers and increased travel times for a small fraction of customers. The overall revenue to cost ratio increased 5 points to 0.73, saving more than 600,000 € per year in operating costs to DFG. This represents a decrease of 8.7% on the number of weekday scheduled kilometers established in the contract, figure which falls within the 10% agreement established with the operator. The number of daily total riders changes from 22,000 to 21,500, but this figure is likely to increase because of the coverage improvements in the areas of San Pedro and Hondarribia.

6.2 Suggestions for Future Research

When implementing changes in the structure of a network it is important to support it with a robust schedule, and to ensure that adequate operational elements are in place. In the specific case of this thesis, the two most important operational elements are reliability and on-time performance. It was noticed that in spite of being a low frequency service, Lurraldebus does not consider reliability as a level of service factor; on-time performance metrics are not in place and only customers at the terminals know the departure time of buses. In the case of Gipuzkoa, these subjects have been treated in more depth by Laidig, D. A. (2010) and Gómez Gélvez, J. A. (2010), however, for these issues it is important to consider the following statements:

First, an unreliable service cannot win the trust of customers. Public transportation must be regarded as a high quality service that need to be delivered on-time, since a service that leaves early or arrives late is useless to customers that needs to be at their destination at a specific hour every day. Informing about the expected waiting time at the stop is not a valid substitute for a reliable schedule, as it does not allow customers to plan their trips in advance; since it only warns them how long would they have to wait once they reach the stop. This renders a less competitive transportation system when on-demand modes, like the car, have a large penetration in the population.

Second, reliability and on time performance are necessary elements to operate successfully with synchronized transfers. Transfers are rejected by customers, therefore reducing maximum waiting times is crucial to successfully operate with timed transfers.

Future research could consider aspects of reliability and on-time performance with the aim of improving the quality of service. With bus location information and transactions information, it is possible to regulate operations using the customer perspective. Tap-in and tap-out information could be used to measure the reliability of individual travel times even when transfers are involved, by enabling the possibility of linking them to on-time performance indicators. These measures could be weighted according to the number of passengers being affected and the deviation of their travel times when a certain level of on-time performance is not achieved.

Exploring ways on how further integration with Donostiabus could be achieved, should be an important contribution to the Province. The non-competition agreement signed between Donostiabus and DFG has come to the rather absurd point of physically separating the stops of both systems. While the services are already being paid with public funds, this situation only works against the customers which could see an improved level of service if such division did not exist. Research on future steps towards the integration of the two main bus networks, Donostiabus and Lurraldebus, could eliminate theses barriers. Both systems count with ADCS enabling a complete economic evaluation of the impacts by eliminating the agreement and implementing different operating scenarios. Additionally, as a direct follow up of this thesis, it is recommended the analysis of the best options to synchronize transfers at Pio XII as well as with the rail services at the city of Irún.

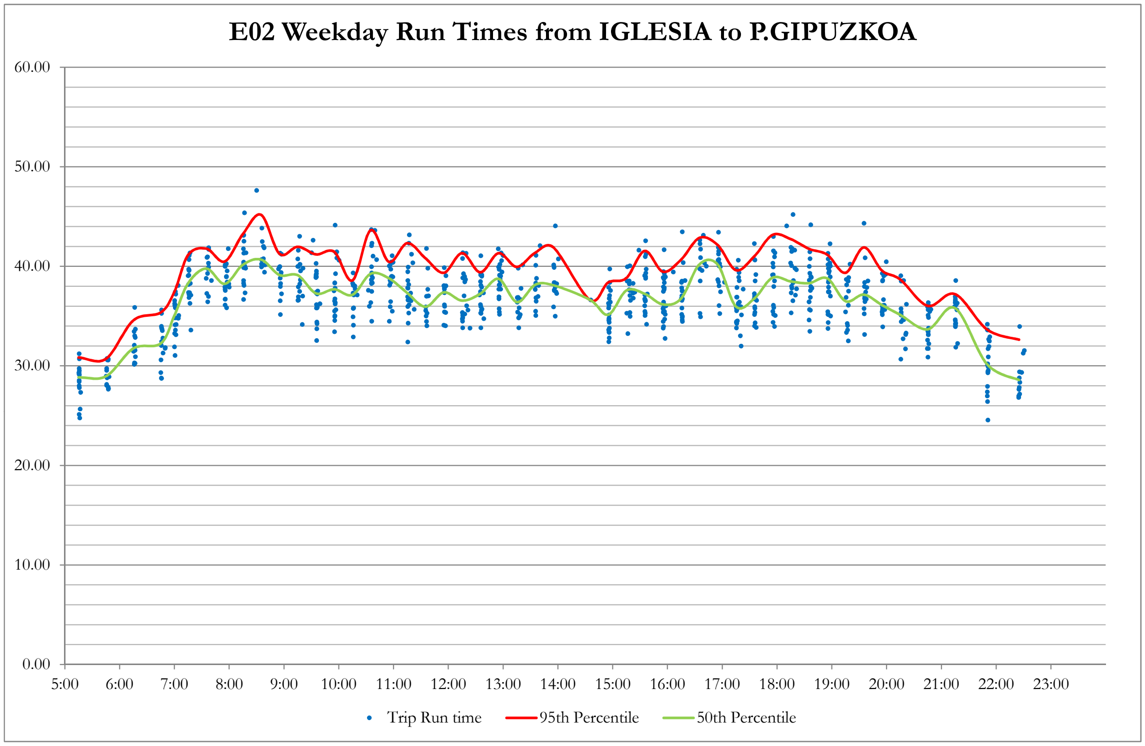
There is also a great opportunity to develop econometric demand analyses to obtain specific elasticity values for different aspects of the level of service and fare changes. Archived information could be used to identify and isolate demand responses to specific situations as the ones used in this thesis, such as elasticities of in-vehicle travel time, frequency changes, transfers, and fare changes. This information will be specially valuable when modeling the effects on the demand of future fare integration with Euskotren and RENFE. Furthermore, Lurraldebus has information about each customer birth date information, thus it could characterize customers response by different age ranges, which will be useful when proposing more complex fare schemes.

Appendix A

Supply and Demand Analysis of Oarsoaldea

Figure A.1: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

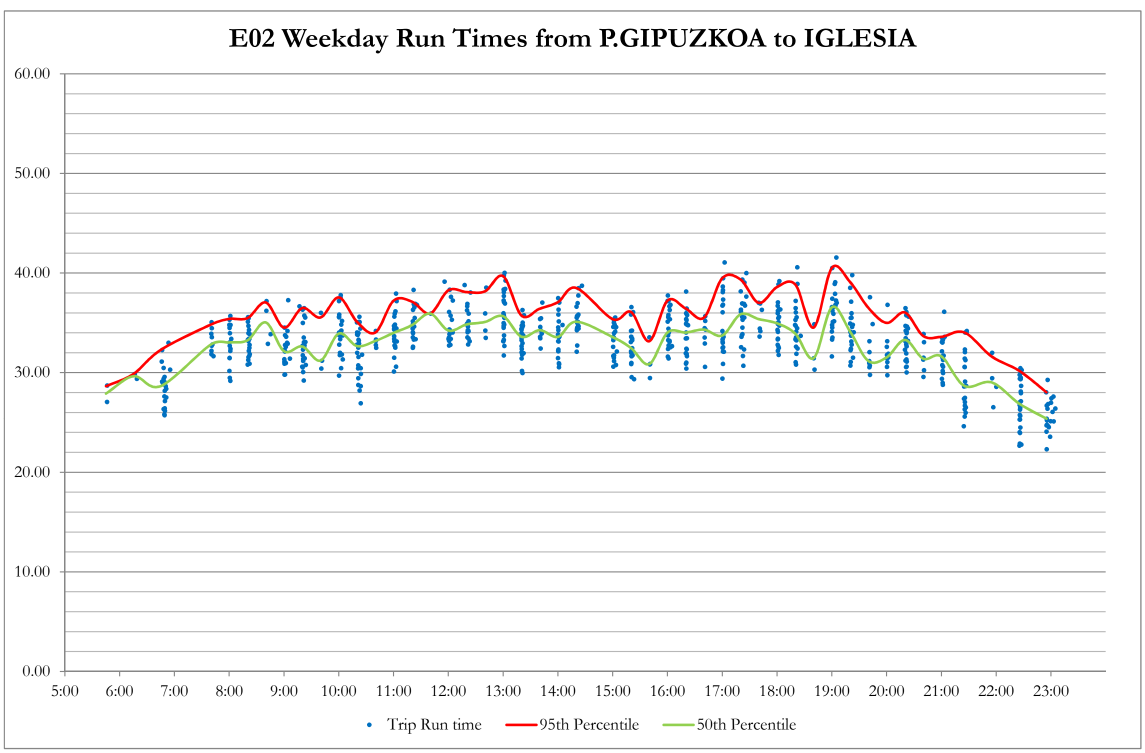
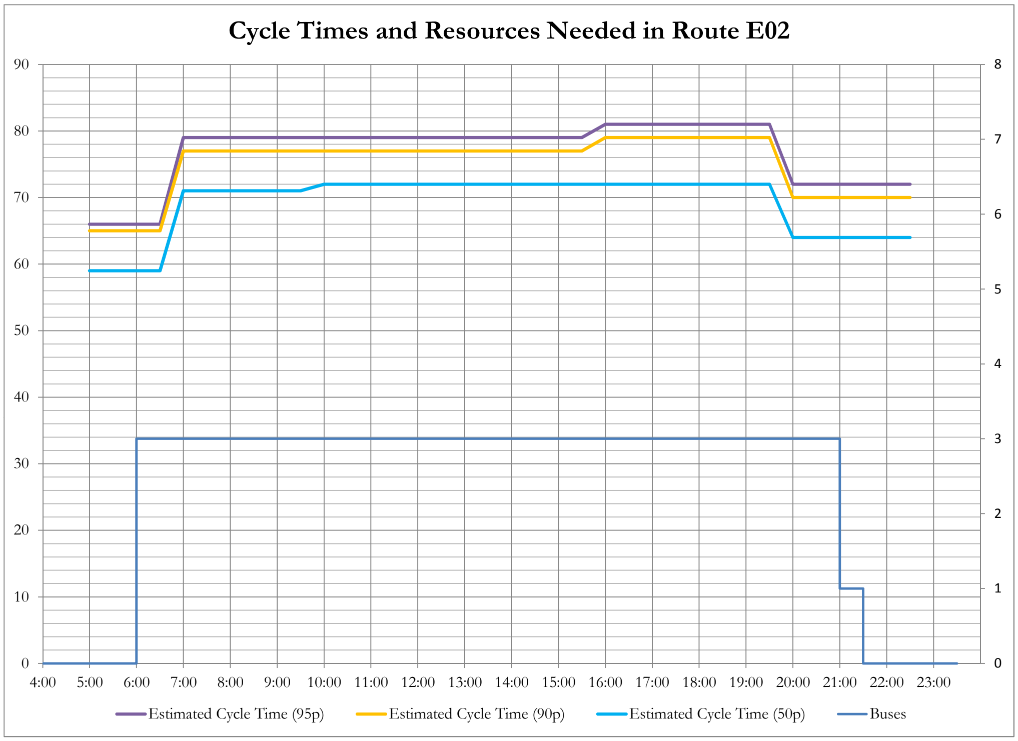


Figure A.2: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

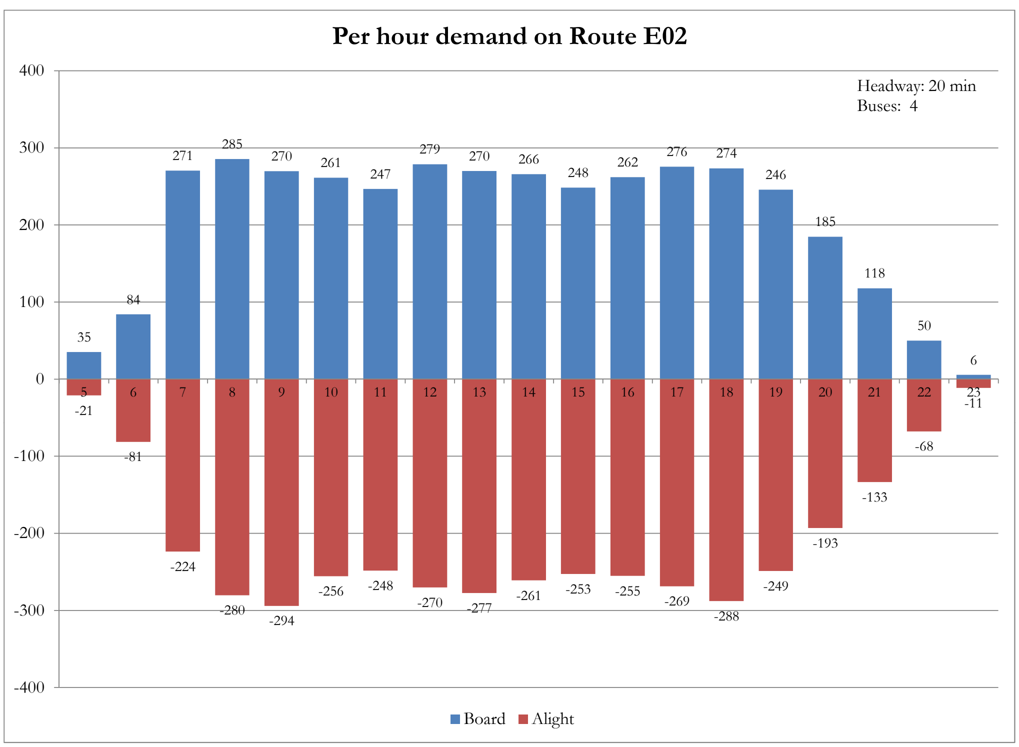
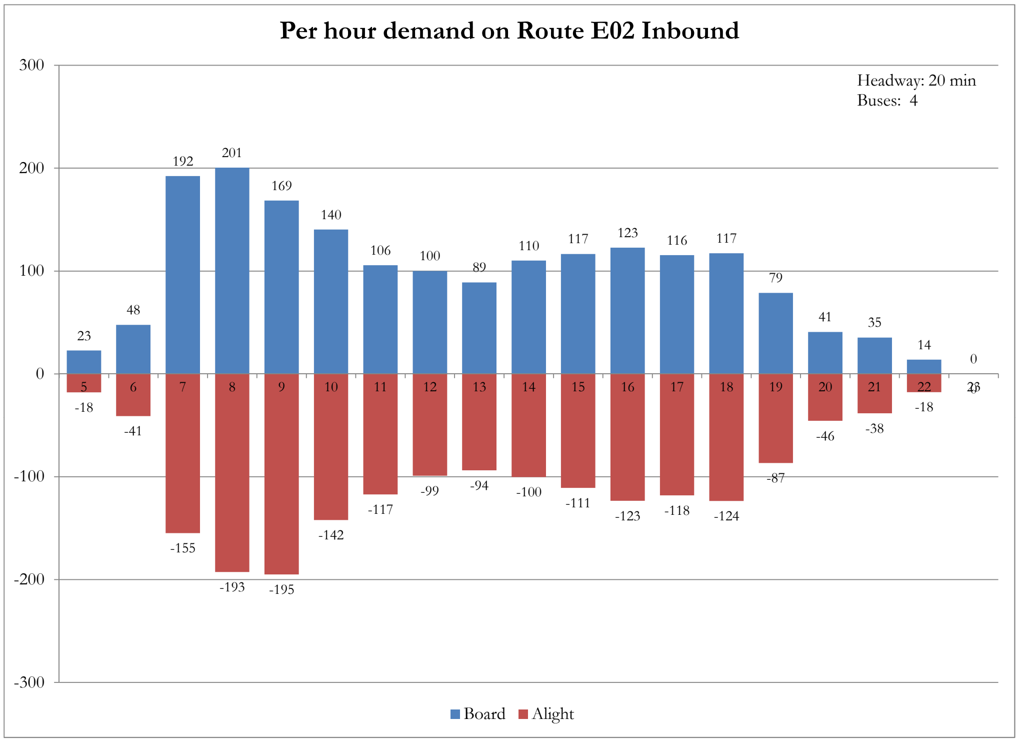


Figure A.3: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

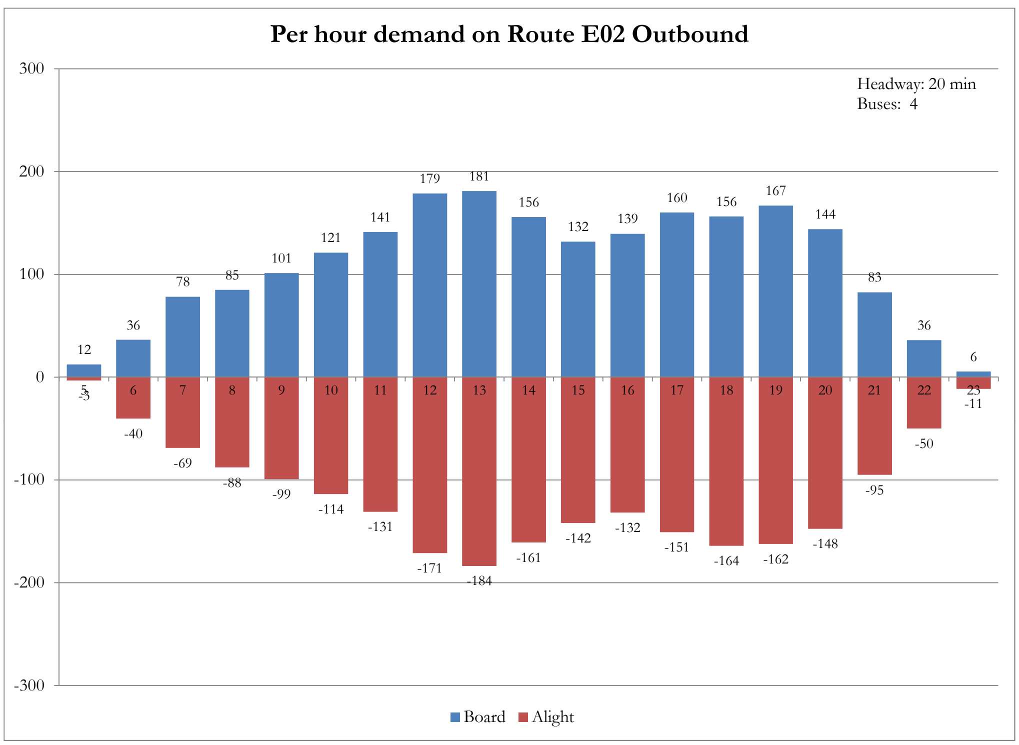
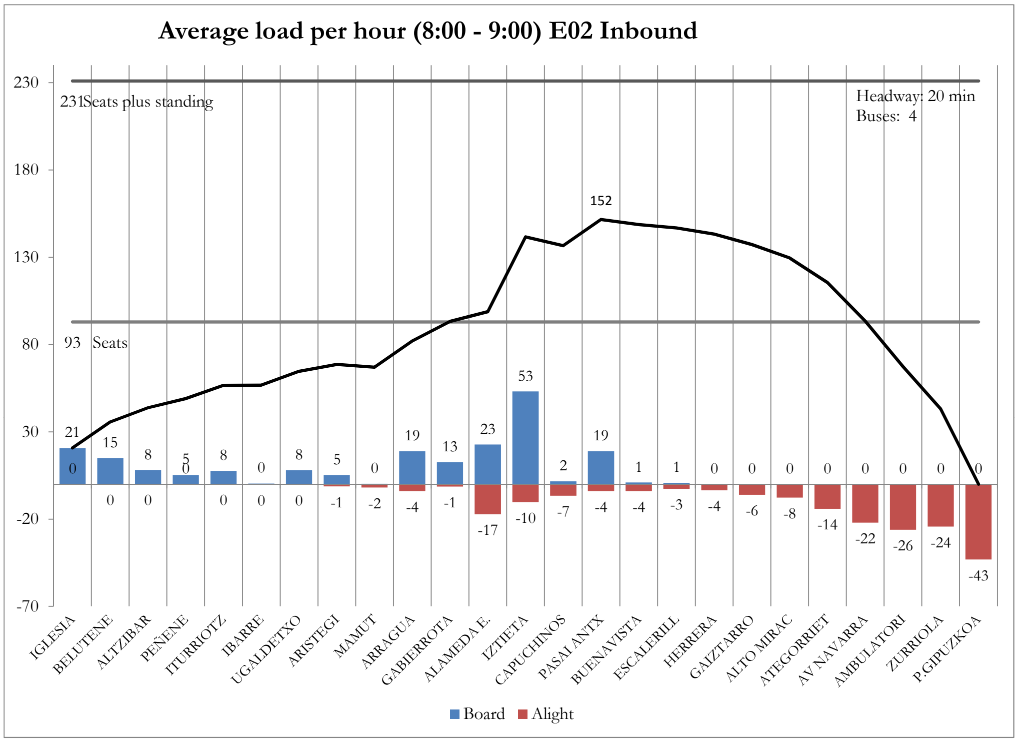


Figure A.4: Load Profiles

(a) Inbound



(b) Outbound

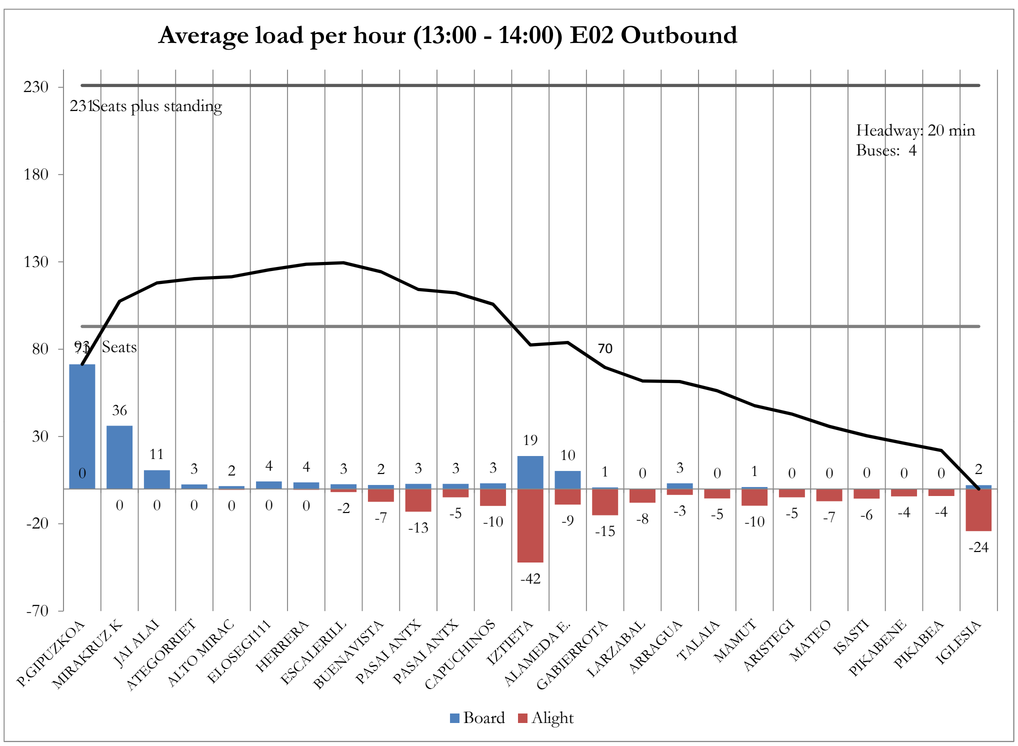
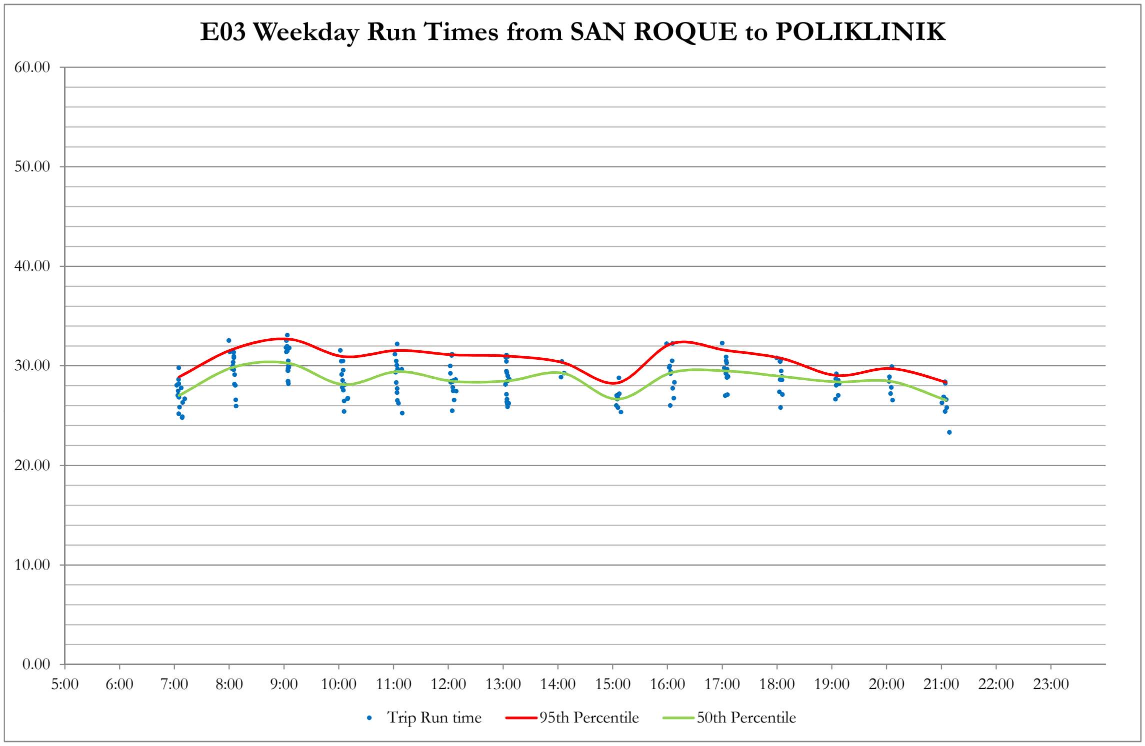


Figure A.5: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

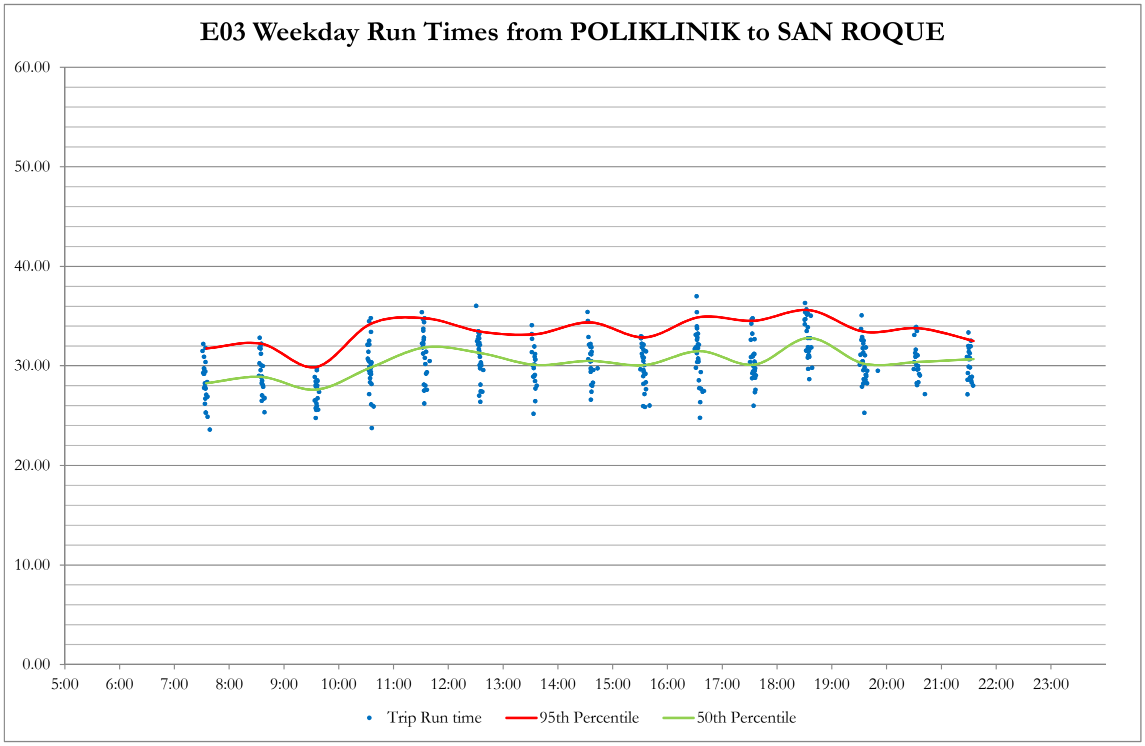
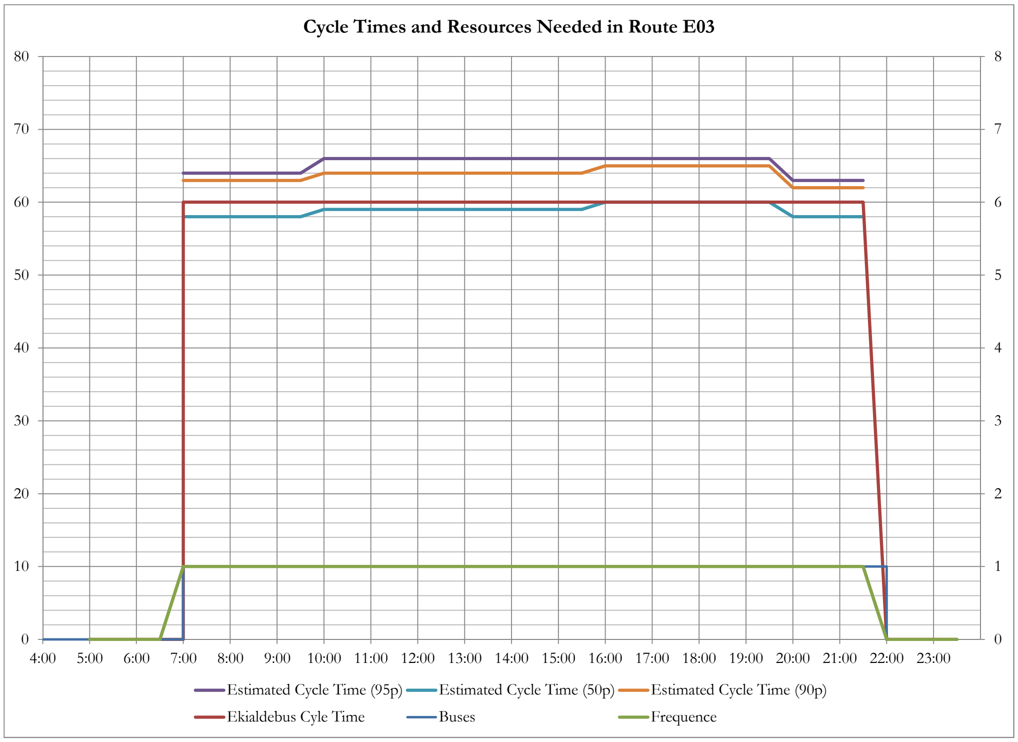


Figure A.6: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

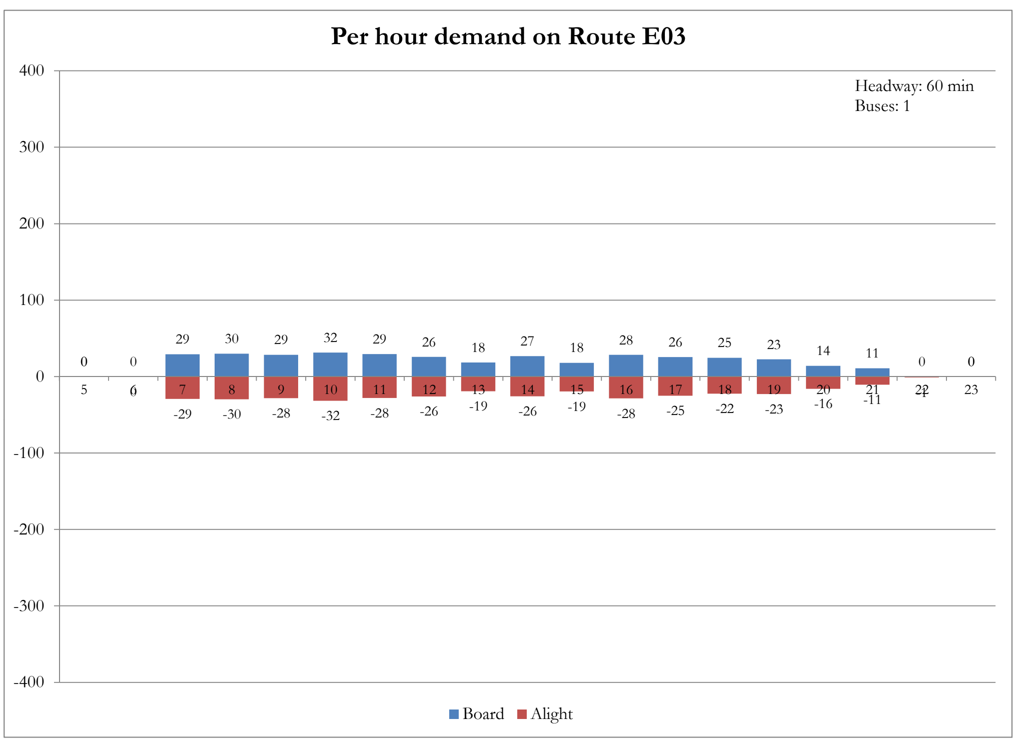
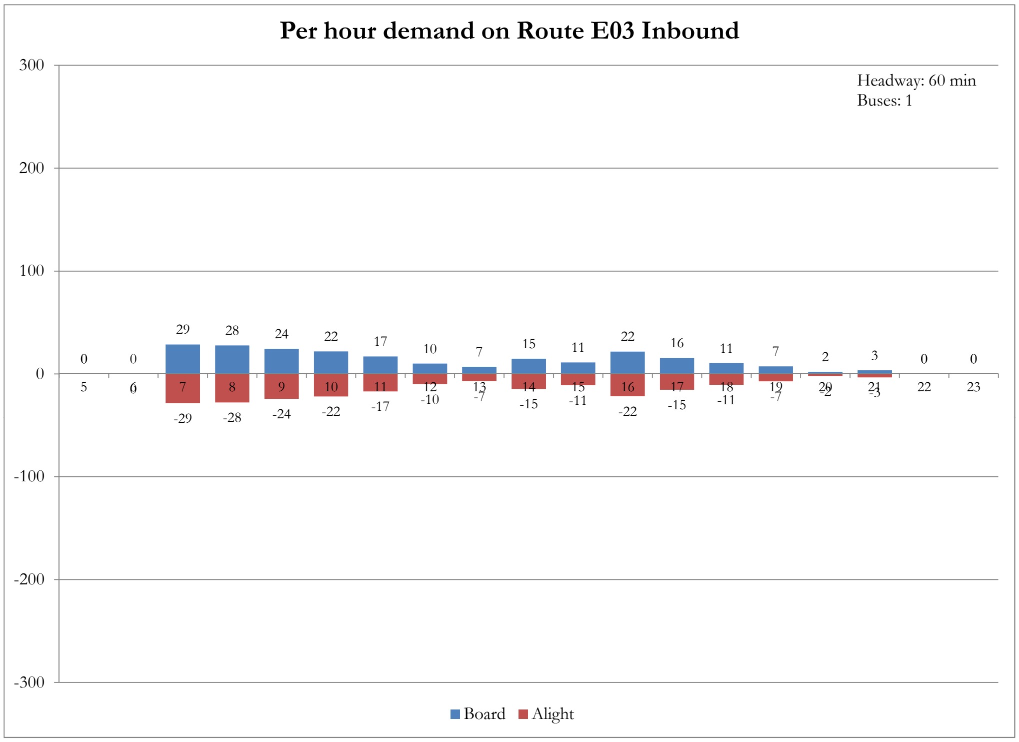


Figure A.7: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

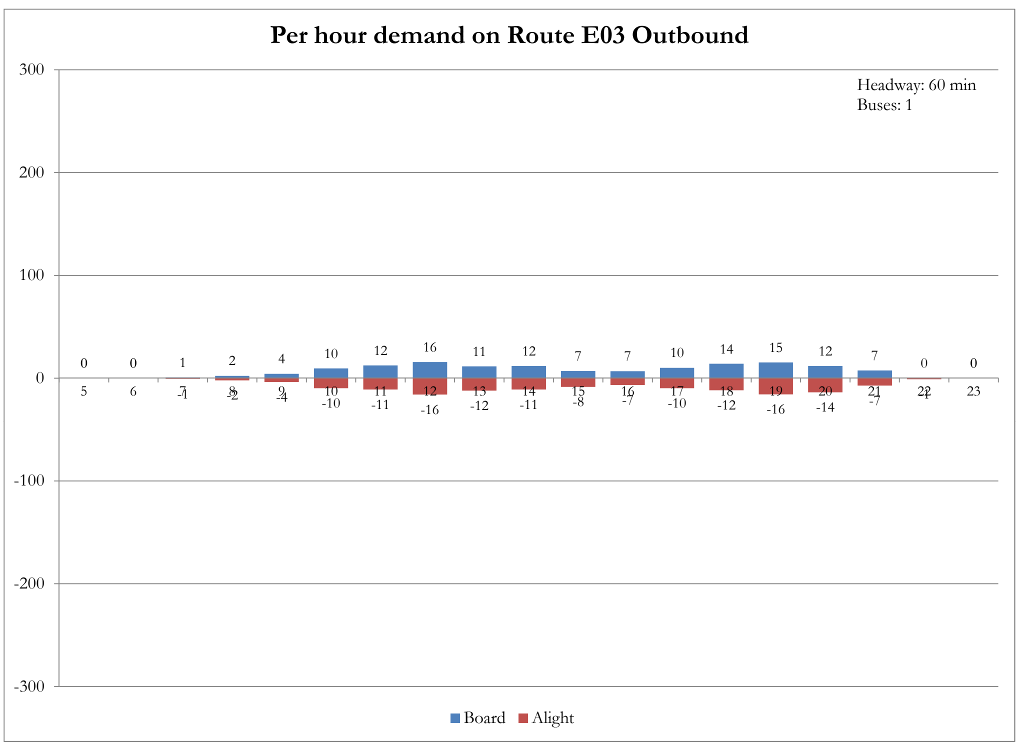
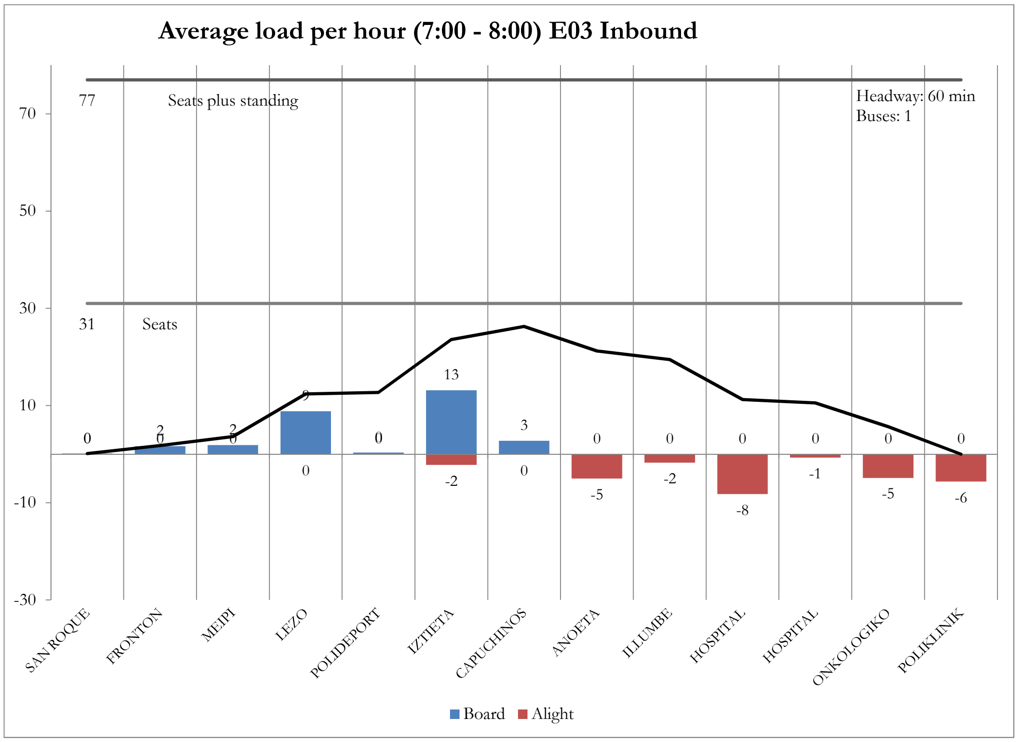


Figure A.8: Load Profiles

(a) Inbound



(b) Outbound

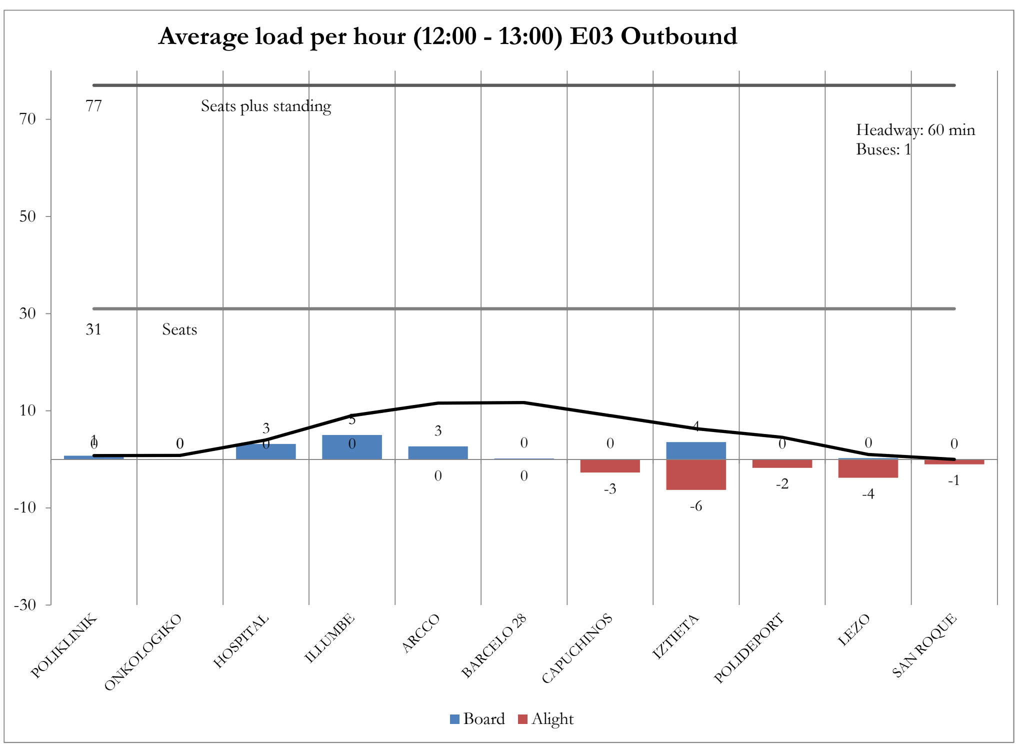
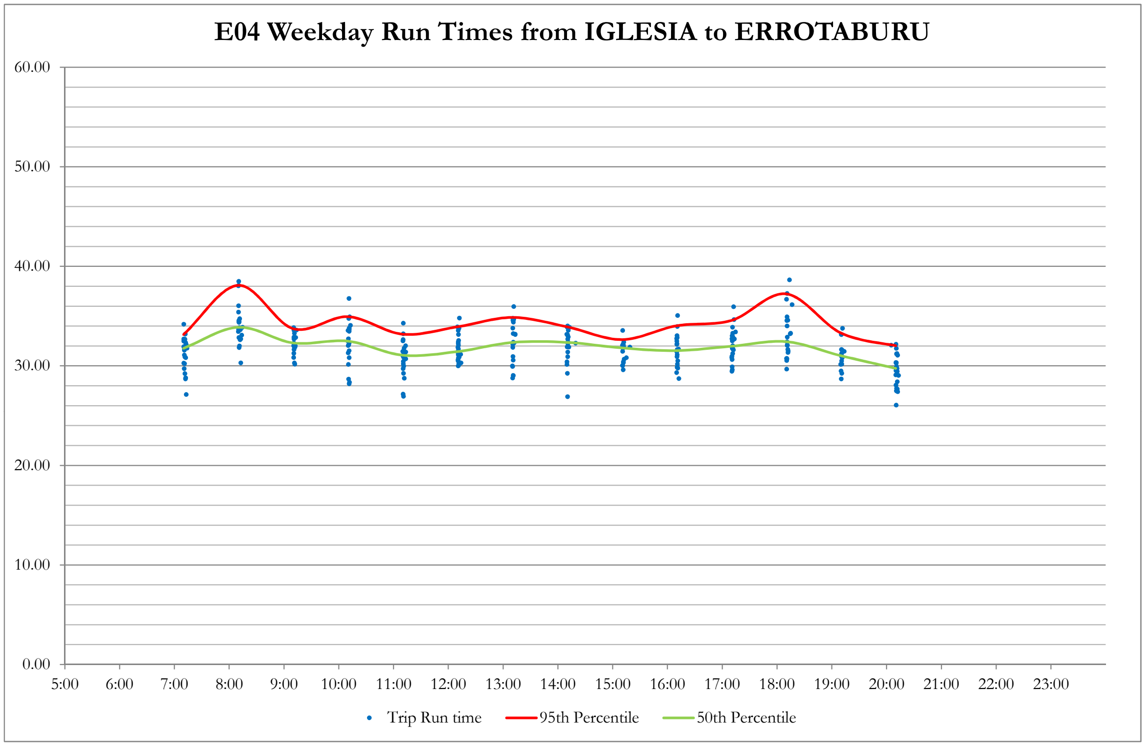


Figure A.9: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

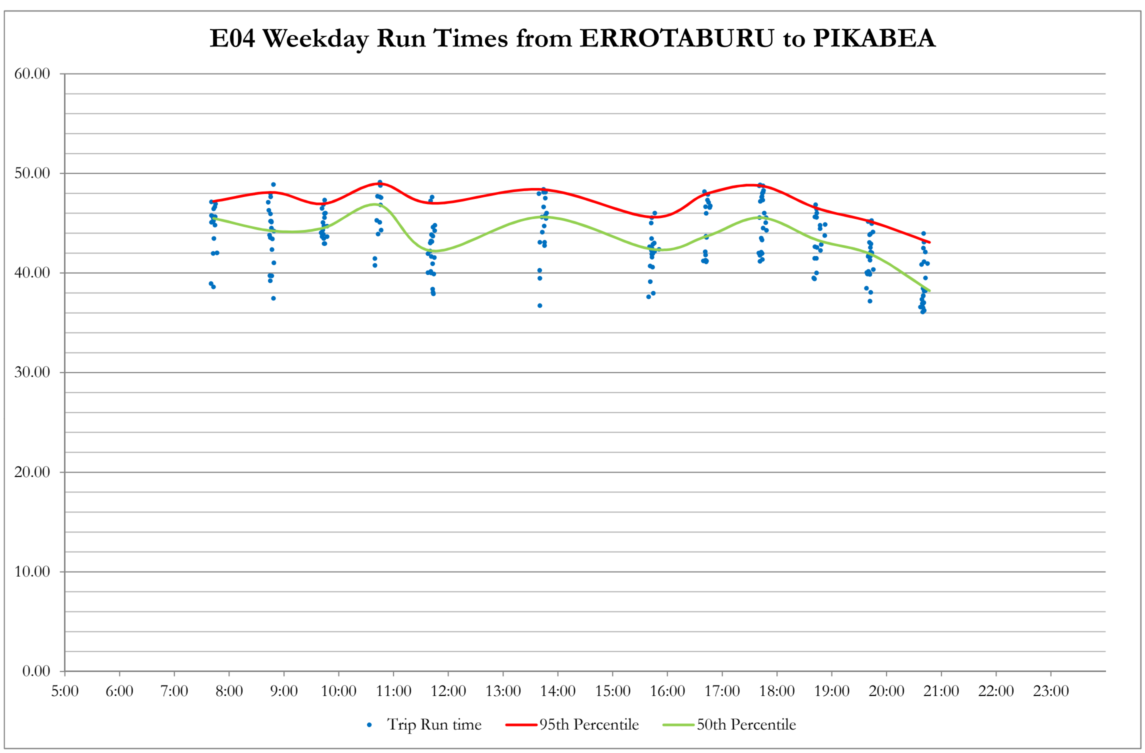
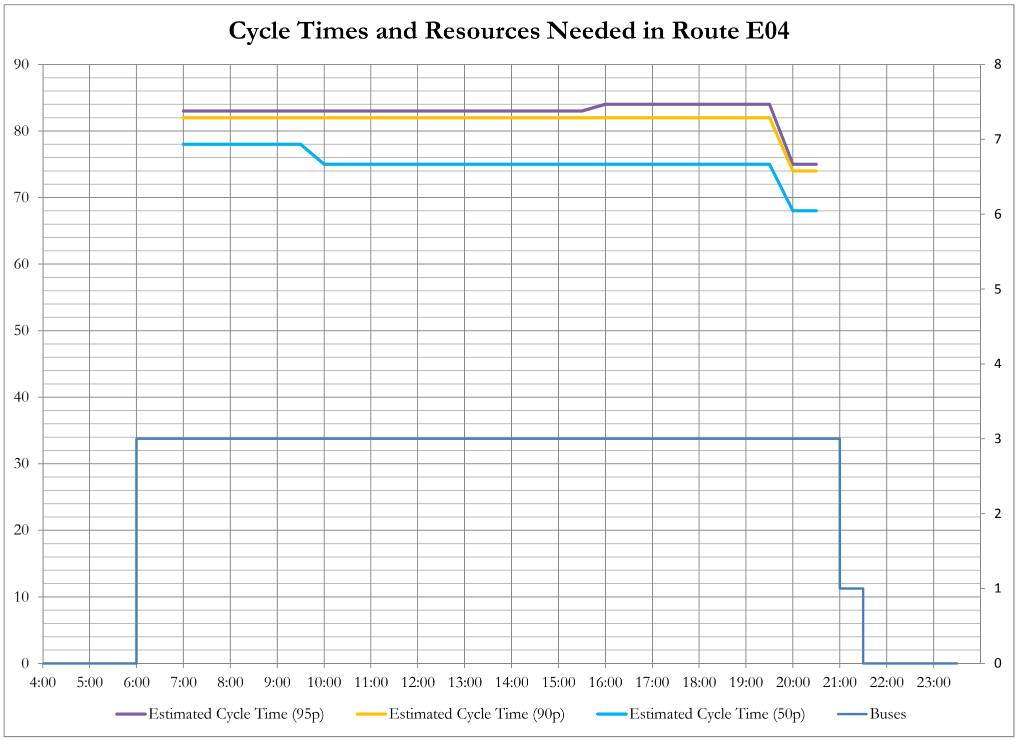


Figure A.10: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

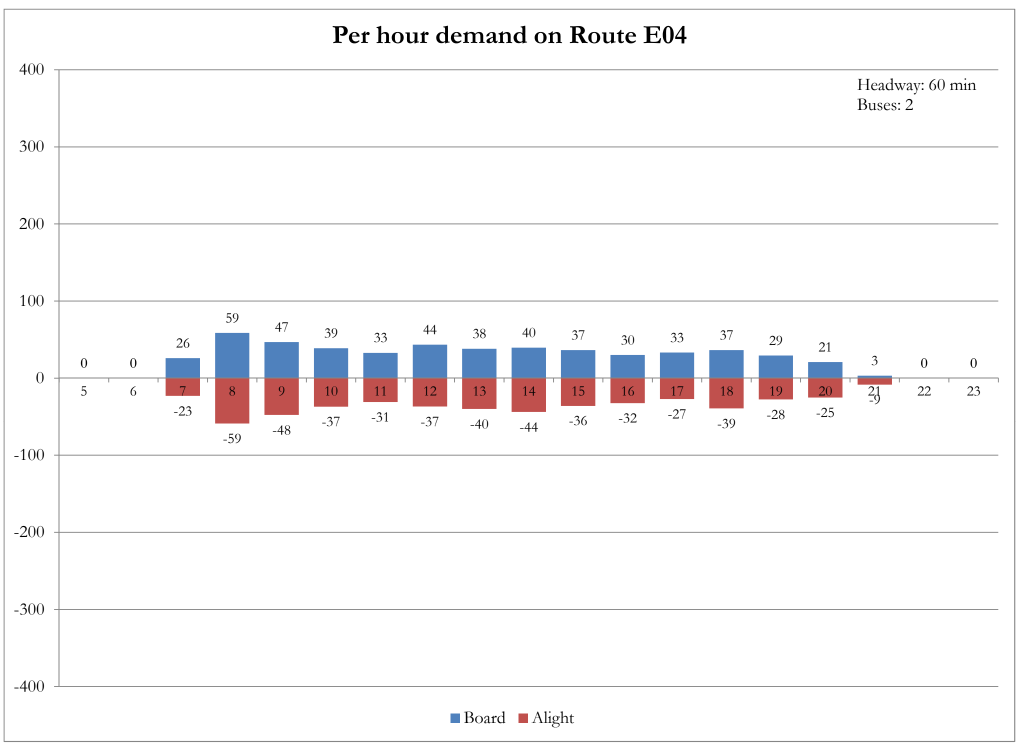
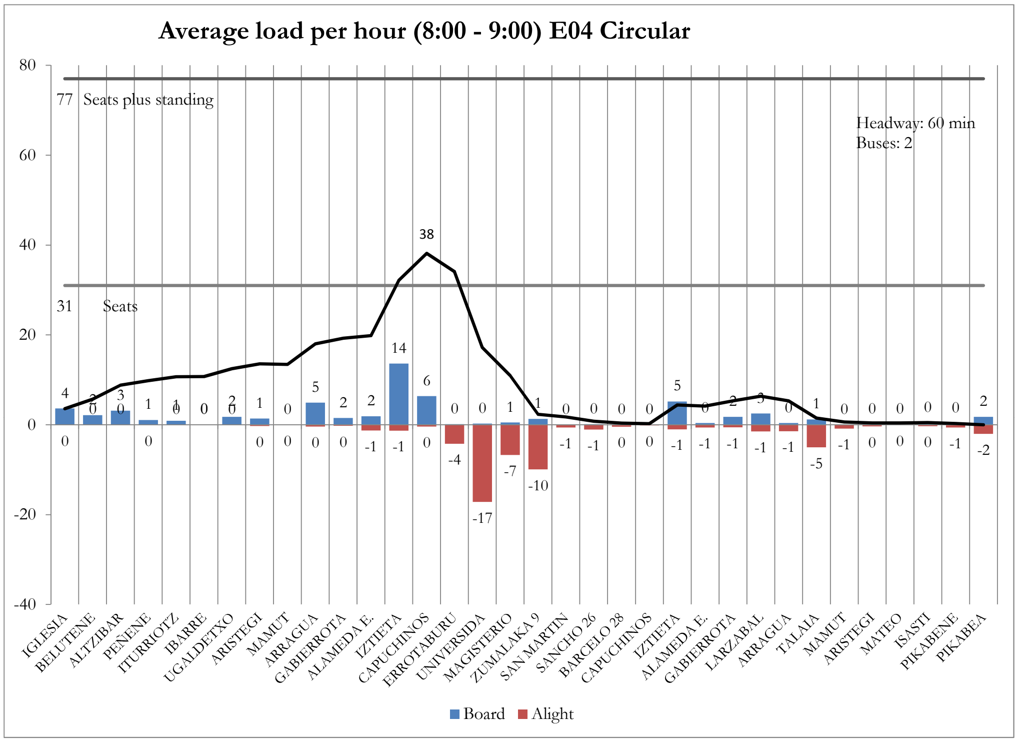


Figure A.11: Load Profiles

(a) Inbound



(b) Outbound

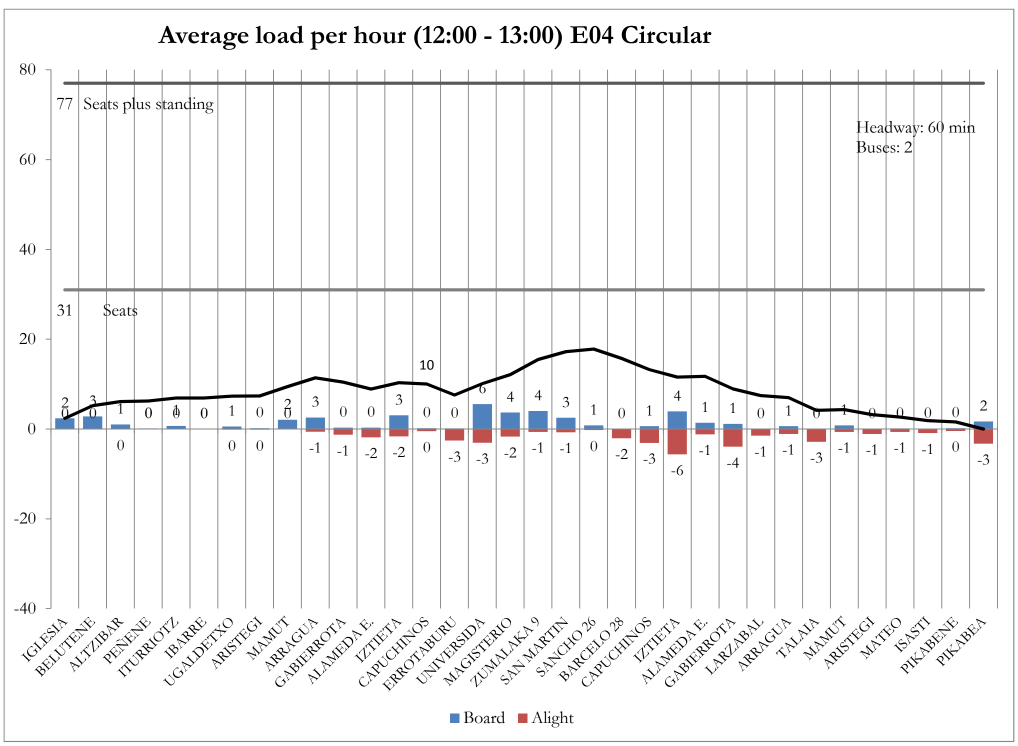
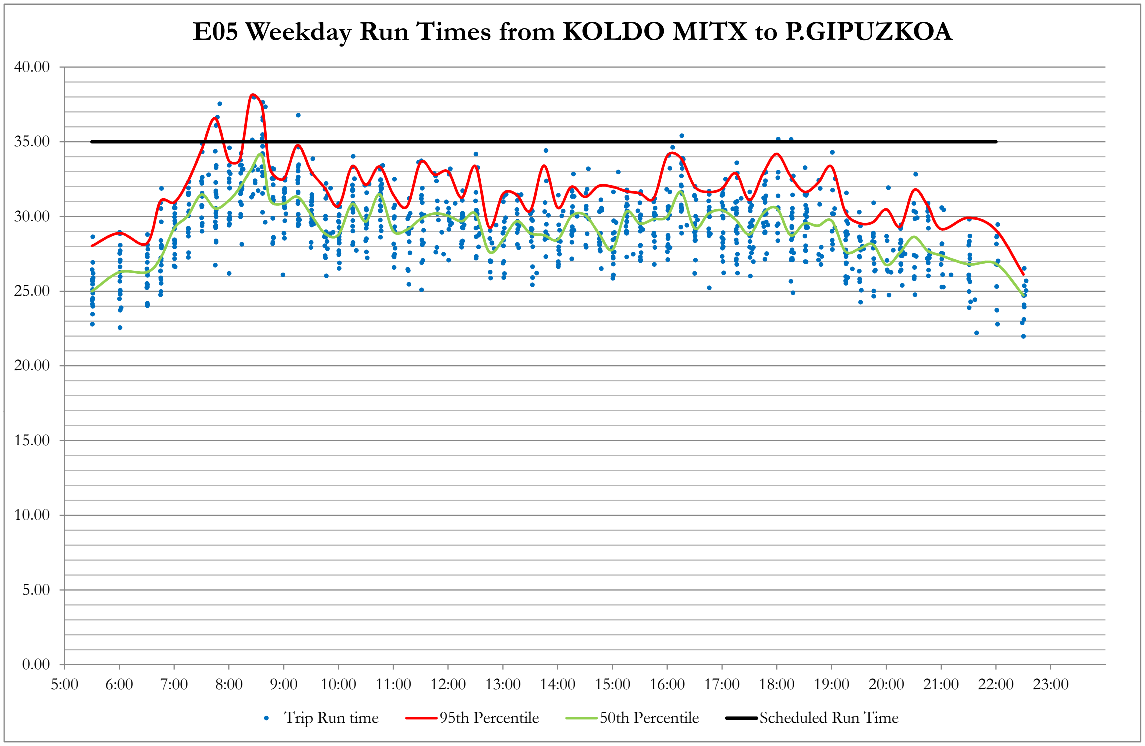


Figure A.12: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

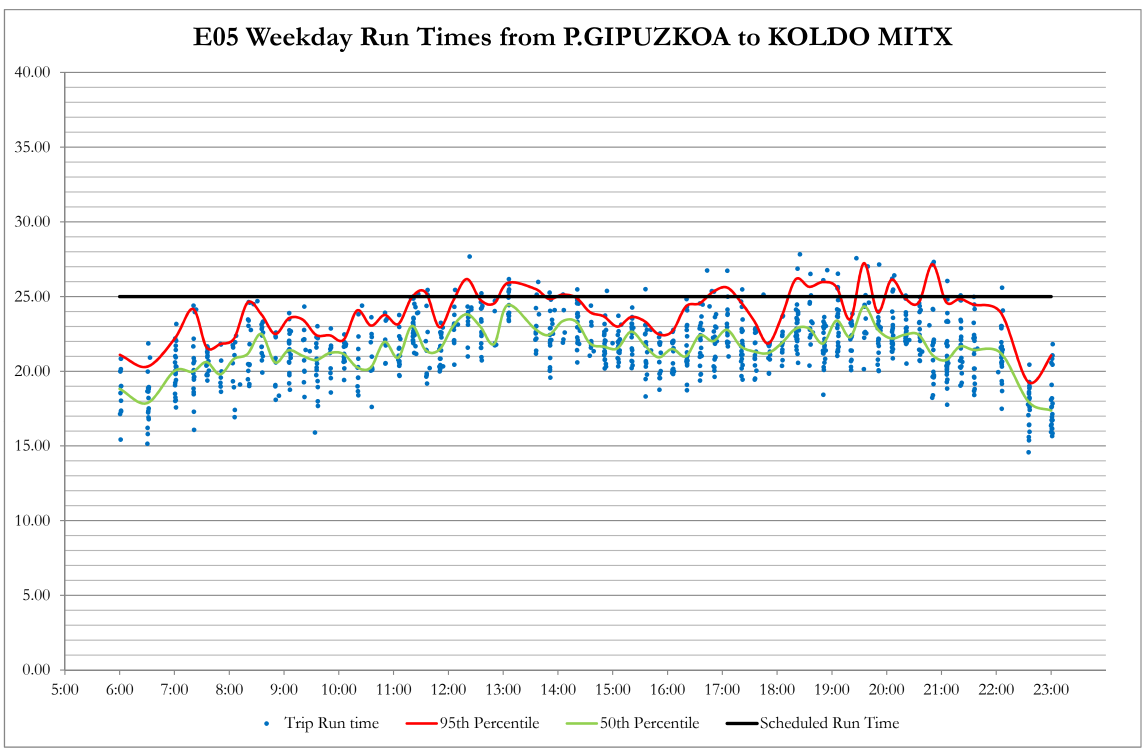
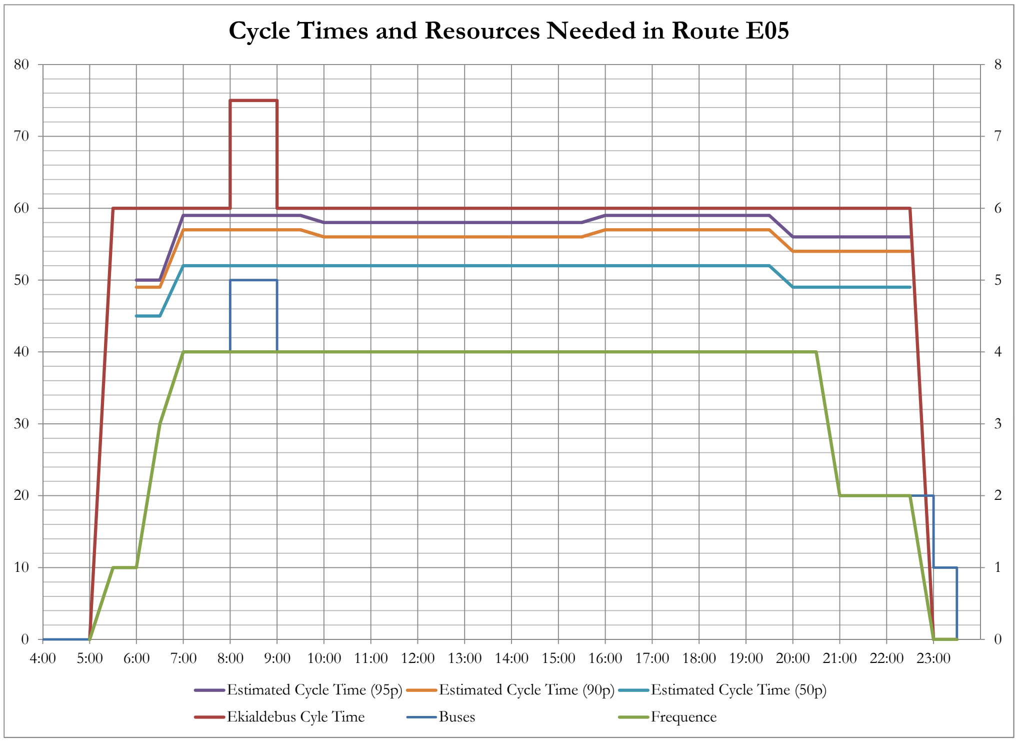


Figure A.13: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

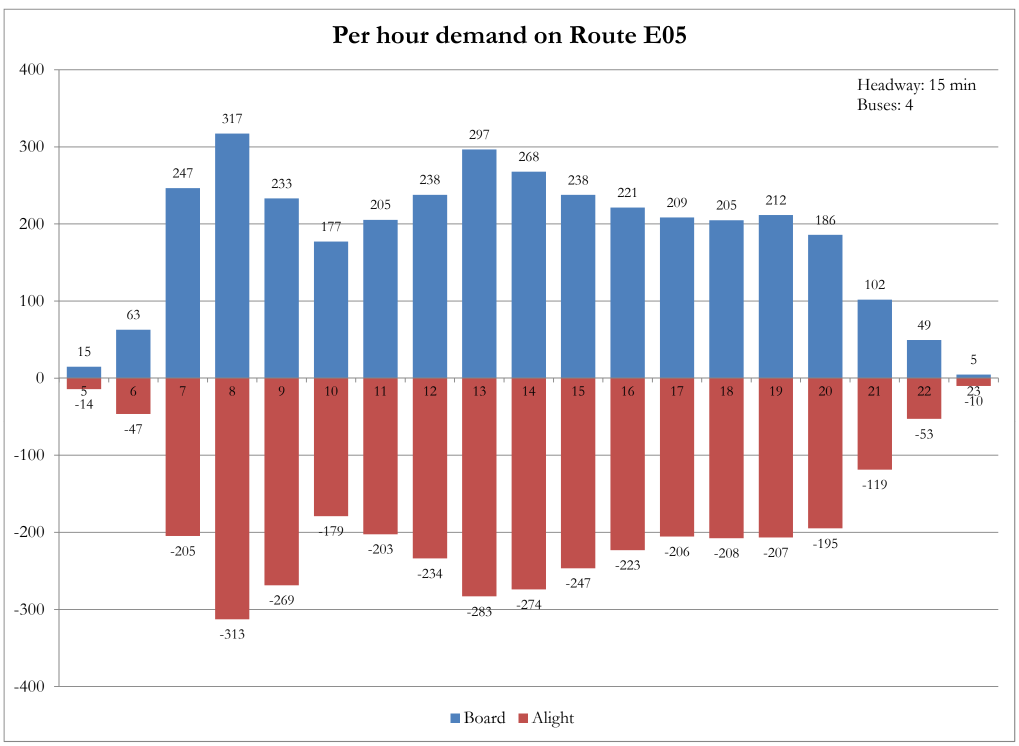
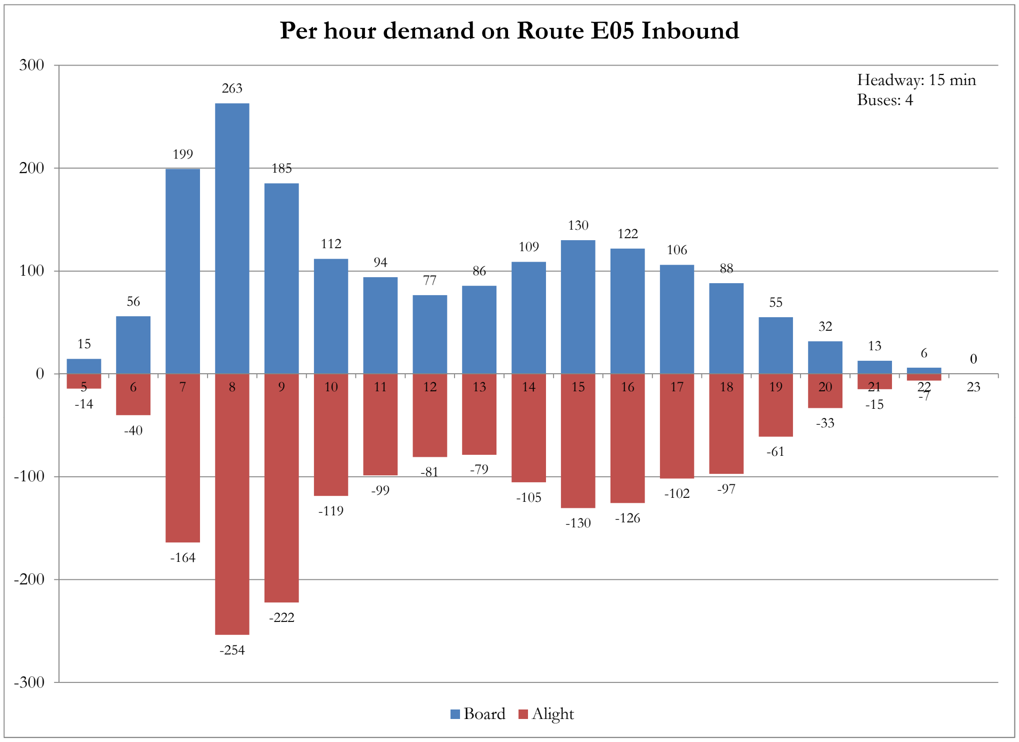


Figure A.14: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

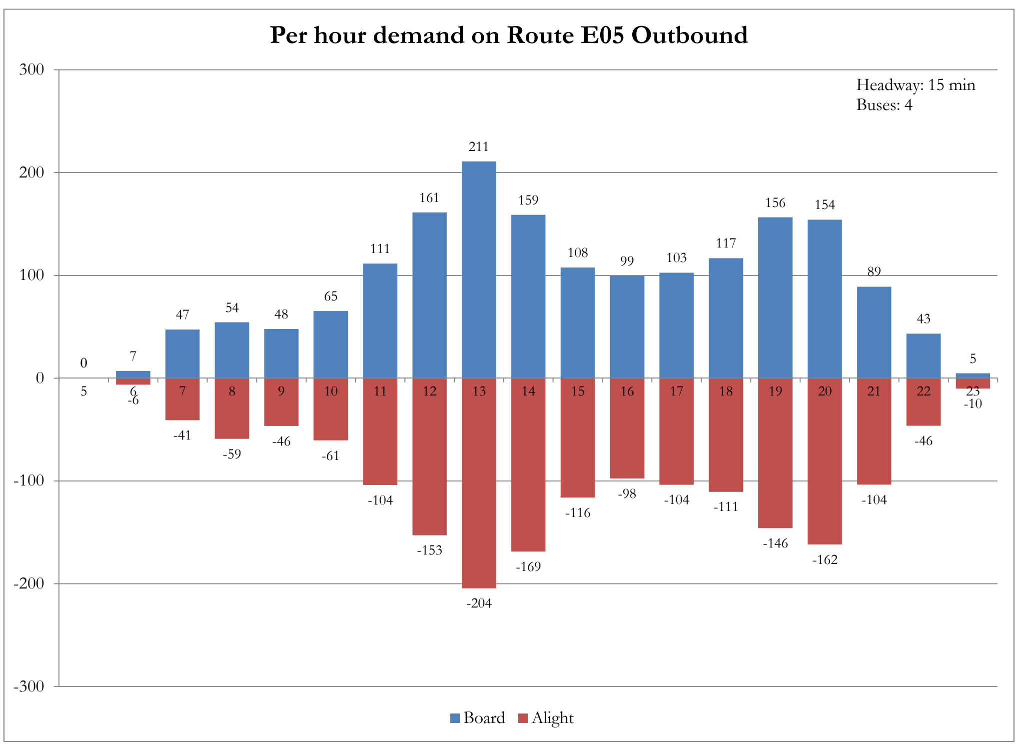
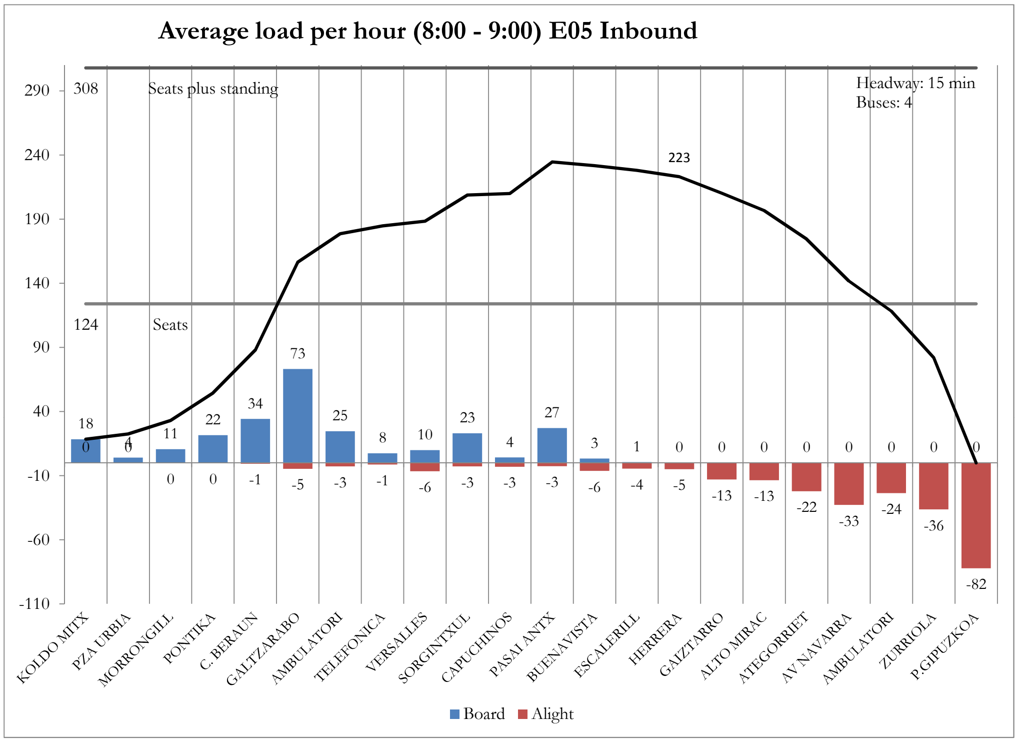


Figure A.15: Load Profiles

(a) Inbound



(b) Outbound

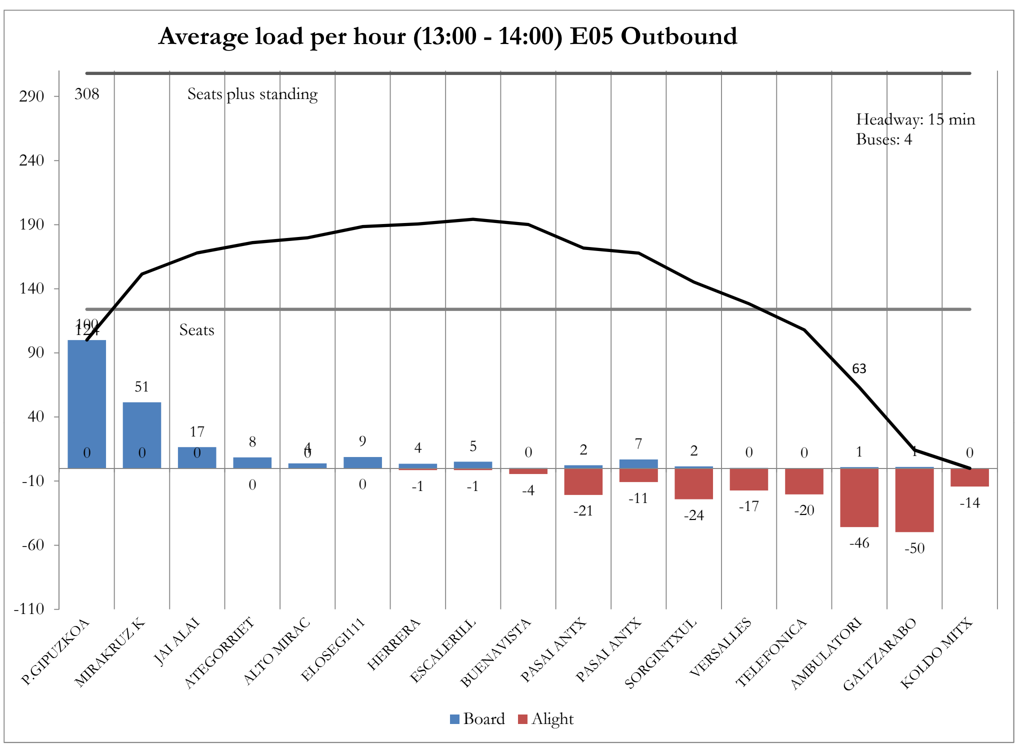
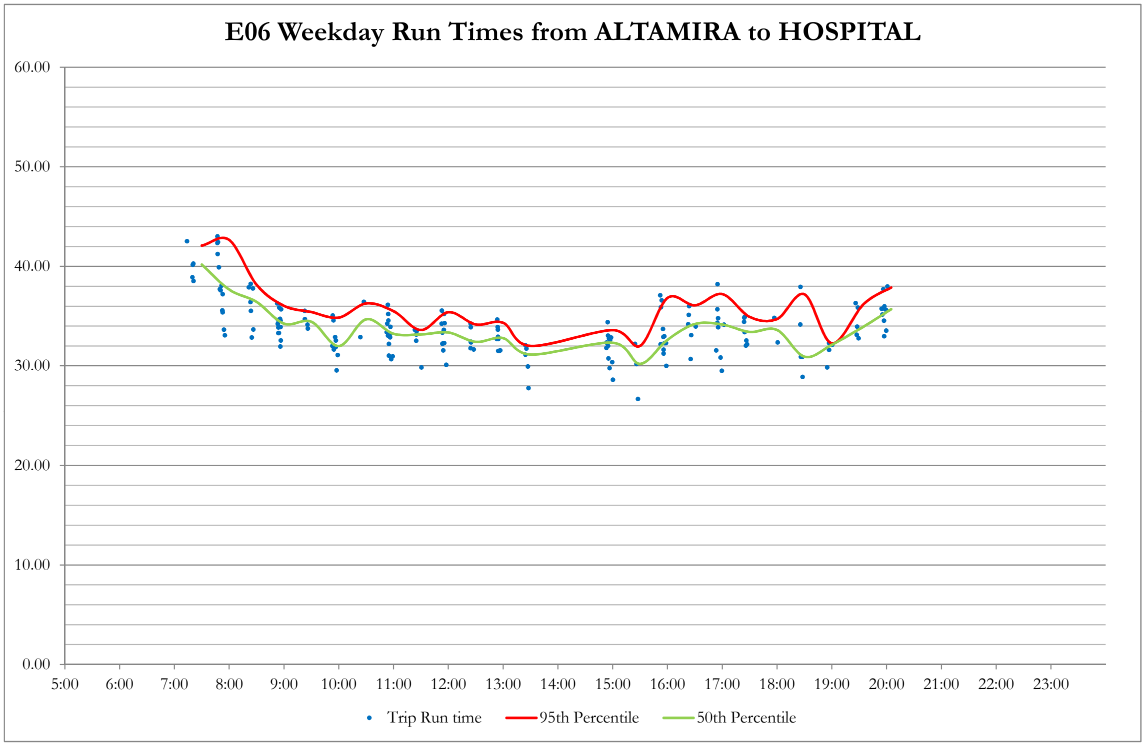


Figure A.16: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

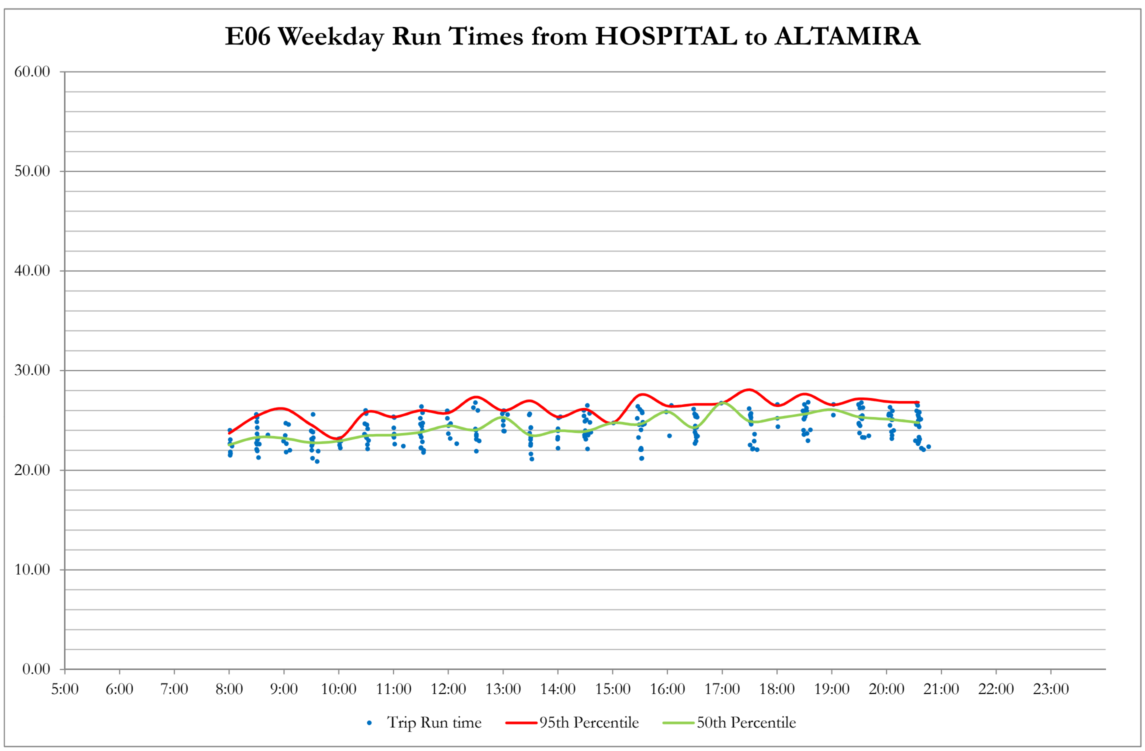
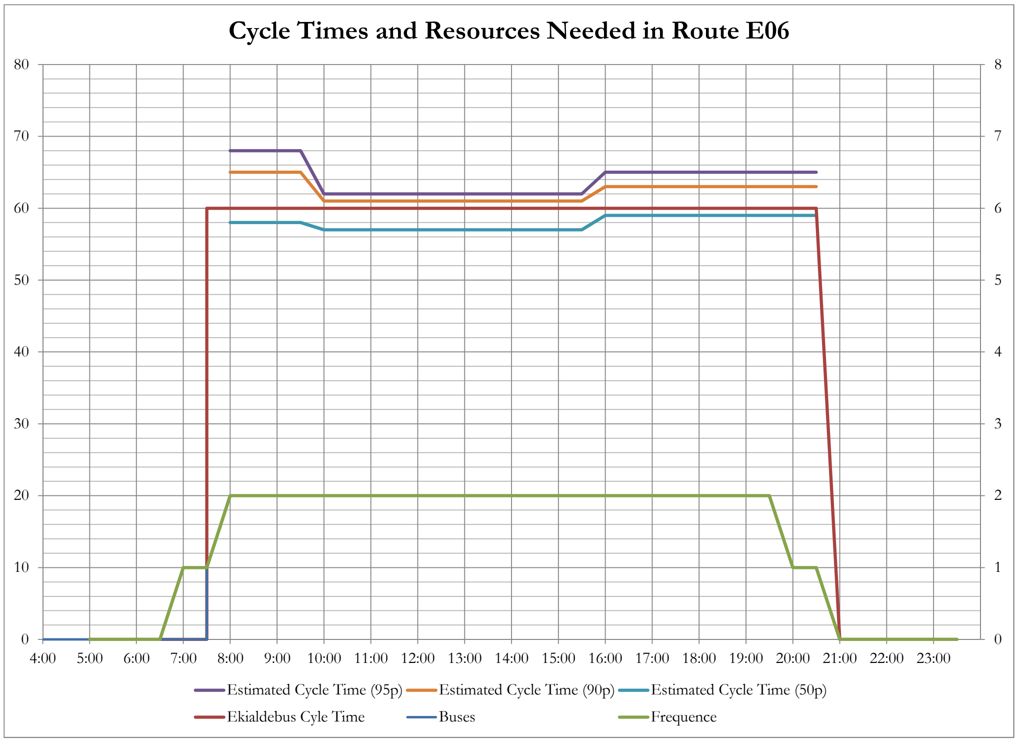


Figure A.17: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

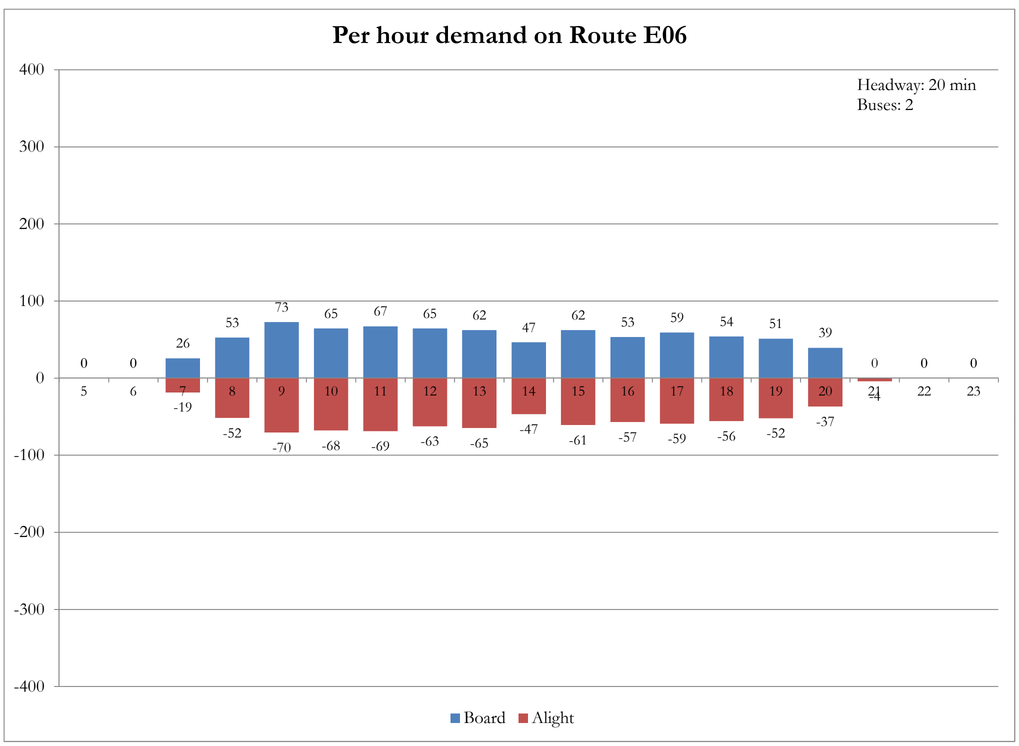
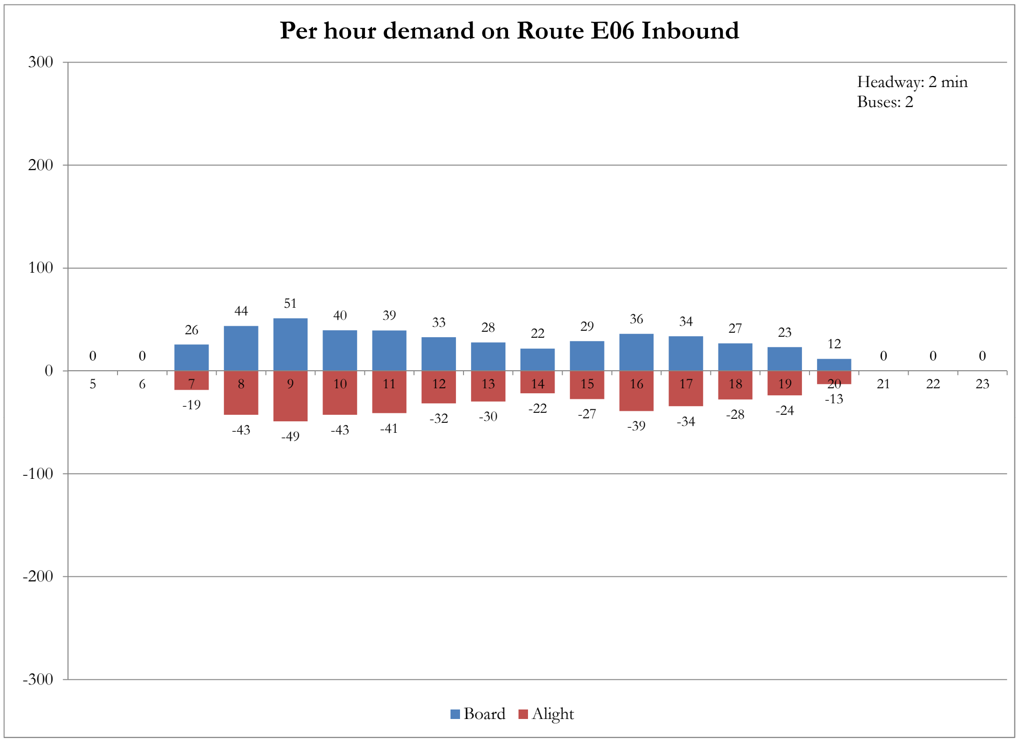


Figure A.18: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

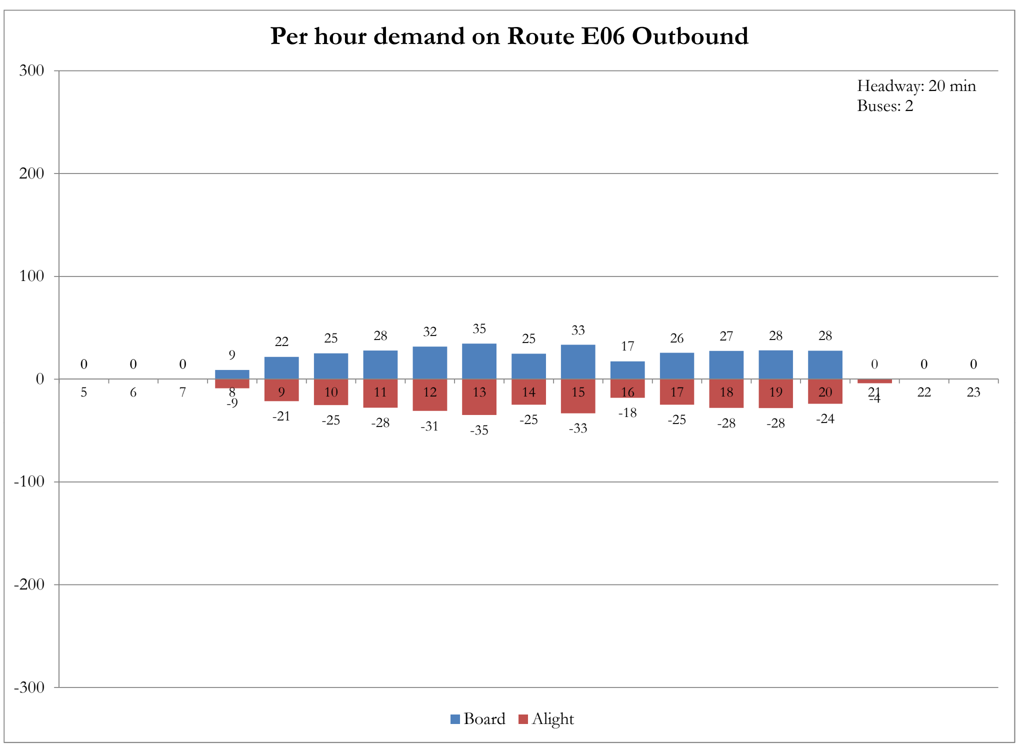
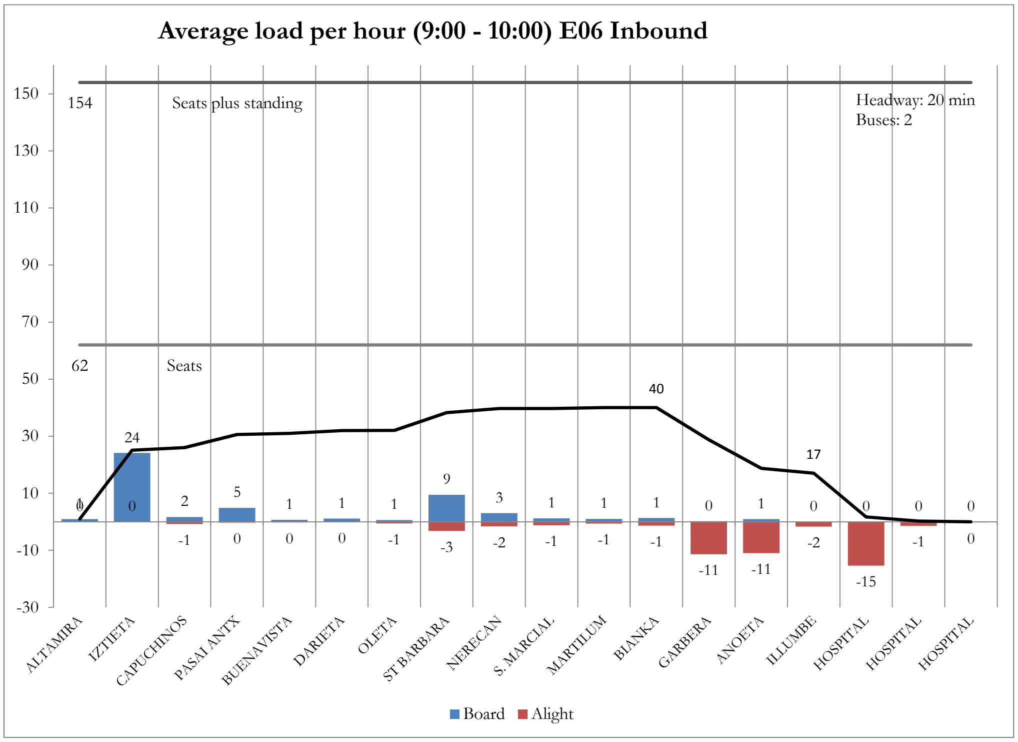


Figure A.19: Load Profiles

(a) Inbound



(b) Outbound

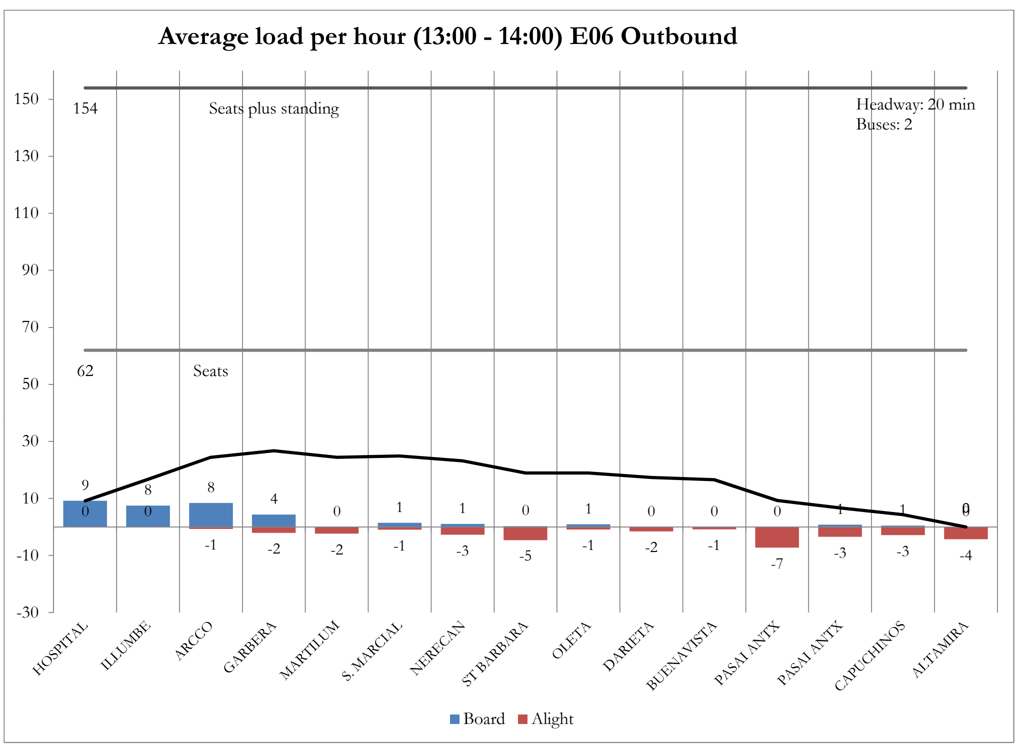
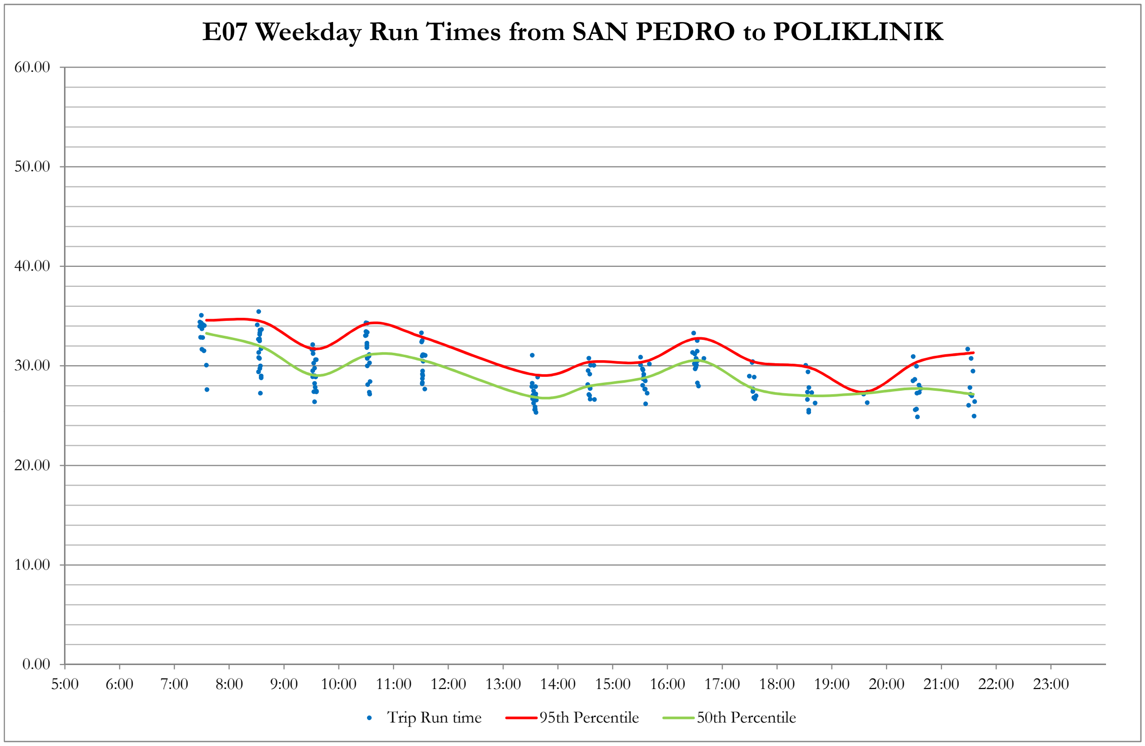


Figure A.20: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

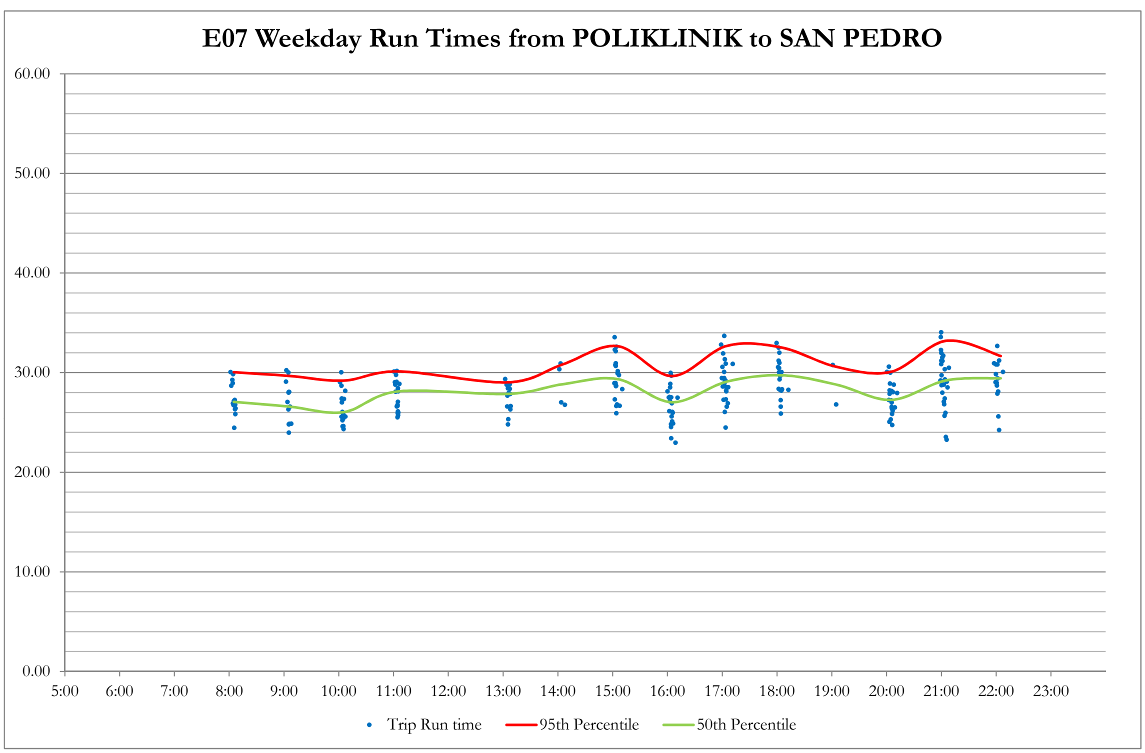
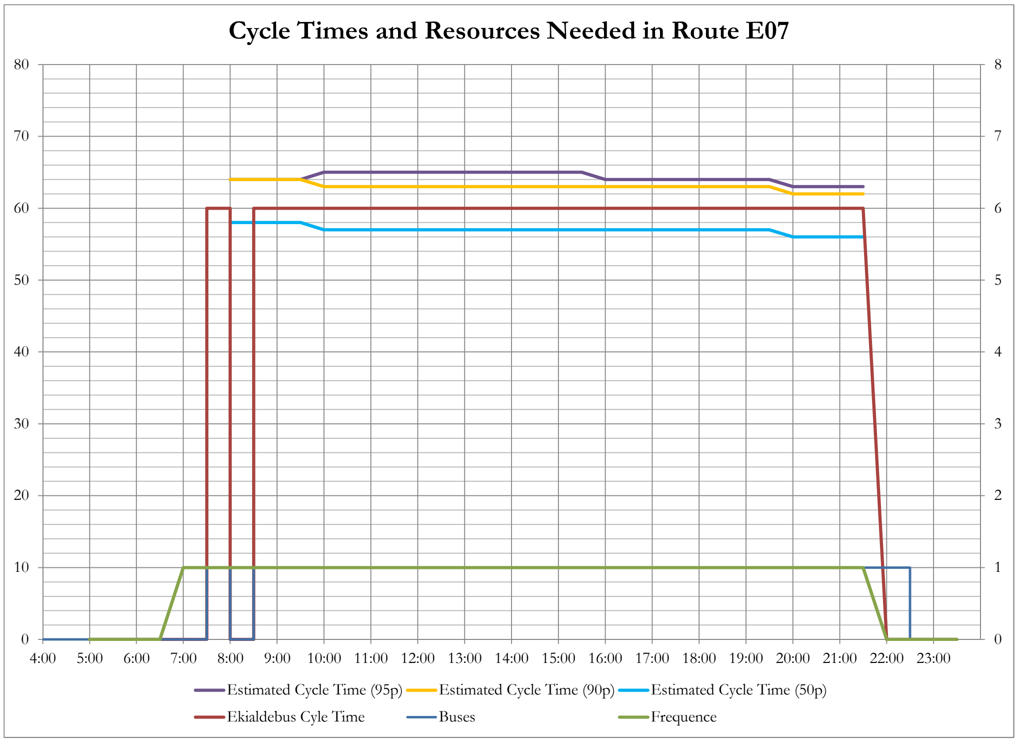


Figure A.21: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

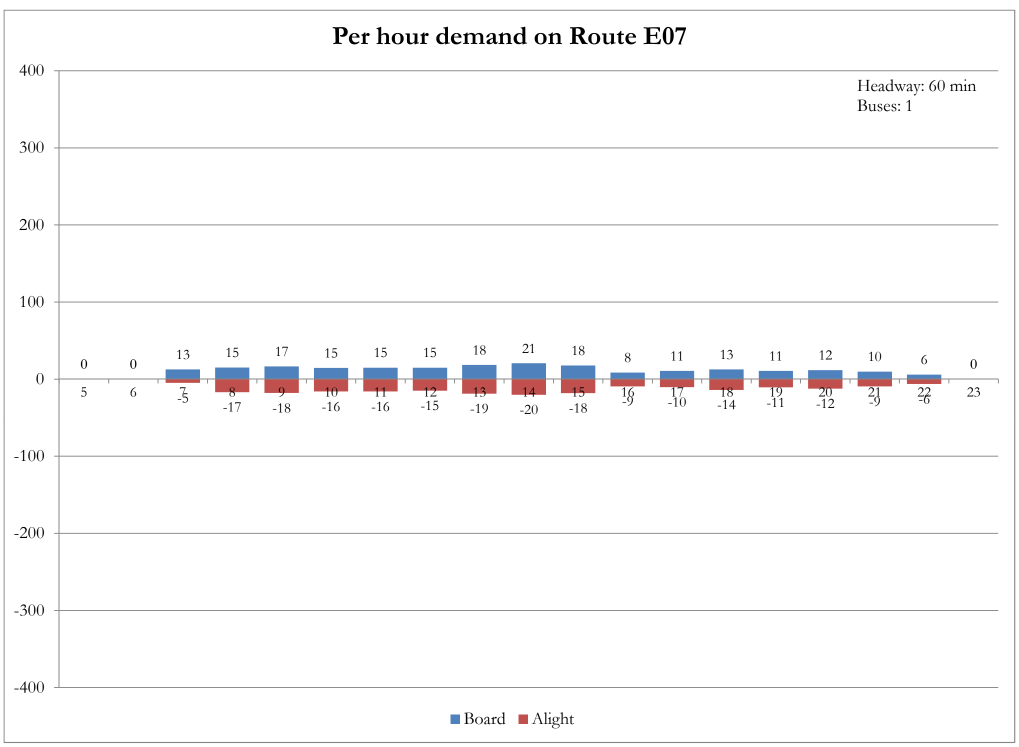
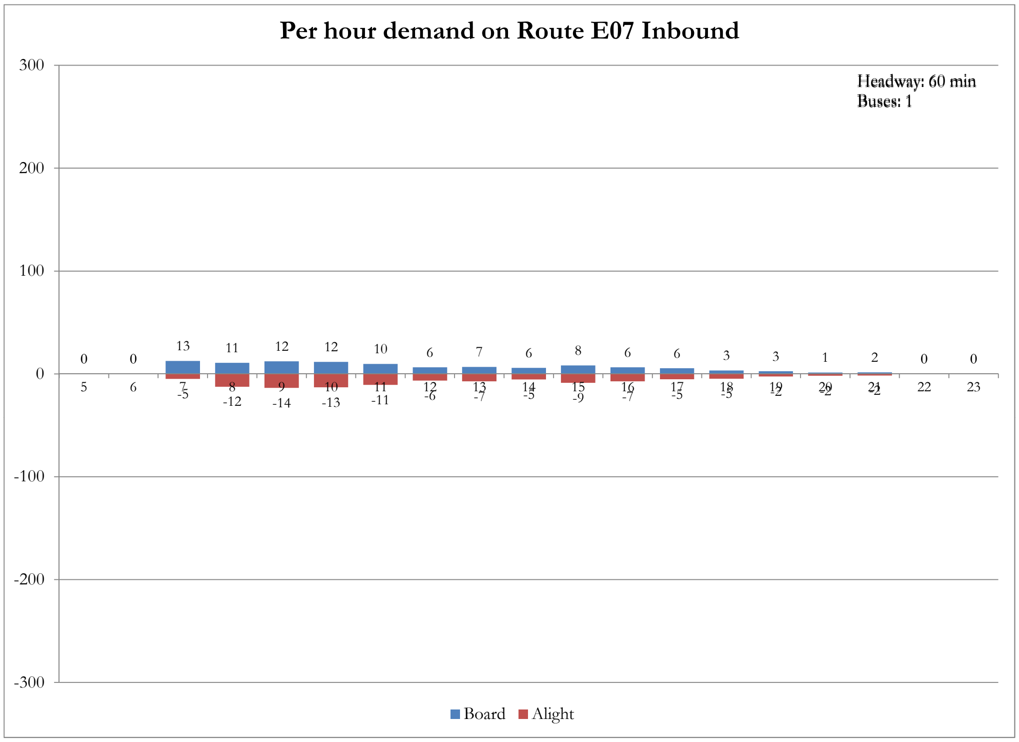


Figure A.22: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

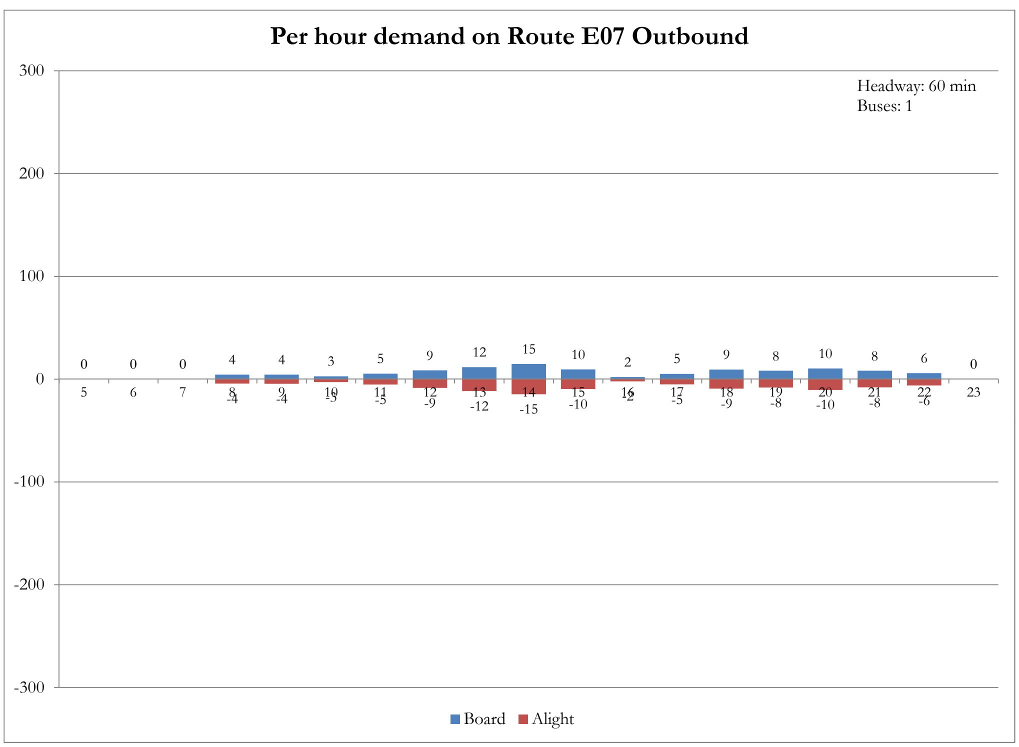
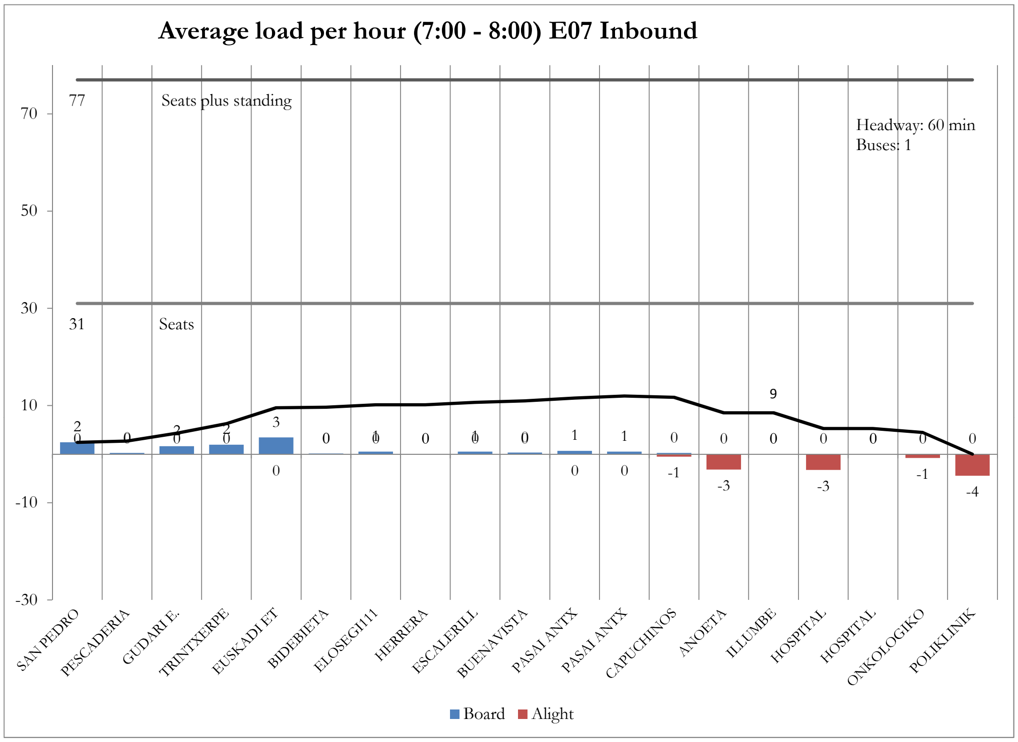


Figure A.23: Load Profiles

(a) Inbound



(b) Outbound

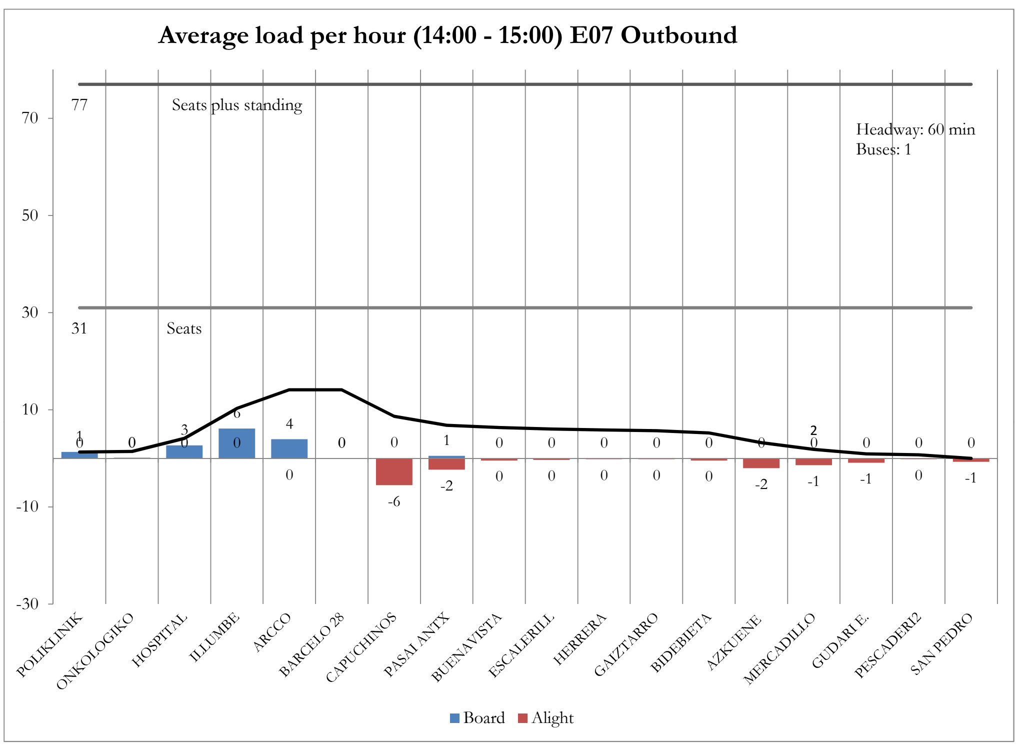
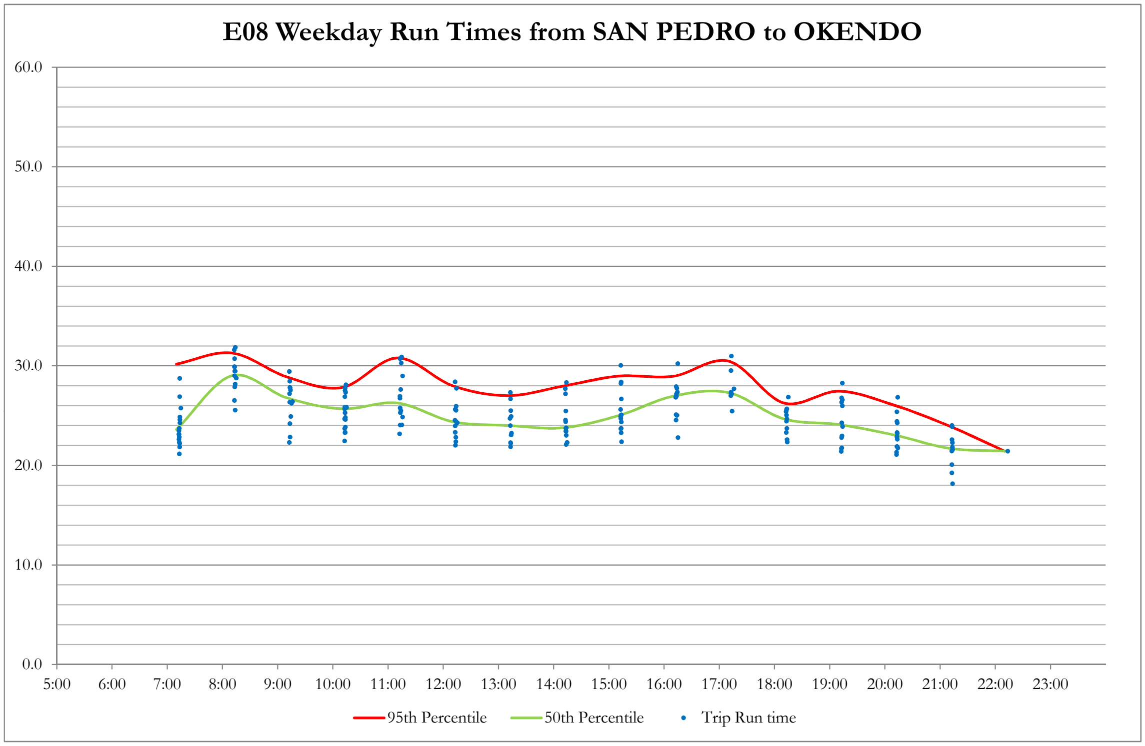


Figure A.24: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

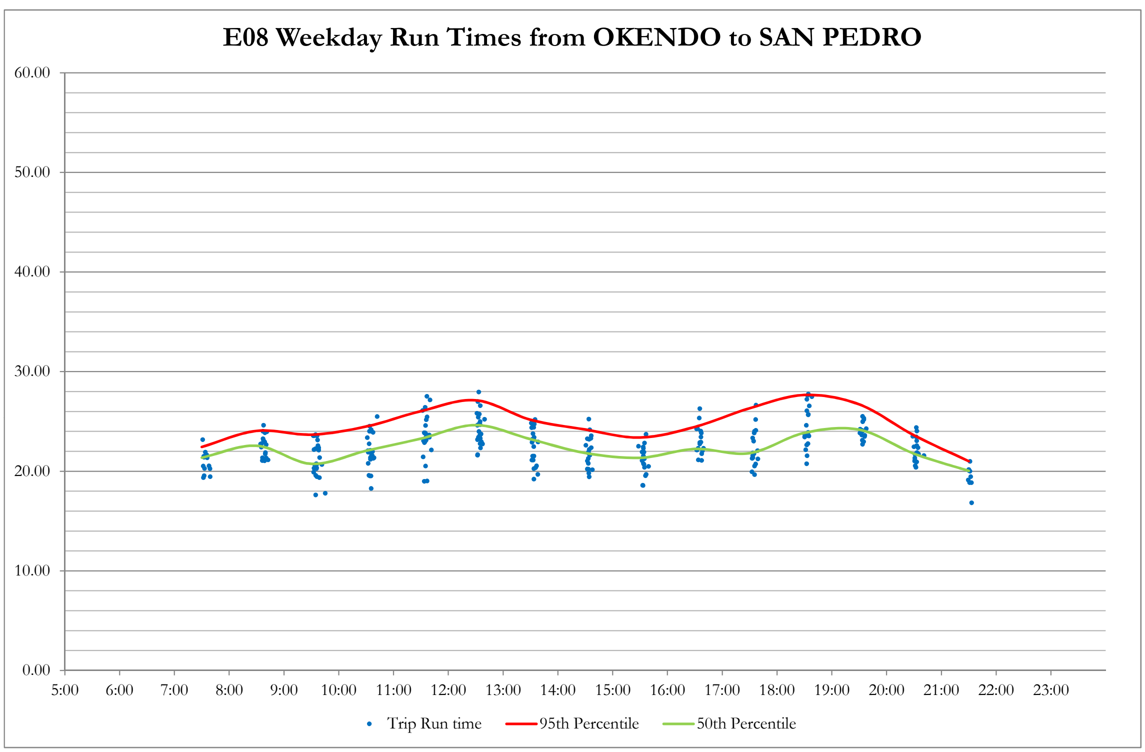
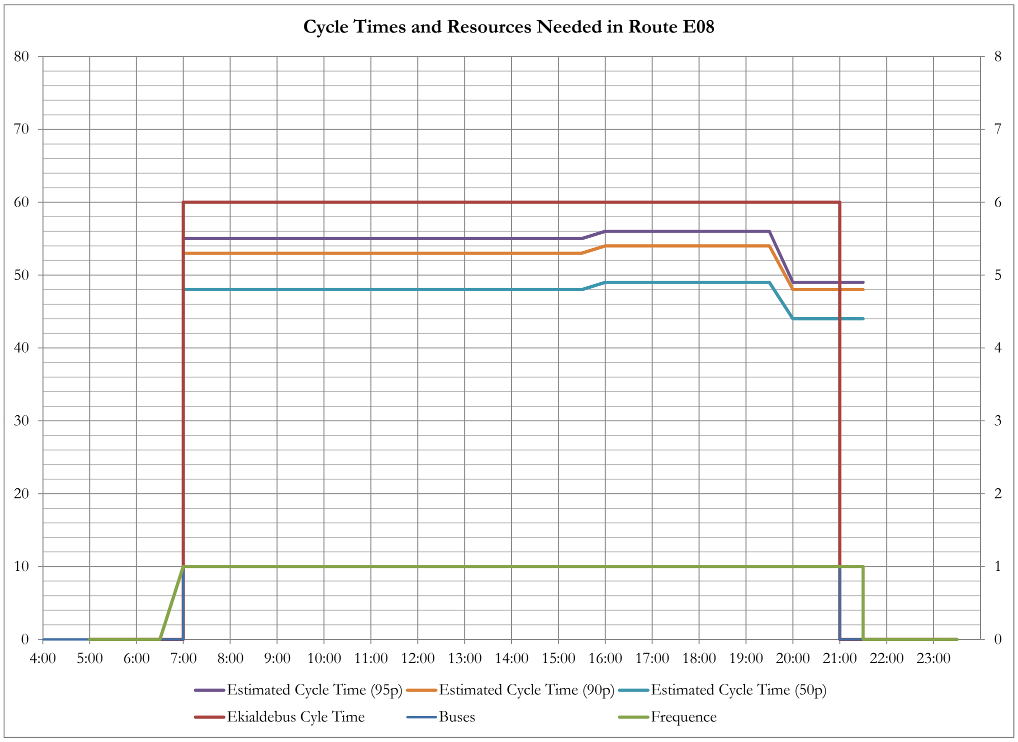


Figure A.25: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

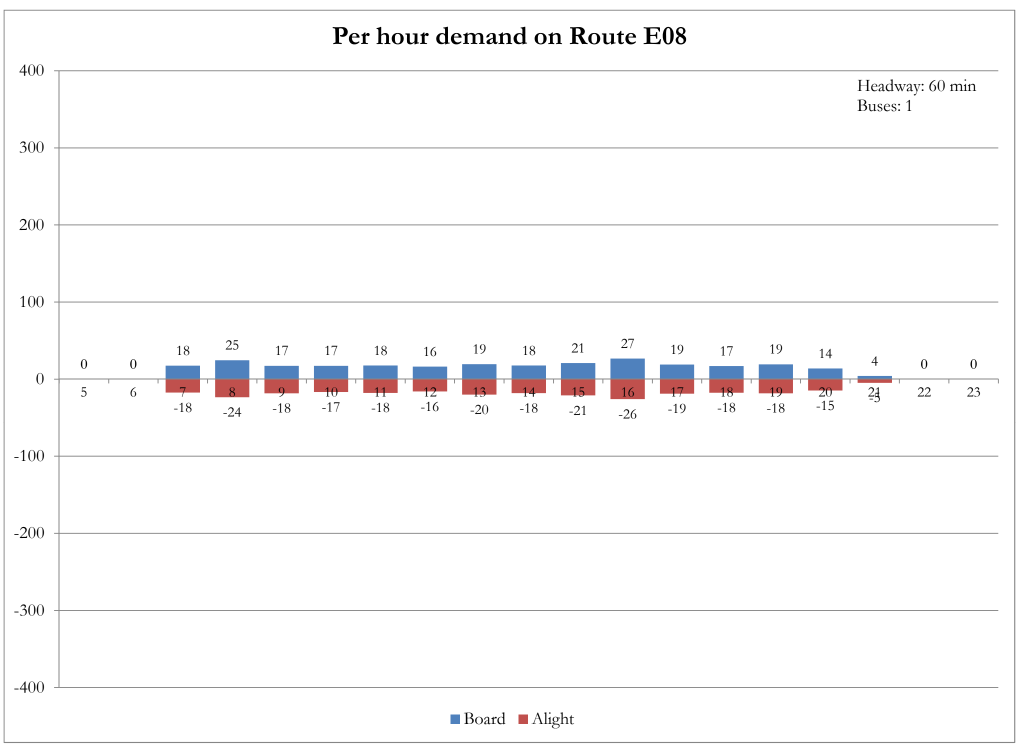
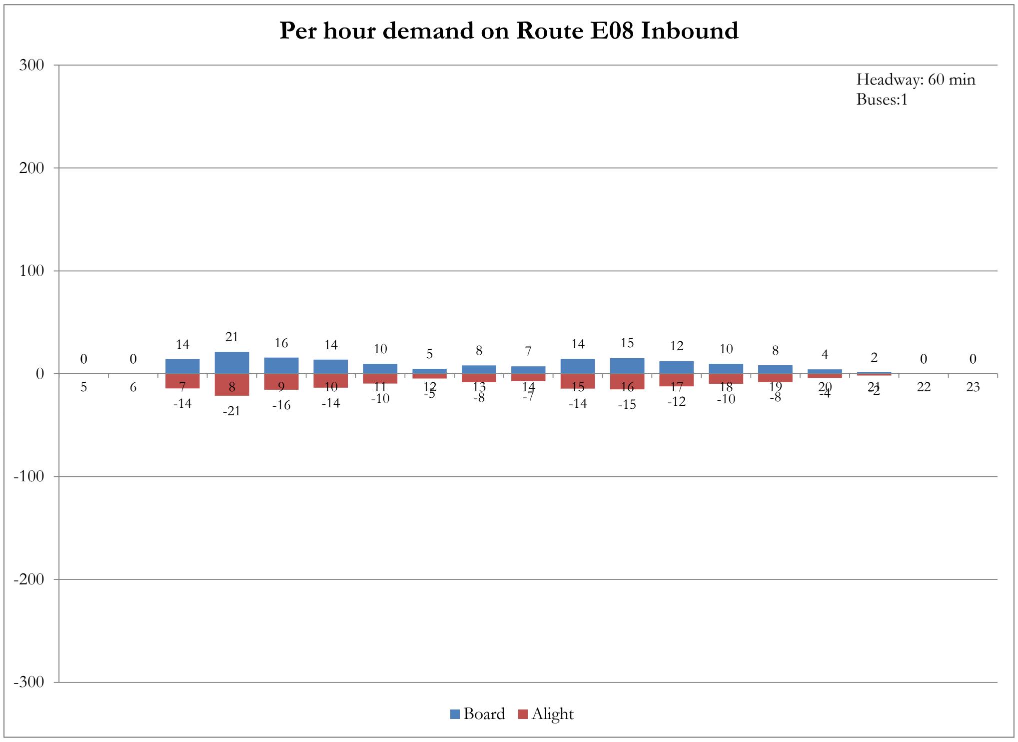


Figure A.26: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

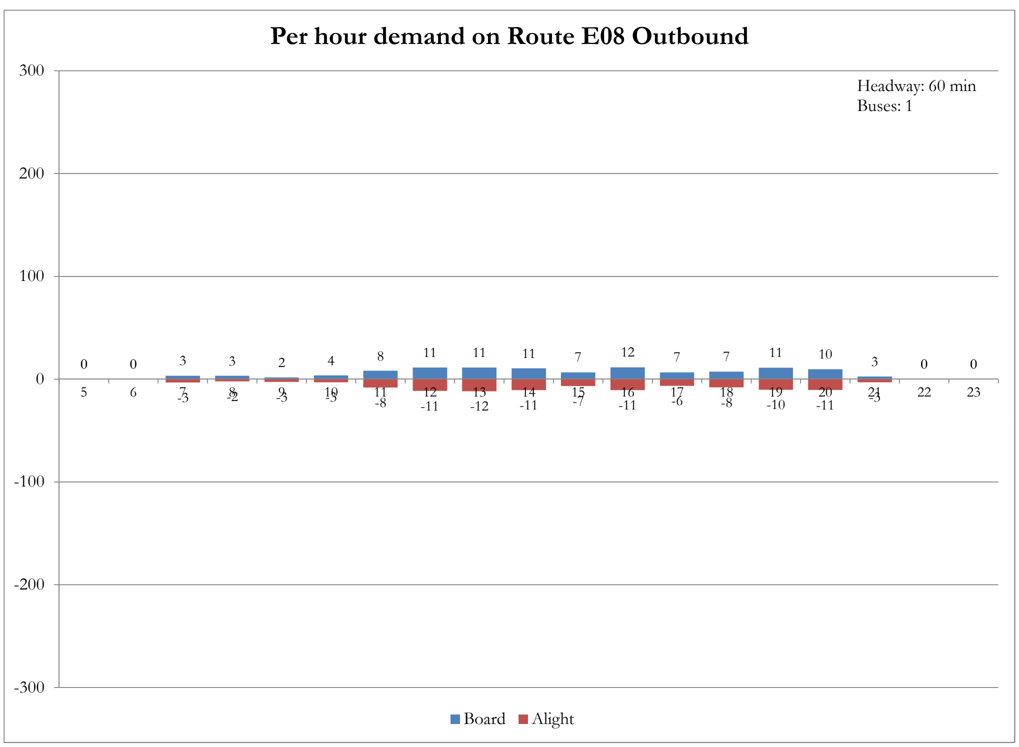
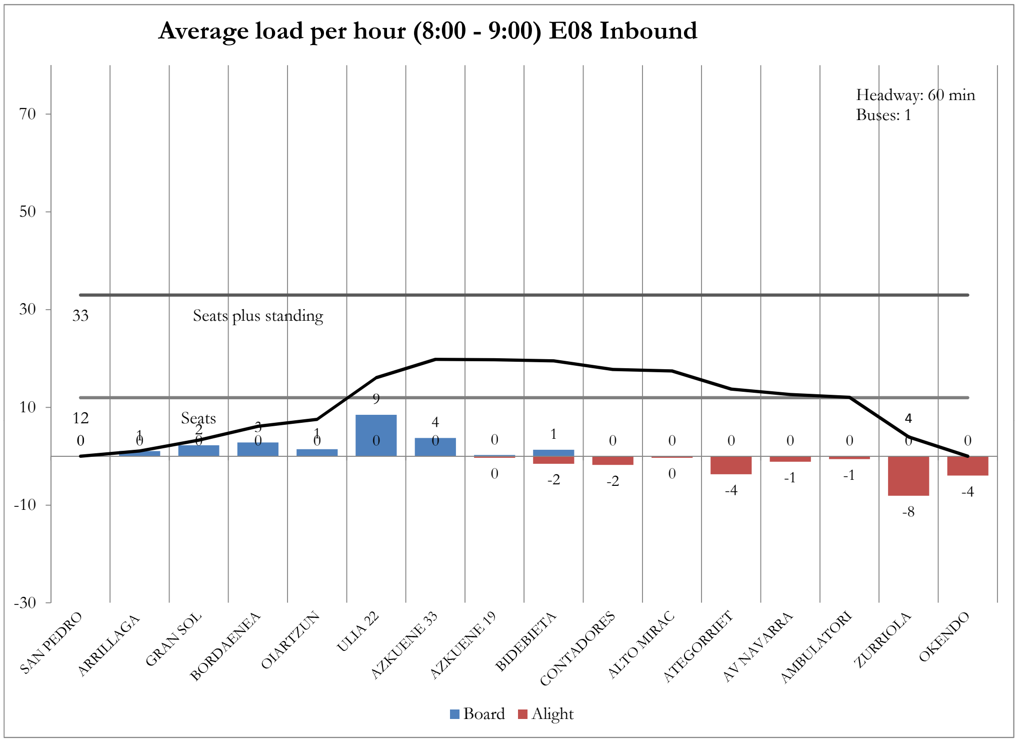


Figure A.27: Load Profiles

(a) Inbound



(b) Outbound

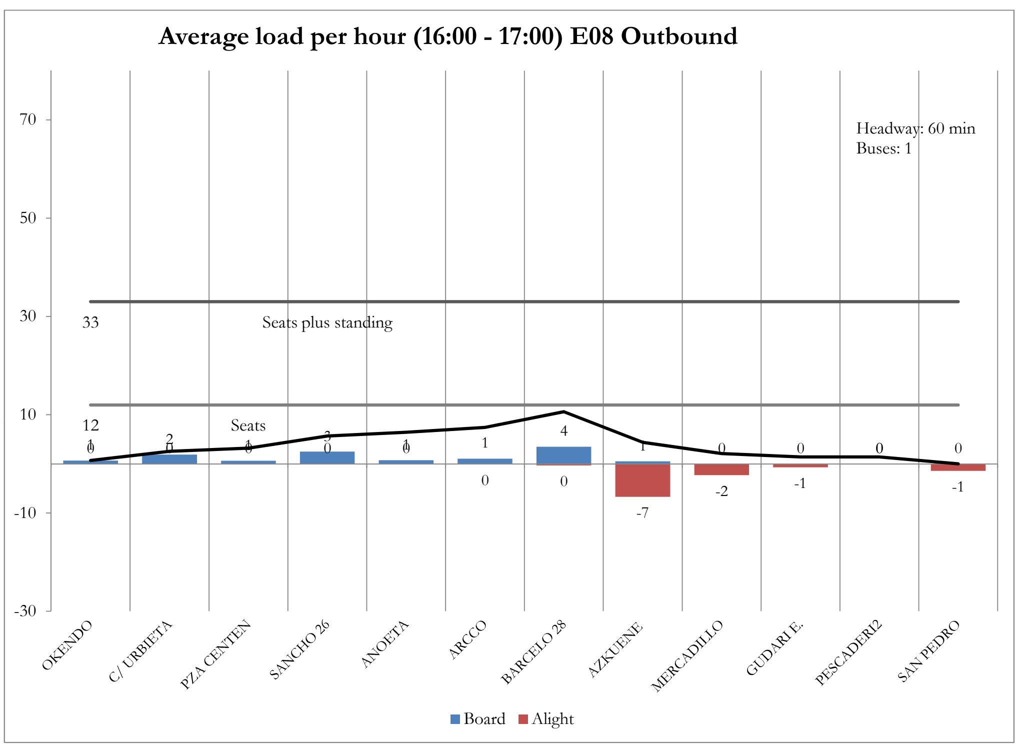
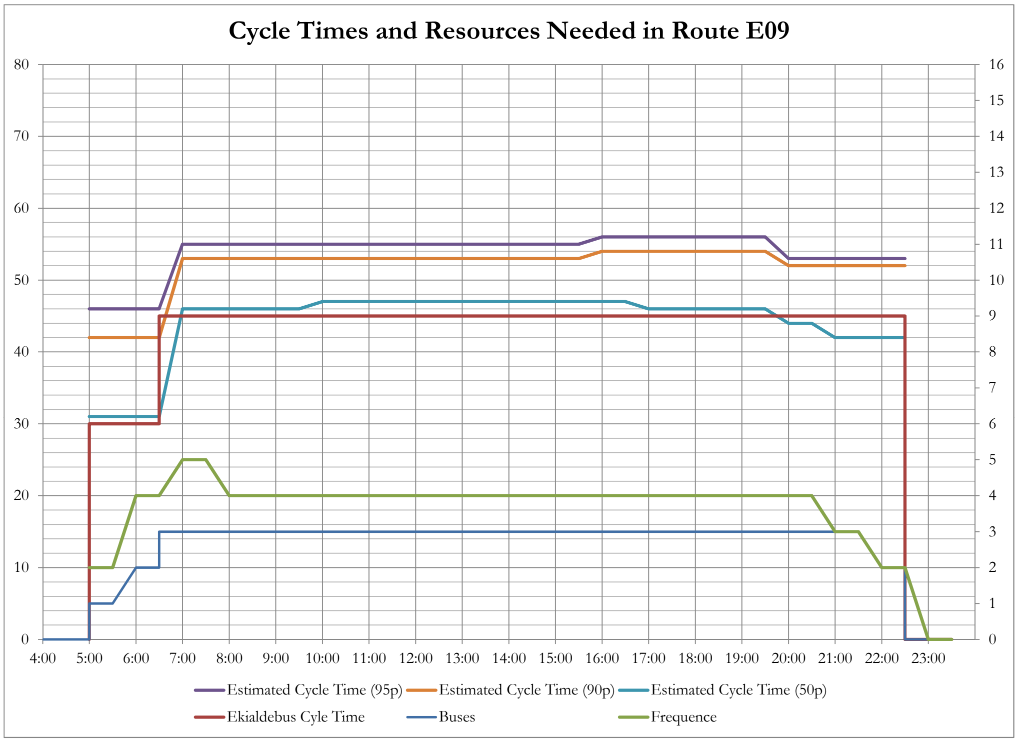


Figure A.28: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

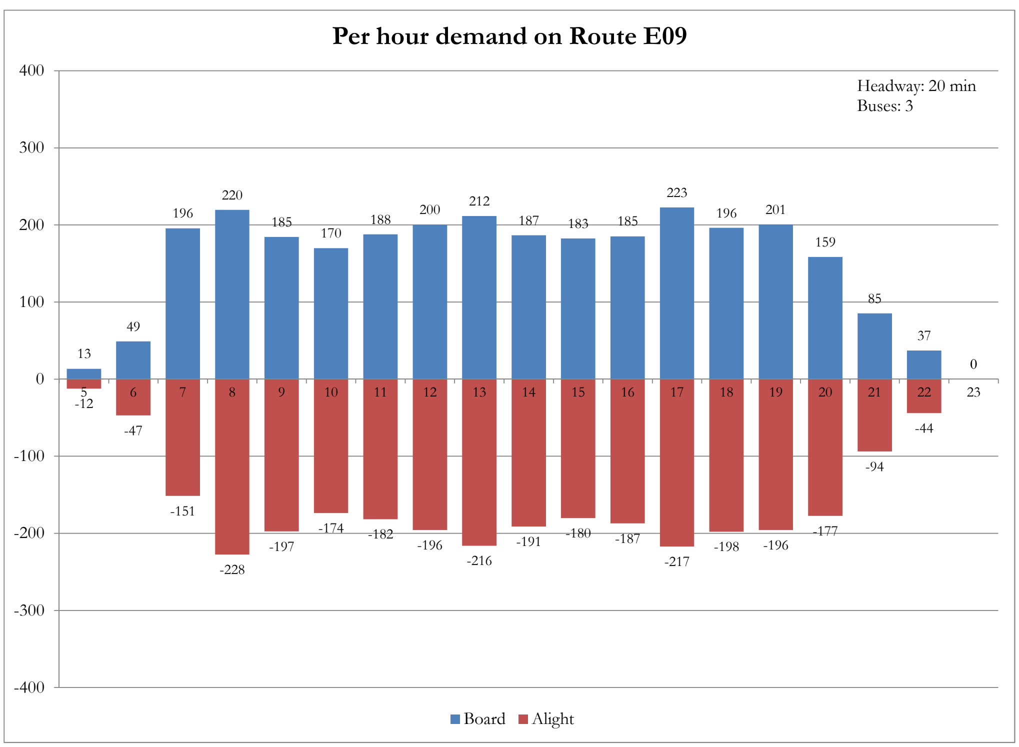
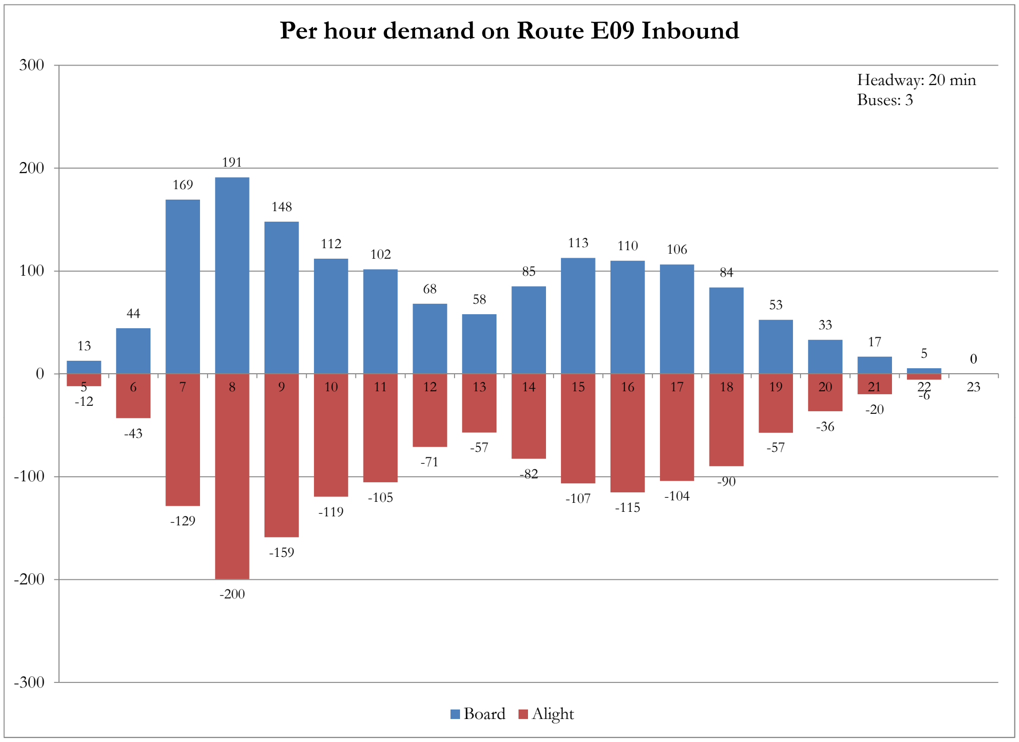


Figure A.29: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

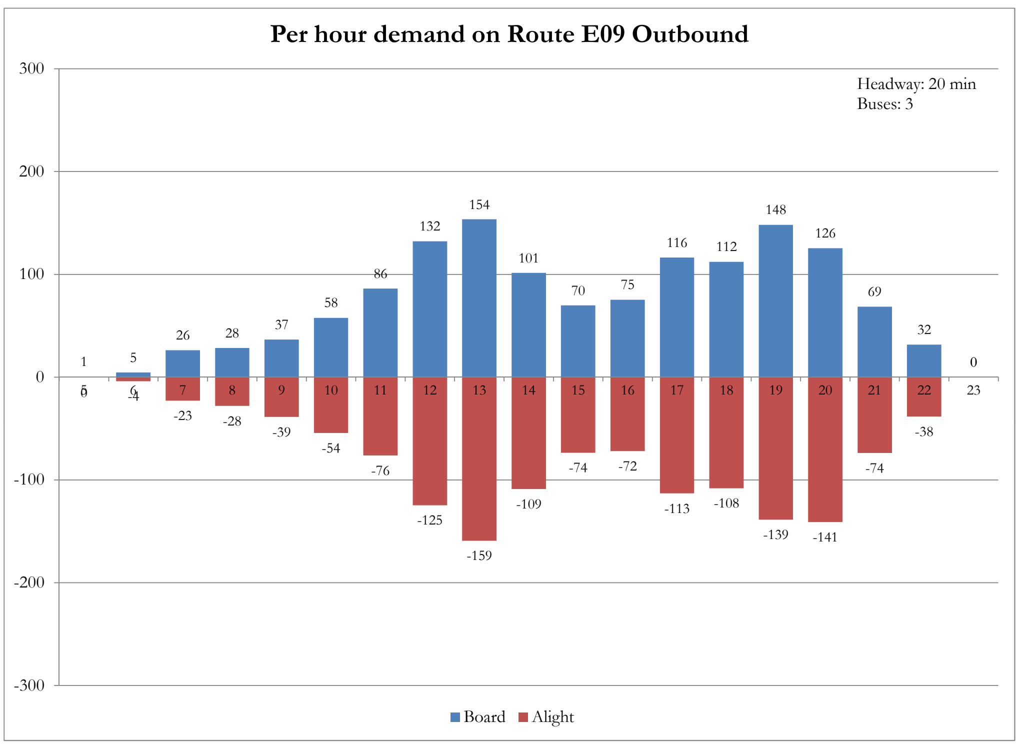
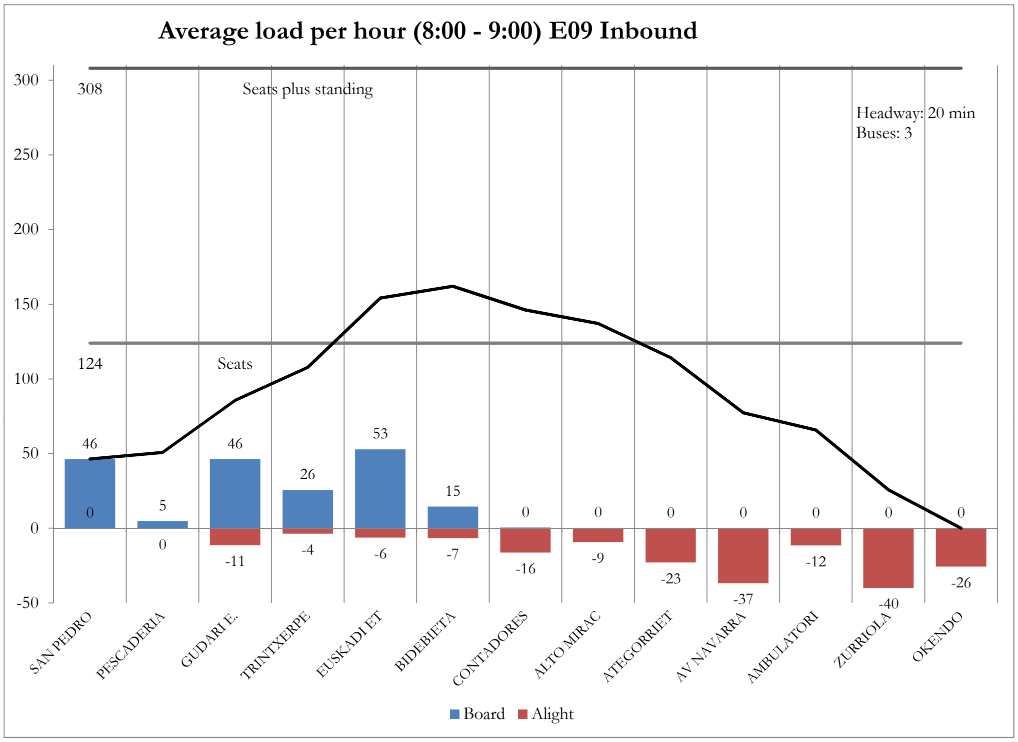
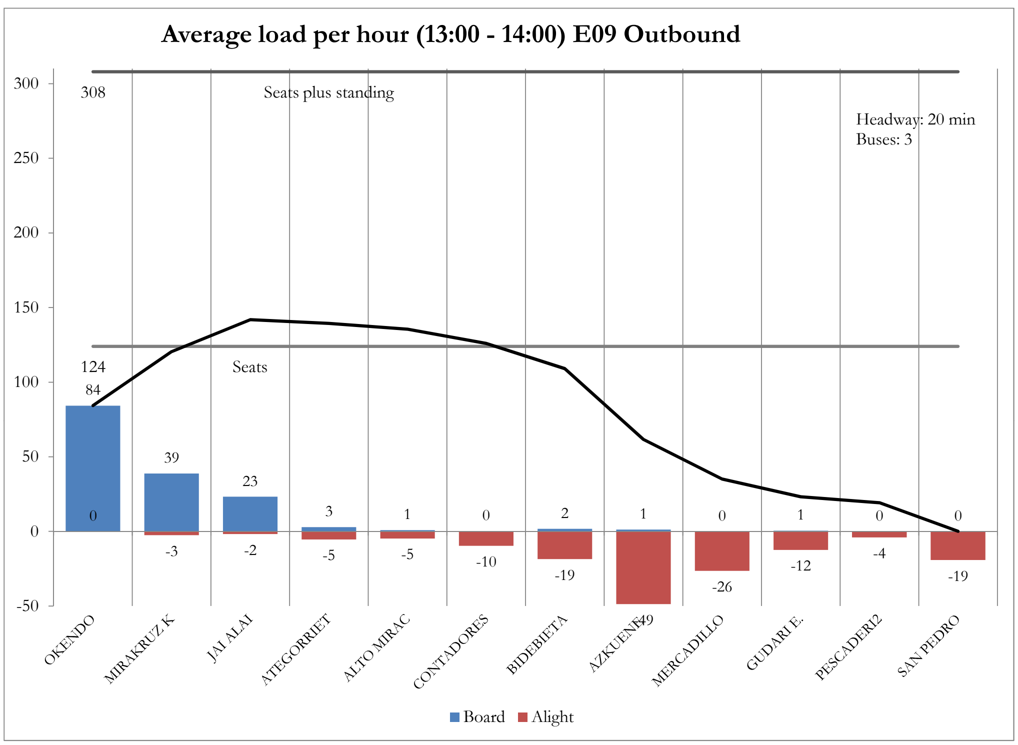


Figure A.30: Load Profiles

(a) Inbound



(b) Outbound

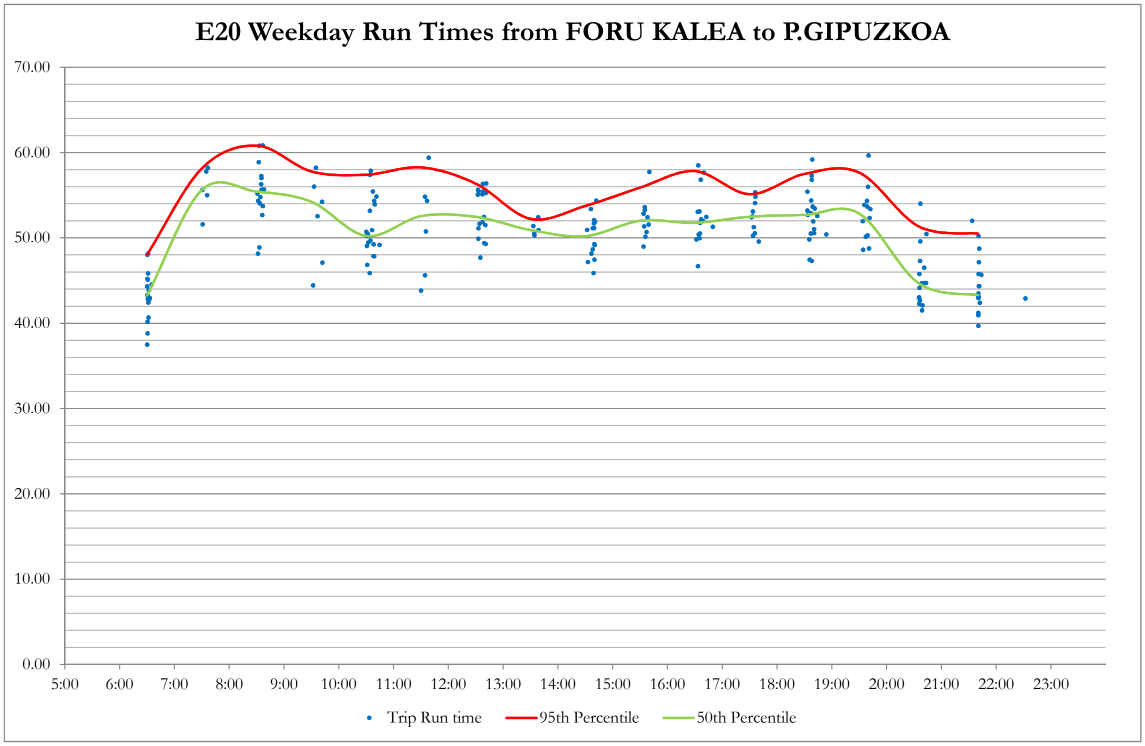


Appendix B

Supply and Demand Analysis of Bidasoaldea

Figure B.1: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

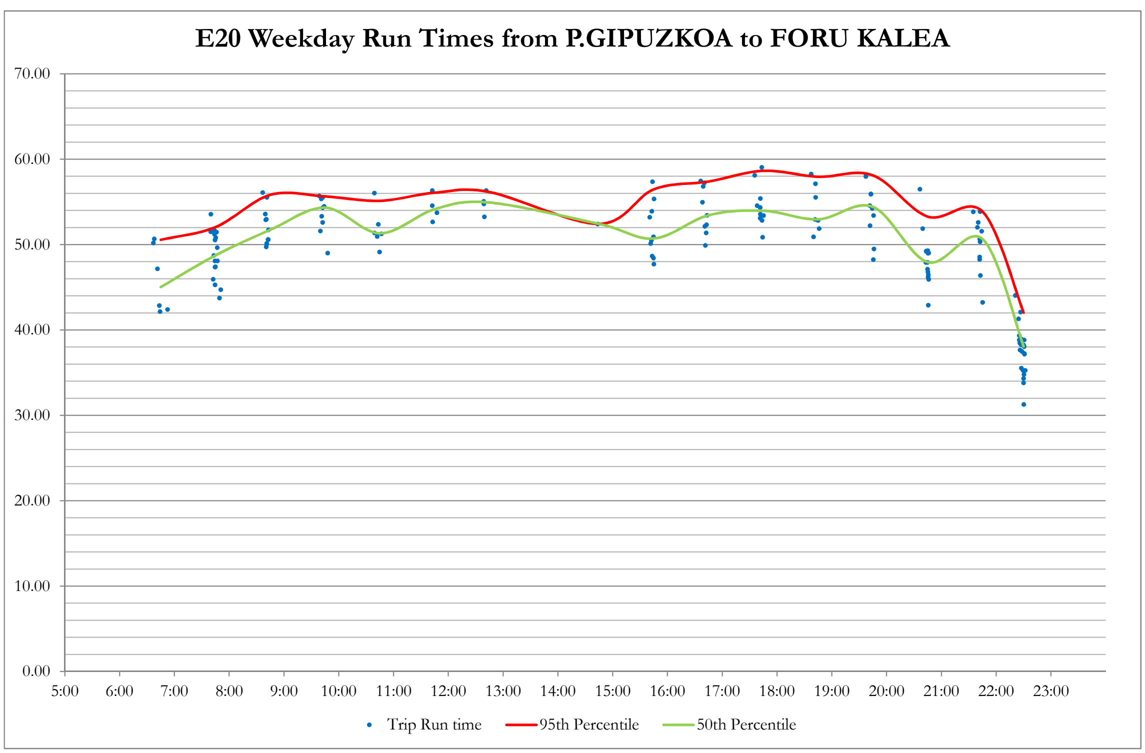
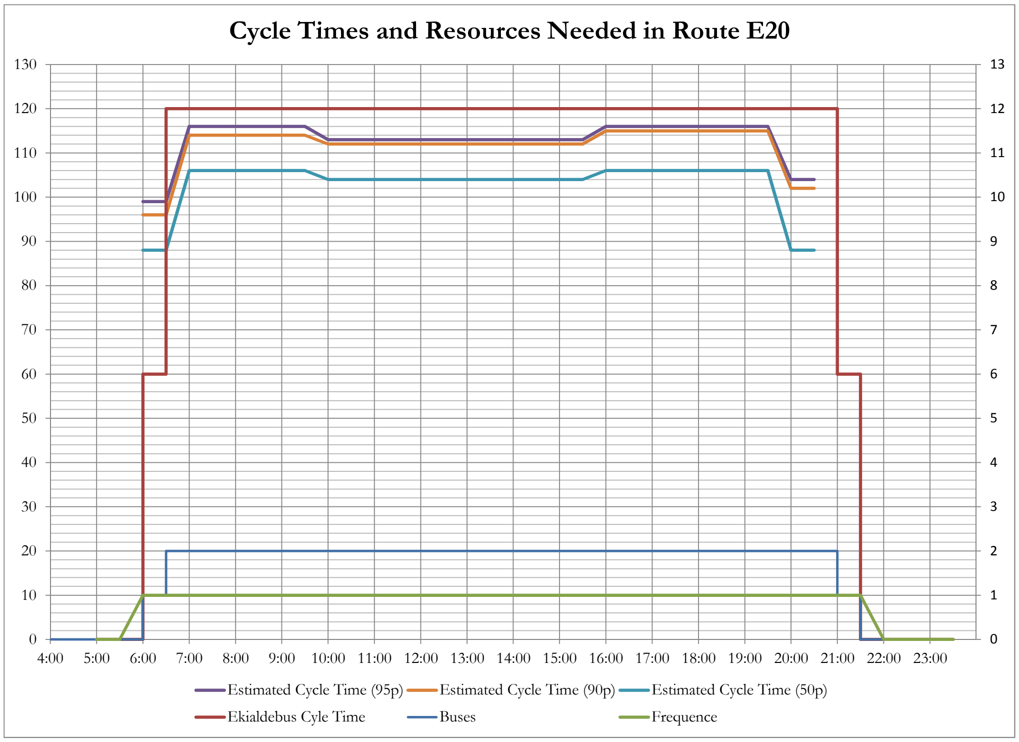


Figure B.2: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

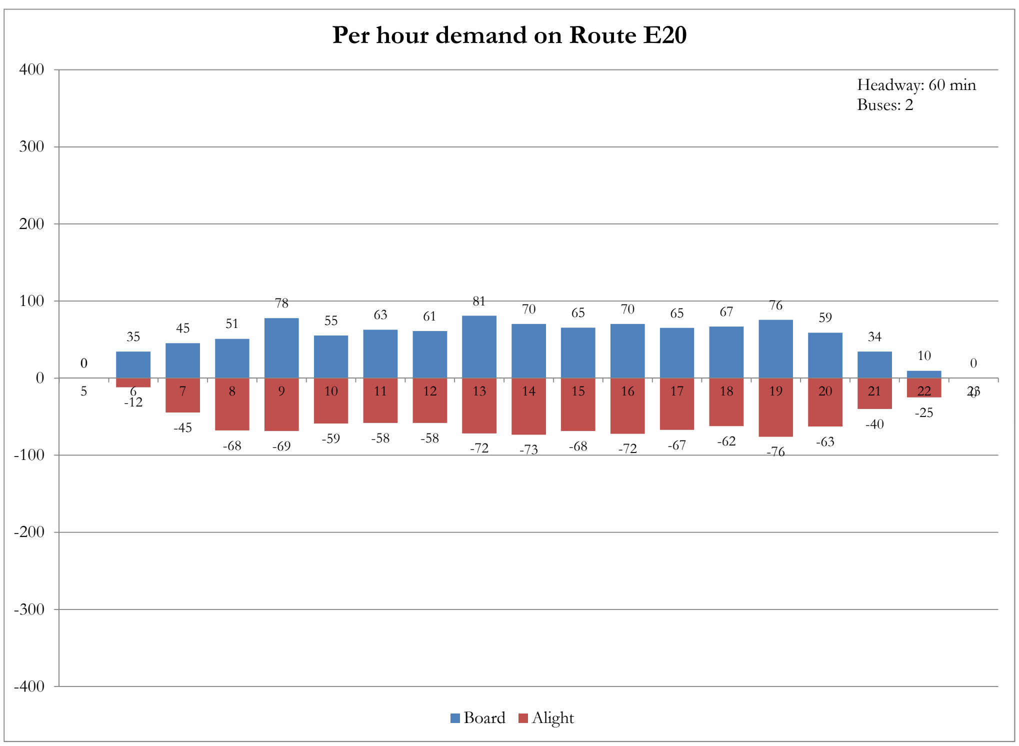
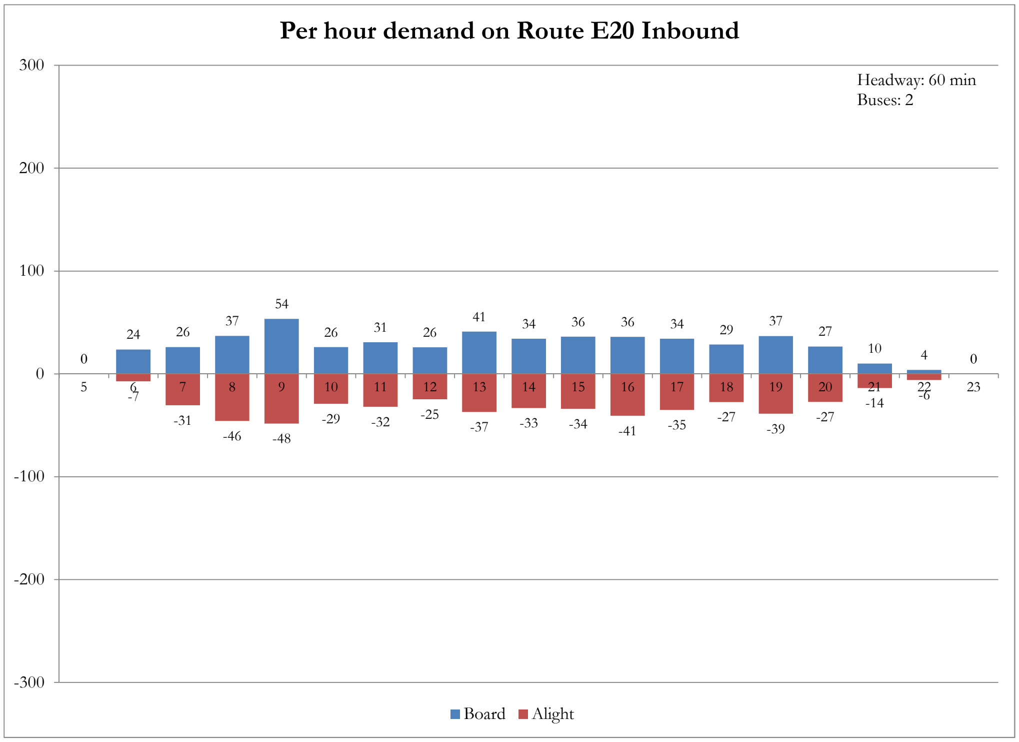


Figure B.3: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

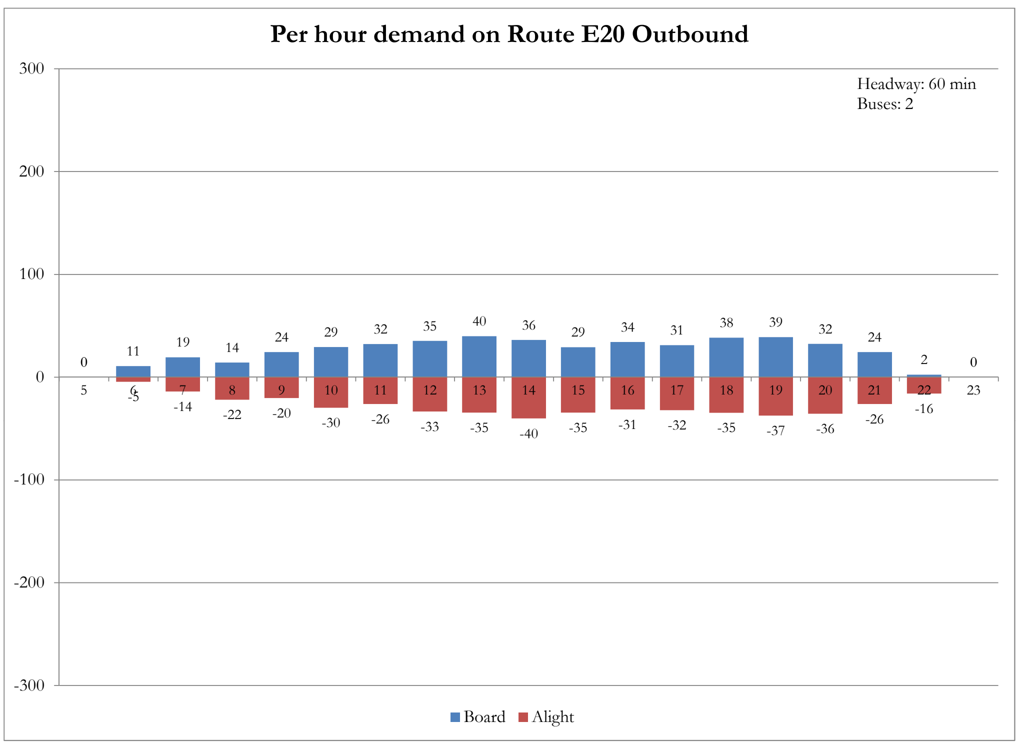
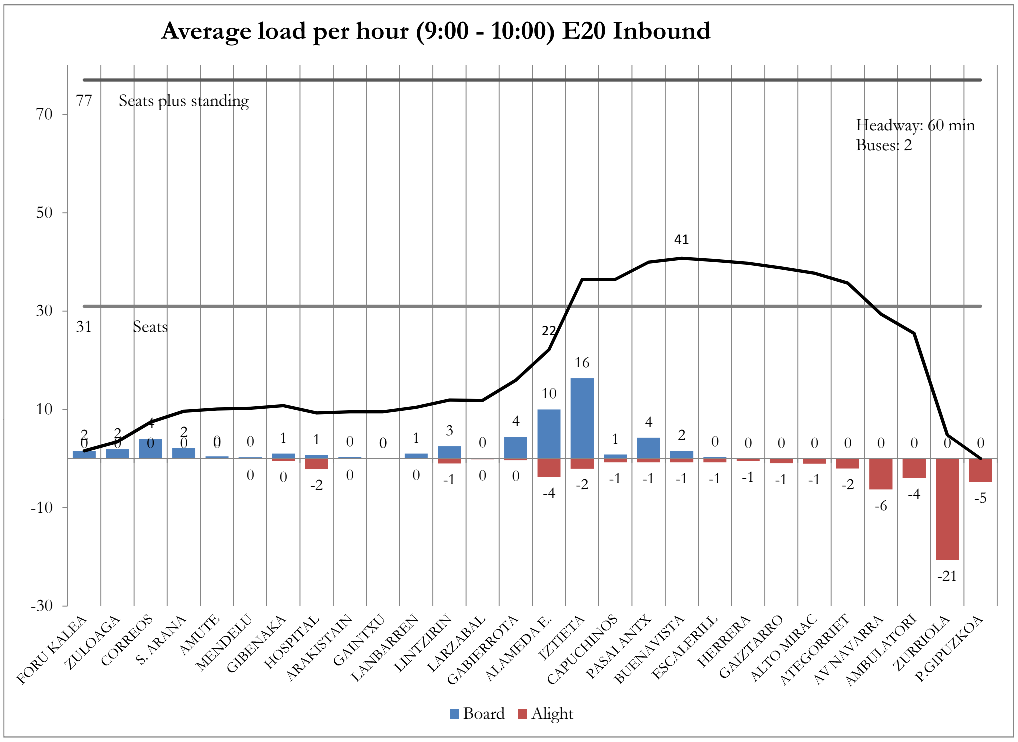


Figure B.4: Load Profiles

(a) Inbound



(b) Outbound

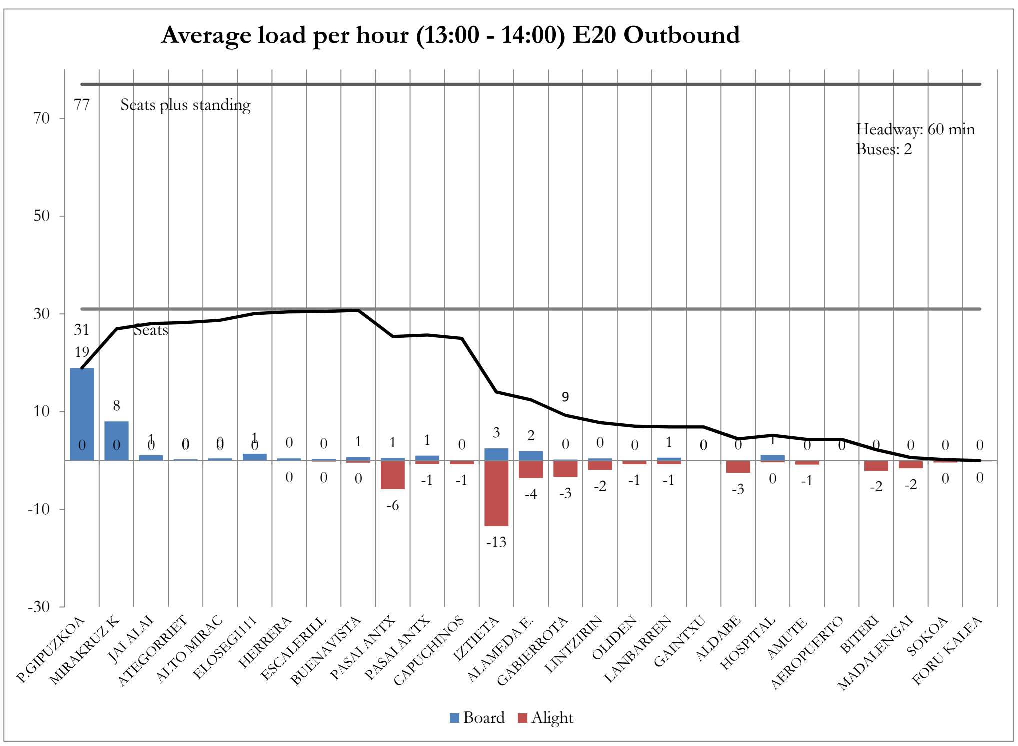
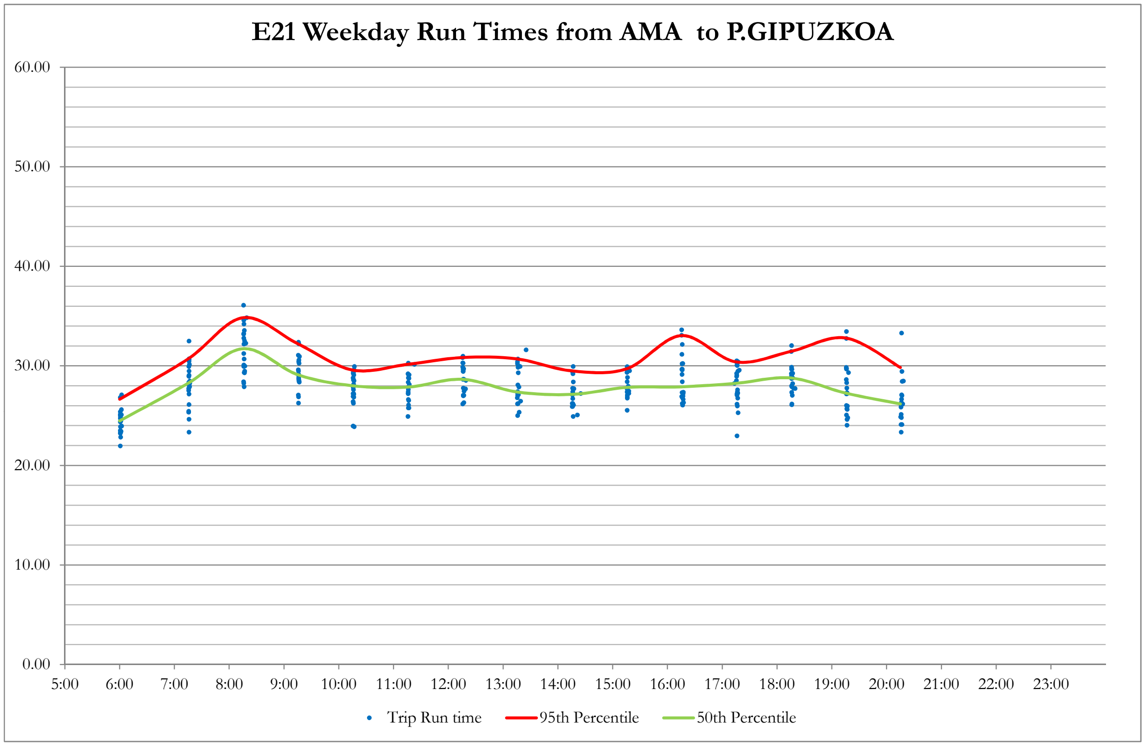


Figure B.5: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

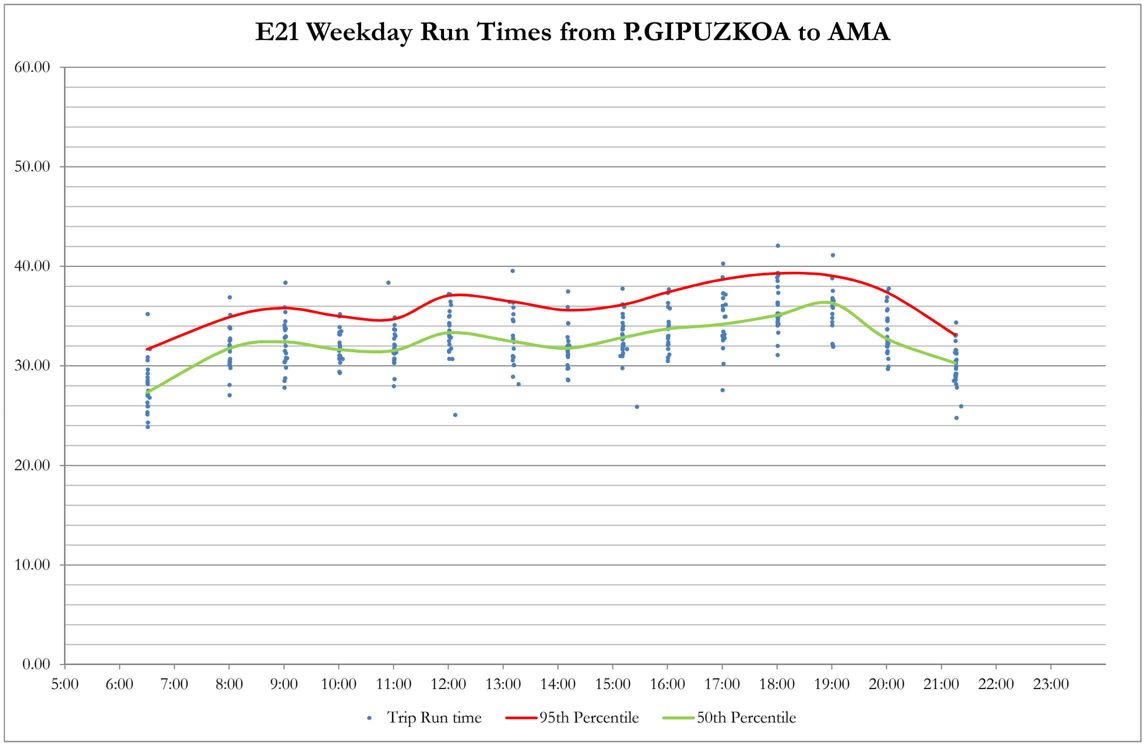
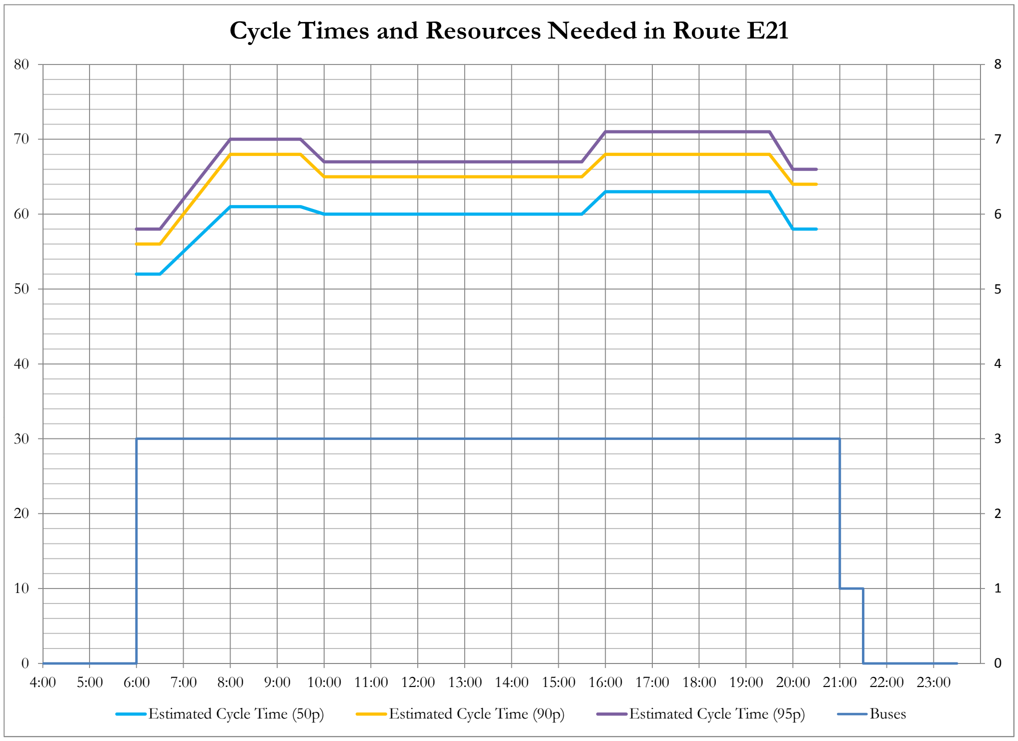


Figure B.6: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

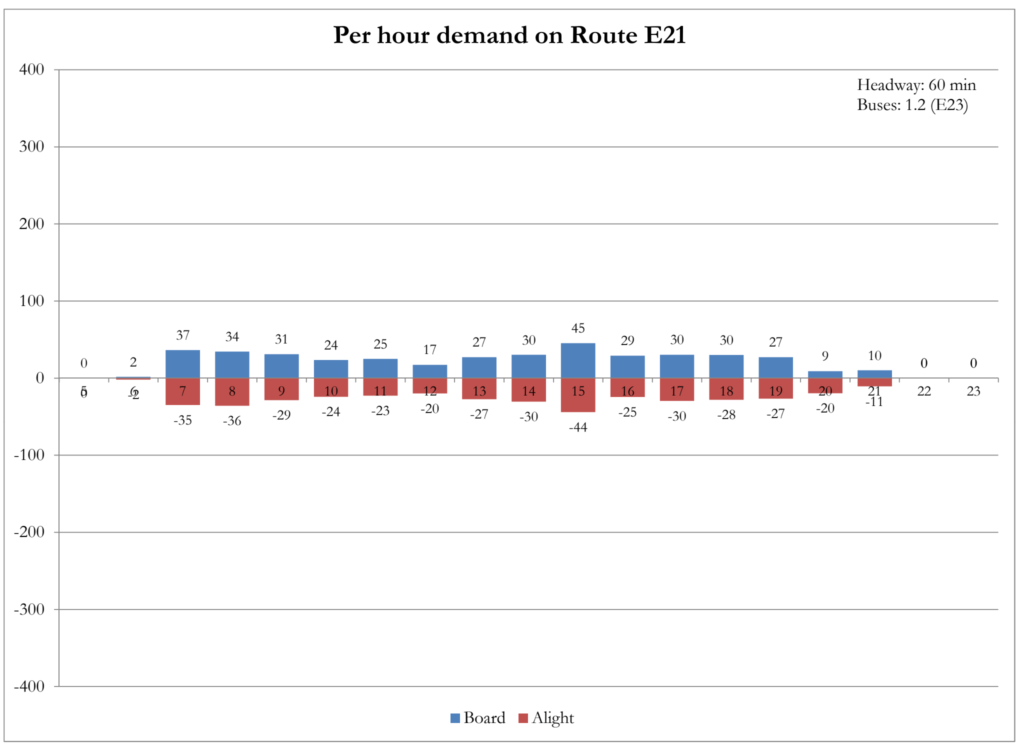
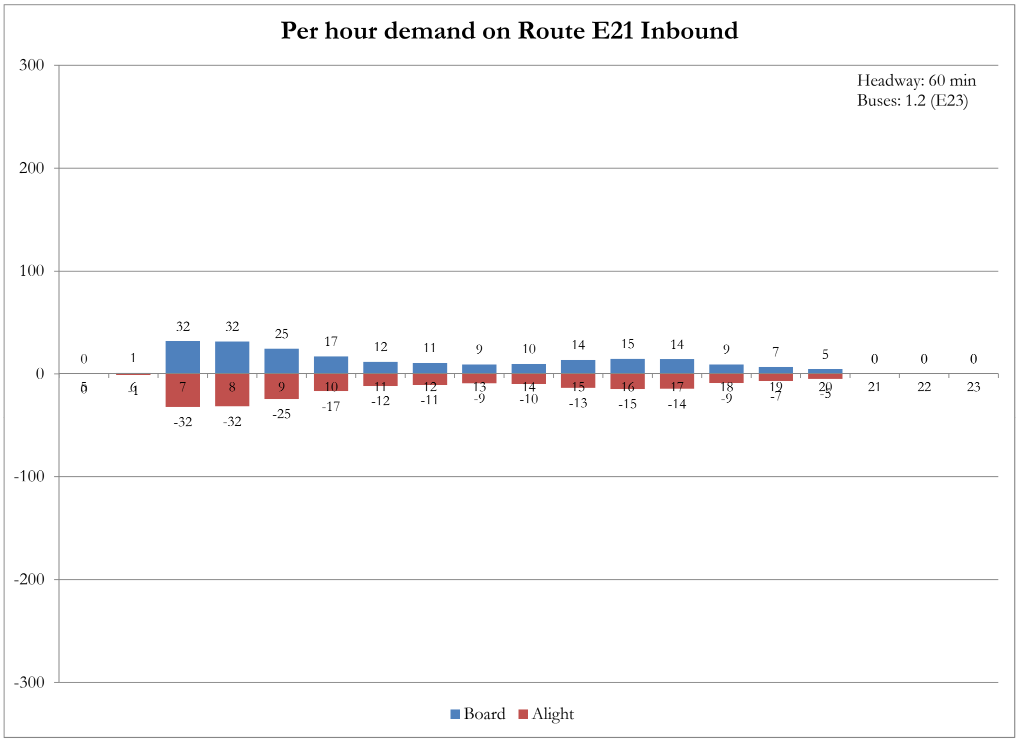


Figure B.7: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

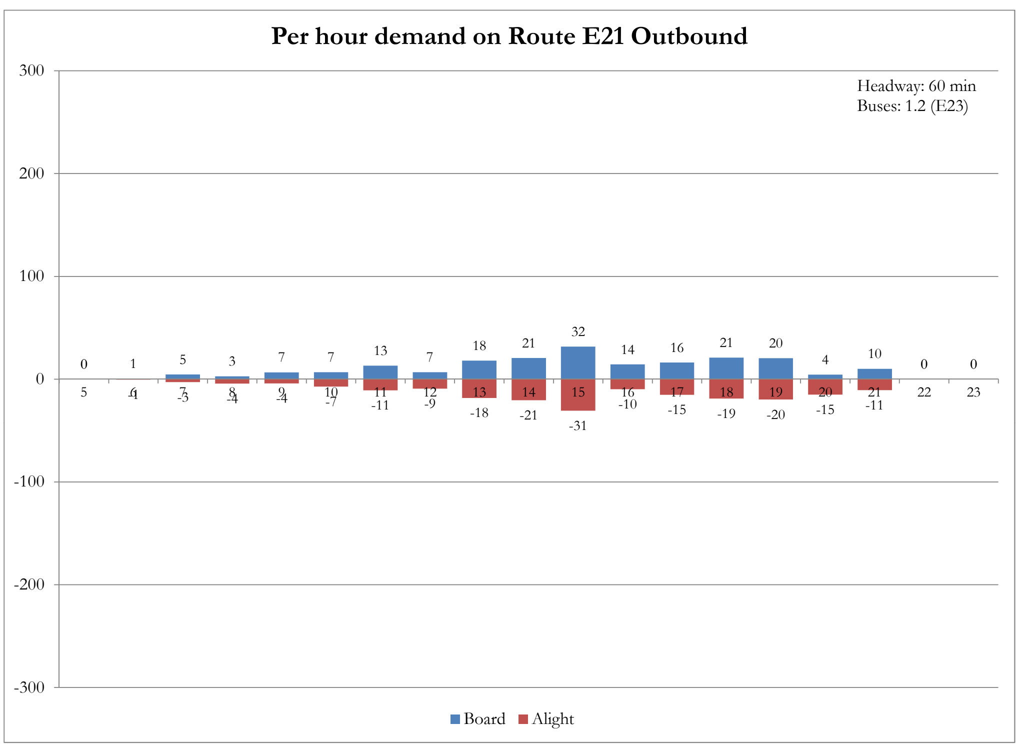
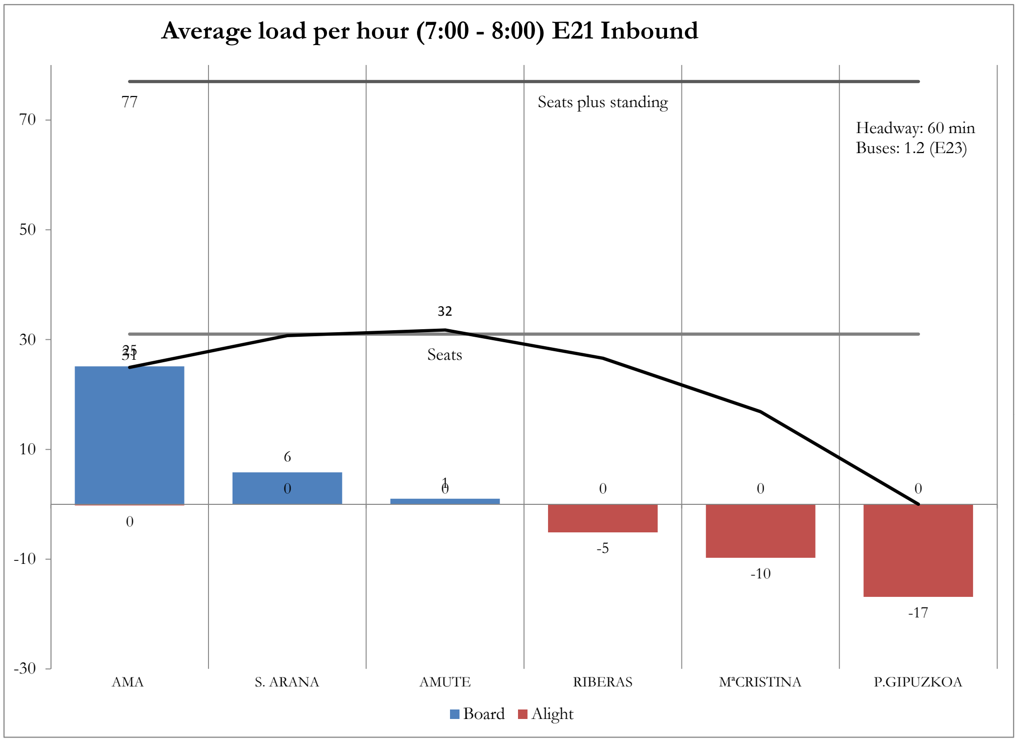


Figure B.8: Load Profiles

(a) Inbound



(b) Outbound

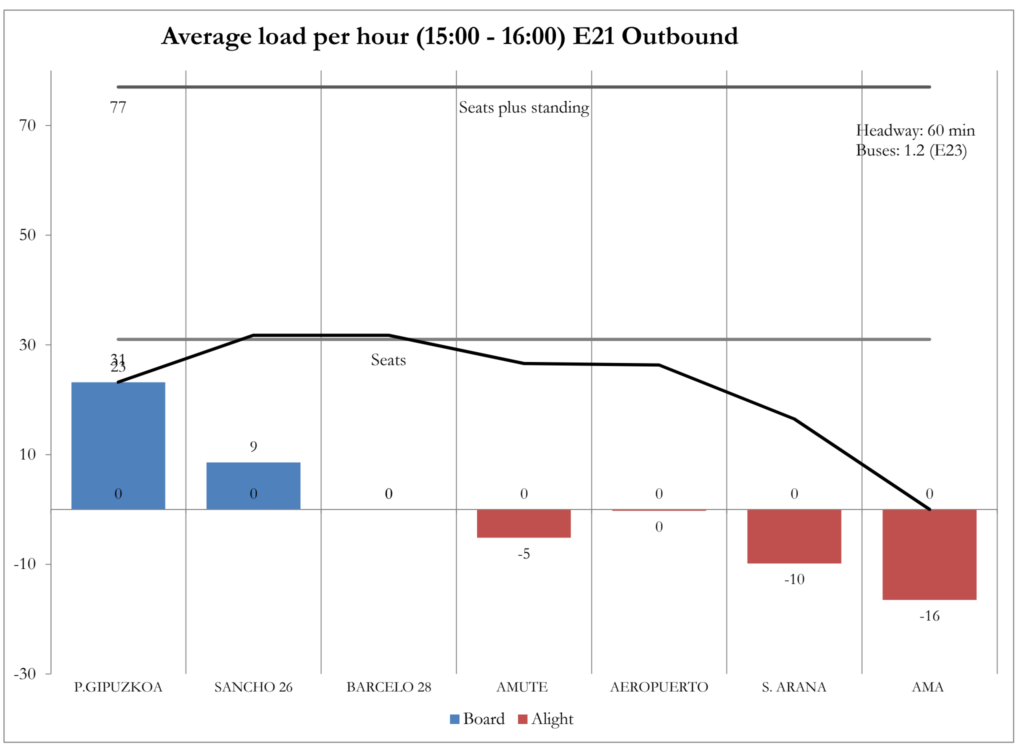
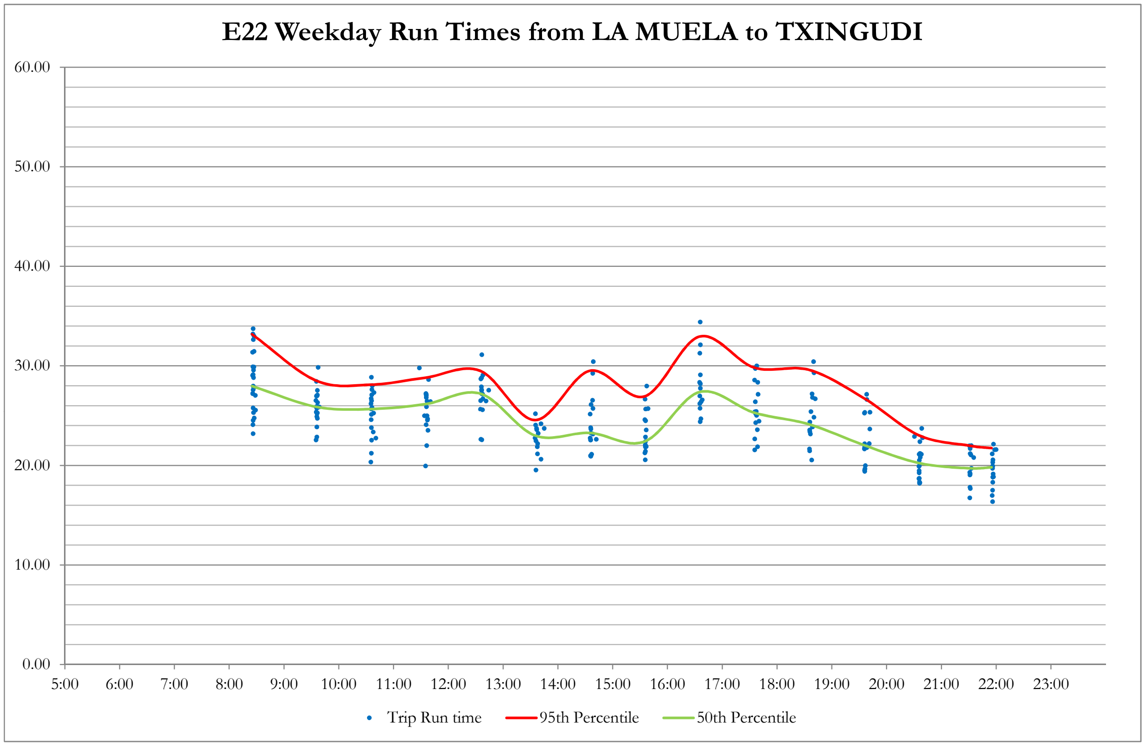


Figure B.9: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

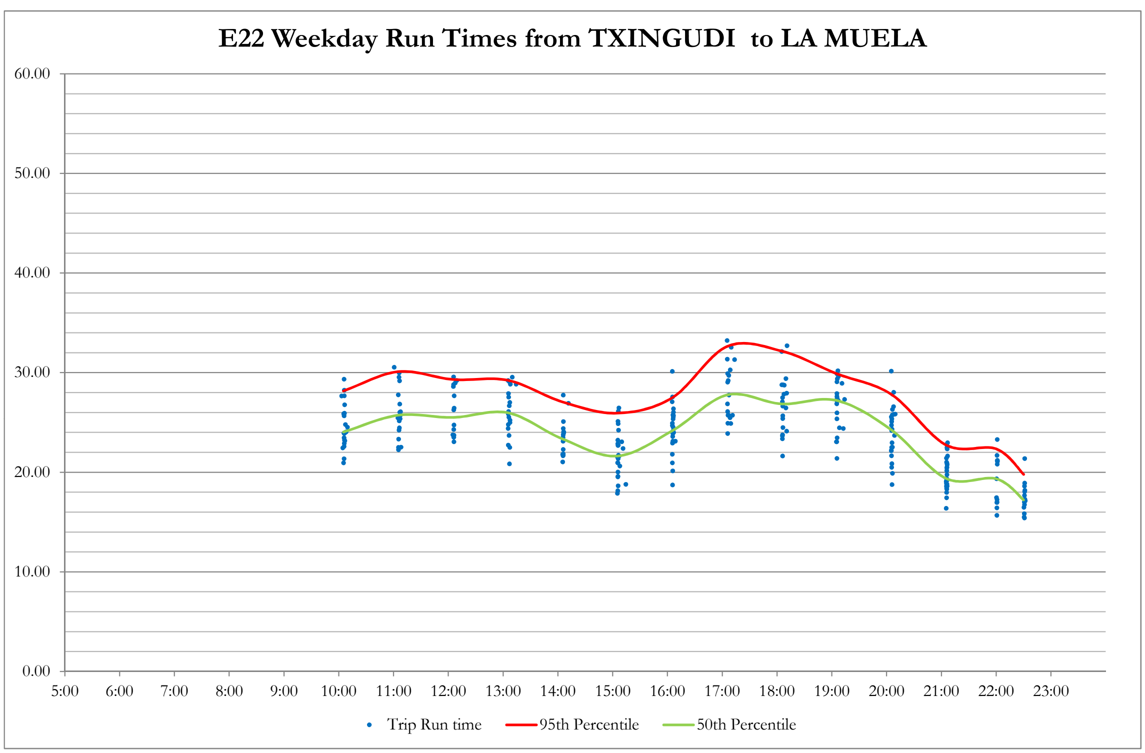
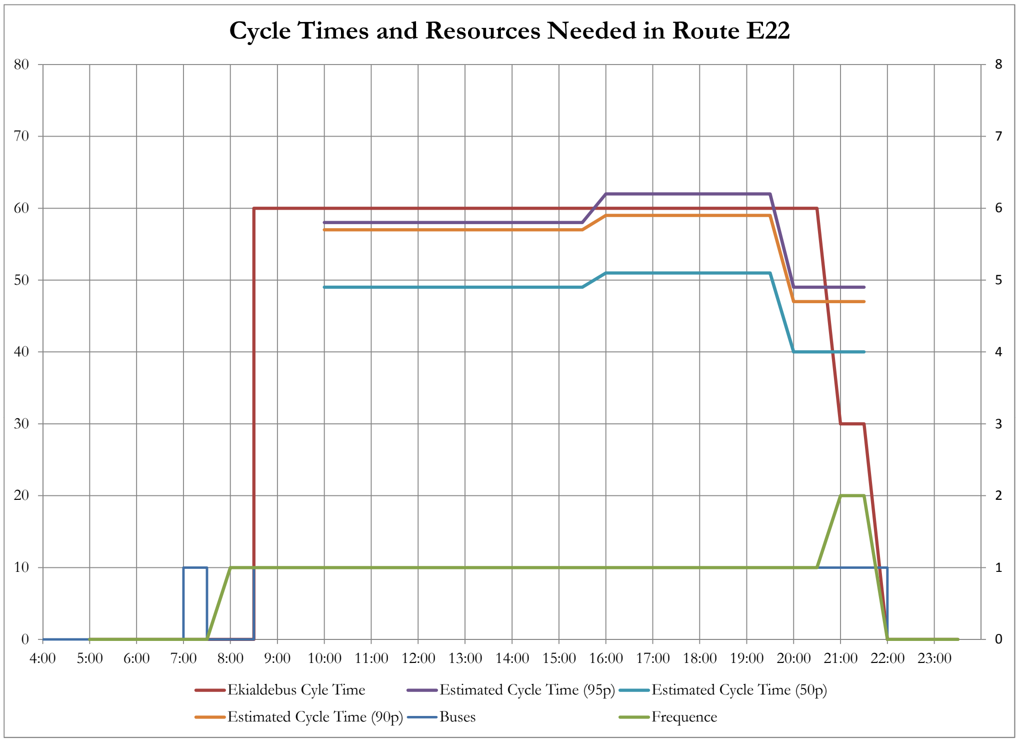


Figure B.10: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

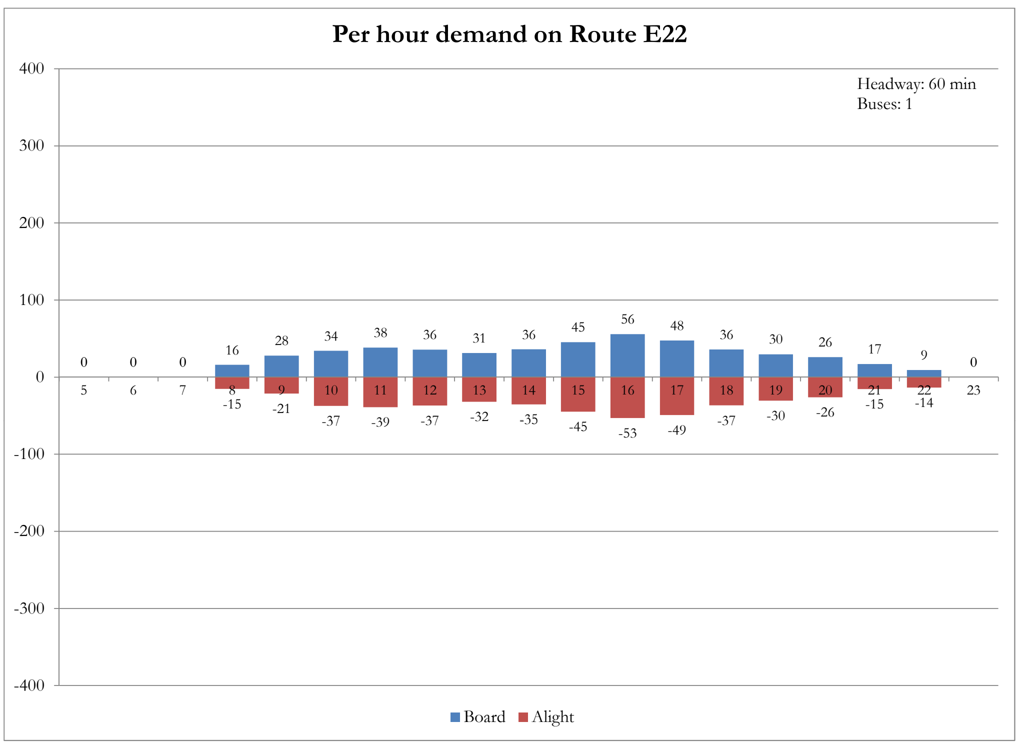
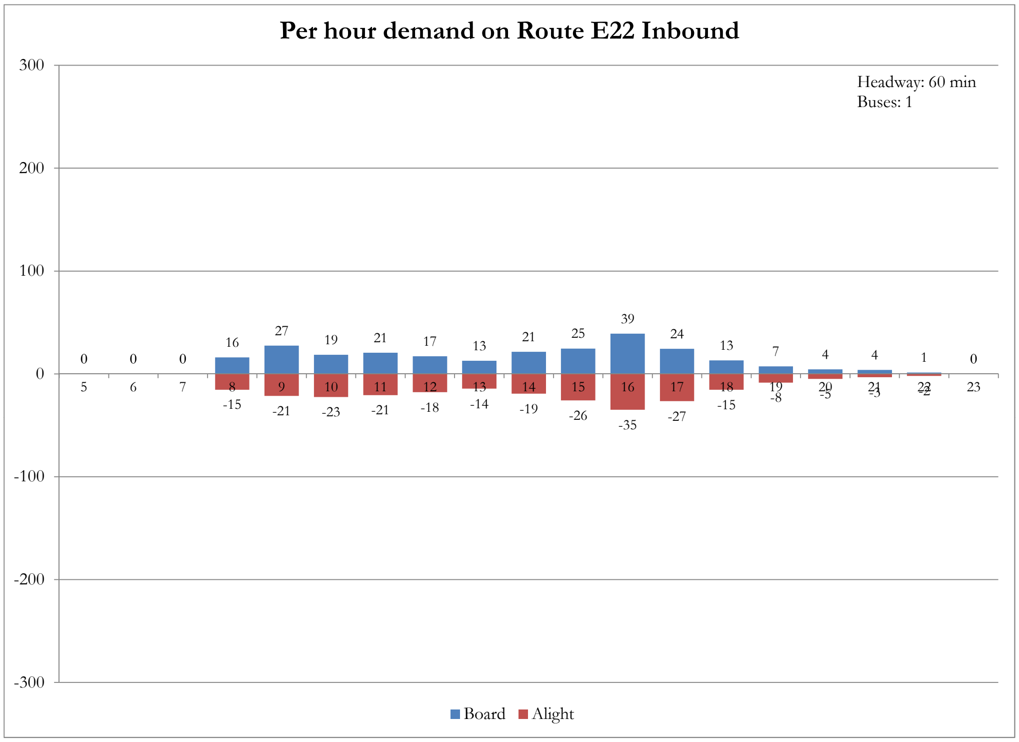


Figure B.11: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

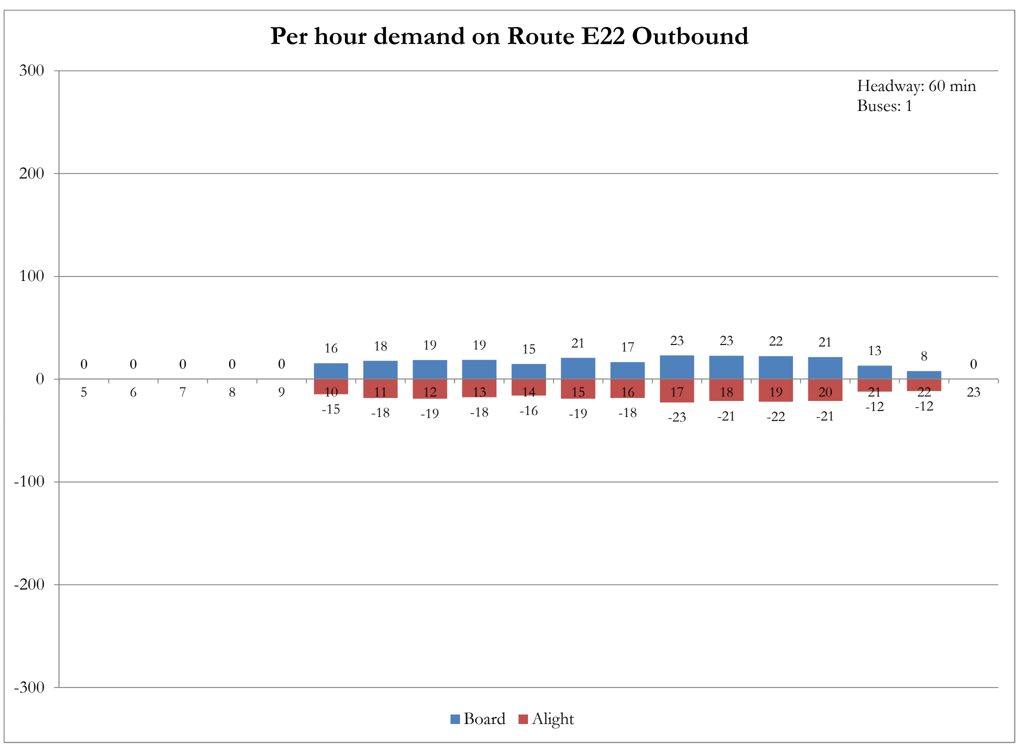
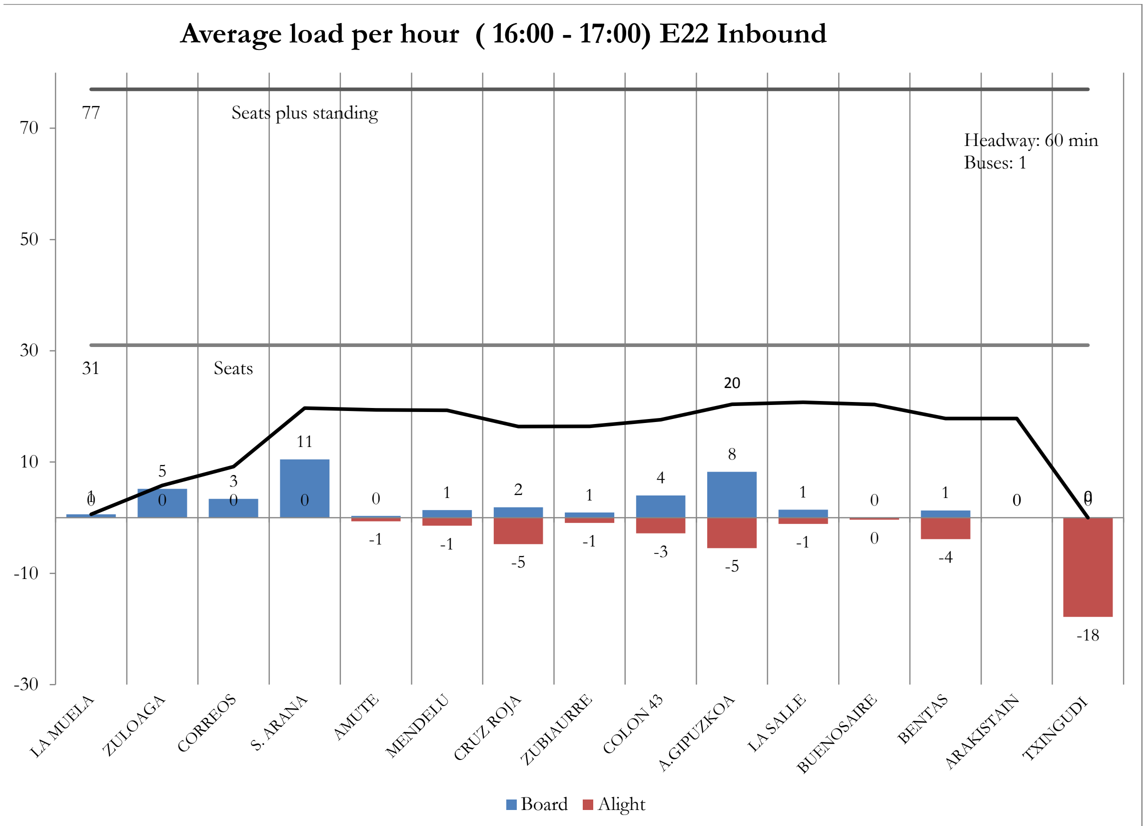


Figure B.12: Load Profiles

(a) Inbound



(b) Outbound

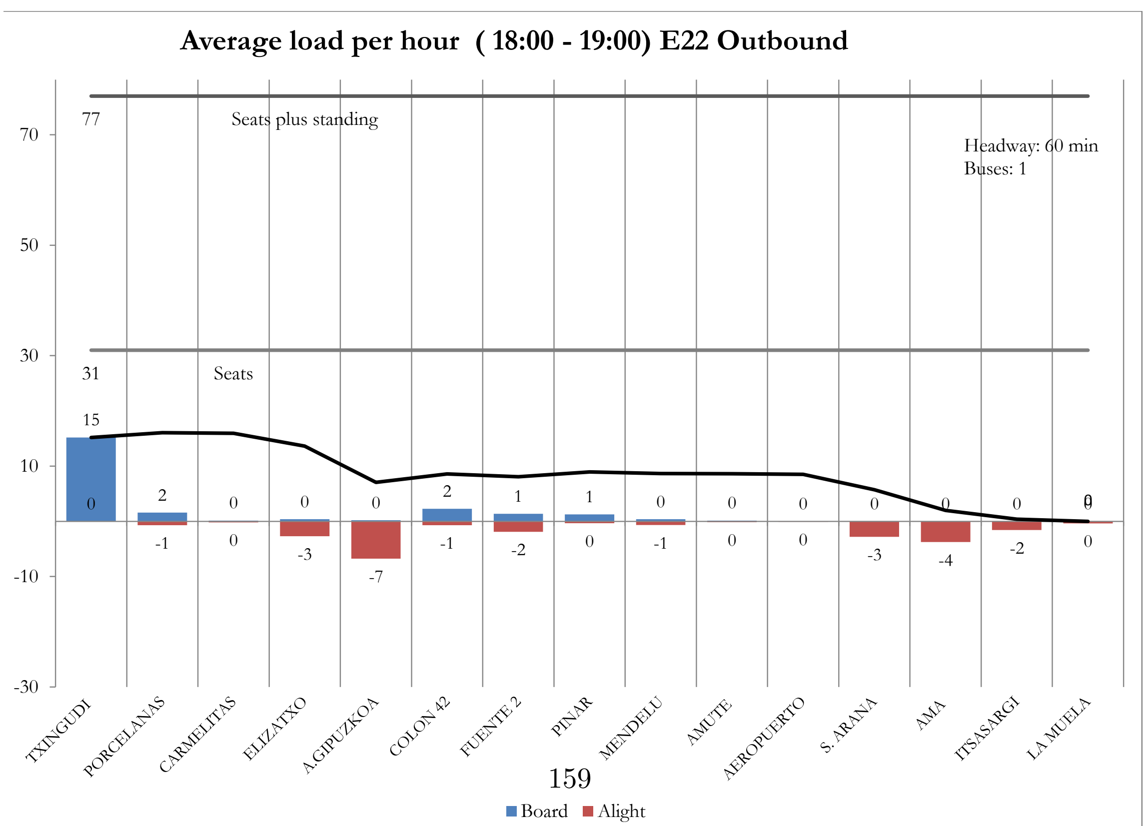
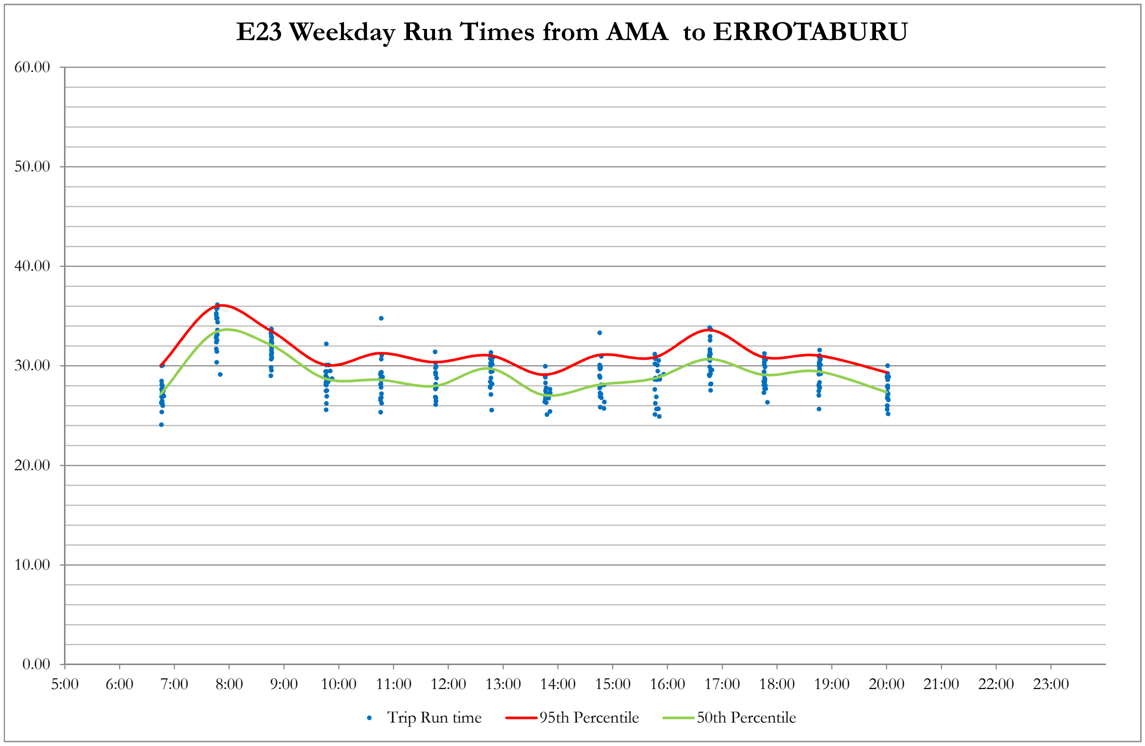


Figure B.13: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

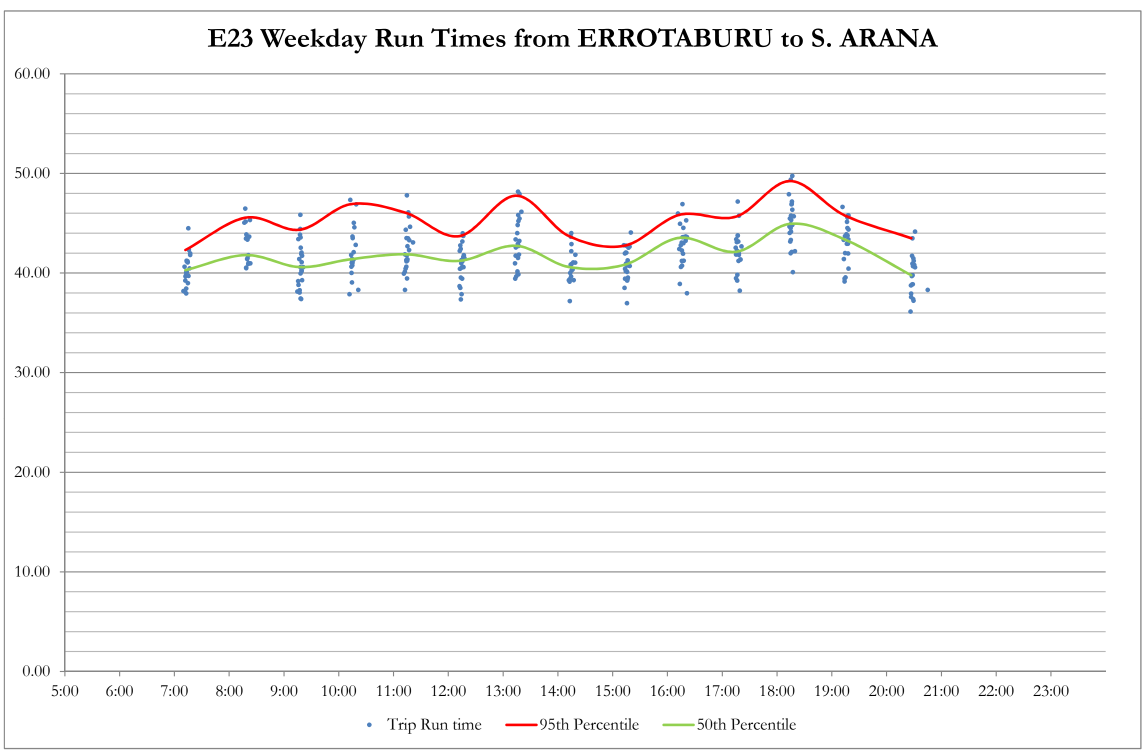
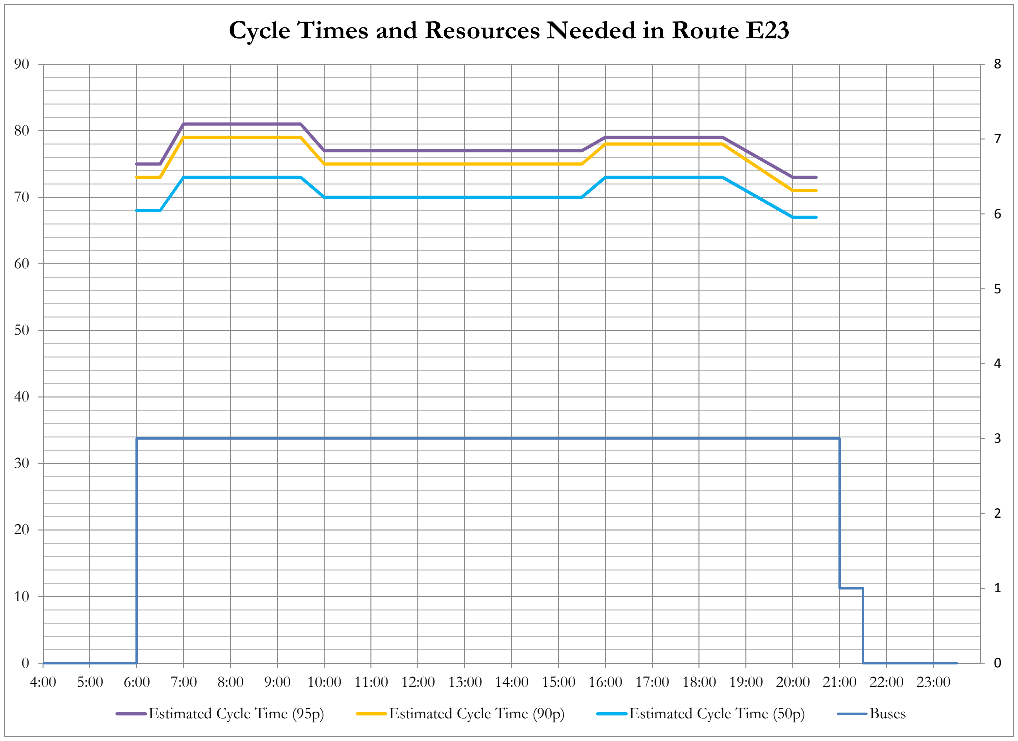


Figure B.14: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

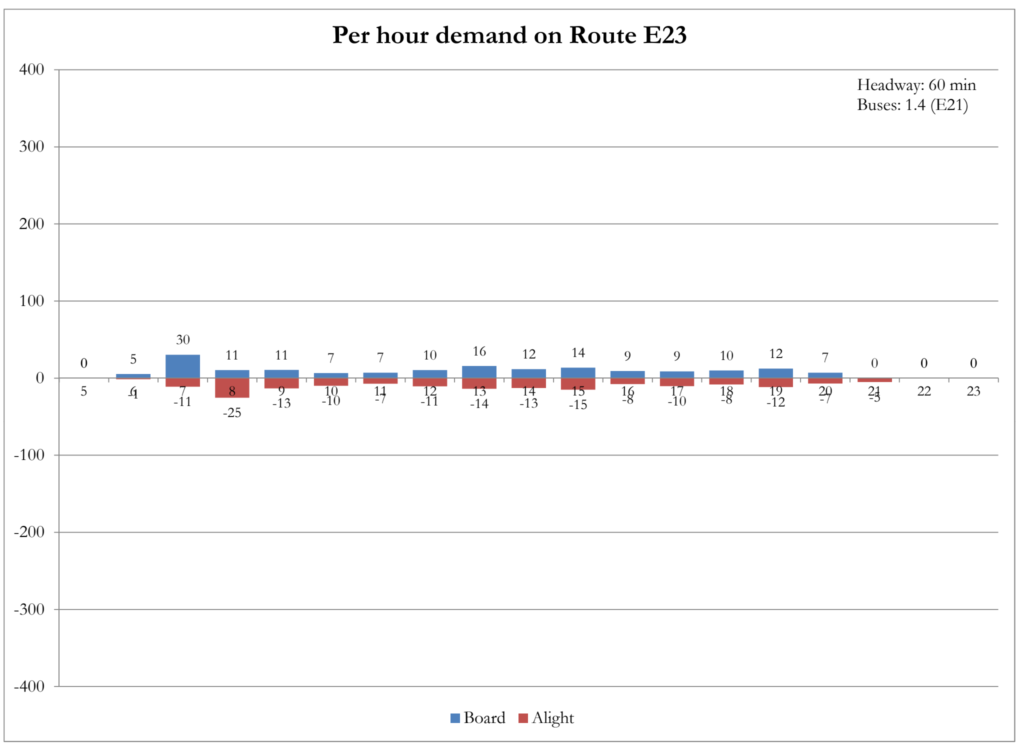
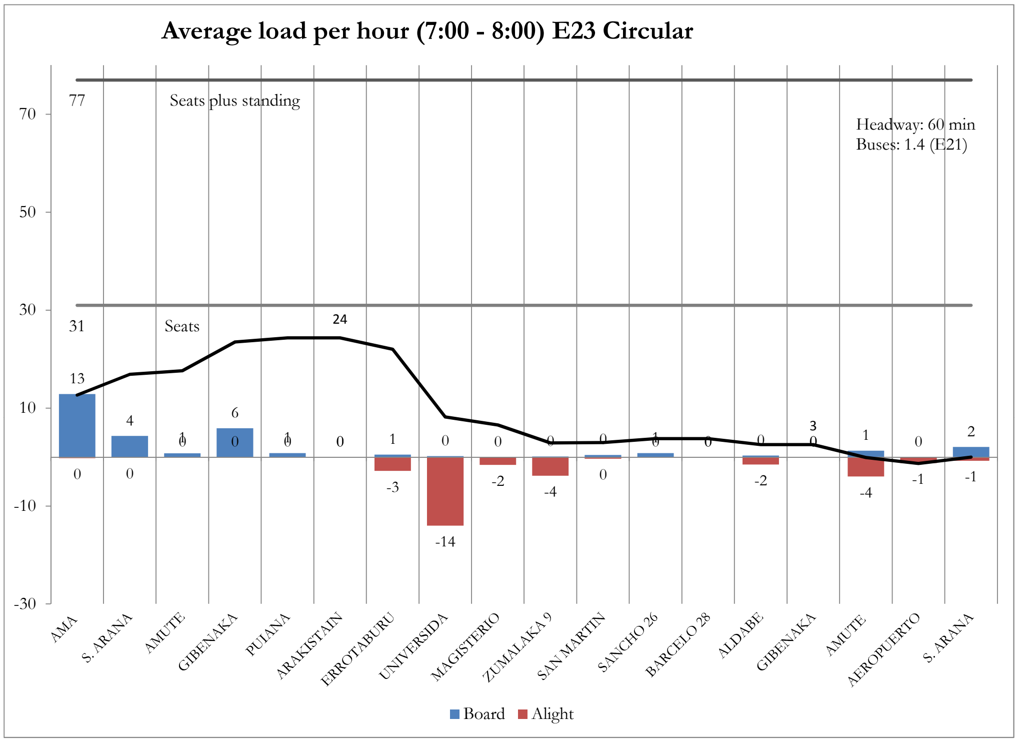


Figure B.15: Load Profiles

(a) Inbound



(b) Outbound

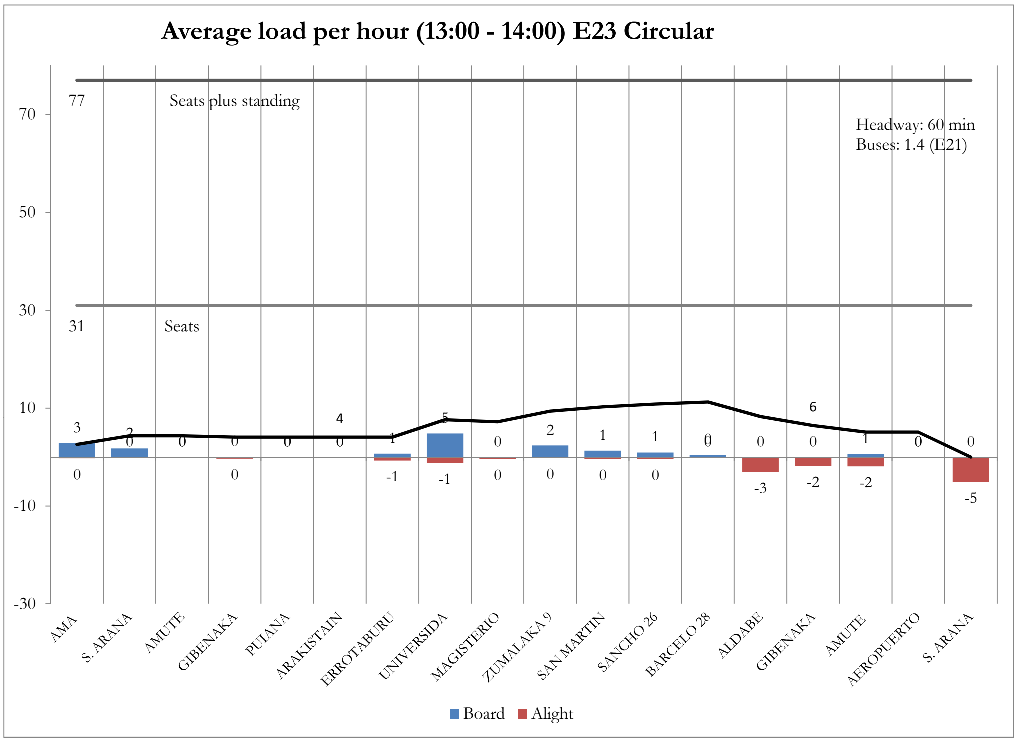
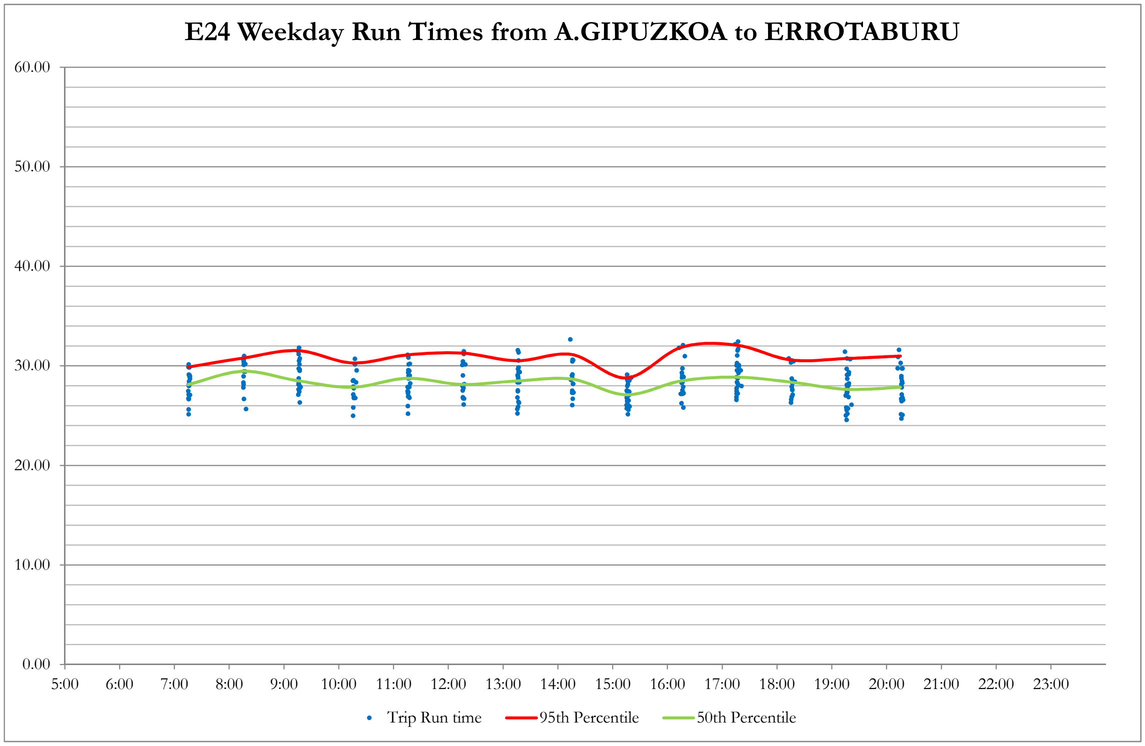


Figure B.16: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

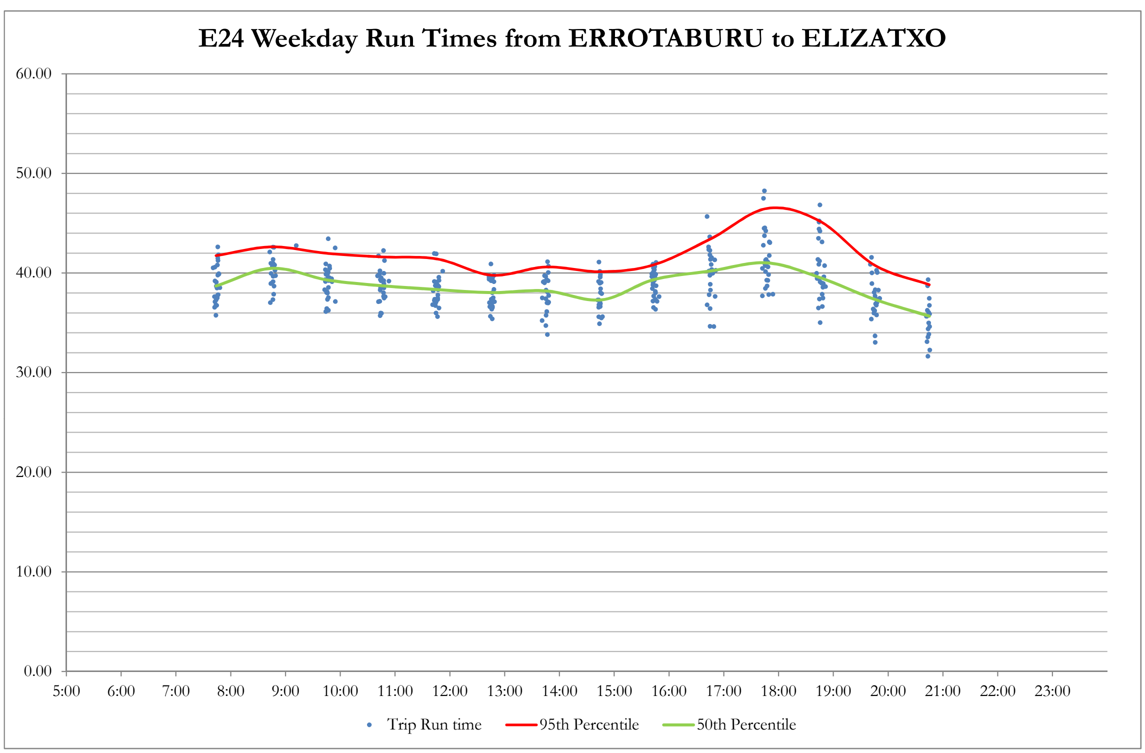
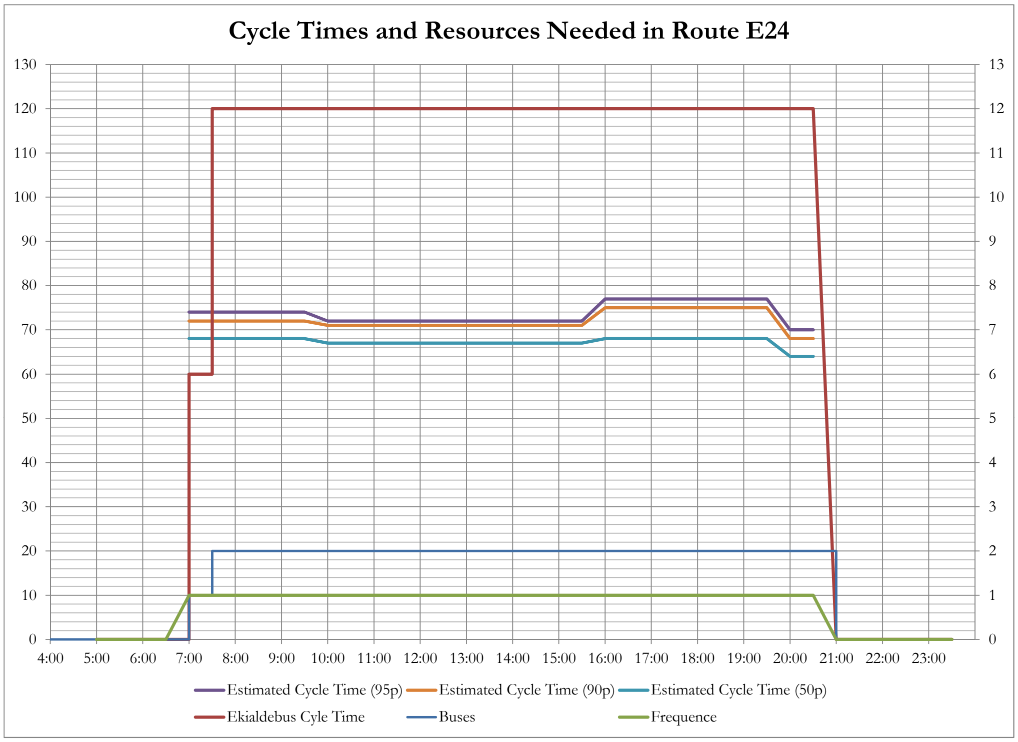


Figure B.17: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

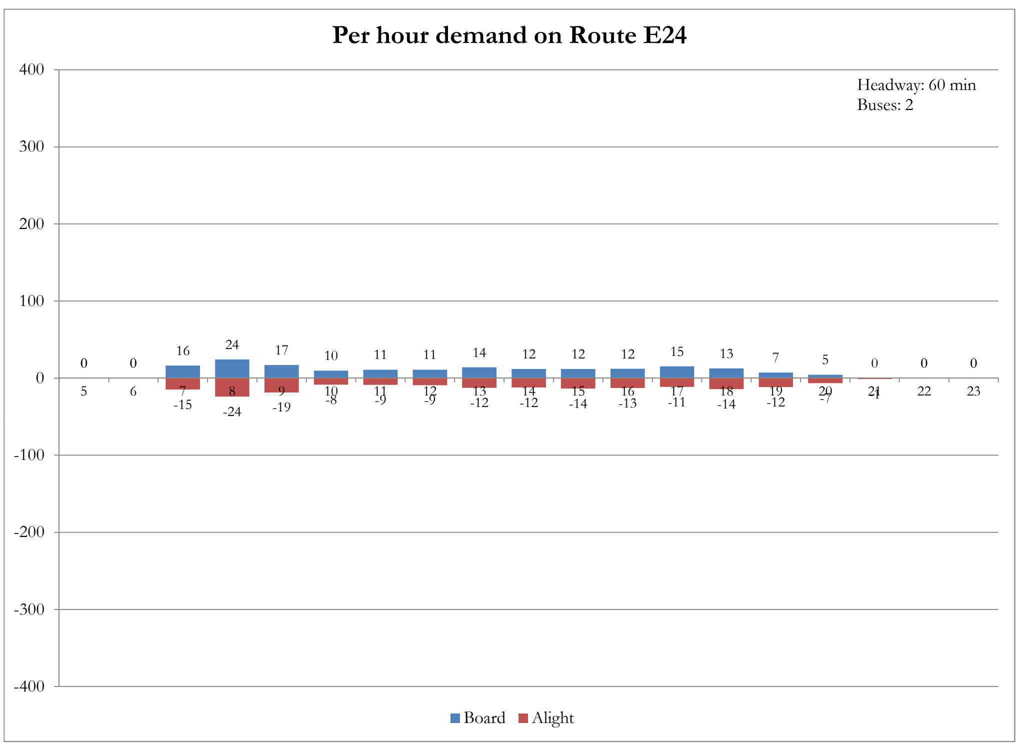
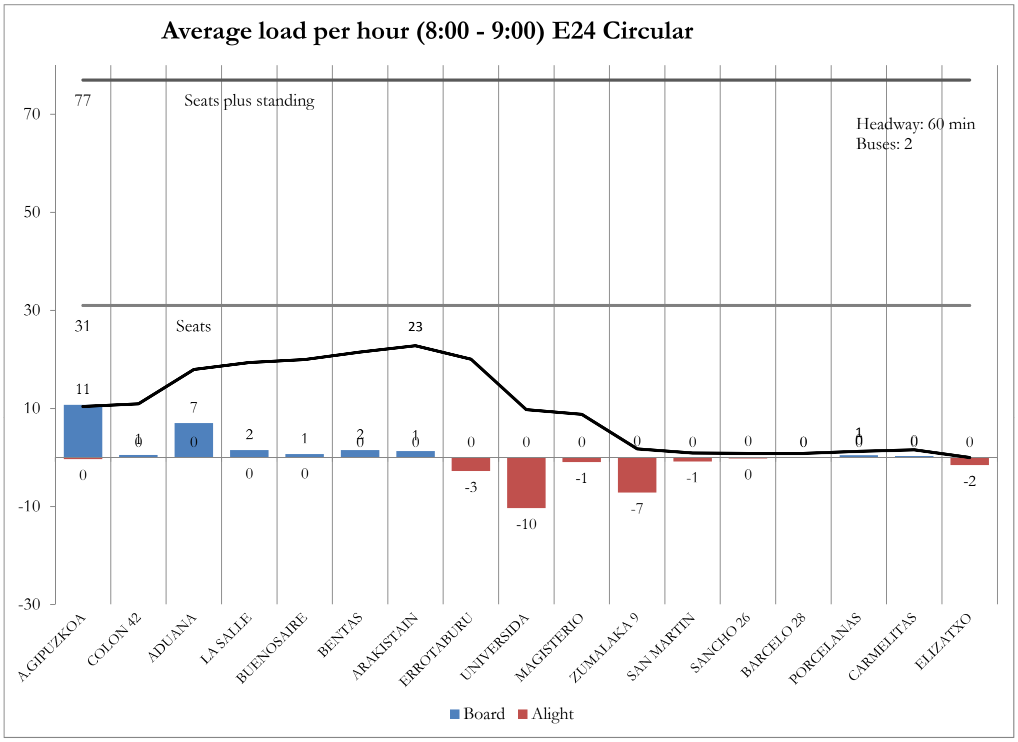


Figure B.18: Load Profiles

(a) Inbound



(b) Outbound

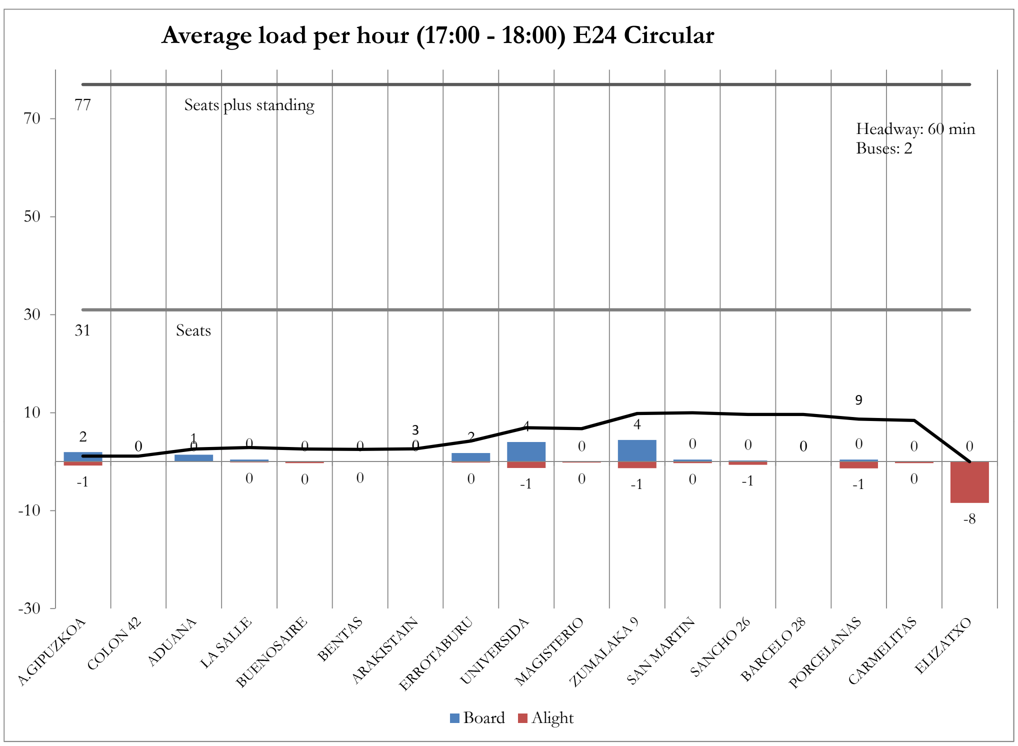
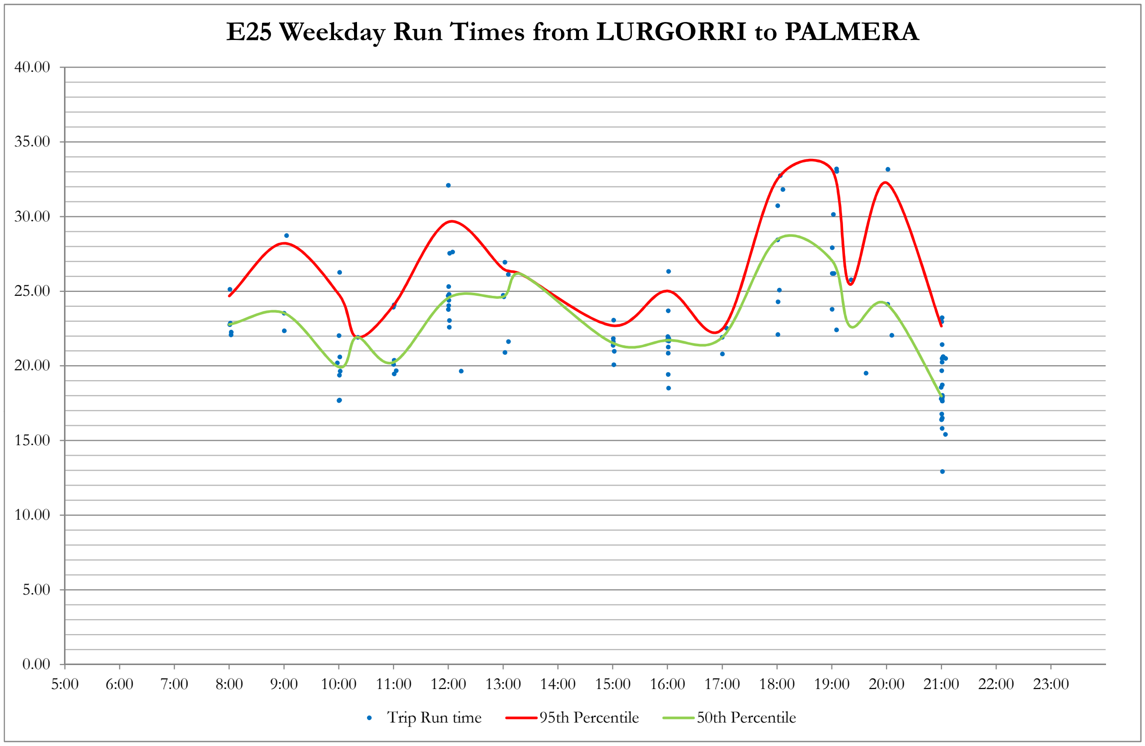


Figure B.19: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

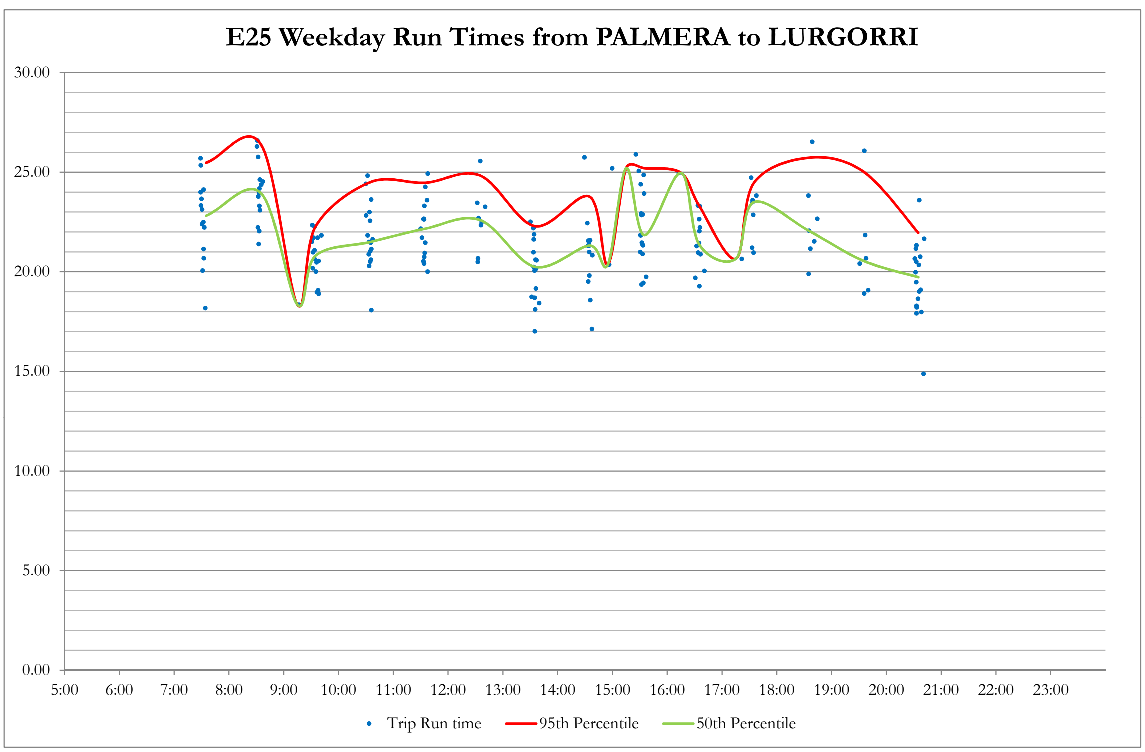
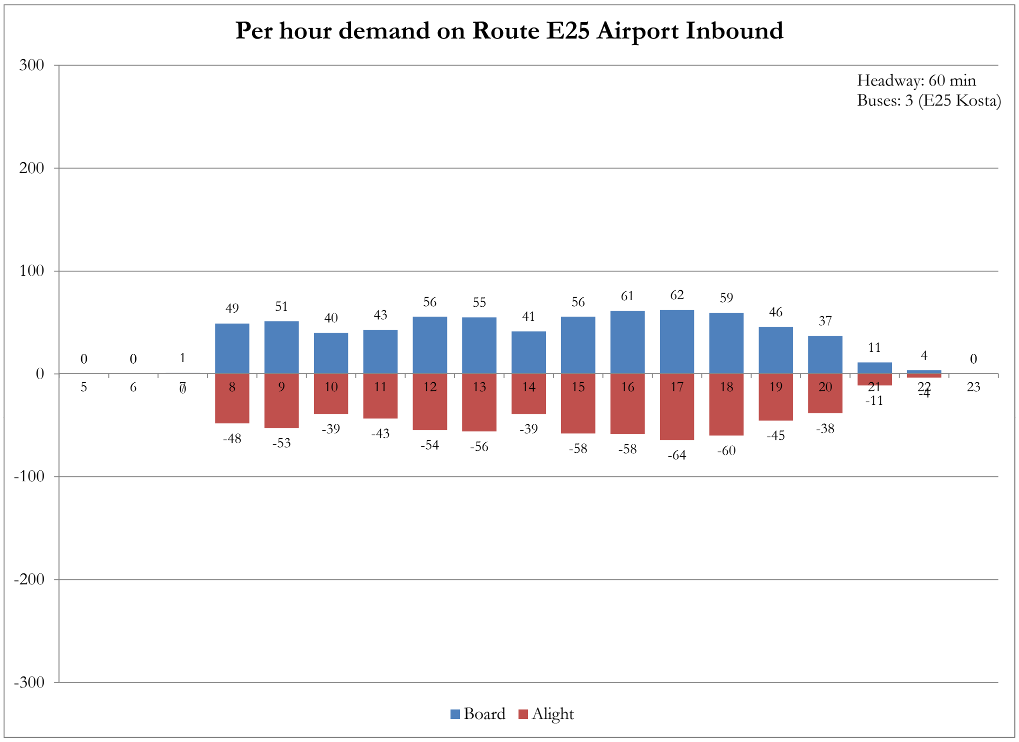


Figure B.20: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

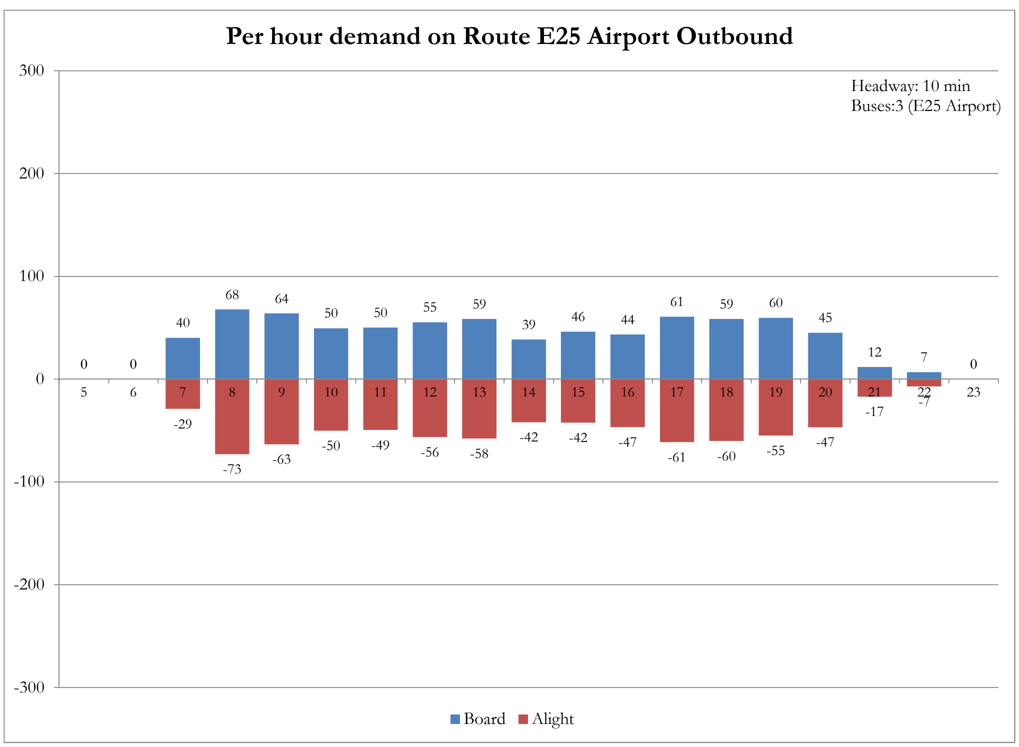
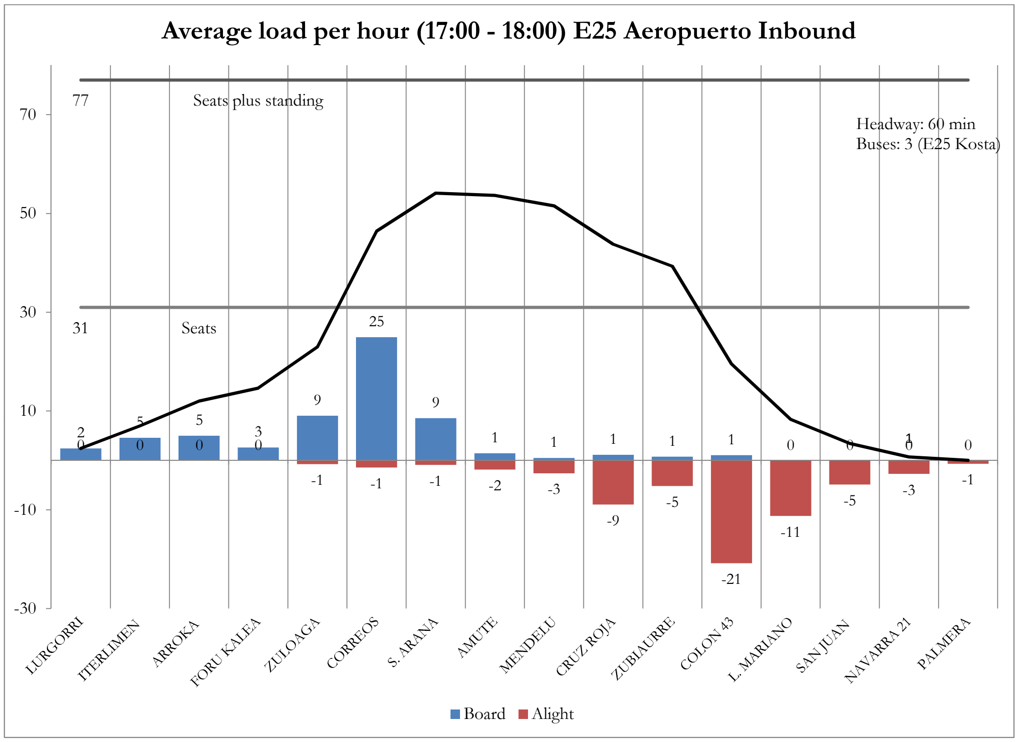


Figure B.21: Load Profiles

(a) Inbound



(b) Outbound

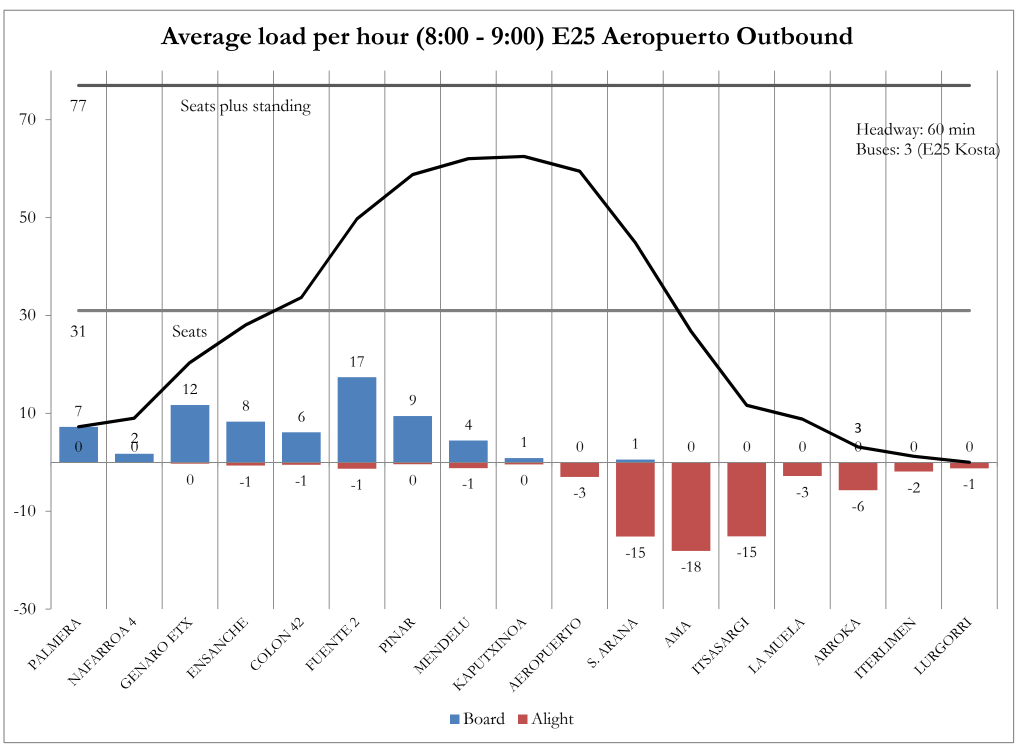
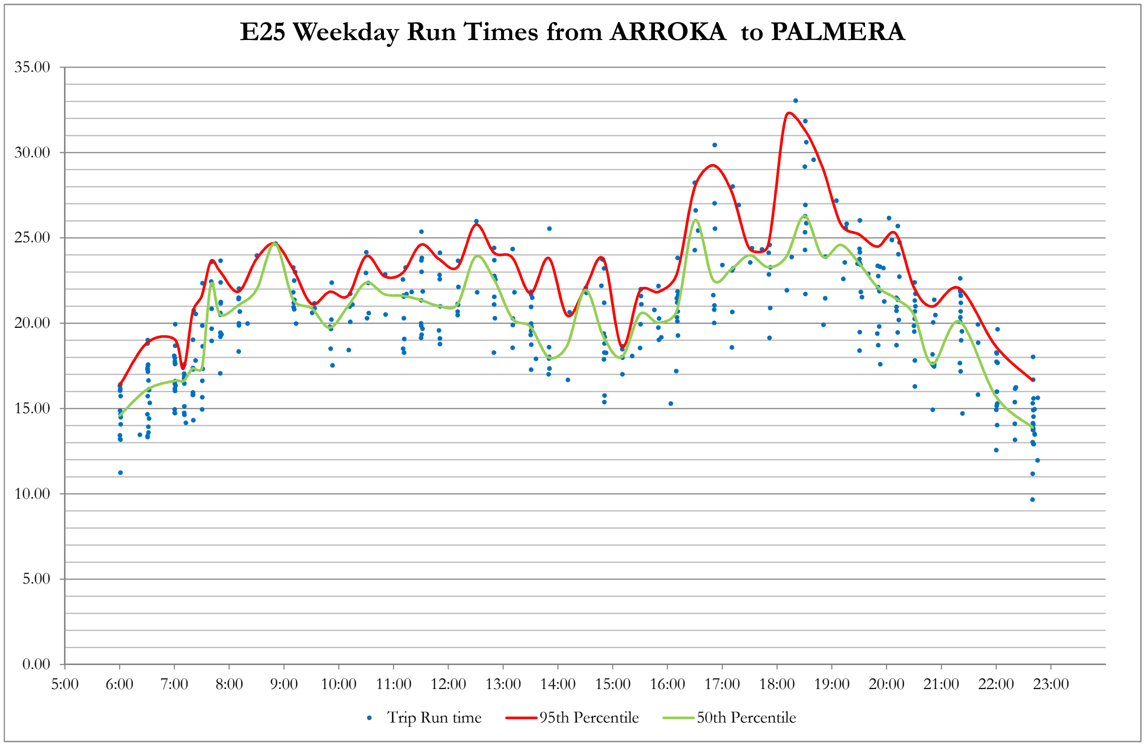


Figure B.22: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

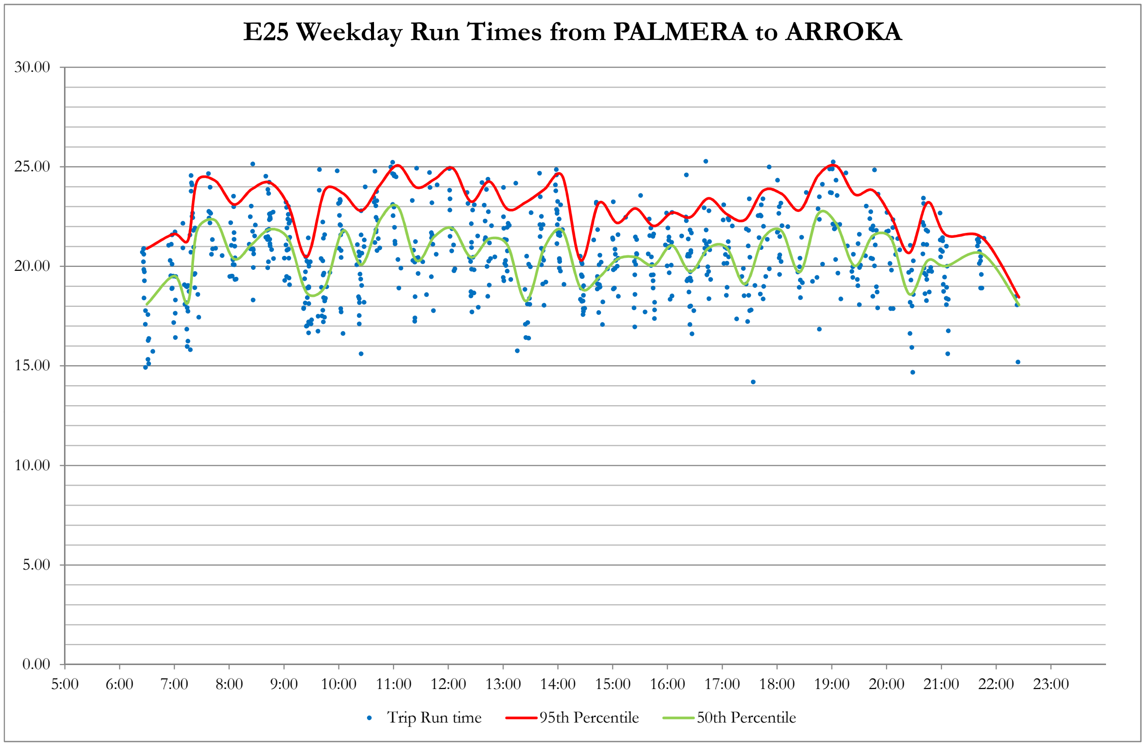
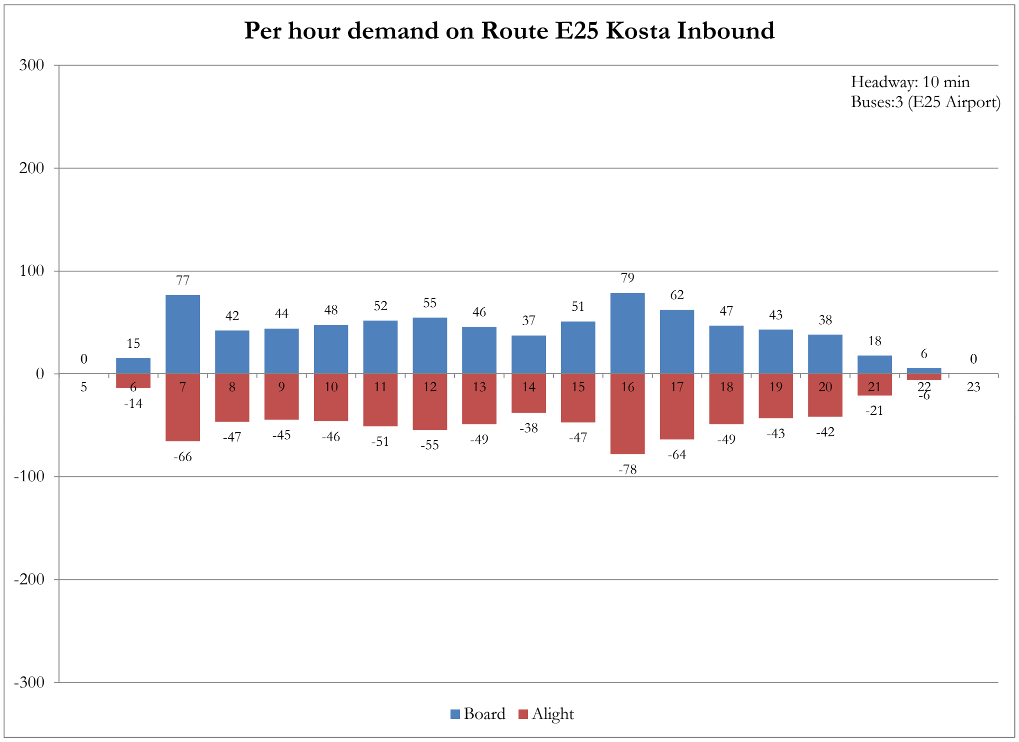


Figure B.23: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

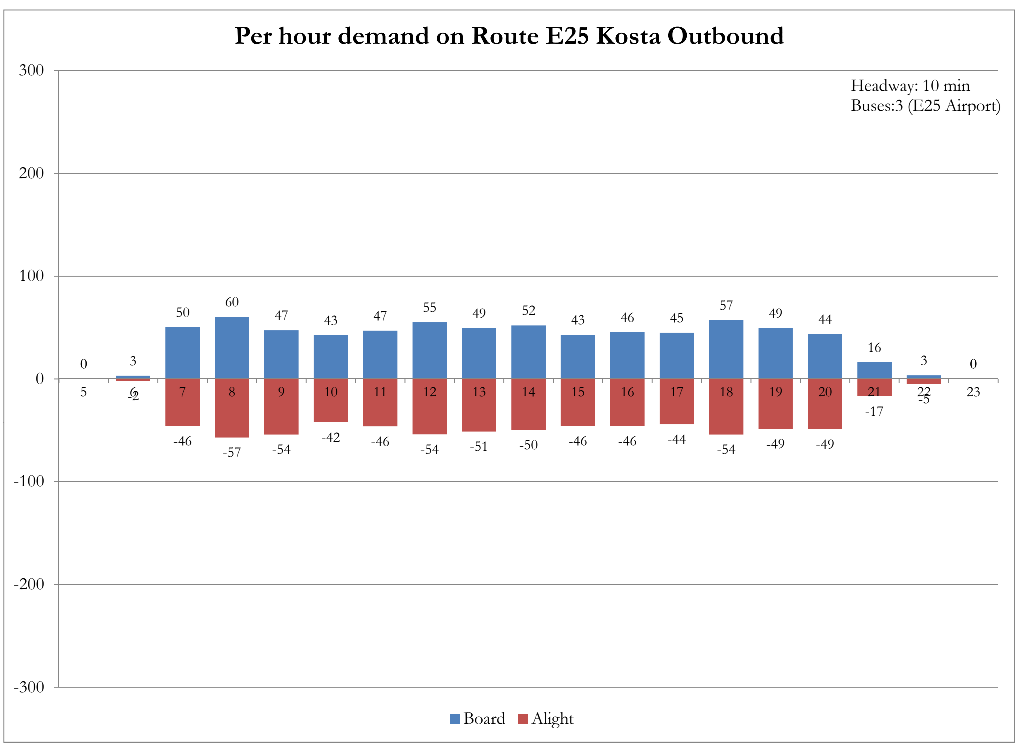
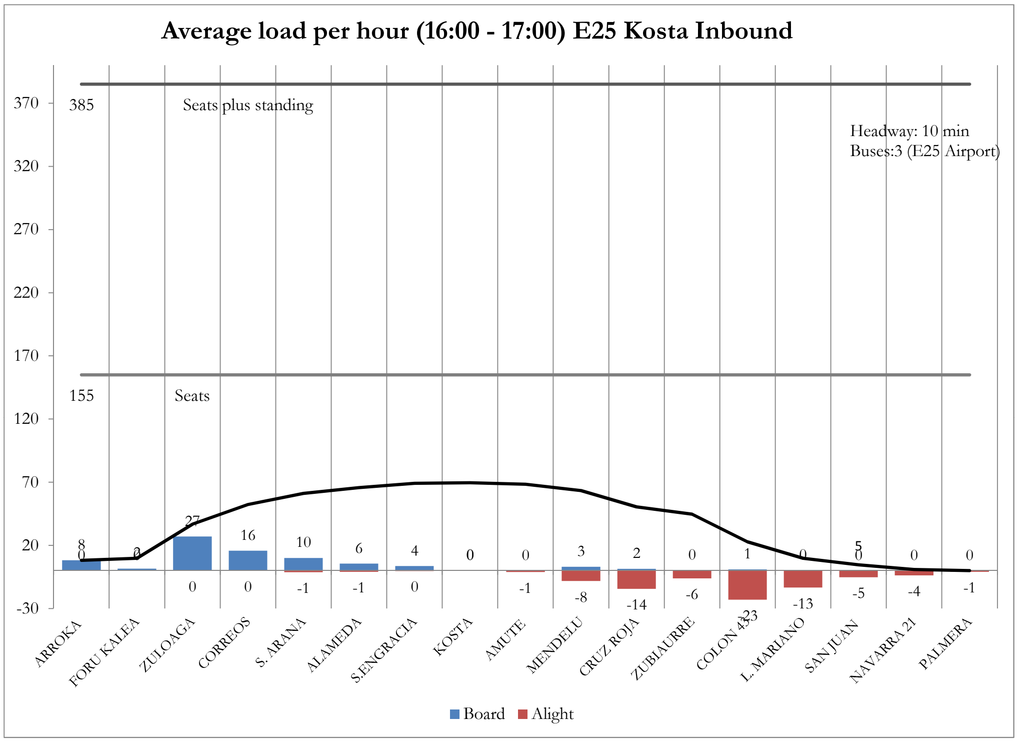


Figure B.24: Load Profiles

(a) Inbound



(b) Outbound

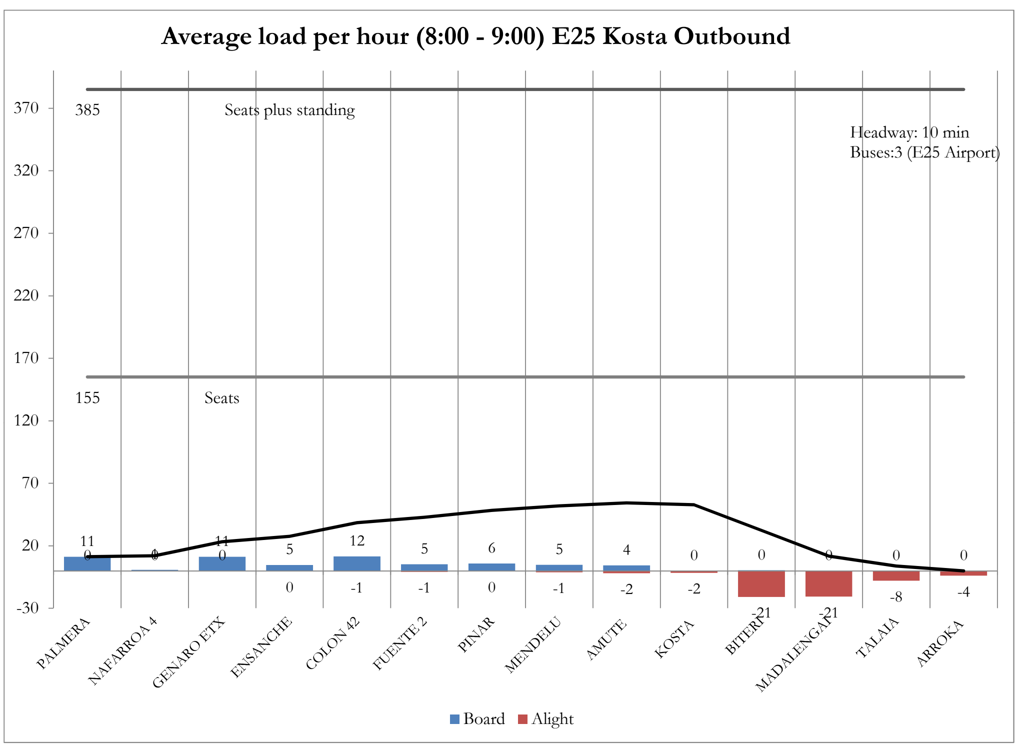
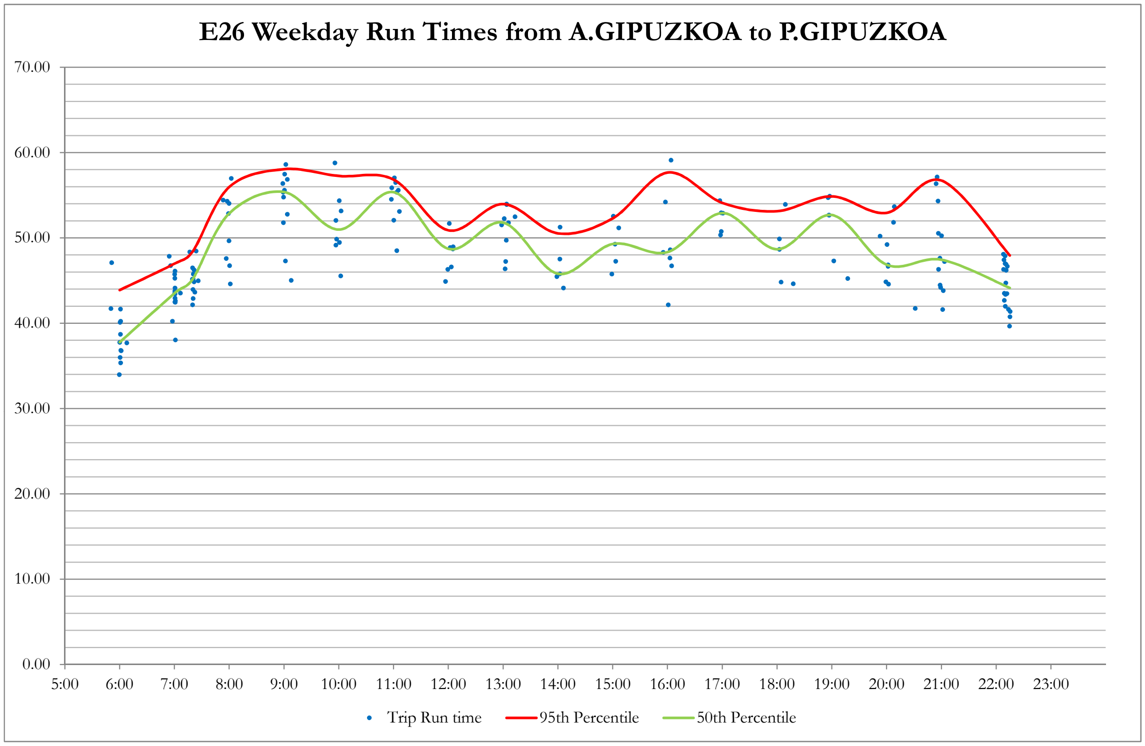


Figure B.25: Run Time Scatter Plot by Direction

(a) Inbound



(b) Outbound

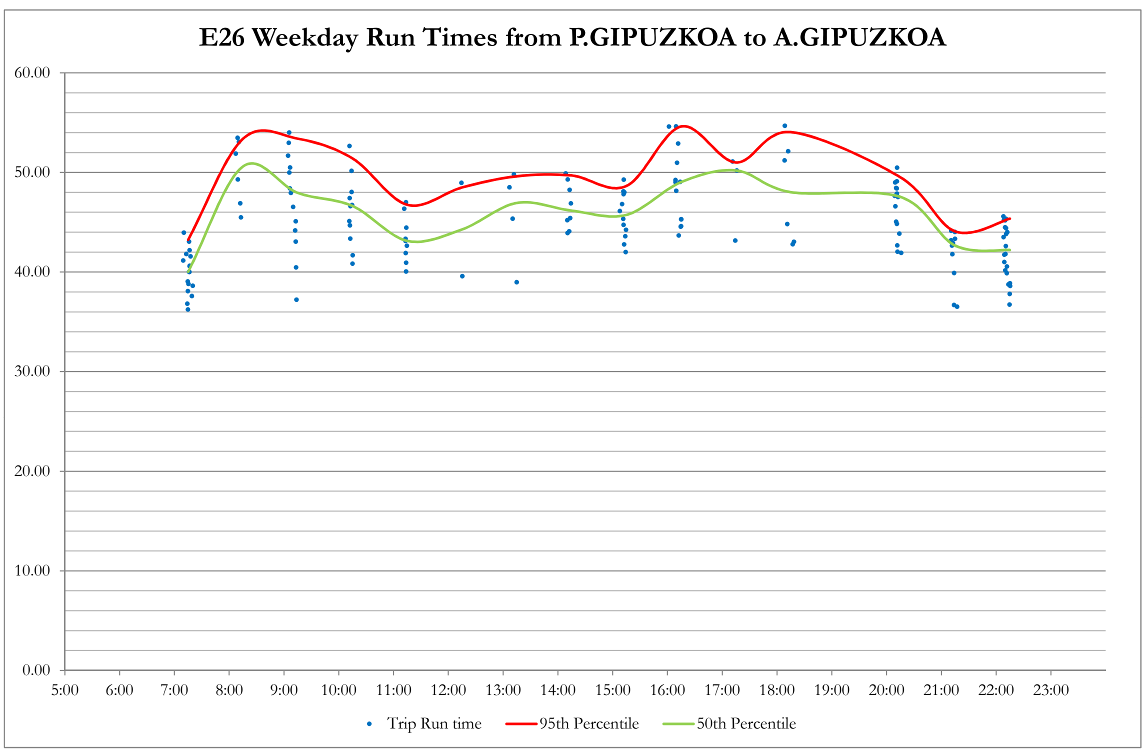
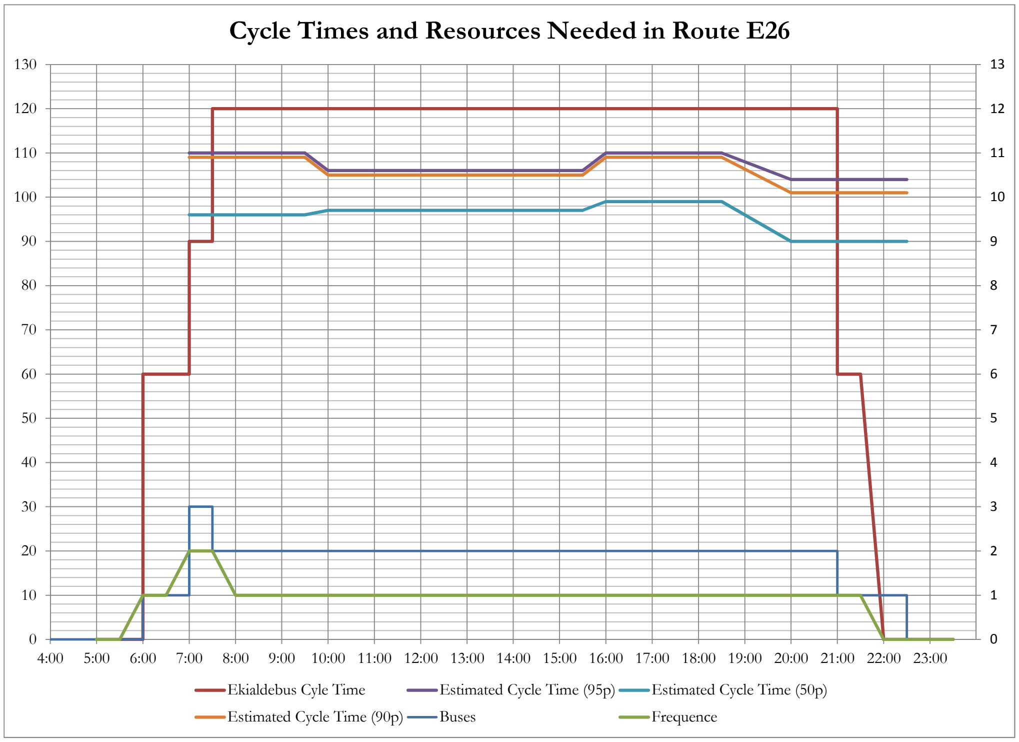


Figure B.26: Cycle Times and Demand by Hour

(a) Cycle Times and Resources Needed



(b) Per Hour Demand Both Directions

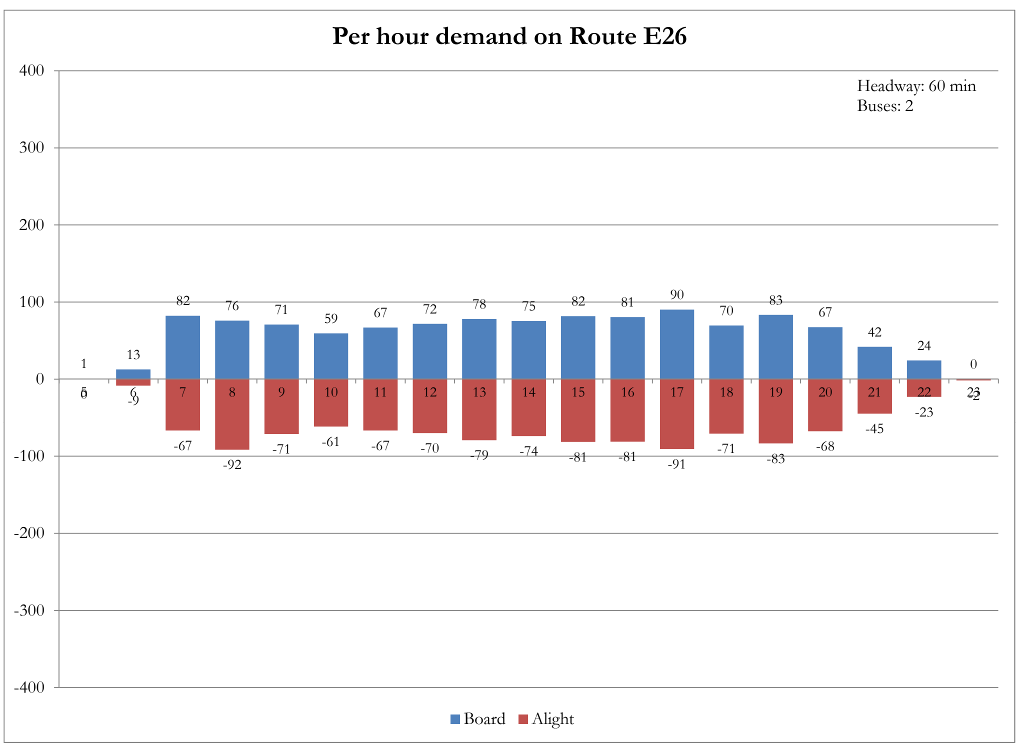
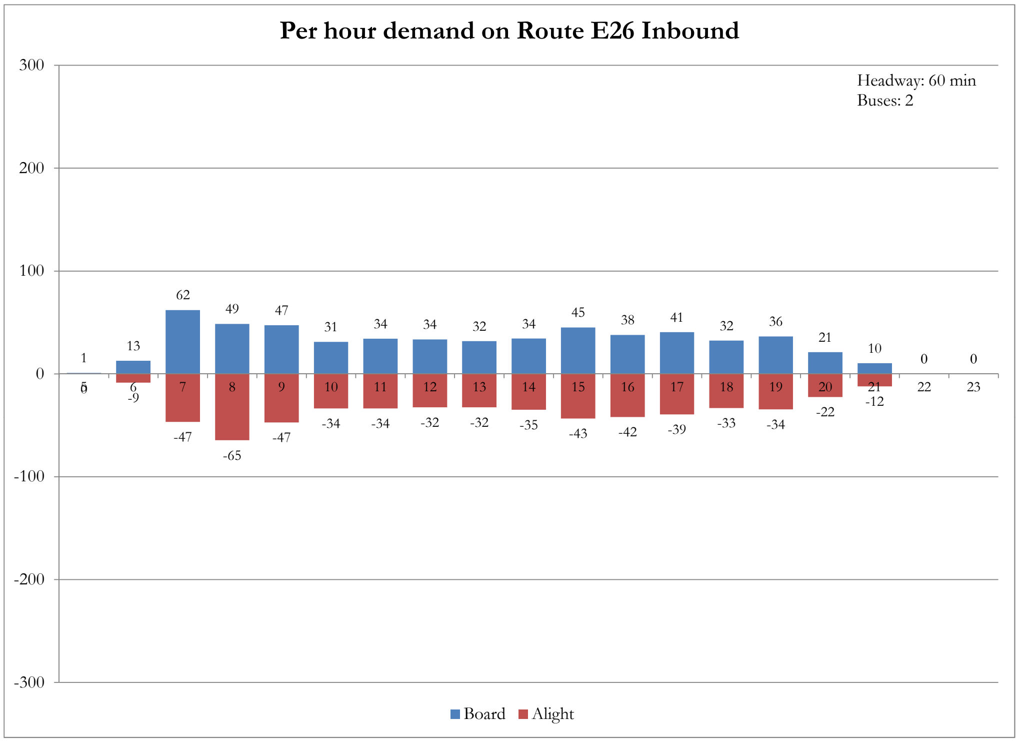


Figure B.27: Per Hour Demand by Direction

(a) Inbound



(b) Outbound

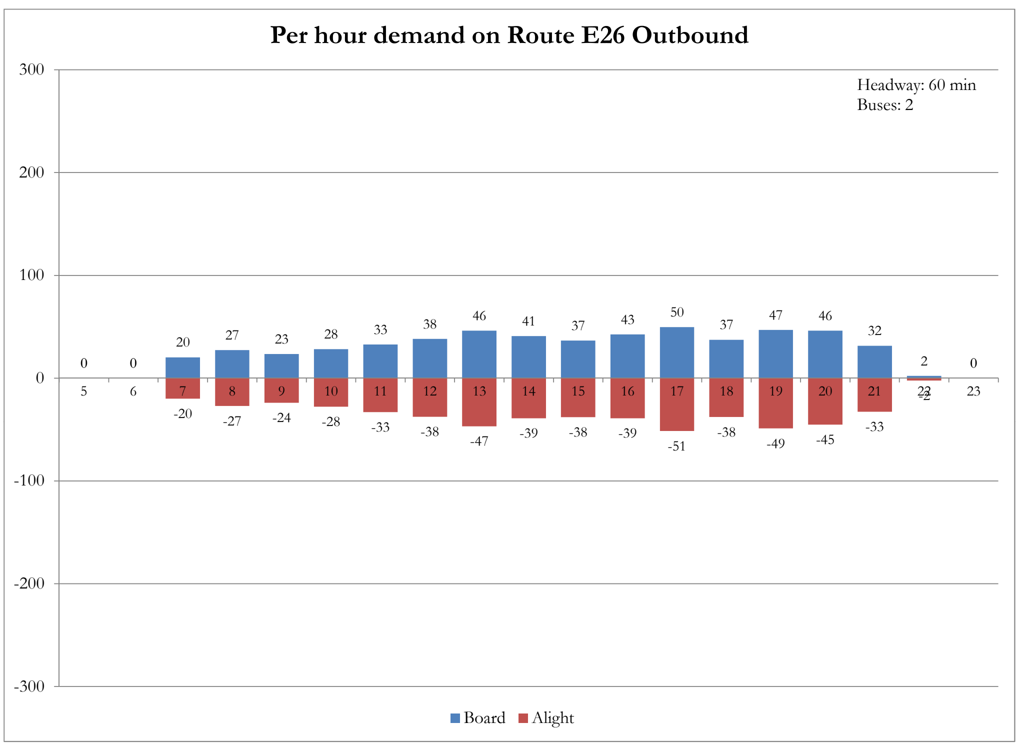
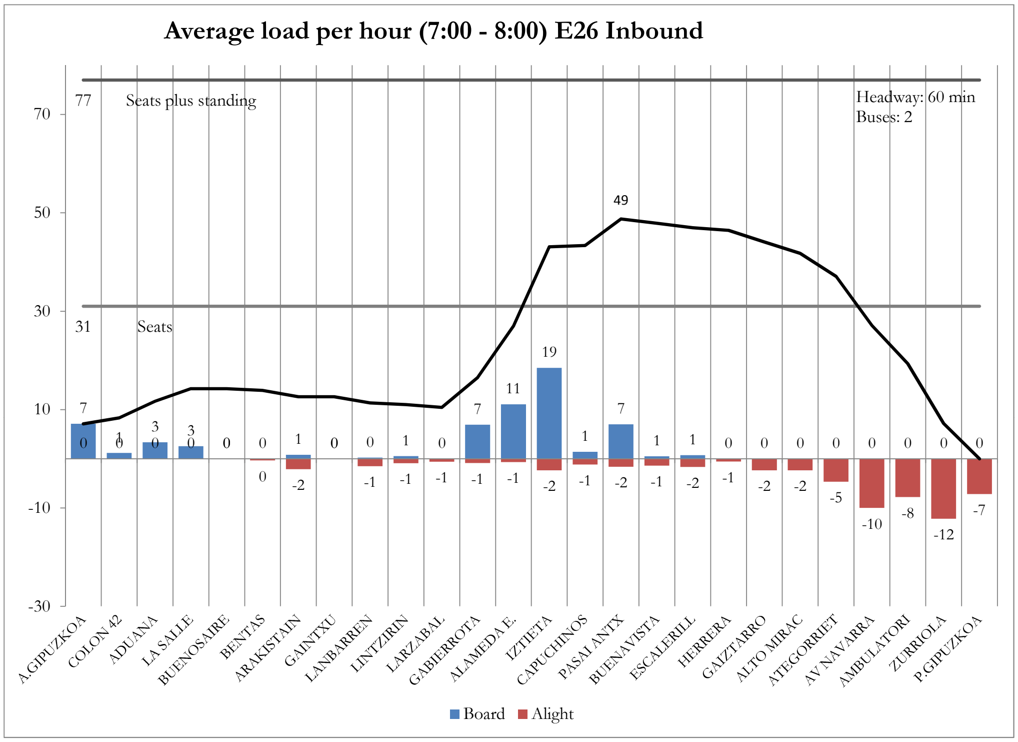
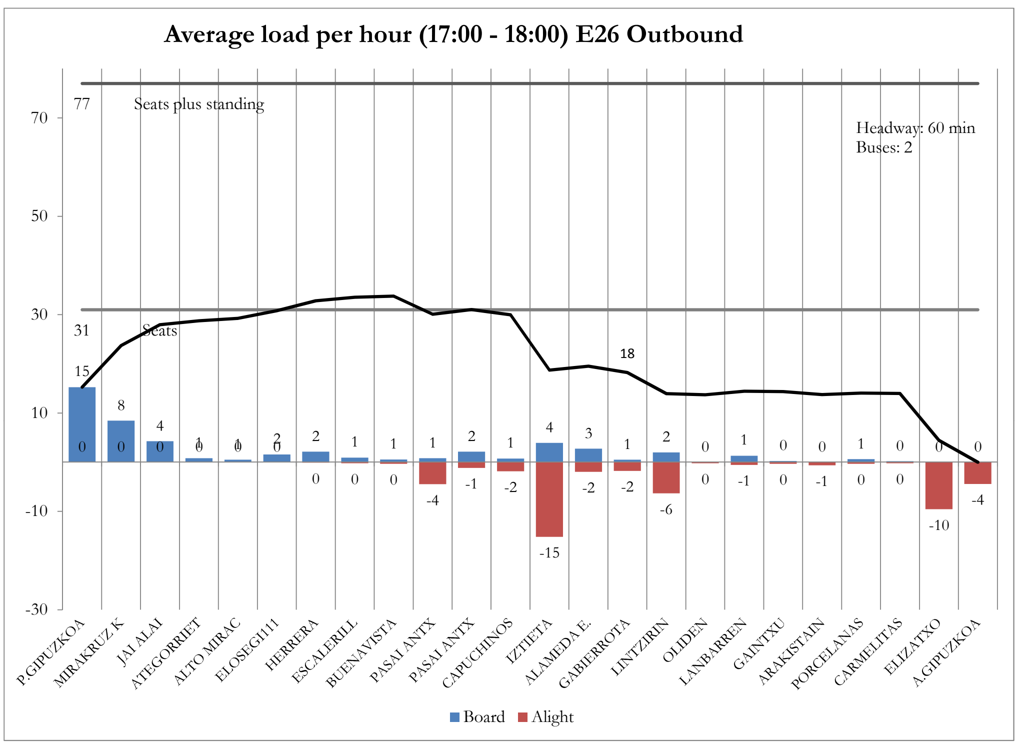


Figure B.28: Load Profiles

(a) Inbound



(b) Outbound



Appendix C

Stop Aggregation by Zone

Table C.1: Definition of Stop Aggregation by Zone

PAR DESCABRV	PAR CODIGO	ZnID	ZnTOWN	ZnCOUNTY
AEROPUERTO	51	AEROPUERTO	HONDARRABIA	Bidasoaldea
BIANKA	827	ALT-CEN	ALTZA	Oarsoaldea
DARIETA	630	ALT-CEN	ALTZA	Oarsoaldea
DARIETA	647	ALT-CEN	ALTZA	Oarsoaldea
MARTILUM	7011	ALT-CEN	ALTZA	Oarsoaldea
MARTILUM	7012	ALT-CEN	ALTZA	Oarsoaldea
NERECAN	633	ALT-CEN	ALTZA	Oarsoaldea
NERECAN	641	ALT-CEN	ALTZA	Oarsoaldea
OLETA	631	ALT-CEN	ALTZA	Oarsoaldea
OLETA	646	ALT-CEN	ALTZA	Oarsoaldea
S. MARCIAL	7013	ALT-CEN	ALTZA	Oarsoaldea
S. MARCIAL	7014	ALT-CEN	ALTZA	Oarsoaldea
ST BARBARA	632	ALT-CEN	ALTZA	Oarsoaldea
ST BARBARA	642	ALT-CEN	ALTZA	Oarsoaldea
GARBERA	4112	ALT-SUR	ALTZA	Oarsoaldea
AMBULATORI	182	BER-CEN	BERAUN	Oarsoaldea
AMBULATORI	189	BER-CEN	BERAUN	Oarsoaldea
C. BERAUN	16	BER-CEN	BERAUN	Oarsoaldea
GALTZARABO	833	BER-CEN	BERAUN	Oarsoaldea
GALTZARABO	1715	BER-CEN	BERAUN	Oarsoaldea
KOLDO MITX	1716	BER-CEN	BERAUN	Oarsoaldea
MORRONGILL	1718	BER-CEN	BERAUN	Oarsoaldea
PONTIKA	185	BER-CEN	BERAUN	Oarsoaldea
PZA URBIA	1717	BER-CEN	BERAUN	Oarsoaldea
SORGINTXUL	179	BER-CEN	BERAUN	Oarsoaldea
SORGINTXUL	193	BER-CEN	BERAUN	Oarsoaldea
TELEFONICA	181	BER-CEN	BERAUN	Oarsoaldea
TELEFONICA	191	BER-CEN	BERAUN	Oarsoaldea
VERSALLES	180	BER-CEN	BERAUN	Oarsoaldea
VERSALLES	192	BER-CEN	BERAUN	Oarsoaldea
BUENAVISTA	29	CAP-BUV	PASAI ANTXO	Oarsoaldea
BUENAVISTA	648	CAP-BUV	PASAI ANTXO	Oarsoaldea
BUENAVISTA	4014	CAP-BUV	PASAI ANTXO	Oarsoaldea
CAPUCHINOS	31	CAP-BUV	PASAI ANTXO	Oarsoaldea
CAPUCHINOS	139	CAP-BUV	PASAI ANTXO	Oarsoaldea
PASAI ANTX	30	CAP-BUV	PASAI ANTXO	Oarsoaldea
PASAI ANTX	78	CAP-BUV	PASAI ANTXO	Oarsoaldea
PASAI ANTX	208	CAP-BUV	PASAI ANTXO	Oarsoaldea
ANOETA	218	DON-AMA	DONOSTIA	Donostialdea
ARCCO	258	DON-AMA	DONOSTIA	Donostialdea
BARCELO 28	736	DON-AMA	DONOSTIA	Donostialdea
RIBERAS	4727	DON-AMA	DONOSTIA	Donostialdea
SANCHO 26	198	DON-AMA	DONOSTIA	Donostialdea
N/A	4030	DON-CEN	DONOSTIA	Donostialdea
OKENDO	1727	DON-CEN	DONOSTIA	Donostialdea
P.GIPUZKOA	653	DON-CEN	DONOSTIA	Donostialdea
P.GIPUZKOA	654	DON-CEN	DONOSTIA	Donostialdea
C/ URBIETA	461	DON-ENS	DONOSTIA	Donostialdea
MCRISTINA	4146	DON-ENS	DONOSTIA	Donostialdea
PZA CENTEN	217	DON-ENS	DONOSTIA	Donostialdea
SAN MARTIN	348	DON-ENS	DONOSTIA	Donostialdea
HOSPITAL	350	DON-HOS	DONOSTIA	Donostialdea
HOSPITAL	351	DON-HOS	DONOSTIA	Donostialdea
HOSPITAL	709	DON-HOS	DONOSTIA	Donostialdea
ILLUMBE	707	DON-HOS	DONOSTIA	Donostialdea
ILLUMBE	714	DON-HOS	DONOSTIA	Donostialdea

PAR DESCABRV	PAR CODIGO	ZnID	ZnTOWN	ZnCOUNTY
ONKOLOGIKO	1781	DON-HOS	DONOSTIA	Donostialdea
ONKOLOGIKO	3940	DON-HOS	DONOSTIA	Donostialdea
POLIKLINIK	349	DON-HOS	DONOSTIA	Donostialdea
ERROTABURU	202	DON-IGA	DONOSTIA	Donostialdea
MAGISTERIO	4038	DON-IGA	DONOSTIA	Donostialdea
UNIVERSIDA	203	DON-IGA	DONOSTIA	Donostialdea
ZUMALAKA 9	380	DON-IGE	DONOSTIA	Donostialdea
ESCALERILL	111	ESC-HER	ALTZA	Oarsoaldea
ESCALERILL	140	ESC-HER	ALTZA	Oarsoaldea
HERRERA	28	ESC-HER	ALTZA	Oarsoaldea
HERRERA	649	ESC-HER	ALTZA	Oarsoaldea
AMBULATORI	142	GRS-CEN	GROS	Donostialdea
AV NAVARRA	95	GRS-CEN	GROS	Donostialdea
JAI ALAI	108	GRS-CEN	GROS	Donostialdea
MIRAKRUZ K	24	GRS-CEN	GROS	Donostialdea
ZURRIOLA	96	GRS-CEN	GROS	Donostialdea
ALAMEDA	4058	HON-CEN	HONDARRABIA	Bidasoaldea
AMA	53	HON-CEN	HONDARRABIA	Bidasoaldea
ARROKA	4047	HON-CEN	HONDARRABIA	Bidasoaldea
ARROKA	4054	HON-CEN	HONDARRABIA	Bidasoaldea
BITERI	4724	HON-CEN	HONDARRABIA	Bidasoaldea
CORREOS	55	HON-CEN	HONDARRABIA	Bidasoaldea
FORU KALEA	1297	HON-CEN	HONDARRABIA	Bidasoaldea
ITERLIMEN	1294	HON-CEN	HONDARRABIA	Bidasoaldea
ITERLIMEN	1296	HON-CEN	HONDARRABIA	Bidasoaldea
ITSASARGI	103	HON-CEN	HONDARRABIA	Bidasoaldea
KOSTA	4137	HON-CEN	HONDARRABIA	Bidasoaldea
KOSTA	1290	HON-CEN	HONDARRABIA	Bidasoaldea
LA MUELA	104	HON-CEN	HONDARRABIA	Bidasoaldea
LURGORRI	1292	HON-CEN	HONDARRABIA	Bidasoaldea
MADALENGAI	4725	HON-CEN	HONDARRABIA	Bidasoaldea
S. ARANA	52	HON-CEN	HONDARRABIA	Bidasoaldea
S. ARANA	56	HON-CEN	HONDARRABIA	Bidasoaldea
S.ENGRACIA	4730	HON-CEN	HONDARRABIA	Bidasoaldea
SOKOA	4729	HON-CEN	HONDARRABIA	Bidasoaldea
TALAIA	4726	HON-CEN	HONDARRABIA	Bidasoaldea
ZULOAGA	54	HON-CEN	HONDARRABIA	Bidasoaldea
ALTO MIRAC	27	INTX-CEN	DONOSTIA	Donostialdea
ALTO MIRAC	174	INTX-CEN	DONOSTIA	Donostialdea
ATEGORRIET	26	INTX-CEN	DONOSTIA	Donostialdea
ATEGORRIET	177	INTX-CEN	DONOSTIA	Donostialdea
ATEGORRIET	4050	INTX-CEN	DONOSTIA	Donostialdea
ELOSEGI111	651	INTX-CEN	DONOSTIA	Donostialdea
GAIZTARRO	650	INTX-CEN	DONOSTIA	Donostialdea
A.GIPUZKOA	10	IRU-CEN	IRUN	Bidasoaldea
A.GIPUZKOA	90	IRU-CEN	IRUN	Bidasoaldea
ADUANA	4086	IRU-CEN	IRUN	Bidasoaldea
COLON 42	1287	IRU-CEN	IRUN	Bidasoaldea
COLON 43	1483	IRU-CEN	IRUN	Bidasoaldea
CRUZ ROJA	91	IRU-CEN	IRUN	Bidasoaldea
ELIZATXO	4053	IRU-CEN	IRUN	Bidasoaldea
ENSANCHE	100	IRU-CEN	IRUN	Bidasoaldea
FUENTE 2	101	IRU-CEN	IRUN	Bidasoaldea
GENARO ETX	4056	IRU-CEN	IRUN	Bidasoaldea
L. MARIANO	1477	IRU-CEN	IRUN	Bidasoaldea
NAFARROA 4	4076	IRU-CEN	IRUN	Bidasoaldea

PAR DESCABRV	PAR CODIGO	ZnID	ZnTOWN	ZnCOUNTY
NAVARRA 21	4067	IRU-CEN	IRUN	Bidasoaldea
PALMERA	4077	IRU-CEN	IRUN	Bidasoaldea
PINAR	48	IRU-CEN	IRUN	Bidasoaldea
SAN JUAN	4061	IRU-CEN	IRUN	Bidasoaldea
ZUBIAURRE	106	IRU-CEN	IRUN	Bidasoaldea
ALDABE	4072	IRU-NOR	IRUN	Bidasoaldea
AMUTE	58	IRU-NOR	IRUN	Bidasoaldea
AMUTE	1288	IRU-NOR	IRUN	Bidasoaldea
AMUTE	4060	IRU-NOR	IRUN	Bidasoaldea
ARAKISTAIN	43	IRU-NOR	IRUN	Bidasoaldea
ARAKISTAIN	85	IRU-NOR	IRUN	Bidasoaldea
GIBENAKA	4068	IRU-NOR	IRUN	Bidasoaldea
GIBENAKA	4728	IRU-NOR	IRUN	Bidasoaldea
HOSPITAL	4071	IRU-NOR	IRUN	Bidasoaldea
KAPUTXINOA	50	IRU-NOR	IRUN	Bidasoaldea
MENDELU	102	IRU-NOR	IRUN	Bidasoaldea
MENDELU	105	IRU-NOR	IRUN	Bidasoaldea
PUIANA	4070	IRU-NOR	IRUN	Bidasoaldea
BENTAS	86	IRU-SUR	IRUN	Bidasoaldea
BUENOSAIRE	4048	IRU-SUR	IRUN	Bidasoaldea
CARMELITAS	4052	IRU-SUR	IRUN	Bidasoaldea
LA SALLE	89	IRU-SUR	IRUN	Bidasoaldea
PORCELANAS	45	IRU-SUR	IRUN	Bidasoaldea
TXINGUDI	5012	IRU-TXI	IRUN	Bidasoaldea
FRONTON	817	JUN-CEN	DONIBANE	Oarsoaldea
MEIPI	818	JUN-CEN	DONIBANE	Oarsoaldea
SAN ROQUE	4104	JUN-CEN	DONIBANE	Oarsoaldea
ALAMEDA E.	34	LAR-IZT	IZTIETA	Oarsoaldea
ALAMEDA E.	79	LAR-IZT	IZTIETA	Oarsoaldea
GABIERROTA	37	LAR-IZT	IZTIETA	Oarsoaldea
GABIERROTA	80	LAR-IZT	IZTIETA	Oarsoaldea
IZTIETA	138	LAR-IZT	IZTIETA	Oarsoaldea
IZTIETA	216	LAR-IZT	IZTIETA	Oarsoaldea
LARZABAL	112	LAR-IZT	IZTIETA	Oarsoaldea
LARZABAL	4166	LAR-IZT	IZTIETA	Oarsoaldea
ALTAMIRA	152	LEZ-CEN	LEZO	Oarsoaldea
LEZO	147	LEZ-CEN	LEZO	Oarsoaldea
LEZO	151	LEZ-CEN	LEZO	Oarsoaldea
POLIDEPORT	819	LEZ-CEN	LEZO	Oarsoaldea
POLIDEPORT	824	LEZ-CEN	LEZO	Oarsoaldea
GAINTXU	42	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
LANBARREN	83	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
LINTZIRIN	38	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
OLIDEN	4957	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
GAINTXU	84	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
LANBARREN	39	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
LINTZIRIN	82	LIN-GAI	INDUSTRIALDEA	Oarsoaldea
ALTZIBAR	131	OIR-CEN	OIARTZUN	Oarsoaldea
ARISTEGI	4105	OIR-CEN	OIARTZUN	Oarsoaldea
ARISTEGI	4106	OIR-CEN	OIARTZUN	Oarsoaldea
ARRAGUA	113	OIR-CEN	OIARTZUN	Oarsoaldea
ARRAGUA	137	OIR-CEN	OIARTZUN	Oarsoaldea
BELUTENE	130	OIR-CEN	OIARTZUN	Oarsoaldea
IBARRE	134	OIR-CEN	OIARTZUN	Oarsoaldea
IGLESIA	126	OIR-CEN	OIARTZUN	Oarsoaldea
ISASTI	4107	OIR-CEN	OIARTZUN	Oarsoaldea

PAR DESCABRV	PAR CODIGO	ZnID	ZnTOWN	ZnCOUNTY
ITURRIOTZ	133	OIR-CEN	OIARTZUN	Oarsoaldea
MAMUT	115	OIR-CEN	OIARTZUN	Oarsoaldea
MAMUT	136	OIR-CEN	OIARTZUN	Oarsoaldea
MATEO	116	OIR-CEN	OIARTZUN	Oarsoaldea
PEENE	132	OIR-CEN	OIARTZUN	Oarsoaldea
PIKABEA	4109	OIR-CEN	OIARTZUN	Oarsoaldea
PIKABENE	4108	OIR-CEN	OIARTZUN	Oarsoaldea
TALAIA	114	OIR-CEN	OIARTZUN	Oarsoaldea
UGALDETXO	135	OIR-CEN	OIARTZUN	Oarsoaldea
ARRILLAGA	7000	PED-CEN	SAN PEDRO	Oarsoaldea
AZKUENE	162	PED-CEN	SAN PEDRO	Oarsoaldea
AZKUENE 19	7006	PED-CEN	SAN PEDRO	Oarsoaldea
AZKUENE 33	7005	PED-CEN	SAN PEDRO	Oarsoaldea
BIDEBIETA	160	PED-CEN	SAN PEDRO	Oarsoaldea
BIDEBIETA	172	PED-CEN	SAN PEDRO	Oarsoaldea
BORDAENEA	7002	PED-CEN	SAN PEDRO	Oarsoaldea
CONTADORES	159	PED-CEN	SAN PEDRO	Oarsoaldea
CONTADORES	173	PED-CEN	SAN PEDRO	Oarsoaldea
EUSKADI ET	171	PED-CEN	SAN PEDRO	Oarsoaldea
GRAN SOL	7001	PED-CEN	SAN PEDRO	Oarsoaldea
GUDARI E.	164	PED-CEN	SAN PEDRO	Oarsoaldea
GUDARI E.	169	PED-CEN	SAN PEDRO	Oarsoaldea
MERCADILLO	163	PED-CEN	SAN PEDRO	Oarsoaldea
OIARTZUN	7003	PED-CEN	SAN PEDRO	Oarsoaldea
PESCADERI2	4100	PED-CEN	SAN PEDRO	Oarsoaldea
PESCADERIA	4483	PED-CEN	SAN PEDRO	Oarsoaldea
SAN PEDRO	1708	PED-CEN	SAN PEDRO	Oarsoaldea
TRINTXERPE	170	PED-CEN	SAN PEDRO	Oarsoaldea
ULIA 22	7004	PED-CEN	SAN PEDRO	Oarsoaldea

Appendix D

Recent Ridership Variation in San Sebastián East

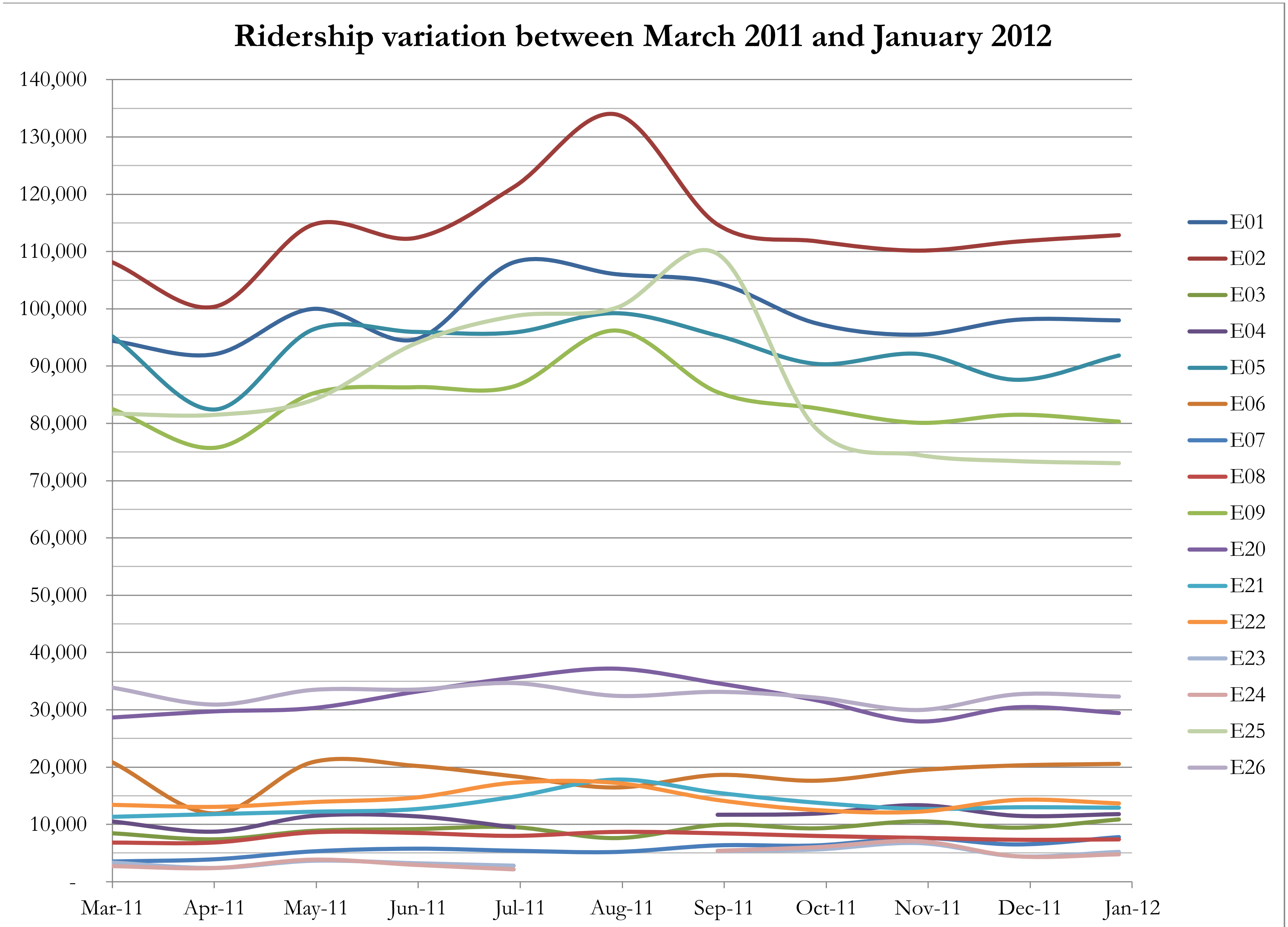


Figure D.1: Ridership Variation in San Sebastián East

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