UNIVERSIDADE da MADEIRA

TRANSPORT MODELLING: MACRO AND MICRO SIMULATION FOR THE STUDIED CASE OF FUNCHAL

A thesis submitted for the degree of Master of Civil Engineering at the Center of Exact Sciences and Engineering of the University of Madeira

by

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To my family

ABSTRACT

The work done in this thesis attempts to demonstrate the importance of using models that can predict and represent the mobility of our society. To answer the proposed challenges two models were examined, the first corresponds to macro simulation with the intention of finding a solution to the frequency of the bus company Horários do Funchal, responsible for transport in the city of Funchal, and some surrounding areas. Where based on a simplified model of the city it was possible to increase the frequency of journeys getting an overall reduction in costs.

The second model concerns the micro simulation of Avenida do Mar, where currently is being built a new roundabout (Praça da Autonomia), which connects with this avenue. Therefore it was proposed to study the impact on local traffic, and the implementation of new traffic lights for this purpose. Four possible situations in which was seen the possibility of increasing the number of lanes on the roundabout or the insertion of a bus lane were created. The results showed that having a roundabout with three lanes running is the best option because the waiting queues are minimal, and at environmental level this model will project fewer pollutants.

Thus, this thesis presents two possible methods of urban planning. Transport modelling is an area that is under constant development, the global goal is to encourage more and more the use of these models, and as such it is important to have more people to devote themselves to studying new ways of addressing current problems, so that we can have more accurate models and increasing their credibility.

RESUMO

O trabalho realizado nesta tese pretende sensibilizar para a importância do uso de modelos capazes de prever e de representar a mobilidade da nossa sociedade. Para responder aos desafios propostos, foram realizados dois modelos, um primeiro no âmbito da macro simulação com a intenção de encontrar uma solução para a frequência dos autocarros da companhia Horários do Funchal, responsável pelo transporte público na cidade do Funchal, e de algumas zonas envolventes a esta. Assim, com base num modelo simplificado da cidade foi possível aumentar a frequência das carreiras obtendo uma redução global de custos.

O segundo modelo diz respeito à micro simulação da Avenida do Mar – de momento está a ser construída uma nova rotunda (Praça da Autonomia), que faz ligação com esta avenida. Foi proposto estudar o impacto desta rotunda no trânsito local, e a implementação de novos semáforos para tal efeito. Foram criados quatro situações possíveis em que foi vista a possibilidade de aumentar o número de vias na rotunda ou a inserção de uma via de autocarro. Os resultados obtidos demonstraram que a melhor opção é a rotunda a funcionar com três vias, pois as filas de espera são mínimas. Para além disso, a nível ambiental este modelo apresenta menos projeções de gases poluentes.

Sendo assim, esta tese apresenta dois possíveis métodos de planeamento da mobilidade urbana. A modelação de transporte é uma área que está em constante desenvolvimento, o objetivo global é incentivar cada vez mais o uso destes modelos, e como tal é importante ter mais pessoas a dedicar-se a estudar novas formas de abordar os problemas atuais, para que seja possível ter modelos mais precisos fazendo com que a credibilidade destes seja cada vez maior.

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TERMINOLOGY

In order to facilitate and clarify the reading of this work, we present some terms and definitions used in the literature regarding the Transport Modelling.

Alpha level – this factor is used to scale the bandwidth settings entered in the "Input" tab, which models the counts as imprecise values based on Fuzzy Sets theory. If one knows, for example, that the number of alighting passengers in an area fluctuates by up to 10 % on a day-to-day basis, but in other areas by up to 20 %, then this is represented by appropriate bandwidths, the exact count values are replaced by Fuzzy Sets with varying bandwidths representing count values close to the average value.

BOT Scheme – The Build-Operate-Transfer network design problem often involves three parties: the government, private sectors, and road users. Each of the parties has different objectives that often conflict with each other.

Micro Simulation – Describes traffic at high level of detail and distinguish single, separate units in the traffic flow (different types of vehicles, pedestrians) and mutual interactions between them. They are usually applied for the detailed analysis of limited segments of transportations systems.

Macro Simulation – Models that describe traffic at a high level of aggregation, as a uniform traffic flow. They are based on deterministic relationships between the quantities characterizing the traffic flow such as: volume, speed and density. Macroscopic simulation has been developed to model an entire transportation network and/or system.

Stochastic Simulation – Is a model that operates with variables that change with a certain probability. Based on a set of random values, generates samples in computing environment and use the said samples for obtaining a result that shows the most probable estimates as well as a frame of expectations.

Substantive rationality – Quantify the costs and benefits associated to each approach with some luck by assuming that we know what our purposes are and we can imagine all alternatives ways of achieving them [1].

Sample – The sample is defined as a collection of elements which has been especially selected to represent a larger population with certain attributes of interest (i.e. height, age, income). Three aspects have to be thought before doing sampling: first, which population the sample seeks to represent; second, how large the sample should be; and third, what is meant by ‘especially selected’ [1].

Population of Interest – This is the complete group about which information is wanted; is composed of individual elements [1].

Simple Random Sampling –It consists in first associating an attribute to distinguish each unit in the population then selecting from these randomly to obtain the sample [1].

Stratified Random Sampling – where a *priori* information is first used to subdivide the population into homogeneous strata (with respect to the stratifying variable) and then simple random sampling is conducted inside each stratum using the same sampling rate [1].

Dynamic Model – Models for short time representation, are closer to reality because the fact ensures direct linkage between travel time and congestion. These models capture accelerating, decelerating, merging, and queuing [2]. If link outflow is lower than link inflow, link density (or concentration) will increase (congestion), and speed will decrease (fundamental speed–density relationship), and therefore link travel time will increase [3].

Static Model – Is a model defined on a quite long time-of-day period. This approach has some limitations as far as the realism with which it represents the actual process (taking place on the road) that gives rise to congestion and increased travel time [3].

Trip or Journey – Is a one way movement from a point of origin to a point of destination [1].

Home-Based Trip – This is one where the home of the trip maker is either the origin or the destination of the journey. Note that for visitors from another city their Hotel acts as a temporary home in most studies [1].

ACKNOWLEDGMENTS

This study has its roots in 2014, when the University of Madeira provided this theme for the dissertation research. This report is a response to the population needs, amelioration of lifestyle, the call for more traffic strategies, and enhanced analysis of data.

The information contained in this document, is based on Census, in Mobility Study done in Funchal and together with the data gathering conducted by numerous agencies, developers, and others individuals. This work is dependent on all that information, because it enhances the database on which we are based. The magnitude of the database bestows credence on the evidence contained in the report.

Therefore I want to express my gratitude to those many individuals who have contributed data, and who continue to contribute, to this effort.

In particular, the company Horários do Funchal and in special to Claudio Mantero and Funchal City Hall, for sharing all the data available.

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Funchal, September 2014

Rita Rodrigues

1

INITIAL CONSIDERATIONS

1.1. INTRODUCTION

Transport planning has gained a much higher public profile in recent years. Good cities need operational public transport (PT). It plays a vital role in creating competitive economies, on population lifestyle, and also in environmental terms. Public transport permits people to contact families and friends, education, health care, jobs, recreation and the many activities that contribute to individual and community comfort. It offers freedom for people who cannot or do not drive. This reproduces increasing worries over unbridled growth in private car use and the key problems associated with it: congestion and environmental problems both at the global level and local level, the climate change and the air pollution respectively.

To continue to improve the level and quality of public transport services, there is the need for real improvements in speed of travel, service frequency, reliability, safety, security, and ease of use. The power and management of public transport systems is an essential component of urban planning. Most strategies facilitates the provision of public transport instead of individual transport (IT), yet there is often a disconnection between land-use schemes and transport plans [4]. A failure to effectively consider the quality of public transport networks in land-use planning analysis has the latent to produce poor planning conclusions in two ways. As first new land-uses may be inefficiently served with public transport services, leading to requirement of another travel methods, such as cars. Second, the failure to identify the implication of well-planned local public transport networks, may end in the preclusion of some land-use options. Mathematical modelling traffic necessitates a lot of data and other information about the road network and the travel demand. The accuracy of the model depends on the quality of the available information, and how this data is combined and weighted from different sources [5].

The travel demand is a crucial component and nearly every traffic model requires a table specifying the travel demand between diverse places in the network. Such table is called an Origin-Destination matrix, or OD-matrix for short; synonymously used terms are trip table or trip matrix.

Macroscopic models are traditionally used for planning in greater networks over a longer time period. With these models it's important to ponder about what to seek in future, as for example: How would the city network be constructed, in respect to some supposition of population growth in the different sub-areas of the city. The microscopic model on the other hand is used for smaller network, since those model results are used for more specific concerns, such as: How can the available space be given transit lanes in the best way, to handle a sequence of intersections or a troublesome intersection? And in many cases microscopic models use data from a macroscopic model as input.

For recovering how a traffic scenario is developed over time, we use a dynamic model. This means a time-dependent model, which can reproduce the reaction of the traffic to a current situation, the input data must provide a large amount of details on the traffic situation and we must make assumptions on how the traffic flow propagates in both time and space. A time-independent model also known as static model, can be described as a steady state in a dynamic model, for example in a situation where reactions and contra-reactions are balanced. Time-independent models give an average report of the traffic situations, and involve less input data. Until today most macroscopic models are time-independent, whereas in microscopic we need a smaller and more detailed network to analyze time-dependent effects.

1.2. MOTIVATIONS

The biggest motivation by doing this dissertation is clearly the fact that is brought the traffic management topic to our society attention. There is an evident and constant problem of poor transport planning strategies implemented in our networks, which has been aggravated over time. To answer these problems, is need to study and improve the implemented strategies of the traffic management in the city such as, facilitating people movement, decreasing the travels time, reducing the costs in public transport, demining the accidents number and produce less pollution, among others.

Therefore urban plans are relevant in this case is important to do a Mobility plan, since transport has become one of the major issues affecting sustainability in European cities, leading to the need of urban strategies intervention. The simulation models are becoming a tool very important to support good city logistics, and is an easy way to show to the public the pretended changes. Introducing this new planning approach capable of linking the domains of land use, transport and environment will be need, if cities want to be able to face the challenges of the future.

1.3. OBJECTIVES

The global objective is to investigate the cumulative impacts of potential development on the bus networks where the principal aim is the elaboration of a robust evidence database. This allows planning an effective and improved long-term transport infrastructure strategy, with the goal of improving the existing problems and the predicted transport capacity issues on Funchal. Due the environmental impacts suffer in the city in the past years was necessary to rebuild and build new areas in the city. Through the macro simulation we aim to evaluate in a global, the traffic behaviour and in particular the frequencies of the bus in the network of Funchal. In the micro simulation we target the study of traffic conditions on Avenida do Mar, and once known those network restrictions the goal was the creation of a scenario with a better traffic behaviour.

1.4. FRAMEWORK

To develop the project it was necessary to separate it into several phases. Initially there was a data collection task. With base on the region Census and land use, was determined an origin destination matrix, which can tell us how much people are generated and attracted by each zone in the city. With this initial step done, since all the data was provided by the company Horários do Funchal, we advanced to macro simulation and the micro simulation.

Through macro simulation, the global study of Funchal, we aimed to obtain an OD-matrix that would match the latest figure of traffic behaviour based on the one provided by the company Horários do Funchal, so we can know the volume of people that is daily in the city, becoming able to determinate for the peak hour studied the busses frequency and at last estimate the costs associated and possible ameliorations. Via micro simulation, we devoted our attention to a specific zone in the city, the Avenida do Mar. Where was analyzed the relevance of the links connected to this avenue, the traffic lights, traffic queue and all others parameters that influence the traffic actual situation, determining the problems existent, with the purpose to find an alternative to improve it.

1.5. LIMITATIONS AND SCIENTIFIC CONTRIBUTION

The present dissertation reports all the work done with the investigation team GIST of the University of Cantabria, in Spain, for a period of six months. The purpose was to create a microscopic and macroscopic simulation model. Consequently it was need to learn how to use the simulation programs.

The license of VISUM itself was an obstacle. The company Horários do Funchal had supplied a macroscopic model of Funchal. But since the license in use by the University of Cantabria only allows, 2000 nodes and 5000 links was necessary to create a new macroscopic model, more simplified, then only allowing time to do one microscopic model.

As scientific contribution, was wrote during this period a scientific article entitled: Macro Simulation for the studied case of Funchal that can be seen in Appendix A. It was present during the XI Congress of Engineering of Transport, CIT 2014 in Cantabria, Spain. Also the models developed can be used as database to study ameliorations to Funchal traffic situation.

1.6. PRESENTATION OF THE THESIS

This dissertation consists of this introductory chapter, followed by five chapters corresponding to the transport modulation process and of a closing chapter where some conclusions and future developments are drawn.

The work developed in this thesis is divided into two parts: theoretical – Chapter 2 , were a fundamental scientific research work was taken care; and a practical work – corresponding to the chapters 3 and 4, The chapters are organized and distributed by the way introduce in the next paragraphs.

One brief theoretical introduction to some of the basic principles of Transport Planning in a general scope is presented in Chapter 2.

Chapter 3 describes the process used on building a macro simulation with the program VISUM. Also is presented the mathematical model to determine the frequencies, with it the respective results obtained, and is discussed some recommendations.

Chapter 4 introduces the explanation of the methodology used for the design of a micro simulation model using the program AIMSUN, where it also presents the results and discusses them.

In Chapter 5 the concluding remarks, show the usefulness of the programs in urban planning.

2

STATE-OF-THE-ART
TRANSPORT PLANNING AND MODELLING

2.1. BACKGROUND

To confront the challenge of sustainable urban mobility, urban planners need models, decision support tools, and input data allowing efficient results from the calculation approaches. To resolve the capacity problem it was thought in the past that, it was simply necessary to provide additional road space. This was the leading strategy applied in the U.S.A in the period of 1960's and 1970's. A lesson learnt from this plan is that adding capacity alone is futile because it induces travel growth that contradicts the benefits of highway expansion. Moreover, is difficult to use this strategy for one reason, that most cities are already built-up areas, therefore it is problematic to carry out any significant expansion work. In practice, it may be neither economically or socially acceptable to balance supply and demand only by increasing road capacity [6].

The progress in urban development during the last two centuries due to the increasing facility in mobility of society and the cheap costs related, brought new concerns about reliable development, also the challenges posed by energy scarcity and climate change, raises even more the necessity for new interventions on urban planning. Urban models serve various purposes, their main function is to help us achieve an enhanced understanding of urban dynamics, and this is society movements, the models permit virtual experimentation allowing the prediction of the impact cause by the implementation of new plans, infrastructures, or technologies. Lastly, models are a powerful tool to simplify involved processes for collective decision making, and also in presenting these solutions to the population. The most recent approach that has gained distinction in traffic management operations is the introduction of Intelligent Transportation Systems (ITS).

Such technologies help to monitor and manage traffic flow, reduce congestion, provide alternate routes to travelers and increase safety, both for people and for goods, and in the modelling area supplies a large number and variety of data. This system offers the prioritization of road users, road hierarchy, equipped with electronic apparatuses and variable message signs, passenger vehicles prepared with navigation system and emergency notification systems, commercial vehicles equipped for nonstop weighing and cross-border credentials checking, transit vehicles containing location and communications systems, infrastructure to automatically track and support the better management of traffic flow.

However, much as they may seem affordable, they are not effectively implemented in most developing countries. A good example is how traffic management can be implemented by application of road hierarchy regulations. A hierarchical road network is essential to increase road safety, amenity and legibility for all road users. Each class of road in the network serves a distinct set of functions and is designed for that reason. The design should express to motorists the predominant function of the road. For example there is an extensive division between local and non-local roads. Basically non-local and local roads are both the support to most of urban road networks. Non-local roads are important transport routes that are designed for high traffic volumes and high speeds, whereas local roads are essentially intended for accessibility, so with low volumes and low speeds.

Due to ITS mobility and transport, a recent explosion of data was available on individual movement at all scales which triggered the rise of studies on mobility networks, allowing a better understanding of the statistics of individuals movements, opening new directions for mobility modelling, and providing new insights into individual behaviour in the social and urban context [7].

2.2. MODELS AND THEIR ROLE

Models are focused on certain elements considered important to represent a part of the real world from a precise point of view. Analytical models are, where the solution to a set of differential equations describing the traffic system is obtain analytically, using calculus. These are extremely tedious and expensive and often involves doubts in the data. The simulation models are where the successive changes of the traffic system over time are approximated reproduced and they can be Macroscopic, Mesoscopic and Microscopic, depending on the level of detail required.

Modelling requires interpreting and understanding the reality and the analytic models behind the programs. Even that they are still simplified representations, these models require large amounts of data to be used, that make them very complex.

They are very important in offering a ‘common ground’ for discussing strategies and examining the authenticity of the situation. One of the most important elements in the complete planners’ tool-kit job, is the ability to choose and adapt models for particular contexts.

2.3. CHARACTERISTICS OF TRANSPORT PROBLEMS

Enough time has passed with poor or no transport planning to improve most methods of transport. The general increase in road traffic and transport demand has resulted in congestion, accidents, delays, environmental problems and as well the growing concern for the fuels shortages, are some of the transport problems in our days.

Mobility in networks can be described as the number of movements of individuals between various locations. This is the hardest task in all modelling process, since to obtain accurate quantities of data in this large set isn’t a simple step. A simple way to ratify this problem is to divide the area of interest in different zones and predict the supply and demand generated by each zone. Where the capacity and modes of transportation infrastructures, over a geographically defined transport system, represent transport supply for a specific period of time, to ensure the satisfaction of a certain demand, which is directly affected by the economy advance. A typical example is the vicious circle of urban decline described in the Figure 2.1, which helps understanding the nature of some transport problems.

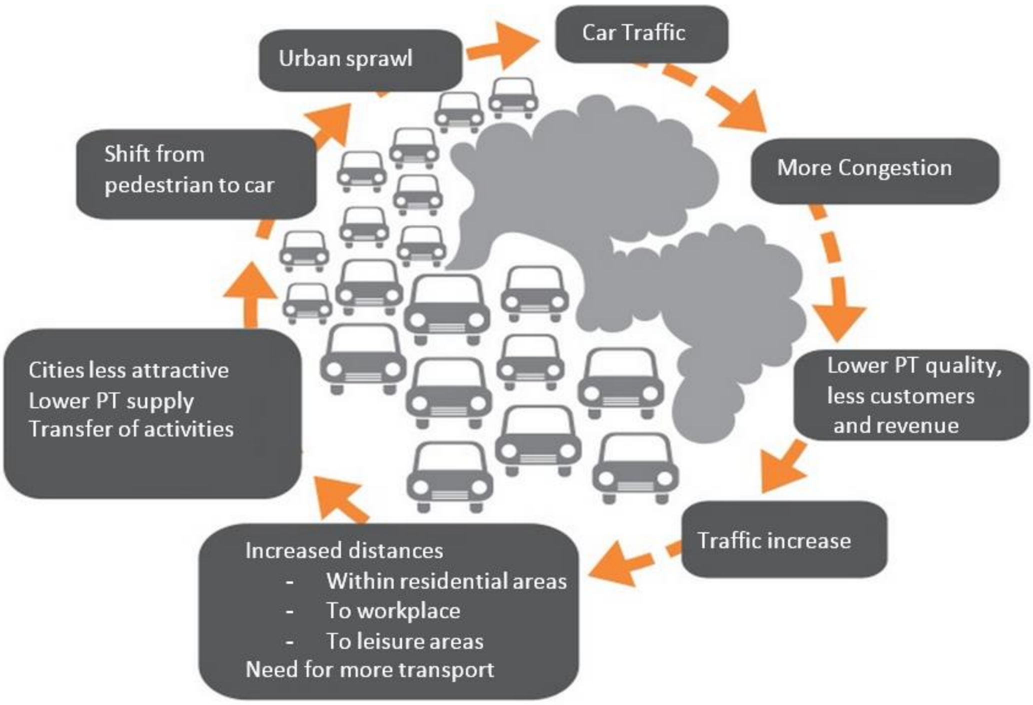


Figure 2.1 – Vicious circle of urban decline.

Economic growth provides the first push to increase car ownership. More car owners means less people using public transport; with fewer public-transport passengers, to which operators may respond by increasing the fares, reducing level of service or both. These measures make the use of the car even more attractive than before and encourage more people to buy cars, thus accelerating the vicious circle.

Moreover there is a more devious effect in the long term, illustrated in the Figure 2.1, as car owners chose their place of work and residence without considering the availability of public transport, will generate urban sprawl, low density developments that are more difficult and expensive to serve by more efficient public transport modes. Through the representation in Figure 2.2, we can also understand what can be done to slow down or reverse this vicious circle.

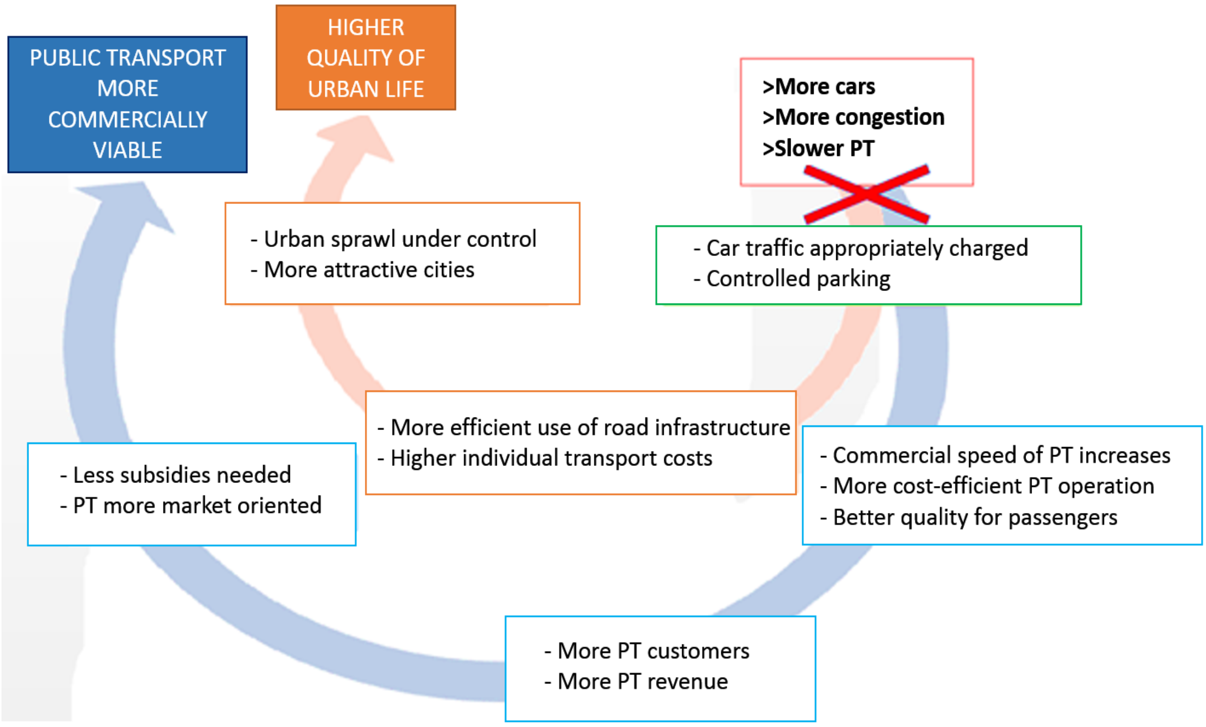


Figure 2.2 – Breaking the car/public-transport vicious circle.

Physical measures like bus lanes or other bus-priority schemes are particularly attractive, because they cost less to the community, need less urban space, are less energy-intensive, pollut less, is the safest mode of transport, improves accessibility to jobs, offers mobility for all as they also result in a more efficient location of road space. Also the urban plans are necessary to put an end to urban sprawl, to promote density around PT stations and routes, encourage integration of activities, limit construction on empty land, control parking standards for residential, office and commercial buildings, encourage car-free residential zones, ensure coherency of housing strategies, and so on.

Car limitation, and in particular congestion charging can help to reduce car use and generate profits that can be distributed to other areas of need intervention in urban planning, implementation of traffic schemes, limiting car use in city centers, controlling parking and developing pedestrian zones. Represent some of the measures that can be taken to amend poor or complete lack of traffic planning.

However, the type of model behind Figure 2.2, is not exempt from risks when applied to different contexts. So the context is also pertinent when looking for solutions; it has been said that one of the main objectives of introducing bus-priority schemes in emerging countries is not just to protect buses from car-generated congestion but to organize bus movements. High bus volumes, imply that they will have priority over other cars, which will generate interference between buses and will occur major source of delay than car-generated congestion.

It should be clear that it is not possible to characterize all transport problems in a unique universal form [1]. Transport problems must be always approached as context dependent and so should be the ways of dealing with them. Models offer a contribution in making the identification of problems and selection of ways to address them more solid based, but is obligatory to study case by case.

2.4. DATA AND SPACE

To effectively do transportation planning it is important to have large amounts of data and cooperation between transportation planning agencies. Advances in technology and the increasing availability of geographic information systems (GIS), are giving transportation planners the facility and ability to advance and use data with a much higher degree of competence. However as mentioned in [8], for information systems to advance, it is essential to provide real data integration/exchange protocols and ways to reduce redundancy and data collection costs. Data compatibility, data access, data quality, metadata, data completeness, hardware, software, and staff expertise are some of many factors that influence the effectiveness of data exchange and data integration efforts.

2.4.1. METHODS TO COLLECT DATA

The selection of most appropriate data collection methods will depend significant on the type of models that will be used in the study, defining which type of data is needed and therefore what data collection methods are more appropriate. The numbers of movements of individuals between various locations describes mobility in traffic networks. These flows are the core of transportation models, they constitute the origin-destination matrix, whose properties have been discussed in a large number of papers [9].

The OD-matrix describes a network, directed and weighted, and in general is time-dependent. These matrices are usually extremely difficult and costly to measure, and it is only recently, thanks to technological advances such as the global position system (GPS) or the democratization of mobile phones together with geographic and social applications, that help to obtain precise quantities on large data sets, opening the door to an improved reckonable understanding of urban movements.

Calls from cell phones are an additional source of mobility data. Is large enough the density of base stations of antennas, that can serve the mobile phone network in urban areas, so that triangulation gives a relatively accurate indication of the users' position (mobile phones are frequently in contact with the base station; triangulation lets determine the location of the device at a resolution that depends on the local density of base stations). Mobile phone data has lately been used to point individual trajectories [10], to identify ‘anchor points’ where individuals pass most of their time [11-13], or statistics of trip patterns [14-18].

GPS is one more fascinating tool in order to categorize individual trajectories. GPS data of individual vehicles show that the total daily length trip is exponentially dispersed [19, 20], and looks to be independent of the structure of road network, directing to the reality of require more general principles governing human movements [21].

In another scale and even at the scale of social networks, Radio Frequency IDentification (RFID) might offer interesting visions. This technology is usually composed of a tag which can interact with a transceiver that processes all information confined in the tag. RFIDs are used in many different cases, from tagging goods or dynamical measures of social networks [22]. Was also found that the traffic is generally distributed, in arrangement with many other transportation links [7], but also that the displacement length distribution is peaked. However, there is need to keep in mind that there are some problems connected with those methods, such as the present privacy issues, which need to be handled carefully.

Surveys are of particular relevance to transport and land-use planning in several specific areas. These may be select based on the influence of three factors: characteristics of the trip maker, of the journey and the transport facility. Land-use surveys are an integral component, they measure spatial location and intensity of land-use activities. The amount of travel which takes place between land-uses will depend on the quality and quantity of the transport system which connects the land-uses, so surveys of the transport system inventory play a major role in specifying the location and characteristics of the available transport system, this is the system performance. The combination of land-use activity, this is understanding which activities attract and generate trips with a transport system, the type of vehicle used to effectuate a trip always results in trip-making matrices.

To measure the trip-making it is necessary to conduct travel pattern surveys, these may be described in terms of who is going where, with whom, at what time, by which mode of transport and route, and for what purpose.

Surveys represent the largest and most comprehensive source of travel data. Each of the previous types of data collection methods has the shared characteristic that it tries to measure the movements flow. The ability to visualize plus forecast future changes in the system is an important part of the planning process. In particular, as a result of changes in the physical system or changes in the operating characteristics of that system the planner is often required to predict the consequential changes in travel demand. Also it is well predictable that various groups in the population will react differently to changes in the transport system, which it is important to consider when trying to minimize the collateral effects that may be formed in attempting to predict the demands which will be placed on a transport system. To categorize these groups, it is necessary to combine demographic and socio-economic surveys within the complete transport survey framework [23]. As we may also need to understand, each entity reacts not to actual changes in the transport system but to perceived changes in that system. For that reason, perception and attitude surveys often are a vital component of transport planning surveys. Therefore data from surveys are habitually used as inputs to travel demand models. In many cases, a transport survey will realize more than one of the above discussed roles.

2.5. TRIP GENERATION AND DISTRIBUTION MODELS

Trip generation aims at predicting the total number of trips generated and attracted to each zone of the study area by an O-D matrix or by considering the factors that generate and attract trips, a Production-Attraction (P-A) matrix.

In general we can say it’s a main resource for determining how many vehicle trips will be added to surrounding roadways as a result of new development. The study of trip generation allows to collect and analyze data on the relationships between trips attracted and produced to and from a development, as well as the characteristics of a determined land. It provides trip rates, equations and data plots based on traffic counts and characteristics of the surveyed land uses. The trip rates are appropriate for planning purposes and traffic impact studies.

While an OD-matrix stores information about the trips from a particular time period, the P-A matrix will cover a longer time span. In other words this stage answers the questions to “how many trips” are originated at each zone, from the data on household and socioeconomic attributes, considering two principles if it is trip or activity based.

Some of the models based in an origin destination matrix are suitable for short-term, tactical studies where there aren't further changes in the accessibility in the network. The P-A are more indicated to when is applied changes in network costs or in tactical studies, that involve important changes in transport prices and are suggested for longer-term strategic. Distribution is often seen as an aggregate problem with an aggregate model for its solution, most of it treatment in this dissertation shares that view.

Trip production is defined as, all trips are home based or non-home based as the origin of the trips. In Figure 2.3, trips can be classified by trip purpose, trip time of the day, and by person type.

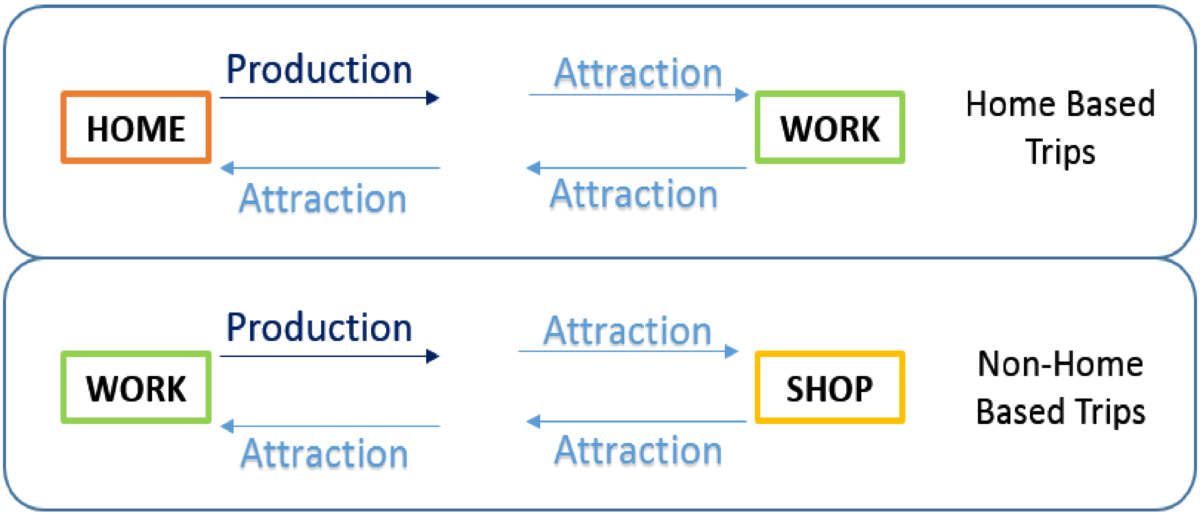


Figure 2.3 – Trip types.

In trip generation models, trips can be organized based on the purpose of the journey such as, work trips, education trips, shopping trips, recreation trips, etc [24]. Another form of classification is built on the time of the day when the trips are made, with an extensive classification into peak trips and off peak trips. Another possible way of classification is based on categorizing the individuals who makes the trips, because the travel behaviour is highly influenced by the quality of life that each traveler has, and they are usually categorized based on the income level, vehicle ownership and house hold size.

In some works [25], it is recognized the importance of main factors that influence trip generation, for example the number of trips produced by a household is extremely dependent on family size and household structure, affecting personal trip production, the profits, and vehicle ownership. In addition factors like the value of land, accessibility and residential density are similarly considered for modelling at zonal levels. The land use influences on the other hand the personal trip attraction.

At the zonal level, it is significant zonal employment and accessibility in trip generation. Being able to model personal trips, freight trips are also of interest. Nevertheless, we should not forget pedestrians, the number of walking trips in denser areas has been more, and therefore those trips must be separated from vehicular ones.

The decision to travel for a given purpose is called trip generation. The trip distribution is the organization of trip generation in a trip matrix, which stores the trips made from an origin to a destination during a particular time period, and may be disaggregated by person and type and purpose of perhaps the activity undertaken at each end of the trip. Thus, trip distribution is a model of travel between zones-trips or links with the purpose to produce a trip table of the estimated number of trips within the study area, estimated by the trip generation models. The modeled trip distribution can then be compared to the actual distribution to see whether the model produces a reasonable approximation.

Different distribution models have been proposed for different sets of problems and conditions, five different models are presented here. These are Growth factor method, Gravity model, Intervening opportunities model, Choice model, and Entropy Model.

2.5.1. GROWTH FACTOR METHOD

Given an matrix of trip distribution, and if the only information available is about a general growth rate for the whole study area, then we can only assume that it will apply to each cell in the matrix, that is a uniform growth rate and usually are assumed inflows equal to outflows. Advantages are that they are simple to understand, and they are useful for short-term planning. Also we can use different types of growth factors, such as: Uniform Factor, Average Factor, Detroit etc. It is a pretty much two step exercise, first we must find the growth factor and lastly apply the factor to all current flows. Limitation is that the same growth factor is assumed for all zones as well as attractions.

Doubly constrained growth factor model, is when there is information available on the growth in the number of trips originating and terminating in each zone, consequently having two sets of growth factors, one for trips in and other for trips out of each zone. This implies that there are two constraints for that model. One of the methods of solving such a model is given by Furness who introduced balancing factors to be multiplied by our matrix zones. In such cases, a set of intermediate correction coefficients are calculated which are then appropriately applied to cell entries in each row or column. After applying these corrections to say in each row, totals for each column are calculated and compared with the target values. If the differences are significant, correction coefficients are calculated and applied as necessary.

2.5.2. GRAVITY MODEL

This model originally generated from an analogy with Newton's gravitational law. In gravity model, we start from assumptions about trip making behavior and the way it is influenced by external factors. An important aspect of the use of gravity models is their calibration.

The gravity model assumes that the trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the origin and the total attractions at the destination. The calibrating term or "friction factor" (F) represents the reluctance or impedance of persons to make trips of various duration or distances. The general friction factor indicates that as travel times increase, travelers are increasingly less likely to make trips of such lengths. Calibration of the gravity model involves adjusting the friction factor. The socioeconomic adjustment factor is an adjustment factor for individual trip interchanges. An important consideration in developing the gravity model is "balancing" productions and attractions. Balancing means that the total productions and attractions for a study area are equal.

Before the gravity model can be used for prediction of future travel demand, it must be calibrated. Calibration is accomplished by adjusting the various factors within the gravity model until the model can duplicate a known base year's trip distribution. For example, if you knew the trip distribution for the current year, you would adjust the gravity model so that it resulted in the same trip distribution as was measured for the current year.

2.5.3. INTERVENING OPPORTUNITIES MODEL

The intervening opportunities model, or more briefly, the opportunity model his, like the Gravity model uses the idea of trip making but is not explicitly related to distance but to the relative accessibility of opportunities for satisfying the objective of the trip. The original proponent of this approach was Stouffer (1940), who also applied his ideas to migration and the location of services and residences. But it was Schneider (1959) who developed the theory in the way it is presented today.

It's based on the assumption that a trip maker prefers to keep a trip short as possible. Trip length is governed by the probability of ending the trip at the nearest destination, but not always a trip maker is satisfied at the nearest destination, so the next nearest destination must be considered and so on until the trip maker reaches a satisfactory destination. The model distributes trips so that the probability of a trip ending at a destination area, is equal to the probability that a trip-satisfying destination is located within the destination area times.

2.5.4. CHOICE MODEL

It is the viewing of urban travel behaviour in a choice framework instead of the traditional demand method, appropriated for describing small areas of traffic behaviours as in micro simulations. Route choice modelling is critical in traffic sub networks approach, designed to be behaviourally realistic. Uses a set of data usually acquired by GPS or the traditional traffic counts, relatively a period of time specified. Mode choice may be influenced by three main groups: characteristics of the trip maker, characteristic only of the journey and the characteristics of the transport facility.

In an aggregate view we have Modal split models that are applied after the gravity or other distributions models, this has the advantage of facilitating the inclusion of the characteristics of the journey and the alternative modes available to undertake them. So this conventional sequential methodology requires the estimation of relatively well defined sub-models. An alternative approach is to develop directly a model subsuming trip generation, distribution and mode choice. This can be of two types: purely direct, which use a single estimated equation to relate travel demand directly to mode, journey and person attributes; and a quasi-direct approach which employs a form of separation between mode split and total O-D travel demand.

To disaggregate choice model we have the multimodal logit model, this is the simplest and most popular practical discrete choice model [26]. Where the ratio of one probability over the other is unaffected by the presence or absence of any additional alternative in the choice set, this means any of two alternatives have a non-zero probability of being chosen.

2.5.5. ENTROPY MODEL

Unlike the previous models discussed here, is not a behavioural model. That is, the entropy model does not strive to predict the trip distribution by modelling the human behavioural aspects related to choosing a destination. This model, on the other hand, attempts to determine a distribution of trips which is most likely to occur assuming that each trip occurs independently of another. For a total number of trips in a network, it is assumed that there are a total of independent decisions. Obviously, a given trip distribution matrix can be obtained through different combination of the decisions. In the entropy models it is considered we have a set of travels but instead of qualifying those travels by identifying each individual traveler, its origin, destination, mode, time of journey and so on, is preferable to work this data in a more aggregate approach. The basis of the method is to accept that, unless we have information to the contrary, all micro states consistent with our information about macro states are equally likely to occur. The classic gravity model is by far the most commonly used aggregated trip distribution model.

There are several possible classes of gravity model specifications, increasing the number of theoretical advantages and there isn’t lack of suitable software to calibrate and use it.

2.6. MODELLING AND DECISION MAKING

It is acknowledged, that the current transportation modelling process is challenging, in the sense that it employs a great deal of data to a large number of consistent models with many parameters [27]. The complexity of the modelling process, however, it does not exceed the difficulty to acquire accurate representation of complex economic and social phenomena.

The difficulty to analyze or even to represent the uncertainty that characterizes transportation systems and traveler decision making, is overcome with the estimation of many data amounts used.

Before choosing modelling approaches, the follow aspects must be take into account when specifying an analytical approach:

- Precision and accuracy;
- The adaptation of a particular perspective and choice;
- Level of detail required;
- The availability of suitable data;
- Resources available for the study;
- Data processing requirements;
- Levels of training and skills of the analysts;
- Modelling process and scope;

Once defined our problem and goal the use of models are required. Also we must take in count that the experience of the modeler is also a feature, since in some situations the interpretation of the traffic behaviour by the modeler is an important step in achieving an accurate traffic simulation model.

A distinction between trip-based and activity-based modelling is important to be done too, allowing us to understand which the target population in our study. Therefore is need to understand the two theoretical methods applied to transport modelling, when we want to decide which kind of approach is more suitable in our problem context to execute the formulation of our matrix.

Trip-based models are as well-known as the classic transportation model or the conventional four-step modelling process, presented in the following Chapter 3.2 of this Dissertation. They are currently the most universal groups of models used. The trip based approach uses individual trips as the unit of analysis. Time-of-day trips is modelled in a limited way often by applying time-of-day factors to 24 hour travel volumes or is either not modelled.

The parameter trip is the base of analysis in separate models for home-based trips and non-home based trips where is not considered the dependence among such trips. The organization of trips is not considered, there is no distinction between a single trip between origin and destination home-based from a home-based trip with multiple stops along the way, although the impact of such multiple stops has proven to be significant in the local environment. The theoretical challenges of these models, such as developing the algorithm for the user equilibrium approach, have basically been solved by the early 1980’s [28].

Activity-based models have been developed somehow as a response to a change in weight from the evaluation of long term investment based capital improvement strategies, to understand travel behaviour responses in a shorter-term congestion management procedure. Focusing on a set of activity patterns rather than an aggregated trip rate per household, these models try to model a comprehensive daily activity-travel pattern for individuals. This enables the modeler to adjust plans in response to temporal and spatial constraints, also allowing activity rescheduling, trip chaining and destination substitution, one example is the micro simulation models when used as input into a dynamic assignment model the model replaces the generations, distribution and mode choice components and produces dynamically specified trip tables [28].

Several practical aspects of activity-based modelling need to be considered. It needs time, survey data and decision making criteria for analysis and forecasting, consequently requiring the collection of data regarding all activities done by individuals over the course of the day. Although it is similar to administrating household surveys, one need to collect in-home as well as out-of-home activities. Therefore the information required is a little more extensive, but experience suggests that the results are not significantly different between travel surveys and time-use, while at the same time provides a much more comprehensive understanding of travel patterns and trip making.

The concept of rationality greatly influences policy analysis on planning. In the planning phases of transportation projects generally occurs decision making. Several procedures for making decisions have been outlined in effort to minimize inefficiencies or redundancies.

The most prominent decision-making process to emerge from systems analysis is rational planning. The Figure 2.4, illustrates how this system works. We can identify three layers of abstraction. The first layer (green) describes the high level, often unquantified objectives, intermediate goals and immediate actions or experiments, which is summarize in six steps. A second blue layer details many of the components of the first layer. A third layer, identified by the orange box, "abstract into model" depends on the problem at hand.

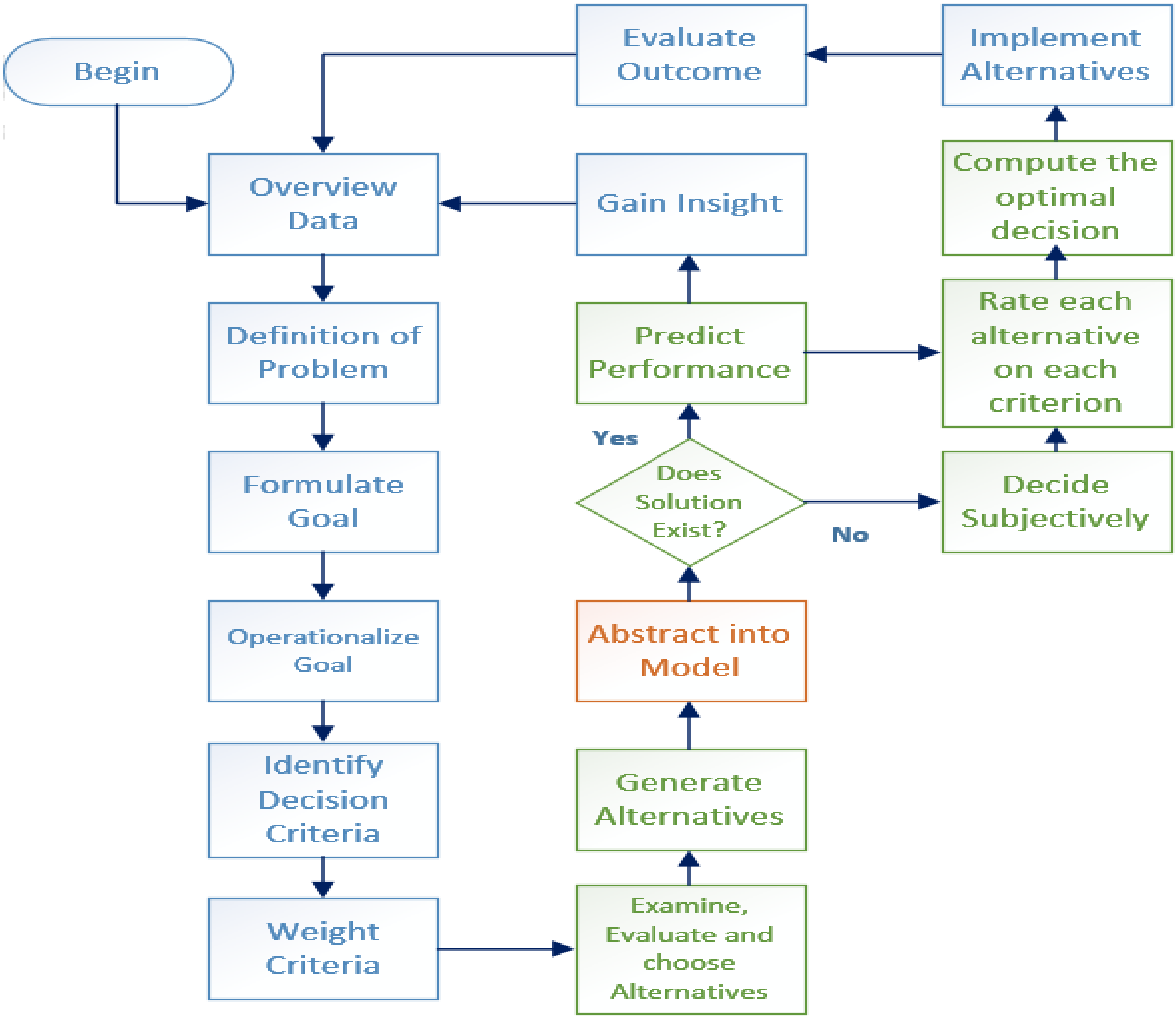


Figure 2.4 – Rational planning.

In practice, no organization attempts to use rationality alone, it is more common to apply a wide-ranging mixture of approaches using models, political context, narratives and sources of evidence. Modelling has an important role in each of these methods and the professional modeler should be ready to offer capacity for adaptation, and flexibility including new variables as required and responding quickly in the analysis of innovative strategies and designs.

3

MACROSCOPIC SIMULATION

3.1. INTRODUCTION

Macroscopic models simulate traffic flow, taking into consideration the several traffic characteristics, flow, speed, and density, but considering their relationships to each other. They can be used to calculate the spatial and sequential extent of congestion caused by traffic demand or incidents in a network, but, they cannot model the interactions of vehicles on alternative design configurations. The simulation in a macroscopic model rather take place on a section-by-section basis than by tracking individual vehicles. Macroscopic models employ equations on the conservation of flow and on how traffic disturbances broadcast through the system like shockwaves [29]. These models were originally developed to model traffic on distinct transportation sub networks, such as corridors including freeways and parallel arterials, surface-street grid networks, and rural highways.

To model and calibrate the road network in analysis we used the program VISUM, a traffic modelling *software* belonging to the German company of Transport Planning and Analysis of Operation. VISUM is a complete and flexible software system that contemplates transportation planning, network data management and travel demand modelling. VISUM is used on all continents due to a wide range of planning applications possible such as, metropolitan, regional, state wide and national. The program is designed for multimodal analysis, integrating all relevant modes of transportation into one reliable network model. VISUM provides a variety of assignment procedures and a 4-stage modelling component which includes trip-end based and as well activity based approaches [30].

Therefore thru this program we can model networks that offers the possibility to determine the various impacts or alterations in study zone, in respect to individual vehicles, public transport networks and inclusive to pedestrians movements.

Our goal for this model is to judge whether the transport system can cope with the predicted passenger volumes, in particular regarding the frequency of the bus company.

3.2. THE FOUR-STAGE MODEL

This model was developed during the 1950s and 1960s for planning the major highway facilities [31], and soon the model was applied in other traffic planning situations and recognized as a standard for macroscopic modelling.

The Figure 3.1 represents the traditional model that follows four sequential stages: Trip generation, Trip distribution, Modal split and Traffic assignment, and depending on the situation, some stages might not be applicable.

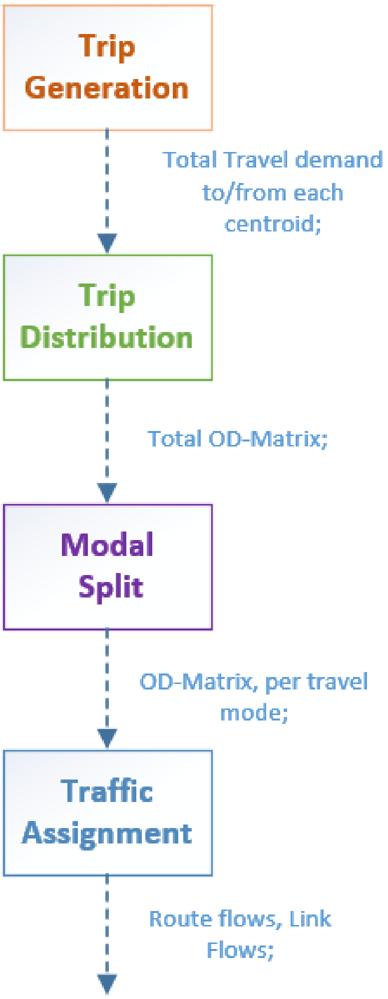


Figure 3.1 – The four-stage model in its basic form.

Although the four-stage model is almost fifty years old, it is still fundamental for strategic traffic planning. The outcome is, however, always a static description of the situation, which does not provide any information on how the traffic fluctuates over time. To have a time-dependent (dynamic) model we had to consider the influence from traffic conditions in a certain time period where in the traffic assignment model not only the route choice and the resulting route flows must be described for the time period studied, but also the interaction in time between vehicle streams.

The four-stage model and the basic ideas in each of its stages, for the dynamic models is more unexplored in comparison to the static assignment models. Though the first models for dynamic traffic assignment were proposed around thirty years ago [32], there is still no standard model framework. The time-dependent models are also unexpectedly poorly described in books and articles. Two exceptions are the literature overview by Peeta and Ziliaskopoulos (2001) and the basics on dynamic modelling given by Han (2003).

3.2.1. TRIP GENERATION

The first stage is Trip Generation, with the aim to determinate how many trips there will be originated or terminated at each zone in the network. The size of these zones in the study zone must be defined with an appropriate accuracy in respect to the purpose of the traffic model. Each zone is represented by a single node in the model which we will refer to as a centroid. To execute this phase it was necessary to collect a variety of data, concerning the characteristics of the trip makers for each centroid, such as age, sex, income, auto ownership, trip-rate, land-use, and travel mode. In general it is a major project to collect the required data, in our study this data was provided by the company Horários do Funchal.

3.2.2. TRIP DISTRIBUTION

The second stage is trip distribution, where we determine the flow of roads between origin and destination for all trips that were developed in trip generation. Trip distribution uses those trips to and from and independent variables on the transportation system to forecast the flows/trip interchanges between geography areas. The considerations are in total trips that begin in the first zone, the number ending in the second zone, and the factors that directly influence the impedance or difficulty to travel, such as cost or time between them.

The estimation and calculation of this initial matrix was done by the team of the Horários do Funchal, which estimated the volumes with base on land-use and on Census of Madeira Island.

3.2.3. MODAL SPLIT

This third stage modal split or known also as modal choice corresponds to the travel demand for each OD-pair and is partitioned into different travel modes. In our case there are only two travel modes available: private car and public transport. In some situations also the purpose of the trip is considered, since, for example, it seems more likely that a person would choose to travel to his work with the public transport, but prefer a private car, if available, for social trips. Further, the purpose of the trip can be important since it might affect the acceptance for a delay or route guidance information. Besides the consideration of available modes and trip purpose, some models also consider the socioeconomic status of the trip-maker. For some people, the travel time is more important than the travel cost, whereas the situation is the opposite for some others. In a simple way the description of the modal split stage is, given the travel demand for each OD-pair, the modal split procedure determines how this volume is disaggregated into different travel modes.

3.2.4. TRAFFIC ASSIGNMENT

The fourth and final stage, in the traffic assignment the OD-matrix for each mode is assigned onto the traffic network, according to some principle. The aim of this procedure is to calculate the link flow volumes. As indicated, each link must be a bearer of one or more travel modes and in the assignment procedure this must be taken into account. There are in general, many possible routes from one node to another therefore the assignment procedure must follow some assumption on how the routes are chosen. The criterion most used is that all travelers are assumed to drive the shortest path. To conclude the description of the traffic assignment stage we can say that given the travel demand for each mode in each OD-pair, the traffic assignment procedure assigns the travelers to routes in the network and predicts the traffic situation in terms of the link flows for all links in the network.

3.3. NETWORK REPRESENTATION

Due to the fact, that the license of the program in use by the University of Cantabria, only allows 2000 nodes and 5000 links, it was necessary to simplify the network to the maximum, without losing information that could compromise the study. Since we want to determine the bus frequencies, was more significant to the dissertation consider first all the bus links with the respective bus stops, and once all links were draw on the model we prioritized others roads where the traffic flow is high, carefully to not exceed the program license capacity.

Accordingly with the four stages model our modulation was sculpted and adjusted with consideration of:

- Study zone;
- Mobility in the zone;
- System of the collective transport;
- Links hierarchy;
- Surveys and count post information;
- Traffic count;
- Speeds;
- Saturation;

3.3.1. STUDY ZONE

The study zone is Funchal one of the ten municipalities that compose the island of Madeira, in Portugal. Madeira has an approximated area of 785 km^2, with many slopes that influence the zoning in most areas of the island. According to the Census of 2011, the Autonomous Region of Madeira had 267.785 habitants with a population density of 334.500 hab/km^2.

The population of Madeira reflects the geographical constraints that characterize it, where in a large part, the population is on the south coast, which led to the definition of two major centers of occupation: Funchal and Machico.

The urban growth of the island was always concentrated around Funchal due it geographic, with the remaining territory fragmented into clusters. The 90’s is marked by the beginning of population regression phenomena in the municipality of Funchal. These phenomena are typical in polarized urban centers of wide areas, reflecting the urban sprawl movement, where the price of housing is more accessible.

Funchal is a predominantly urban city, occupying an area of 73 km^2, where 44% of the territory is covered by urban areas. Is divided in 42 parishes, and has about 104 thousand people residing in Funchal, for modelling effect we had consider some others surrounding cities due to them influence in Funchal demand, concluding with a study zone divided in 51 areas. From the data of 2001 Census, there was a present population in Funchal around 7% superior (over 7.192 individuals), than the residents count, reflecting in part the weight of tourism.

In the Figure 3.2, we can see the 42 zones that compose Funchal and in the Appendix B can be consulted the districts names.

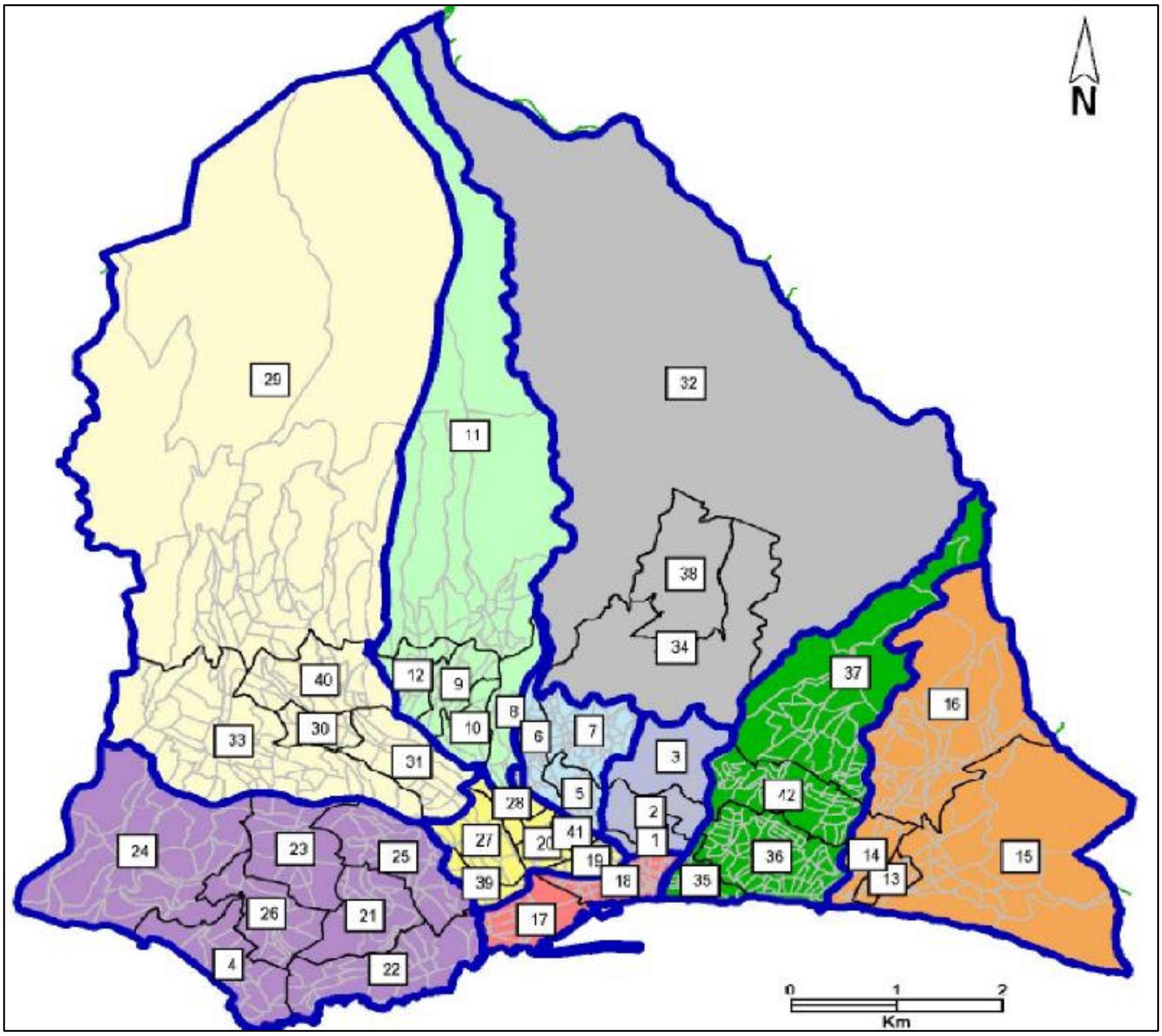


Figure 3.2 – Funchal zone distribuition.
Source: Survey of Mobility in the city of Funchal, 2006/2007.

3.3.2. MOBILITY IN FUNCHAL

Based in the summary report of the Study of Mobility in Funchal, of 2006/2007, were effectuated household surveys to residents and telephone surveys to non residents. The extrapolation of the survey, allows estimating that this population performs daily around 144.3 thousand trips, of which only about 200 trips don’t have a start or end in Funchal.

Based on the results of the counts and surveys done to the non resident population , but that performs activities in the study zone, it is estimated that daily "go in" Funchal approximately 24.6 thousand people, which perform about 60.3 thousand trips with end or start in Funchal. The duration of the trips varies, according to the factors considered. By analyzing the transport mode as function of the travels performed internally to city, or the travels generated from others cities to the study area, was possible determinate the average time of these travels. The results are shown in Table 3.1:

Table 3.1 – Average duration of travels: Total and by typology of movement. Source: Survey of Mobility in the city of Funchal, 2006/2007.

Segment	Travels inside Funchal	Travels to/from Funchal
IT	18,4 min	23,7 min
PT	24,7 min	44,1 min
On-Foot	19,7 min	14,0 min
TOTAL	**20,7 min**	**30,7 min**

3.3.3. SYSTEM OF COLLECTIVE TRANSPORT

The public transport network of Funchal is based mainly on heavy road passenger transport: city and intercity bus networks. The exploration of the road transport service of passengers within the limits of Funchal is the responsibility of a single operator, the company Horários do Funchal.

This is composed by three types of trips:

- Regular journeys, moving generally from the center of Funchal or another destination within the city limits;
- Journeys of high areas, which serve locations with difficult access through special vehicles to rough terrain;
- Journeys of the dawn, serving the municipality of Funchal during night period;

In total, the network is composed by 63 buses routes, of which 55 do regular trips, 5 trips to high zones of Funchal and 3 of the dawn. They run an extension with a little over 170 km daily, and ensures spatial coverage in the study zone. Except for all the high areas journeys all trips shall commence in the city center.

3.3.4. HIERARCHY OF ROADS

The objective is to serve people and the economy, so the hierarchy of the road network is established from the importance of links offering, and culminates in the profile type and operating conditions that the route must submit. Contribute to this, the dimension and importance of urban agglomeration, the capacity of each link, the tourist interest in the area, the economic activities and establishing links with the outside. In this understanding the following levels in the road hierarchy for Funchal were set as:

- **Level 1 -** Structural Network
  Must ensure the main accesses to the city;
- **Level 2 -** Primary Distribution Network
  Should guarantee the distribution of the largest flows of traffic in the city, as well as average routes and access to 1st level;
- **Level 3 -** Secondary Distribution Network
  Must ensure the next distribution, as well as the routing of traffic flows to routes of higher education;
- **Level 4 -** Network Proximity
  Composed of structural pathways of neighborhoods, with some flow capacity;

In the Figure 3.3 we can see which routes were considered in this project.

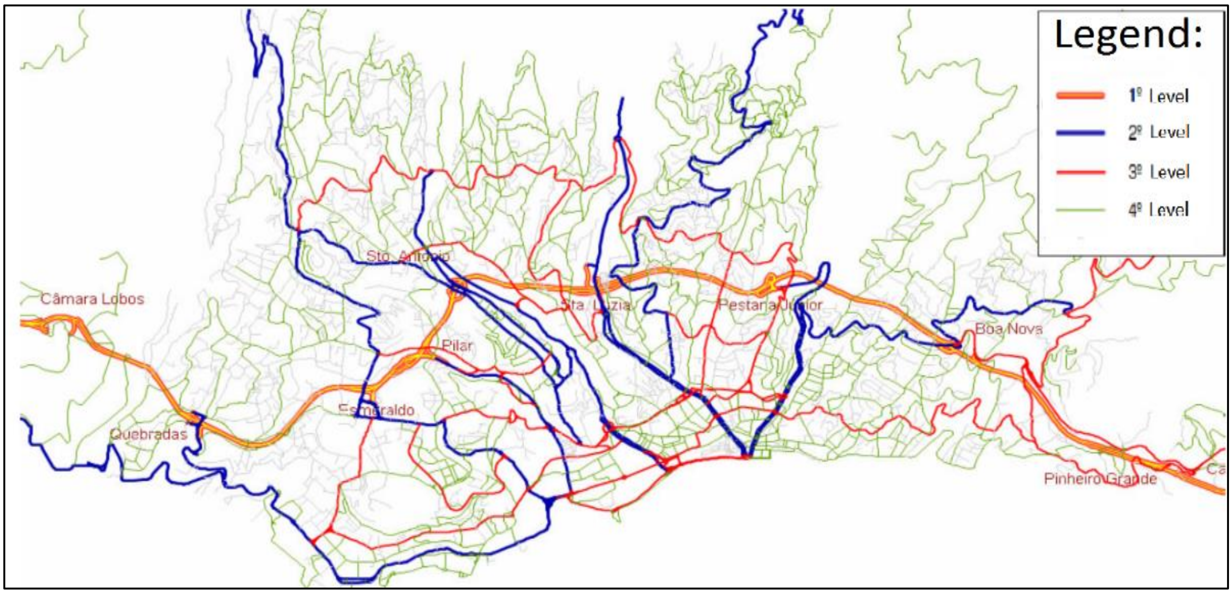


Figure 3.3 - Classification of the road network by hierarchical level.
Source: Survey of Mobility in the city of Funchal, 2006/2007.

3.3.5. SURVEY AND COUNT POST INFORMATION

For the characterization of the resident population mobility in Funchal were conducted household surveys to residents and telephone surveys to the non resident population. These surveys cover the winter of 2006/2007 and part of the 2007 spring. In a total 3,105 valid surveys were conducted which allow characterize the mobility of the population living in the study area.

The count post were attributed based on the importance socio-demographic of the area, the road network that serves, and the network of public transport to serve. This lead to this data distribution map shown in the Figure 3.4:

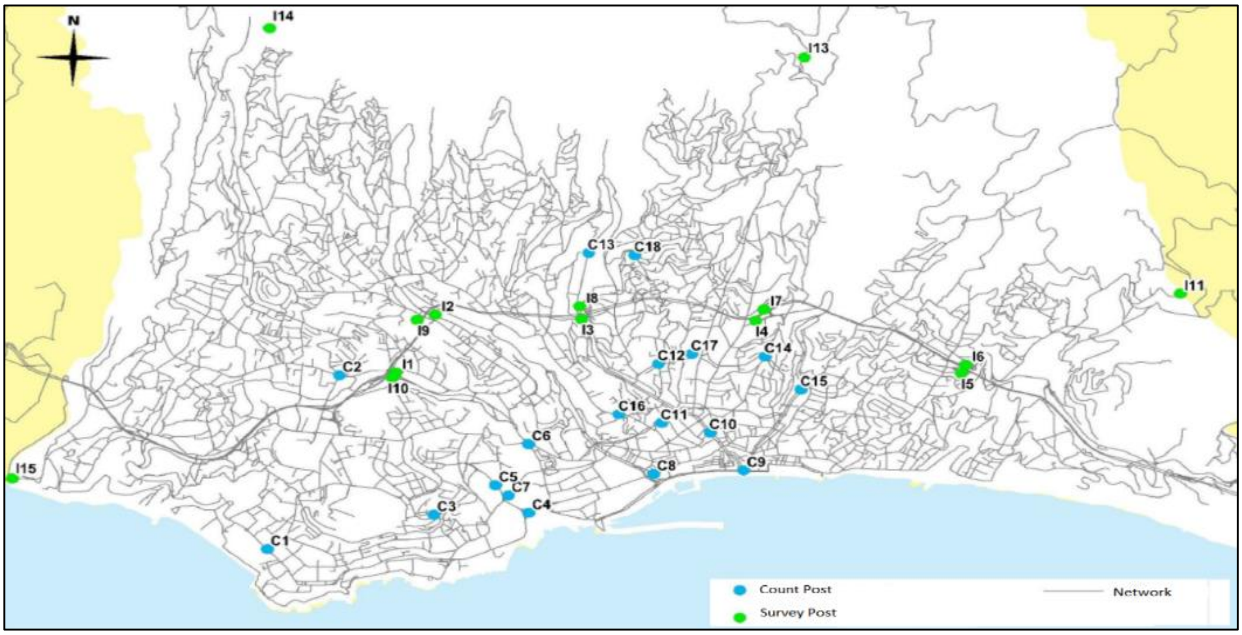


Figure 3.4 – Data Post Locations.
Source: Survey of Mobility in the city of Funchal, 2006/2007.

3.3.6. TRAFFIC COUNT

The collected volumes were obtained with resource to traffic counts, in intersections and main links, where is counted the number of vehicles turns in a determined period. To analyze the collected data values, we considered three disaggregated periods: in the morning, lunch and afternoon. In the morning peak period were counted, on average, about 43.800 vehicles, while the afternoon peak period corresponds to an average of about 45.600 vehicles. In what concerns the lunch peak period, it was noted that while it is possible to identify a slight increase in car traffic, is not substantially different from what happens throughout the day, with an average of 36.201 vehicles.

Therefore the macro and micro simulation models were made to the afternoon peak period, between 18:30 min until 19:30 min, shown in the Figure 3.5, as the highest peak hour of the day:

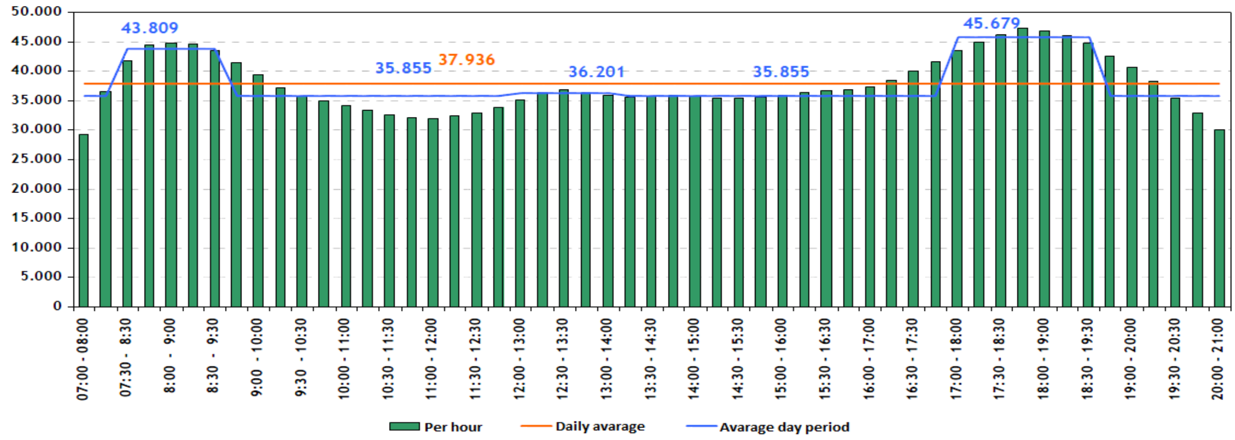


Figure 3.5 – Progress of traffic in the sum of all the counting stations.

Source: Survey of Mobility in the city of Funchal, 2006/2007.

3.3.7. SPEEDS

To measure the road speed practicable in the network was used the GPS technology was used. This allows us to measure with great accuracy the average velocities practiced in the network. It was observed that the highest speeds were recorded in the arcs of higher hierarchy, and as expected the central area of the city offers reduced speeds of circulation, due to concentration of traffic and others factors.

The velocity of circulation is the indicator commonly used to evaluate the performance of a road network, since it allows a direct comparison between the different arcs that constitute the network. The velocity of circulation is calculated based on the theoretical velocity of circulation, which is influenced by the volume of traffic flowing on the road, becoming more significant aggravated as the volume of flow approaches the capacity of the circulation route.

Aside the known congestion problems caused by the under sizing of the roads, the loading and unloading of goods, when occurs for long periods of time causes troubles in the traffic normal circulation. Also the parking maneuver in the parking lots next to some of the roads existent in Funchal affects directly the traffic behaviour.

Observing the velocities in the Figure 3.6 we can see it is less than the legal limits of circulation velocity, which implies disturbances to the free circulation of vehicles: parking, crosswalks, and traffic lights, among others.

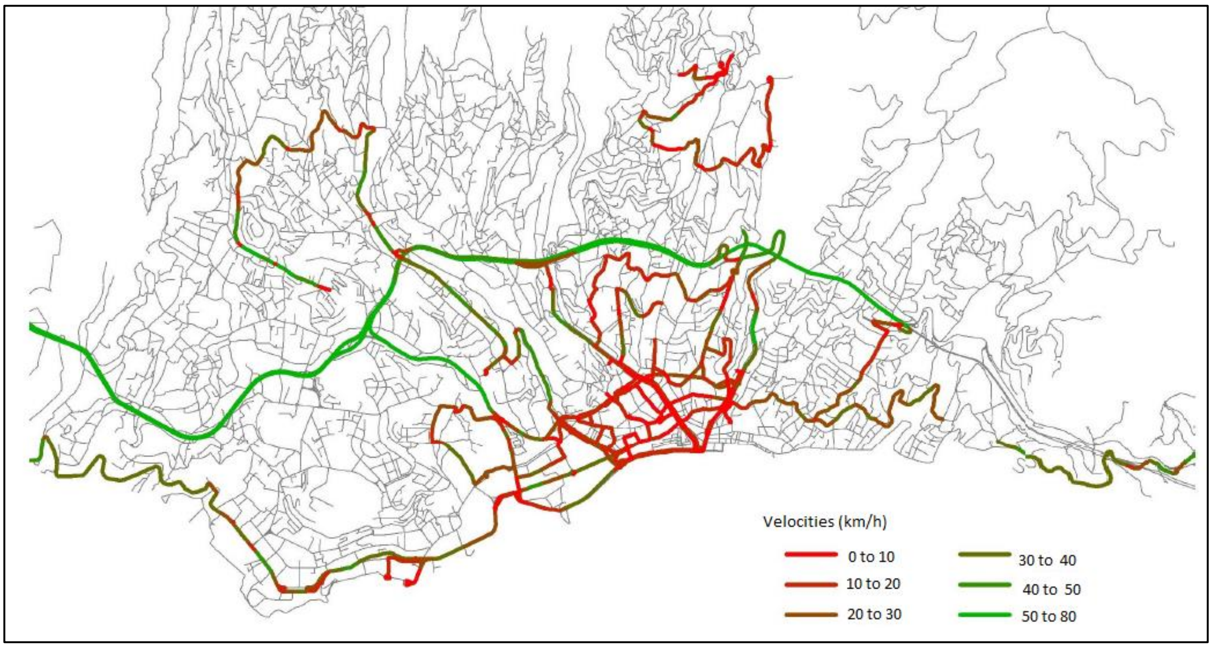


Figure 3.6 – Average Velocities.

Source: Survey of Mobility in the city of Funchal, 2006/2007

3.3.8. SATURATION

The configuration and performance of the road network were also measured through the degree of saturation of their arteries. The network saturation occurs when the traffic received is more than can be routed. This is a phenomenon that appears when the number of vehicles received, approaches the maximum capacities that each network has. In the peak afternoon hour, we have areas, where traffic exceeds 75% of the maximum capacity of the route, and saturations above 100% corresponding to a conditioned and highly unstable circulation. This means, the volume of traffic exceeds the capacity of the artery causing the formation of queues and stop-start waves.

3.4. PERFORMANCE INDICATORS

From the Mobility Study of 2006/2007 was possible for us to have reliable data and a comparable set of network performance indicators. With additional tools to the program from PTV VISSION was possible to determine key performance indicators for traffic management and intelligent transport system included in the model. Cities today face many common transport problems and implement similar urban traffic management solutions, with ITS playing a prominent role. These indicators are important to manage and monitor the performance of the problems in traffic networks.

3.4.1. AVERAGE WAITING TIME AT ORIGIN

The average time that the customer has to wait to enter the public transport system, in areas where the supply is less, the waiting time increases, as are the cases of the north areas Monte, Santa Maria Maior and São Gonçalo. However in coastal and central areas the waiting time is relatively short, not exceeding 5 minutes, while the upland areas can sometimes exceed 7 minutes.

3.4.2. AVERAGE SPEED OF MOVEMENT

Is an indicator that evaluates the relationship between the distance traveled, and the time spent on realization of the trip. The average speed of travel, to the trips started in Funchal is generally 9.0 km/h, presenting a minimum of around 6.5 km/h in central areas of São Roque and Imaculado Coração de Maria.

3.4.3. AVERAGE TRAVEL SPEED

It matches the speed of the route between the stops, including the times of overflow, which allows the evaluation of the speed of the transport system.

On average moving speed of travel of public transport began in Funchal is 16 km/h. It appears however that the trips started in the city center, have considerably higher average speeds of around 18 km/h, since mostly correspond to long distance trips that split to several axis with commercial speeds. In generally, it is observed that the trips initiated in the western part of the county have higher speeds than trips started in the central and eastern areas.

3.4.4. AVERAGE NUMBER OF TRANSSHIPMENTS

The average number of transshipments allows us to estimate the quality of travel started in determinate area, since the greater the number of transshipments to perform, worse are the levels of network performance and consequently the satisfaction of passenger. The transshipments in the district occur especially in long distance travel that, often, need for transshipment to the network of Horários do Funchal. It occurs between trips from external and internal areas of the region. The practice of transshipments in Funchal is not significant. However, it should be noted that the existence of only one point of transshipment, reduce the average number of transshipments but implies greater travel times.

3.4.5. PERCENTAGE OF DIRECT TRAVEL

The percentage of direct travel, allow us to judge, to what extent the current network meets the mobility needs of each zone. In a convenient way, identifying connections where supply system is satisfactory, and calculating to what extent it is justified the introduction of more direct connections between certain areas. The areas with the biggest problems are the zones 1 and 4, where the percentage of direct travel is less than 25%. However, despite the area 4 present a low percentage of direct travel, this area recorded one of the largest volume demand. In overall, it appears that more than half of the areas where the trips started, experience more than 75% of direct travel, and there are even several cases where all journeys started, correspond to a direct travel.

3.5. NETWORK CALIBRATION AND VALIDATION

With base on the above parameters was possible to calibrate a macro simulation model to Funchal. The OD-matrix estimation problem amounts to finding a trip table which, when it is assigned onto the network, induces link flows close to those which have been observed in traffic counts. To update our initial O/D matrix with data of 2006/2007 we used VStromFuzzy (Figure 3.7), this tool allows the correction of a given matrix in such a way that the result of the assignment closely matches the latest figures.

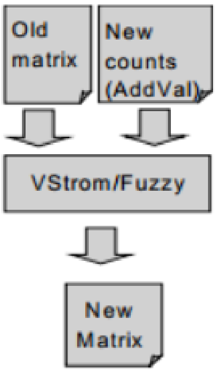


Figure 3.7 – VStromFuzzy method.

In our simulation we obtained a matrix origin-destination of 51 per 51 due to the external zones to Funchal considered in the model, and to adjust the matrix was used 2013 traffic counts leading to a good approximation to the real situation of traffic with an Alpha level of 0.57, concluding the validation of the model.

3.6. BUS FREQUENCIES

The correct planning and management of a public transport system can provide a competitive structure with the private motor cars and an efficient coverage of the space of the territory. When attracting travelers from others modes of transport, we are reducing the traffic congestion and obtaining derived benefits like road safety and lower atmospheric and noise pollutions. As seen in the report lent by Horários do Funchal there is a detected frequency problem in this company system.

The correct design of fleet size, routes, timetables and frequencies are primordial for the efficient management of resources [33].

The in-vehicle travel time becomes shorter when the buses have to stop at fewer places, because the distance between bus stops increases and the distance on foot between them too. The opposite is true if the distance between stops is reduced, access time to them is also reduced, but the buses have to stop in more places causing an increase in overall journey time [34]. The bus stops location, accessibility and an attractive overall journey times, are especially important when modifying one public transport system in a city. All of which has direct influence on the size of the fleet and the frequencies within the system.

This work proposes an optimal timetable model to minimize the social cost of the overall transport system, taking into account that our demand is constant, we considered congestion on buses, interaction with private traffic, and operational variables (fleet, frequency, operator budgets).

A heuristic algorithm is introduced to solve this problem which, starting from a current feasible solution arrives at a solution which minimizes the overall social cost.

3.6.1. PROPOSED OPTIMIZATION MODEL

Based on the article [35], a mathematical bi-level optimization model [36], is proposed to answer the problem of bus frequencies because with a bi-level equation we can equilibrate both terms in order to obtain the results proposed. The lower level includes a Mode Choice – Assignment Model [37], and takes into account the influence of private traffic and congestion on the public transport vehicles [38]. An upper level minimizes a cost function both for the user and the operating company [39].

The structure of the cost used in the objective function of the upper level considers the operators costs (OC) and the cost of the users (UC). While the lower level considers all the costs related with users that are obtained by Mode Choice in the traffic assignment model which are directly affected by decision variables.

Their formulation is a follows:

$$UC = \phi_a TAT + \phi_w TWT + \phi_v TIVT + \phi_t TTT + \phi_v' TCTT$$

where,

TAT	Total access time
TWT	Total waiting time
TIVT	Total in-vehicle time
TTT	Total transfer time
TCTT	Total car travel time
ϕ_a	Value access time
ϕ_w	Value of waiting time
ϕ_v	Value of in-vehicle time
ϕ_t	Value of transfer time
ϕ_v'	Value of car travel time

The direct costs are made up of three factors: personnel costs (CP), hourly costs due to standing still with the engine running (CR), rolling costs (km covered) (CK) and fixed costs (CF). The operator's costs are taken to be the sum of all the direct costs (DC) plus the indirect costs (IC). Others studies have shown that the indirect costs (exploitation, human resources, administrative-financial, depot and supplies, management and general costs) tend to be about 12% of the direct costs. The total cost of the kilometers covered will be equal to:

$$CK = \sum_l \sum_k L_l f_l CK_k \delta_{k,l}$$

where L_l= length of route l (km per bus), f_l= frequency of route l (bus per hour), CK_k= unit cost per kilometer covered by bus type k (€ per km), $\delta_{k,l}$= mute variable worth 1 if the bus type k is assigned to route l and 0 if not.

The personnel cost is found by:

$$CP = C_p \sum_l (tc_l / h_l)$$

where C_p= is the unit cost per hour of the staff (€ per hour), tc_l=is the time of a round trip (min), h_l= is the headway on route, l (min) = $1/f_l$, $\sum_l (tc_l / h_l)$= fleet size (bus).

The total financial fixed costs can be represented as the product of a constant fixed unit bus cost with the total number of buses actually circulating and are calculated with the following formula:

$$CF = \sum_{l} \sum_{k} ((tc_l / h_l). CF_k. \delta_{k,l})$$

where CF_k= unit fixed cost per hour of bus type k (€ per hour). This cost structure therefore defines the optimization at the upper level (€) by:

$$minZ = \phi_a TAT + \phi_w TWT + \phi_v TIVT + \phi_t TTT + \phi'_v TCTT$$
$$+1{,}12. \left(\sum_{l} \sum_{k} L_l \, f_l CK_k \delta_{k,l} + C_p \sum_{l} (tc_l \,/ h_l) + \sum_{l} \sum_{k} ((tc_l / h_l). CF_k. \delta_{k,l}) \right)$$

where the first constraint defines the characteristics of the binary variables $\delta_{k,l}$ and the rest of the constraints represent the group of operational which need to be implemented in the model, such as maximum operator cost (OC), fleet restrictions (fls), and maximum and minimum allowed frequencies for each bus route (fl).

Revenue from fares is not considered in the objective function because, the system used the criteria to minimize the costs from a social and operating point of view.

3.6.2. PROJECTED SOLUTION

The solution proposed is not the ideal solution, the best solution would have been found if we would have more time to evaluate the different possibilities to solve our problem. However the solution that we chose to present to improve the frequency of buses was to lower the time interval between trips when starting a journey, because is easy to implement this option. We admitted that our matrix of people was constant to facilitate the study, and the minimum time between journeys should vary from 10min to 60min and was admitted the cost for a bus journey of about 8€, which is one of the standard values in use at Spain. And based on this value we defined the next values of time in the Table 3.2:

Table 3.2 – Values of time used.

Variable	Value (€/h)
Journey time (BUS)	8,00
Access time (BUS)	9,39
Waiting time (BUS)	15,52
Transfer time (BUS)	24,15
Journey time (CAR)	8,75

The lower level has the function to feed the variables needed by the objective function at the upper level. The model performs the modal distribution and corresponding multimodal assignments providing the variables needed for calculating the social cost at the upper level, given a demand represented by an O-D matrix and utility functions for each mode of transport considered. Then with the model created with VISUM, it was possible to gather the following parameters shown in the Table 3.3:

Table 3.3 – Variables of the lower level function.

TAT (min)	8908
TIVT (min)	2987
TCTT (min)	24406
ϕa	0,1564
ϕw	0,2587
ϕv	0,1333
ϕt	0,4024
ϕ'v	0,1458

And to simplify the determination of TWT and TTT, we admitted that the waiting time TWT, plus transfer time TTT, are obtained from the transit assignment model by the calculated variable ϕ.

The general running personnel and fixed costs were calculated from data given by the operating company of Horários do Funchal. These others variables for our equation where the cost per kilometer CK_k is estimate on about 0,857€/km, the staff cost C_p is 17€/h and the fixed costs CF_k is represented by 0,5€/km which includes the tax value.

3.7. RESULTS AND DISCUSSION

Once validated the traffic assignment model created with VISUM it was possible to identify the key traffic characteristics in the city of Funchal. Daily can be seen that takes place in Funchal about 67.400 trips in public transport. It appears that virtually all areas with more offers are the areas with most demand. Although they are not segregated, there are about 23.500 trips, one third of the total, with one end/start outside of Funchal, which implies the use of interurban transportation. As we have seen before the tourism and the geographical position of the city, has an influence in the city traffic.

Concluding the interurban transportation has impact in the daily trips. The greatest number of transshipments trips are interurban trips, which in several cases, needs transshipment to the company Horários do Funchal. And trips started in one extreme zone of Funchal, where the radial nature of the network means, that the travel with destination to another extreme, needs at least one overflow.

The waiting times at bus stops are high, which reflects the low frequency of most journeys of Horários do Funchal. It is complemented by the evaluation of bus schedules, where the intervals between buses journeys vary from 15min to 120min in some periods of the day, which indicates a big gap between travels. Consequently we can say that there is a detected frequency problem in the bus company, and with a simplified model of optimization for bus frequencies, we increased fleet size and changed the timetable departure of each trip, taking us to a higher frequency between bus journeys, and this implied a lower cost associated to users, with a 31% increase in the cost of operators but the overall costs are reduced.

This was a two steps process, once calculated the value of global costs to the current situation we created a generic algorithm (GA) that would change our headway times per trip according to our initial admitted restrictions, attaining our optimal situation and the respective final costs to our solution. The Table 3.4 resumes the results obtained:

Table 3.4 – Results for the Optimization Model.

Scenarios	Fleet (busses)	Commercial Speed Bus (km/h)	Number of trips	Average time of a round trip (min)	Costs of the users (€)	Operator costs (€)
Existing situation	177	18,75	168	21,35	12776,79	2815,70
Optimal situation	223	18,75	246	21,35	5896,24	4056,22

Observing the results obtained can be seen that as mentioned before this solution is not the ideal optimization model, since we should have considered other parameters that also influence the frequency. What we proposed was an amelioration in the timetables of the company, in a simplified approach, with the objective to reduce the global costs.

Based in a constant matrix, we are saying that when increasing the number of journeys per route, we aren’t causing any impact in the target population, resuming we are admitting that the population won’t change at all, their behaviour with the increase of the bus frequencies. The GA serves the purpose to change the bus frequencies table according to our defined constraints. In other words the algorithm will change the bus routes frequency after many interactions to the defined journey intervals, the minimum and maximum allowed frequencies of 10min and 60min per route, respectively.

Considering the costs for a bus journey of 8€ we can calculate some of the bi-level equation values and from the model done in the program we acquired the other unknown values. Then from the bi-level equation results, we can see the impact of our implemented changes and since we opted to minimize the users costs by approximately half, the overall costs are equilibrated with the operators costs, and that is why our results reflects an increase in the OC. The aim was to influence more users to use the public transport, transforming the service more appealing, decreasing the car use, and consequently obtaining less traffic issues, but our model doesn't reflect this behaviour since we admitted a constant matrix. Also with the proposed intervals between buses journeys to vary from 10min to 60min, we seek that per travel be effectuated less bus stops, since there is a higher frequency, leading to faster journeys times. So from the results we obtained, shows that was possible to reduce all costs by a total of 37%, even by increasing the frequency of buses, which means increasing fleet size and of course the operation costs.

Since we couldn't have the time necessary to study all the parameters that influence bus journeys we had opted to simplify to the max and present this simplified solution, but we recommend another deeper study, where we should not admit a constant O-D matrix and have involved the number of bus stops per travel, as the socio-demographic characteristics of each zone in the study area. Also it is important to remind the reader, that the island of Madeira is known for its constant slopes, which is an essential element to keep in mind when studying the public transport system, since it will directly influence the bus operating costs, when calculating the optimization of the bus services.

The current research's [40], attempt more and more to contain analysis from the combined impact of different OD pairs (in order to simplify the OD approximation process), the model parameters impact on traffic simulations, and so on, to achieve more credible models.

When focused the public transport it is important to determine the optimal transit frequencies, since it represents a short and long term strategy. Concerns, such as network forecasting or operation plan scheduling, while being defined a strategy has to be taken into consideration. In frequency models the objective is usually the operating costs and passengers' costs minimization. Since the basic data on transit network is uncertain, namely the passenger flow and passenger demand, due the many effects and factors, such as socioeconomic characteristics, traffic incidents, population development, land use property, and changing travel patterns. Also the difficulty of the prediction process can likewise make passengers demand uncertain. Therefore, the results of a transit frequency decisive model, will be more useful and robust if an uncertain passenger demand is considered.

In the models of frequency-based or schedule-based, times are not directly considered, but modelers refer to it as the service headways, or the service frequencies. Consequently it is not possible to calculate explicitly the attributes that all users consider in relation to individual route option.

Only the average attributes that relate to some route and are important by the users point of view, will be considered. Frequency-based models constitutes the classical approach as it is usually simpler, requiring less input data and less computational power than schedule-based approaches. It corresponds to the secure state approach to user equilibrium duty and therefore allows the use of some of the same techniques.

All practical choice models share one fundamental rational assumption about the passenger: that he tries to minimize expected total generalized costs. Therefore frequency-based transit assignment aims to model the choices of passengers who select their itinerary without knowing exact departure times beforehand, only based on their assumptions of routes, service frequencies, and travel times.

Most studies [41-44], in road networks defend that an uncertain travel demand can be described as a probability distribution function with variance known and mean. In studies about transit network design that incorporate an uncertain demand, it is more likely to be given attention to transit operation performance indices based on probabilities. For instance, it is assumed that the demand and running time of transit are stochastic, but it is from the perspectives of the transit administration community, the operator and passengers separately, that it is defined the system wide travel time, direct boarding waiting-time reliability, reliability, and schedule reliability. Otherwise, there are still few researches focused on transit problems related to uncertain demand.

To get closer of a realistic model, an uncertain demand has to be considered instead of a constant demand allowing the programmer to attain more trustworthy results for bus frequency optimization. When defined a matrix united with a simulation procedure, we achieve a model capable of representing the actual situation viewpoint. Then as we proceed, a mathematical bi-level model of transit frequency determination is formulated first. In the lower-level equation is considered the in vigor transit network robustness performance, that directly affects the user costs, indicated by the variance in passengers travel time and is acquired based on the actual strategy transit assignment model. In the upper-level formula, the transit network and operator costs are combined with the lower-level as the upper-level objective is to reduce the total cost of transit system, overall size of the bus fleet among others depending in the modeler assumptions. With this we obtain the actual overall costs for an actual situation.

Let's admit that a generic algorithm combined with the preview model results, has been used to obtain new bus frequencies and after many interactions the overall costs given by the mathematical bi-level formula will be minimized.

So from here we get a solution, only by applying the GA to the base model frequency table, but it is necessary to study the impact of the found solutions in the study zone.

It is required the modulation of a new model that represents these new assumptions. When modelling the new bus frequencies in the simulation program a new uncertain matrix must be considered. Once we consider a new matrix we are admitting that our implemented changes to the initial model caused impact in the population of interest. It is up to the modeler to analyze the impact of those changes and then build a new matrix capable of reflecting the new expected behaviour of our target population.

With resource to sensitivity-based, scenario-based, and or min-max models for example, is proposed the development of a robust optimization improvement scheme that can describe transportation performance to uncertain demands or allow the system to perform better in the face of a worst-case demand scenario.

At last from the results obtained from this last model, with a new uncertain matrix and new frequencies we get the optimal solution. This requires an interaction process since it won’t be at a first attempt that we will find the optimal solution. It is advisable to bring this solution into microscopic simulation to understand in some key links of the area, how the solution will affect the traffic behaviour, [45-47].

4

MICROSCOPIC SIMULATION

4.1. INTRODUCTION

Microscopic traffic simulators are the most powerful and handy traffic analysis tools. Its ability to replicate to a significant level of accuracy the detected traffic conditions in a wide variety of circumstances makes the skilled users become very demanding, requesting for new features and functionalities in the never ending process of fitting well the growing complexity of traffic occurrences. According with the manual of AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) [48]. We can describe this program as a microscopic traffic simulator to offer a better response to the necessities in two main areas: improvements on the dynamic assignment capabilities, and the embedding of the simulator in the AIMSUN/ISM (Intermodal Strategy Manager) a versatile graphic environment for model manipulation and simulation based traffic analysis and evaluation of advanced traffic management strategies. AIMSUN/ISM includes two specific tools, the Scenario Analysis Module to generate and simulate the traffic management strategies, and the (OD Tool) to generate and manipulate the Origin-Destination matrices describing the mobility patterns required by the dynamic analysis of traffic conditions.

The micro simulation of Avenida do Mar is analyzed in four models. Due to the constant natural catastrophes suffered in Madeira, it was necessary to reconstruct some parts of the city of Funchal. The models represent the changes that are taking place in the structure of the roadways.

The main goal of the modulation is to be the closest as possible from the reality and to obtain a good data base. Is crucial to evaluate a conjunct of external factors that the program can’t predict and only observing the traffic flow, is possible simulate an accurate traffic behaviour. This isn’t an easy task, the exact placement of the traffic parameters in the program, does not always reflects the real situation.

Per example, in some roadways drivers don’t respect the speed limits stated. As such, is convenient to always adjust the modulation to what really happens to obtain a valid output data.

Concluding the purpose of the dissertation, is with the help of AIMSUN to be capable to predict the impact of the new geometry changes in the Praça da Autonomia that will affect directly the Avenida do Mar traffic and to explore the similarities and differences in traffic performance and driving behaviour on this urban network.

4.2. STUDY ZONE

The area we considered for micro simulation is Avenida do Mar (Figure 4.1), with an approximated extension of 700m. Is an important link in the city of Funchal, and it is the connection between the old zone and the new zone of the city, in the parish of Sé, a central zone in Funchal.

In this zone there is the Funchal Marina, where has origin the cruises and ferries trips. Also in this avenue are localized most of the bus stops that serves the company Horários do Funchal.

In the nearby area to Avenida do Mar we can find the Funchal Harbor , the Casino, Hotel units, Courts, Fire department, Schools, social support equipment amongst others. From the observed traffic behaviour in this zone shows existing congestion problems, therefore the need for an intervention.

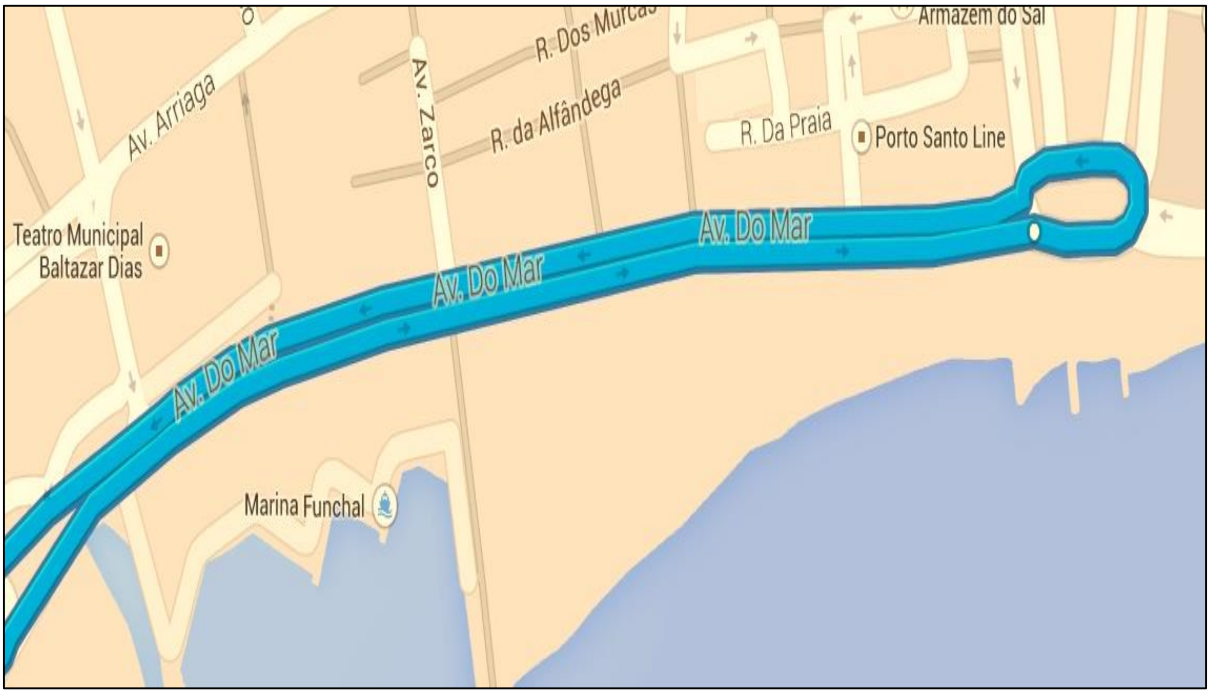


Figure 4.1 – Avenida do Mar.

4.3. NETWORK REPRESENTATION

Dynamic simulations are characterized by the high level of detail at which the system is modelled. The quality of the model is highly dependent on the availability and accuracy of the input data.

Therefore, to build a good AIMSUN model, the following data was required:

- Network Layout
- Traffic Demand Data
    - Centroid definitions: traffic sources and sinks
    - Vehicle Types and attributes
    - Vehicle Classes (for reserved lanes)
    - Number of trips going from every origin centroid to any destination one
- Traffic control
- Public Transport
- Initial State

4.3.1. NETWORK LAYOUT

The network layout was created with resource to the program AUTOCAD and then imported into AIMSUN model, the layout includes not just the Avenida do Mar, but some important links that connect to this one. We considered important to insert the Praça da Autonomia in our model, since it geometry has been changed, beside the roundabout we also considered the Avenida Zarco, Rua Cónego Jerónimo Dias Leite and Rua do Conselheiro, so we can interpret how traffic flows in the avenue links, giving us a global perspective of the actual problems.

A model is composed of a set of sections that are one-way links, connected to each other through nodes that represent intersections. These contain different traffic structures, such as: details of the number of lanes for every section, side lanes, reserved lanes, and possible turning movements for every junction including details about the lanes from which turning is allowed and for allowed turns the correspondent turning speed at every intersection with concrete lines marked on the road surface, and speed limits for every section.

4.3.2. TRAFFIC DEMAND DATA

Our traffic demand data was defined by and O/D matrix estimated from traffic counts, and to model the following input data was necessary know first:

- Centroid locations, for traffic sources and sinks, in our project we defined six centroids;
- Vehicle Types and attributes, we defined two types the traditional car and truck;
- Vehicle Classes, we opted by creating private and the public classes;
- Number of trips going from every origin centroid to any destination one;

The input values of the trip matrix are based on the traffic counts values, with approximately 2349 vehicles in our network representing the afternoon peak hour. Once was defined the preview parameters in our traffic simulation model we obtained the following matrix in Table 4.1:

Table 4.1 – Generated Matrix with base on Traffic Counts.

Centroids Considered	Alfândega	Anadia	EEM	Rotunda Sá Carneiro	Marina	Sé
Alfândega	2	50	42	92	0	1
Anadia	88	18	151	332	0	0
EEM	111	113	0	418	0	0
Rotunda Sá Carneiro	68	206	180	0	0	1
Marina	0	10	0	0	0	0
Sé	150	229	6	79	0	2

Where some of the values had to be estimated due to the lack of data. An example is the Marina, with use of Trip Generation Handbook, 2nd Edition, we estimated the number of trips that are generated and attracted, based on the number of berths (Table 4.2).

Table 4.2 – Land use trip generation parameters.

Description/ITE Code	**Units** Independent Variable	**Expected Units**	**Total Distribution of Generated Trips**		
			PM In	PM Out	Pass-By
Marina 420	Berths	150,0	17	11	0

Since we have two vehicle types, it was necessary to divide the original matrix into two separated matrices, one representing the trucks and the other reflecting the cars volumes into our study network. These two matrices were assigned to our model, where 97% of the traffic corresponds to the use of cars and 3% of traffic is represented by trucks.

4.3.3. TRAFFIC CONTROL

AIMSUN takes into account two different types of traffic control: traffic signals and give-way signs. These two types are used in intersections. The traffic signal control, is a phase-based approach applied in which cycle of the intersection and is divided into phases, where each phase has a particular set of signal groups with priority of way at same time, and the units used for defining the phases of a control plan are seconds. The duration of a phase determinates the duration of the green time of the signal groups assigned to the phase.

A signal group consist of the set of turning movements that are controlled by the same indications of traffic lights [49]. Therefore, the signalized movements that have priority are simultaneously grouped into one signal group. Then, a sequence of phases is defined for the whole intersection. Each phase is associated to a signal groups. In each signal stop can be set a different stop line too, that is, the distance from the intersection that vehicles will stop at.

In Avenida do Mar we have two situations. The first situation remotes to the traffic lights situated in the avenue from 1 to 5, and the second situation is from the traffic lights in the roundabout marked as 6, according with the Figure 4.2:

Figure 4.2 – Traffic lights location.

For the signals located in the positions 1 to 5 we opted by leaving them with the ruling current times. All avenue has a cycle time of 96 seconds. The southern and northern routes have different phases, and pedestrians are retained in the center of the tracks on purpose for security reasons and to not extend the cycle times.

These are represented by the following times in the Table 4.3:

Table 4.3 – Avenida do Mar traffic lights times.

1 - Avenida do Mar North		**1** - Avenida do Mar South		**1** - Rua do Conselheiro	
Green Time (sec)	50	Green Time (sec)	50	Green Time (sec)	30
Yellow Time (sec)	3	Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	43	All-Red Time (sec)	43	All-Red Time (sec)	63

2 - Largo das Fontes North		**2** - Largo das Fontes South	
Green Time (sec)	65	Green Time (sec)	65
Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	28	All-Red Time (sec)	28

3 - Avenida Zarco Up		**3** - Avenida Zarco Down	
Green Time (sec)	24	Green Time (sec)	24
Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	69	All-Red Time (sec)	69

3 - Cais North		**3** - Cais South	
Green Time (sec)	24	Green Time (sec)	24
Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	69	All-Red Time (sec)	69

4 - Tap North		**4** - Tap South	
Green Time (sec)	54	Green Time (sec)	54
Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	39	All-Red Time (sec)	39

5 - GNR North		**5** - GNR South	
Green Time (sec)	55	Green Time (sec)	55
Yellow Time (sec)	3	Yellow Time (sec)	3
All-Red Time (sec)	38	All-Red Time (sec)	38

As for the traffic lights in 6 which corresponds to the roundabout traffic lights, we had to study a new solution with resource to Furness Distribution Model. It is necessary to optimize the new traffic lights that will take place in the roundabout zone, because with the changes of the geometry in the roundabout, we can't keep same old traffic light times, it is need to adapt those to the new geometry.

4.3.3.1. FURNESS DISTRIBUTION MODEL

This is a distribution model that produces a new origin-destination trip matrix, to replicate new trips in the future made by the population, employment and other demographic changes, and also to reflect changes in people's choice of destination. They are used to predict the origin-destination pattern of travel into the future [50], and produce a trip matrix which can be assigned in a model or put into a mode choice model. The distribution model seeks to model a result of new developments, shops, offices, etc, in a form to produce a new trip matrix for the future travel situations.

To simulate new cycle times to the new roundabout being built at the moment, was necessary to know in the old roundabout the traffic flow. First was essential to learn were the new traffic lights were going to be placed, and with this information we created four groups of signals, as we can see in Figure 4.3:

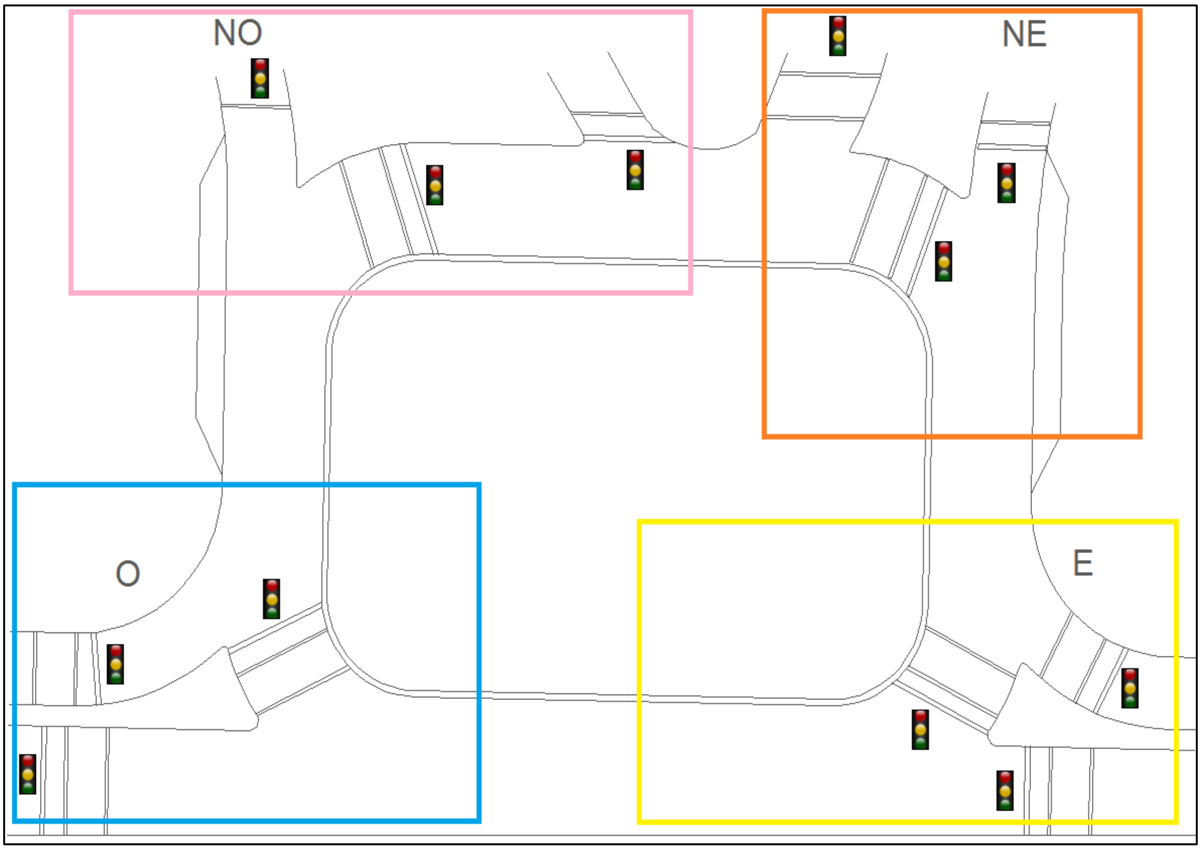


Figure 4.3 – Traffic lights location in the roundabout.

Since we only had data from the number of vehicles that enter and leave the roundabout but not the number of cars that are in the roundabout, we have initial admitted the following situation in Table 4.4:

Table 4.4 – Furness base Matrix.

Centroids	O	E	NE	NO	∑
O	0,1	0,5	1	1	**931**
E	1	0	0,5	1	**642**
NE	1	1	0,1	1	**589**
NO	1	1	1	0,1	**187**
∑	**925**	**379**	**626**	**419**	

We admitted that none of the cars entering from East will do the roundabout to take this same exit, and considering the others entries, we said that only a very small percentage of cars want to perform the roundabout to follow by the same exit.

After several iterations to adjust the percentages of traffic going from each origin to destination attributed, we managed to make the number of vehicles entering and leaving the roundabout coincide with the values of the traffic counts.

Once we obtained the base matrix on the calculation sheet of Furness, we got the following movements in the roundabout, as shown in the Figure 4.4:

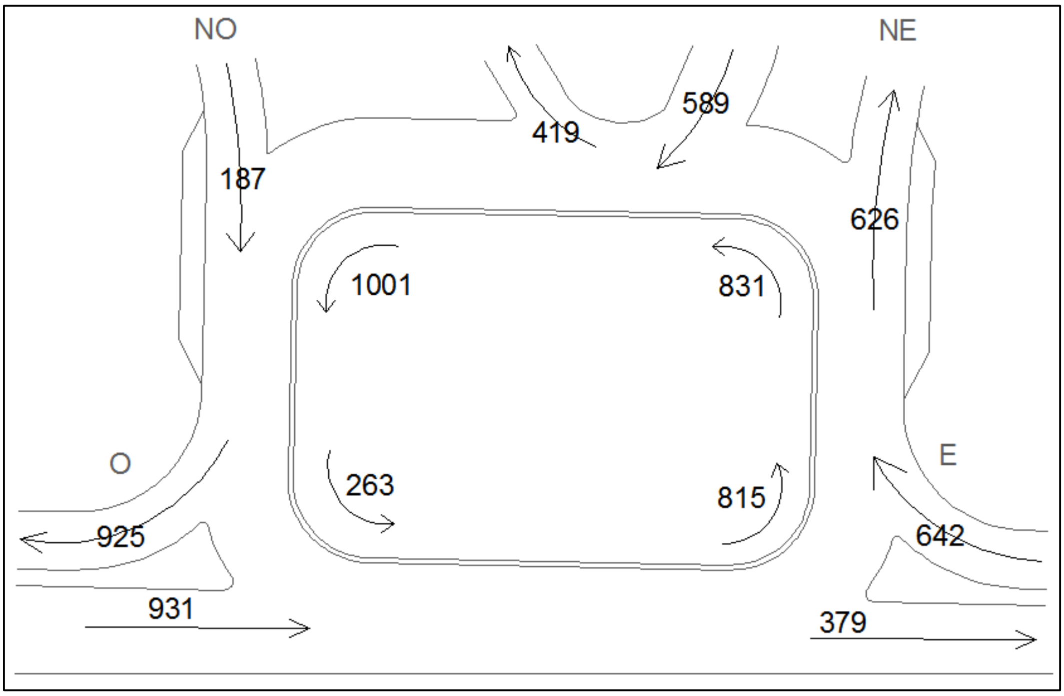


Figure 4.4 – Flow on Praça de Autonomia.

After obtained the traffic flow, the next step was to study the optimization of the traffic lights time for each intersection with the help of the program Sidra Intersection. We decided to have all traffic lights working with the same cycle as Avenida do Mar (96secs), so the times obtained to the intersections with help of the program are as follows in the Table 4.5:

Table 4.5 – Sidra Intersection cycle times to the roundabout.

O - West			
Phase	A	B	C
Green Time (sec)	56	11	14
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	61	16	19

E - East			
Phase	A	B	C
Green Time (sec)	56	14	11
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	61	19	16

NE - Northeast			
Phase	A	B	C
Green Time (sec)	59	11	11
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	64	16	16

NO - Northwest			
Phase	A	B	C
Green Time (sec)	59	11	11
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	64	16	16

After implanted these traffic lights times in the AIMSUN traffic model, was necessary to adjust them since with Sidra Intersections we studied intersection by intersection and when observing in a global the roundabout traffic behaviour, it was working separately and the traffic was not flowing as expected. With AIMSUN model we adjusted these times to make the roundabout traffic lights work as one, so the Table 4.6 resumes the final times obtained (these times don't show the different phases considered):

Table 4.6 – Final AIMSUN roundabout cycle times.

O - West			
Traffic Lights	Entry	Exit	Inside
Green Time (sec)	67	38	43
Yellow Time (sec)	5	10	5
All-Red Time (sec)	24	48	48

E - East			
Traffic Lights	Entry	Exit	Inside
Green Time (sec)	24	62	67
Yellow Time (sec)	10	10	5
All-Red Time (sec)	62	24	24

NE - Northeast			
Traffic Lights	Entry	Exit	Inside
Green Time (sec)	43	62	62
Yellow Time (sec)	5	10	10
All-Red Time (sec)	48	24	24

NO - Northwest			
Traffic Lights	Entry	Exit	Inside
Green Time (sec)	48	62	38
Yellow Time (sec)	5	10	10
All-Red Time (sec)	43	24	48

4.3.4. PUBLIC TRANSPORT

The Public Transport was taken into account, and the input data required to define it was as follows:

- Public Transport Lines: a set of consecutive sections composing the route of a particular bus;
- Reserved lanes;
- Public Transport Stops: location, length and type of public transport stops in the network;
- Location of Public Transport Stops to Public Transport Lines;
- Timetable: departures schedule (fixed times or frequency), type of vehicle, and stop times (specifying mean and deviation) for each public transport stop;

In a total for the study peak hour we have drawn 49 bus lines that depart from some point in the island to end travel in Funchal doing a total of 93 arrivals, and 47 that depart from Funchal doing a total of 88 departures, which depending of which bus line is, can do one to five travels in this period. And a total of 15 bus stops were considerate in our study zone. For these stops was estimated an average time per stop of 20 sec, it reflects that per stop will aboard about 10 people, and each person takes 2 sec to get in the bus.

4.3.5. INITIAL STATE

An initial state was also defined, this allows us to start a simulation having vehicles distributed for the whole network. It keeps track of Public Transport and private vehicles in sections and nodes. This is important so when we start our simulation we can have an approximated perspective of traffic behaviour since the second it starts.

4.4. MODEL CALIBRATION AND VALIDATION

The application of the proposed model requires proper calibration (estimation) of parameters. Under different traffic conditions it is important for the real time application, the bus travel times, traffic volumes signal timings, and practiced vehicles speeds calibration in the traffic model. Using and fusing all the available data for parameter estimation can be quite computation intensive. Validation process has been done using the afternoon-peak-hour traffic counts data.

From re-running the experiment traffic model using the afternoon-peak-hour demand data as input and comparing these traffic counts values with the value of the flow obtain at the end of each simulation we can determinate, depending on the deviation of the values in each link, if our model represents a good perspective of the reality traffic behaviour in the study zone.

The comparison of the results from the collected data with those from the AIMSUN traffic simulation model shows that the proposed model can well represent the traffic state in Avenida do Mar.

4.5. SCENARIOS

Once the base model was created, we tried study the possibilities to ameliorate the known traffic issues in Avenida do Mar. The following designation was attributed to the roundabout entries and exits as seen in Figure 4.5:

- Avenida do Mar entry and exit;
- Empresa de Eletricidade da Madeira (EEM) entry and exit;
- Anadia entry and exit;
- Alfândega entry and exit;

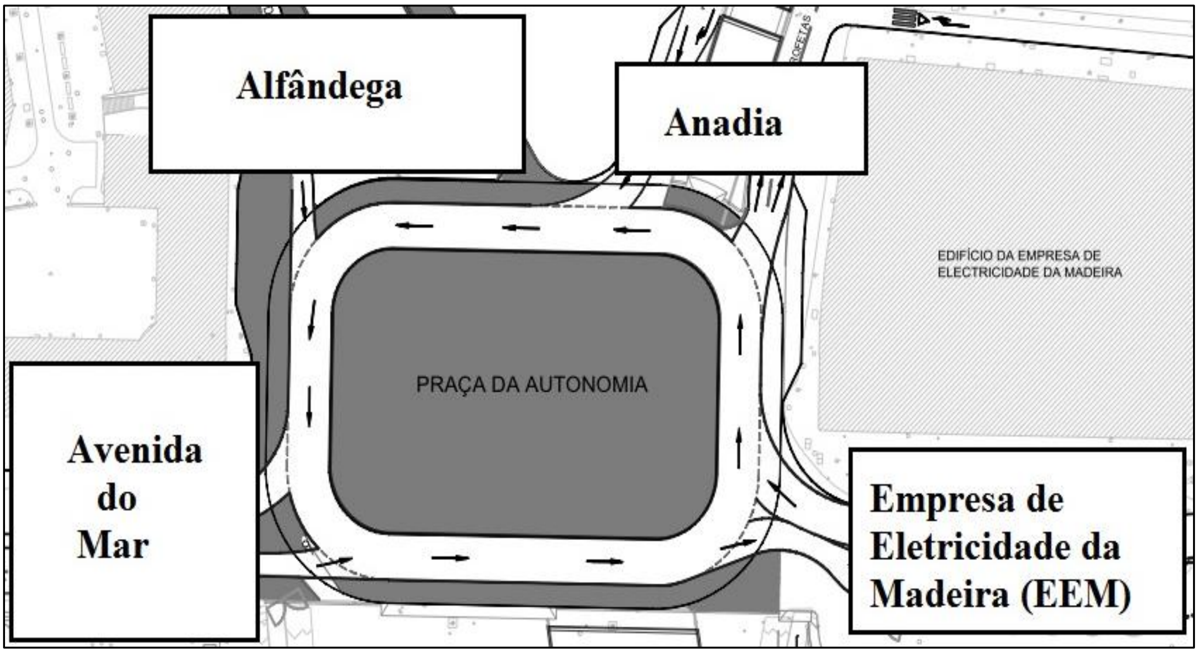


Figure 4.5 – Praça da Autonomia entries and exits designations.

Therefore, four scenarios (Figure 4.6 to 4.9) were created where all of the changes were done in the new roundabout, we tried see the impacts caused by changing its geometry by adding more traffic lines and reserved lines to the network.

In the first case studied, we opted to add in the roundabout three lanes of traffic;

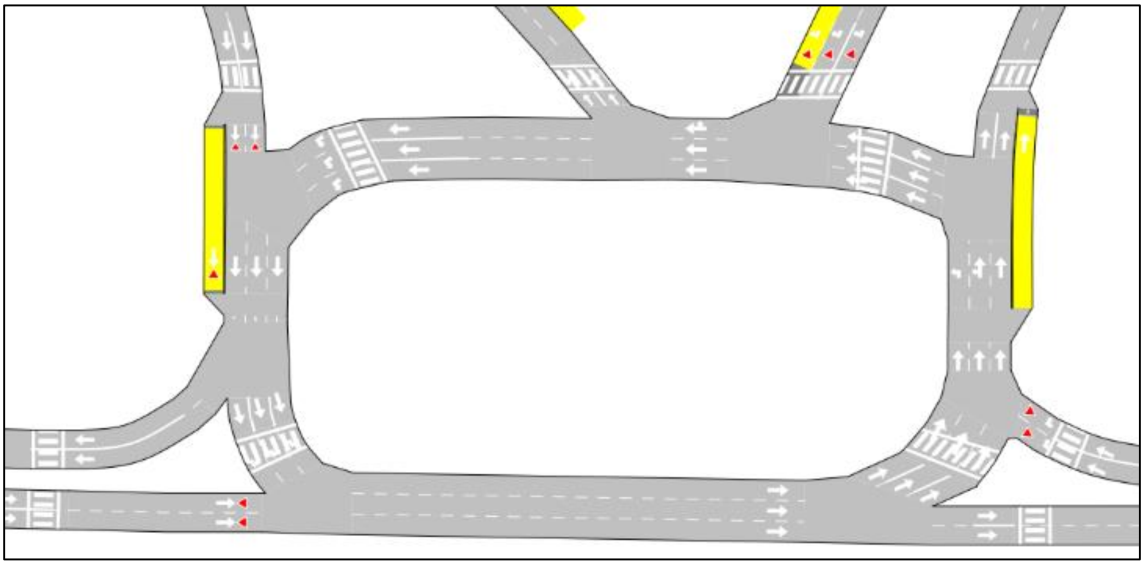


Figure 4.6 – Model of Case 1.

The second case, we simulated the roundabout with two traffic lanes, this scenario is the one that matches the old roundabout geometry for Avenida do Mar;

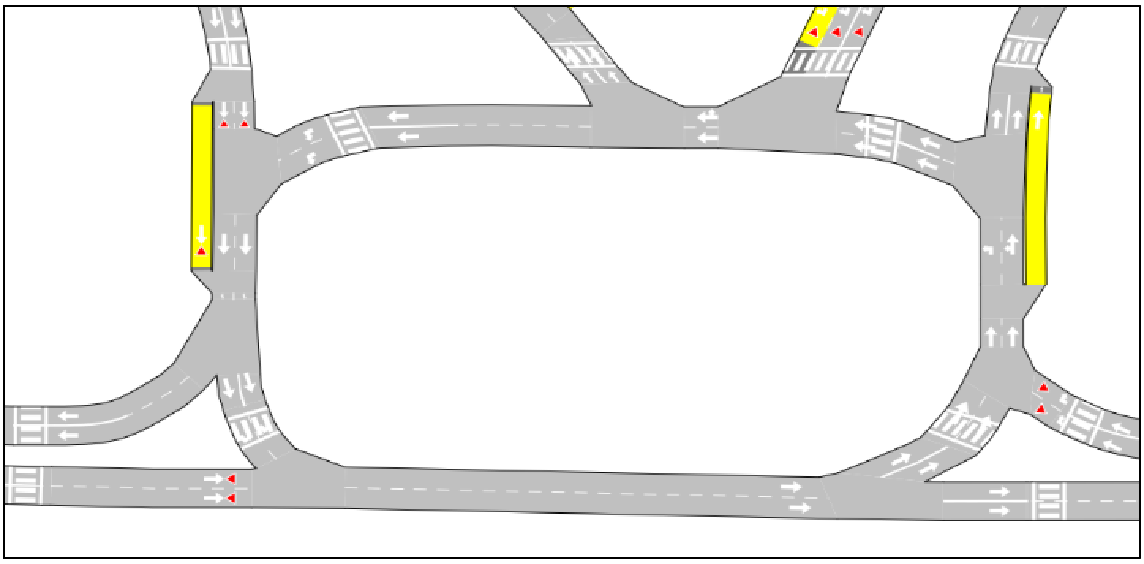


Figure 4.7 – Model of Case 2.

The third case corresponds to three traffic lanes in the roundabout, but one line is reserved to the public transport transit. It is theoretically and in practice considered, that having a roundabout functioning with a reserved line it is not a much feasible solution, because it is hard for the buses execute some maneuvers, it is an already built up zone, and considering a lane reserved for buses we aren't treating this zone as a roundabout.

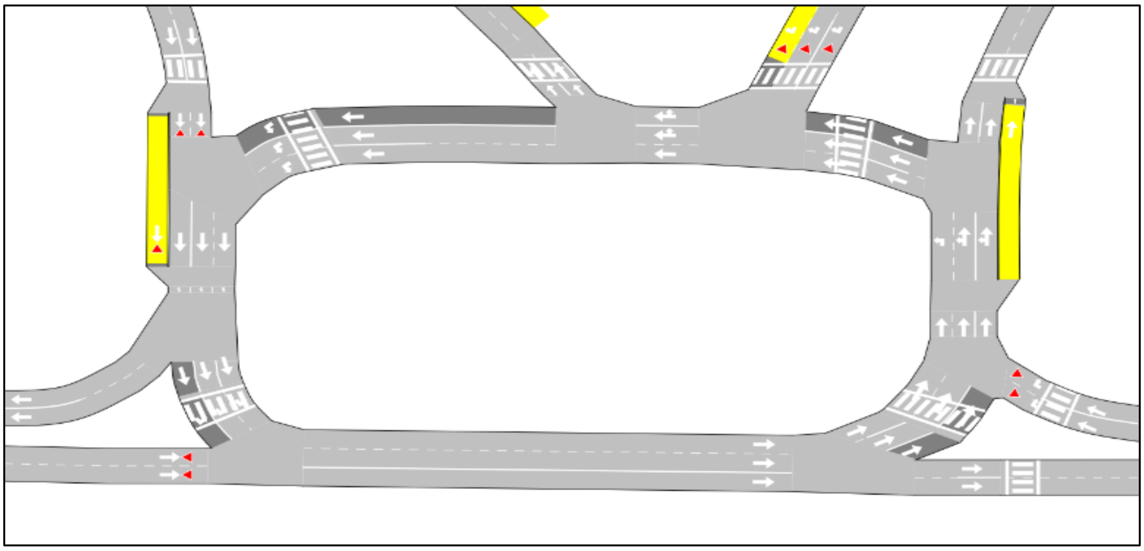


Figure 4.8 – Model of Case 3.

The fourth case is represented by a reserved lane from the roundabout Sã Carneiro until the Praça de Autonomia and vice versa. The roundabout works with two free traffic lanes;

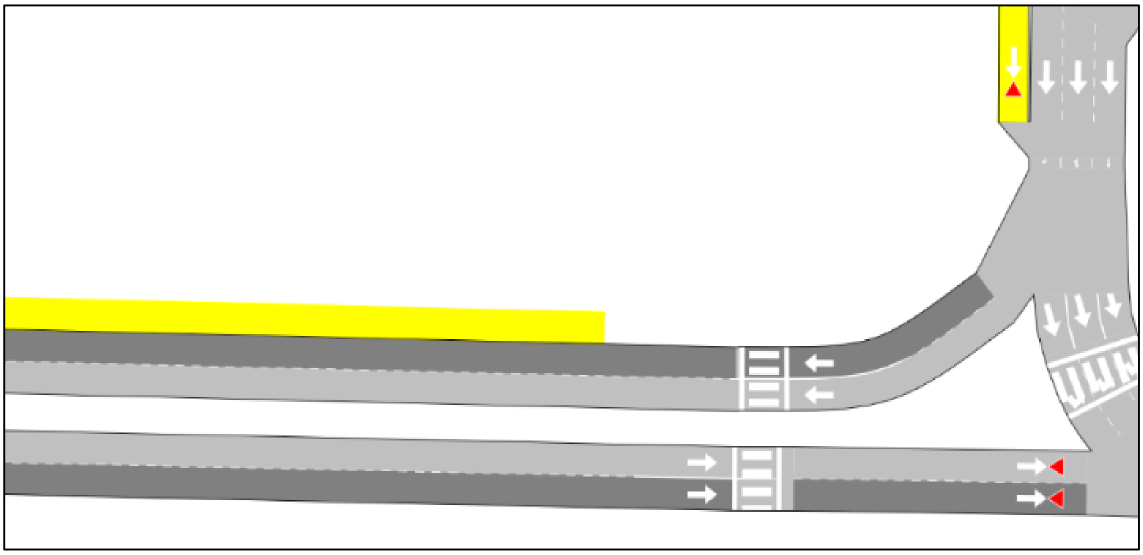


Figure 4.9 – Model of Case 4.

4.6. RESULTS

For each scenario we ran five dynamic simulations, and then an average result was obtained. In the dissertation we focus on the average queue length, density, delay time of all vehicles, and the bus velocity, because they are the most important variables that directly influence the network performance.

Wherefore the measured average queue lengths, for each scenario are in the Figures 4.10 to 4.14:

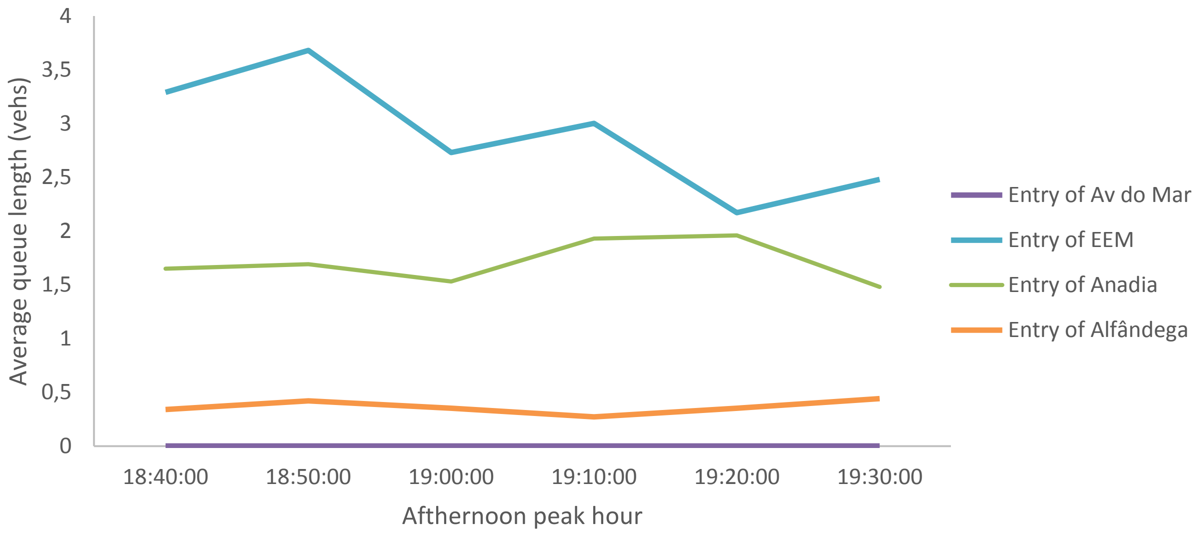


Figure 4.10 – Queue length formed by cars in the entry of roundabout to Case 1.

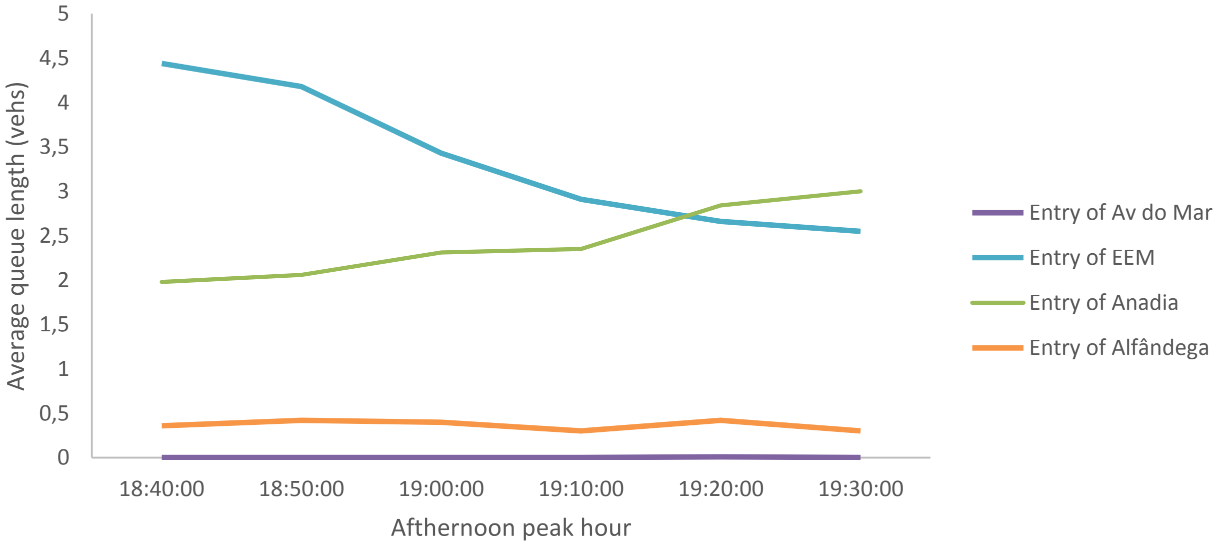


Figure 4.11 – Queue length formed by cars in the entry of roundabout to Case 2.

From Appendix C to F can be found a full results sheet, to each scenario considerate. We can consult the results of parameters such as, Average virtual queue waiting, Maximum virtual queue waiting, Total distance traveled, Flow, Number of Stops, Delay Time, Stop Time, Time Travel, Wandering Inside Vehicles, amoung others. Each one of these results is described in four diferent modes of traveling: Bus, Cars, Trucks, and an averege result from all traveling modes. This last, has the intention to give us a global perspective of the interaction of all the vehicles in our traffic model.

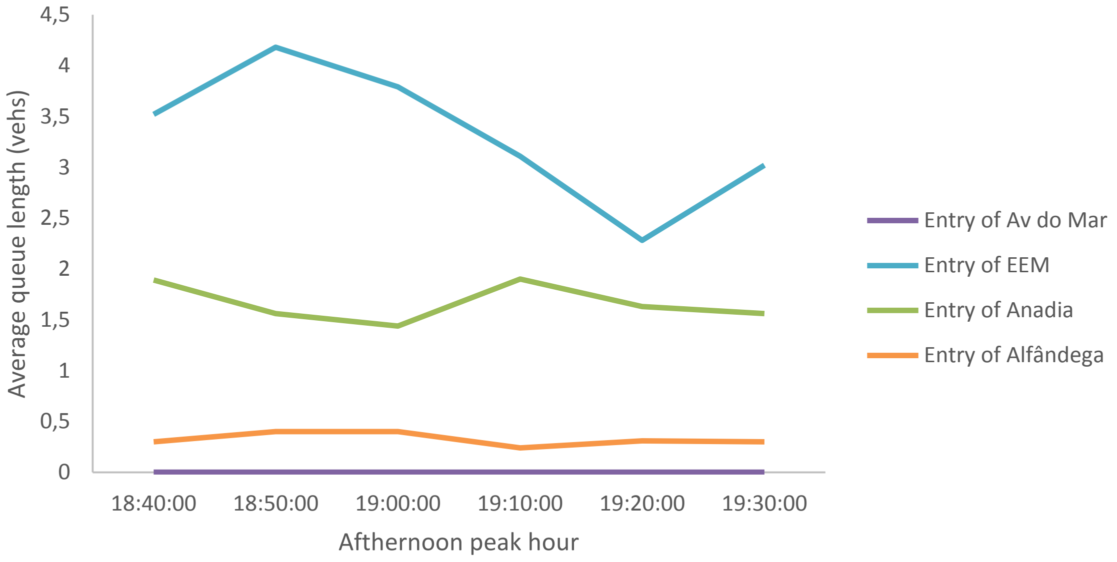


Figure 4.12 – Queue length formed by cars in the entry of roundabout to Case 3.

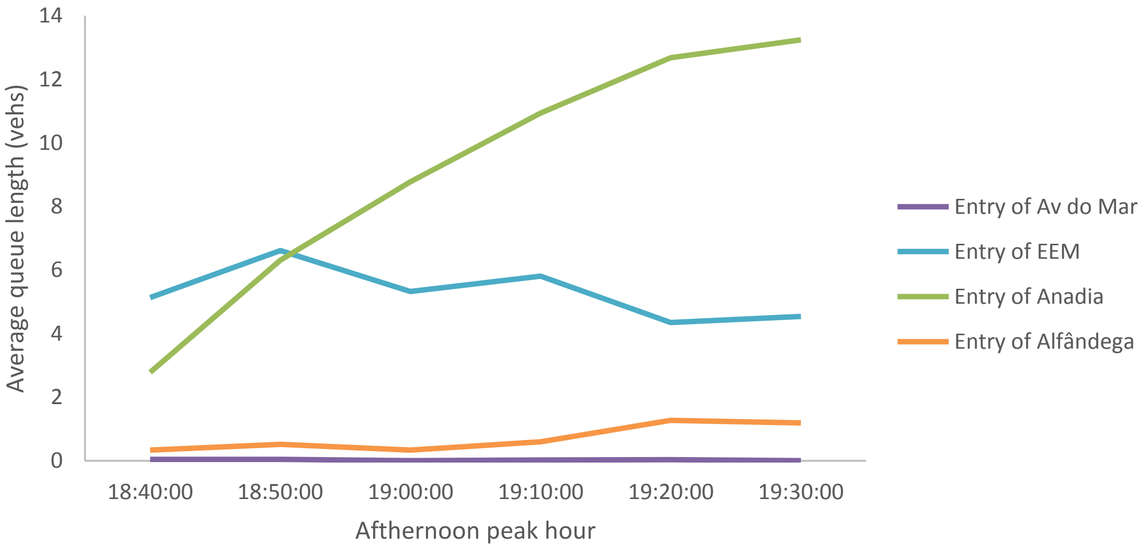


Figure 4.13 – Queue length formed by cars in the entry of roundabout to Case 4.

Since there isn't significant queue lengths in the exits of the roundabout verified in our simulations, we have consider that is not necessary to detail these values with graphics. We opted to show those values in the next Table 4.7 where is resumed the average queue length of all four simulations:

Table 4.7 – Global Value of Average queue length.

	Global Value of Average queue length (vehicles)							
	Entry Av Mar	Exit Av Mar	Entry EEM	Exit EEM	Entry Anadia	Exit Anadia	Entry Alfândega	Exit Alfândega
Case1	0	1	3	0	2	0	0	0
Case2	0	1	3	0	2	0	0	0
Case3	0	1	3	0	2	0	0	0
Case4	0	1	5	0	9	0	1	0

As for the density, delay time of all vehicles and the bus velocity, we obtained the values in Table 4.8:

Table 4.8 – Density, Delay time of vehicles and Bus Velocity.

	Case 1	Case 2	Case 3	Case 4
Density for all (veh/km)	12,33	13,90	12,65	24,02
Delay time for all (seg/km)	84,38	98,41	88,10	231,82
Bus velocity (km/h)	16,35	15,69	16,24	15,57

As said before we decided to only focus on four variables that we consider the key to evaluate the local traffic, but we can consult a more detailed exposition of all variables obtained with the program in the corresponding Appendix. Where in the Appendix C is presented all results obtained to Case 1, as the Appendix D shows Case 2 values, Case 3 is shown in Appendix E and at last Appendix F has the outcomes of Case 4.

4.6.1. ENVIRONMENTAL STUDY

AIMSUN provides three Environmental Models, we only used two, the Fuel Consumption Model and Panis et all Pollution Emission Model. The consumptions model was used in all models while we only applied to the scenario 1 and 3 the emissions model, because are the two models with results approximately alike.

Fuel Consumption Model, assumes that each vehicle is either cruising or idling at a constant speed, or accelerating or decelerating [49]. Once determined the state of each vehicle the model uses the appropriate formula to calculate the fuel consumed for the correspondent state.

So for the fuel consumption and emission models, is assumed that each vehicle is operating in one of four possible modes: idling, cruising, acceleration or deceleration. For idling and decelerating vehicles, the rate can be assumed to be constant.

For accelerating and cruising vehicles, it is given by an appropriate formula for calculating fuel consumption; the following equations show the formula for:

Acceleration Fuel Consumption

$$F_u = (C_1 + C_2 \times a \times v) \times \Delta t$$

Cruise Fuel Consumption

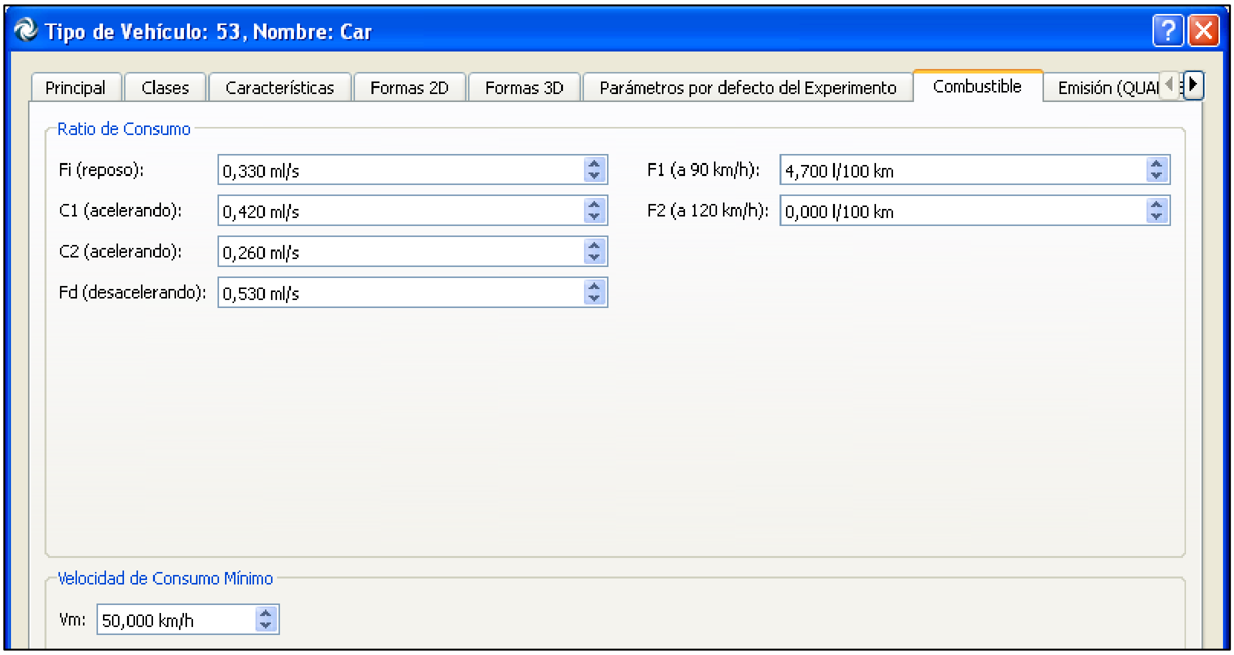
$$F_u = (F_1 \times (1 + (v \div 2V_m)^3) + F_2 \times v) \times \Delta t$$

The next parameters where specified for the above models:

- F_u: fuel consumption for every vehicle mode in (ml);
- C_1 and C_2: two constants in the model for the fuel consumption rate for accelerating vehicles;
- F_1 is constant defined based on the fuel consumption rate, in liters per 100 km, for vehicles travelling at constant speed v_1 90 km/h;
- F_2 is constant defined based on the fuel consumption rate, in liters per 100 km, for vehicles travelling at constant speed v_2 120 km/h;
- V_m: the speed at which the fuel consumption rate, in ml/s, is at minimum for a vehicle cruising at constant speed;
- a: vehicle acceleration (m/s/s);
- v: vehicle speed (m/sec);
- Δt: simulation time step;

For each type of vehicle, (where we considered that bus and trucks have the same consumption rates), the following six parameters, which stipulate the vehicle’s fuel consumption rates, was specified according to Ferreira 1982 and UK Department of Transport 1994.

The standard consumptions rates used are shown in the next Figure 4.14:



Tipo de Vehículo: 53, Nombre: Car

Ratio de Consumo

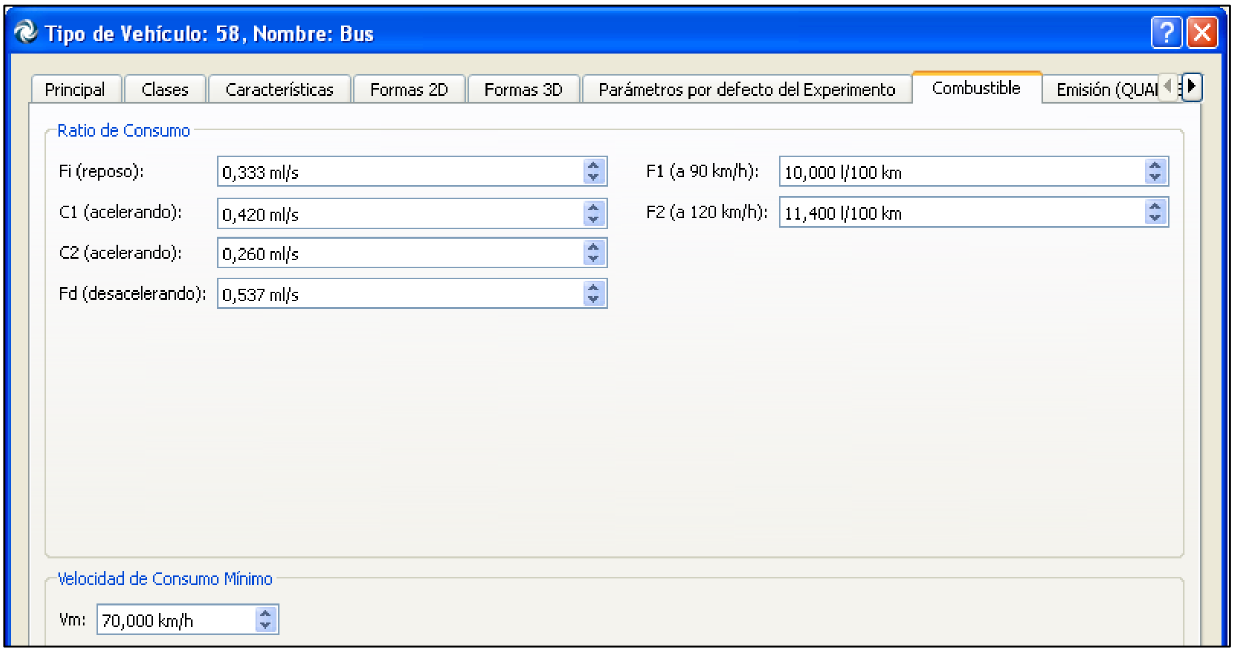
Fi (reposo): 0,330 ml/s
C1 (acelerando): 0,420 ml/s
C2 (acelerando): 0,260 ml/s
Fd (desacelerando): 0,530 ml/s
F1 (a 90 km/h): 4,700 l/100 km
F2 (a 120 km/h): 0,000 l/100 km

Velocidad de Consumo Mínimo

Vm: 50,000 km/h

Figure 4.14 – Consumption rates for Cars.

As for the trucks and buses we assumed the same standard values for both vehicles modes as shown in the Figure 4.15:



Tipo de Vehículo: 58, Nombre: Bus

Ratio de Consumo

Fi (reposo): 0,333 ml/s
C1 (acelerando): 0,420 ml/s
C2 (acelerando): 0,260 ml/s
Fd (desacelerando): 0,537 ml/s
F1 (a 90 km/h): 10,000 l/100 km
F2 (a 120 km/h): 11,400 l/100 km

Velocidad de Consumo Mínimo

Vm: 70,000 km/h

Figure 4.15 – Consumption rates for Busses and Trucks.

From Fuel Consumption Model, we obtained the follow values of Table 4.9 to each situation:

Table 4.9 – Values of fuel consumption.

	Case 1	**Case 3**
Fuel consumption of bus (l)	5,89	6,00
Fuel consumption of car (l)	2,89	2,94
Fuel consumption of truck (l)	3,21	3,27
Fuel consumption Total (l)	3,09	3,15

Combining a traffic simulation with emissions modelling, we can analyze in fine detail the environmental impacts of our ITS deployments and traffic management decisions, leading to a cleaner transport network for all. Through Panis et al Emission Model it was possible to consider the effect of traffic emissions where the model calculates the emissions based on emission factors defined for the same four operating modes discussed earlier. In particular, an instantaneous emission is the base to model the traffic emissions caused by acceleration and deceleration operating modes of vehicles. Integrating those in a microscopic traffic simulation model it permits for the accounting of lower average speeds which might be associated to less variability resulting in environmental benefits.

The emission model is based on empirical measurements. Those relate vehicle emission to the acceleration of the vehicle, the instantaneous speed and type of vehicle. With the traffic simulation model is captured the second-by-second speed and acceleration of all individual vehicles travelling in a road network based on their individual driving style, the vehicle mechanics, and their interaction with other traffic and with traffic control in the network [51].

So once inserted the standard values in the program was possible to obtain the results of Table 4.10, where CO_2 stands for carbon dioxide, NO_x represents nitrogen oxide and VOC is hydrocarbons:

Table 4.10 – Results of the Emission pollutants considered.

	Case 1			**Case 3**		
	CO_2 (g)	NOx (g)	VOC (g)	CO_2 (g)	NOx (g)	VOC (g)
Bus	233039,17	1905,39	143,38	233966,23	1895,31	142,88
Car	743849,90	1134,66	955,80	760837,91	1161,57	972,95
Truck	175265,04	1219,90	38,10	170025,55	1183,91	37,05
All	1152154,11	4259,94	1137,29	1164829,69	4240,79	1152,88

4.7. DISCUSSION OF RESULTS

The accuracy of a traffic-simulation system depends highly on the quality of the traffic-flow model at its core, with the two main critical components being the car-following and lane-changing models. In Gipps car-following model, vehicles are classified as free or constrained by the vehicle in front. When constrained by the front vehicle, the follower will automatically try to adjust its speed in order to obtain safe space headway to its leader. If it is possible for the follower to respond to any reasonable leader action without colliding with the leader, we can consider that specific headway as safe. When free, the vehicle's speed is constrained by its desired speed and its maximum acceleration [52].

Gipps [53], introduced the first lane-changing model intended for micro simulation tools. The model covers various driving situations, in which transit lanes, traffic signals, obstacles, and the presence of heavy vehicles affecting drivers' lane selection. The model contemplates the necessity, appeal, and safety of lane changes. Drivers' behaviour is governed by two basic considerations: maintaining a desired speed and being in the correct lane for an intended turning manoeuvre. The zone the driver is in, defined by the distance to the intended turn defines which one of the preview concerns is active. It has no effect on the behaviour when the turn is far away and the driver concentrates on preserving a desired speed. In the middle zone, lane changes are considered only to the turning lanes, or lanes that are adjacent to them. Close to the turn, the driver focuses on keeping in the correct lane and ignores other factors. The zones are defined deterministically, ignoring distinction between drivers and inconsistencies in the behaviour of a driver over time. When more than one lane is acceptable the conflict is resolved deterministically by a priority system considering locations of obstructions, the presence of heavy vehicles, and potential speed gain [54].

Our current research to verify an alternative to the traffic behaviour in Avenida do Mar, has lead us to a traffic model created with base on traffic counts instead of a matrix extracted from a macro model. Once again the lack of time to build a matrix, starting from the Funchal OD-matrix done in the macroscopic model into a smaller one corresponding to the volumes of demand in the zone of Sé, was our biggest barrier. This doesn't make our model less valid but if we want use this model in the future is necessary to update the traffic counts values or another alternative would be determinate a growth factor and multiply our matrix by this value. In our model, all individuals are simulated simultaneously over a pre-defined time period, the afternoon peak hour. All individuals are consider as aging simultaneously, the computational demands definitely increase. In a continuous time framework, the computer power can still be a bottleneck for this kind of simulation, current models typically have population sizes of less than one million in our case we simulated a population with 2349 individuals. The comparison of the results achieved with the models showed different traffic behaviours, dependent on network geometry.

The first case studied, we had altered the roundabout to three lanes of traffic, where we could observe a good traffic behaviour, but initially we can observe some queue (due to the initial specified parameters), which tends to decrease as time passes. On second case, we simulated the roundabout with two lanes of traffic, which is a situation very close to the actual geometry of Avenida do Mar. By the results is shown a traffic queue increasing with time, which isn't a favourable situation. In the third model, that corresponds to three lanes in the roundabout but one is reserved to public transport, in a very similar way to the first case the traffic queue tends to decrease and or become constant. The last case is the reserved lane in all of the avenue until the roundabout, and it is possible to see a high queue length compared to the others situations, which increases as time passes. Also the biggest queues formed are at the entry of EEM followed by Anadia, Alfândega and Avenida do Mar.

Density, which traduces the number of vehicles per unit length of the roadway, this is the average number of vehicles that occupy one kilometer of road space, expressed in vehicles per kilometer. Consequently as higher the values obtained is, worse will be the traffic behaviour, so the case 4, then case 2, case 3 and at last case 1 shows the worst densities scenarios. Congestion often means stopped or stop-and-go traffic. It is relatively easy to recognize, roads filled with cars, trucks, and buses, sidewalks filled with pedestrians. In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower and sometimes much slower, than normal or "free flow" speeds. The delay time obtained refers to the average time that a number of vehicles that occupy one kilometer of road space, will spend due congestion. Related directly to the density, therefore the higher values recorded are equally seen in case 4, then case 3, tracked by case 2 and case 1.

At last the registered bus velocity is approximately 16 km/h to all cases. This value reflects the network geometry similarity, where the only factor that will drastically change is the OD-matrix, but in our models it is constant, since the only thing we changed between models is the geometry of the roundabout. Therefore, we can select the model 1 and 3 as the ideal traffic scenarios, but to choose which one will be in general a better solution, we decided to combine emissions modelling with traffic simulation, where we could analyse in higher detail the environmental the impact on traffic management decisions, leading to a clear choice of the best case modelled.

Urban transport is essential for citizens to perform their activities, but at the same time constitutes one of the major sources of urban pollution (GHG emissions, local air quality, and noise), directly affecting citizens' health and well-being. Urban traffic produces 40% of CO_2 emissions and 70% of emissions of other pollutants (CO, NO_x, SO_x, particulate matter) produced by road traffic. Traffic accidents are also increasing, with two thirds of the accidents and one third of the victims taking place in cities.

The quest for environmentally sustainable urban transport, while ensuring competitiveness and addressing social concerns such as health problems or the needs of persons with reduced mobility, is a common and urgent challenge for all major cities in Europe [7].

Air pollutant emissions come from both natural and anthropogenic sources. The emission of air pollutants has led to several air quality issues, although major efforts have been made over the past decades to reduce air pollution and improve air quality, these issues have proven to be quite persistent and continue to exist despite the implementation of several air quality strategies. One factor that contributes to the continued emission of pollutants is the growth in road traffic, through the combustion of liquid or gaseous fossil fuels. We only focused on three, the products of incomplete combustion, hydrocarbons (VOC), products of high-temperature combustion processes, the nitrogen oxides (NO_x) and greenhouse gases (are not concerned with respect to air pollution, but are important with respect to climate change) the carbon dioxide (CO_2).

The values we obtained don’t show a big difference between both cases, but in the overall results, case 1 has slightly inferior values in comparison to case 3, we can also state that busses emits less pollutants than cars. Concluding that the best model is the case 1, with tree lines in the roundabout. Where the full capacity of the network is not exceeded, suggesting better traffic behaviour, short queue lengths, and better traffic speed.

5

FINAL CONSIDERATIONS

5.1. CONCLUSIONS AND FINAL REMARKS

Throughout this dissertation we shown in detail all the experimental work in view of the stated objectives. As a starting point of this work we had as main goal, the evaluation of the global traffic on Funchal, in order to achieve a model with an economical and robust solution, just by changing the frequency of the buses. In the second instance the validation of a model that represents the conditions of traffic on Avenida do Mar, in order to create an efficient response to known traffic problems, demonstrating its advantages and identifying the best solutions for traffic lights cycles and geometry of the roundabout, with the introduction of environmental study.

However, this paper is intended to be an incentive for the use of new technologies in the strategic planning of traffic where all work is supported by experimental models developed with the respective programs.

In macro simulation was based on a detailed model of Funchal, which was used to guide us in the creation of our own model. We carried several models gradually until achieve the final model, and although our model is a more simplified version of the entire network, the matrix we obtained has a low deviation of the initial matrix. Founded on the model we obtained all the values necessary for the first level, of our optimization function, and through the values provided by the bus company, we could fill the second level of our function. With an algorithm has defined as our variable the time gap between bus departures, and after many interactions we obtained a reduction of total costs.

As for the micro simulation, with the various data we constructed a representative model of the traffic on Avenida do Mar. we studied the cycles of traffic lights and the geometry of the network , and between all four models created was possible to obtain a solution to the current problems, based on an environmental study. One of the goals of this dissertation was to learn how to use the programs which are currently in the market to assist the planning of transit.

Therefore was also created a model equal to case 1, with the program VISSIM (a microscopic simulation program from the company PTV VISSION). Would have been interesting to compare results between AIMSUN and VISSIM to discuss the advantage and disadvantages of the different programs but the model created in VISSIM is unfinished, missing the traffic lights times, this last step wasn't done since the available license crashed which made impossible to end in time this model.

In a final approach all proposed objectives were achieved, in a simplified form. In future it is proposed that further studies be done on how best to address the frequencies of buses. Within the context of micro simulation would be interesting to make a model based on a matrix able to predict population growth.

Besides, given the results discussed in Chapter 3 and 4, we can take some conclusions at a global level of traffic simulation. Some advantages of the traffic simulation [55]:

- Simulation is cheaper than many forms of field experimentation and analytical modelling, in terms of time, resources and cost;
- Simulation is a powerful tool for comparing the consequences' of a number of alternative strategies and improvement plans;
- The task of developing the logic of various events and their occurrences involves the collection of pertinent data. The engineer gains an insight into the traffic characteristics and the way traffic interaction takes place during the process of collection of data and modelling. This may ultimately lead to a better formation of an analytical model;
- In real life situations, it is extremely difficult to obtain conditions in the field which are needed for building a better analytical formulation;
- Simulation techniques can be employed to check uncertain analytical solutions;
- Simulation techniques provide opportunity for controlled experimentation, altering one variable at a time or specific variables simultaneously, and the final effect can be observed. Traffic systems in particular, are highly complex systems, with many variables, interactions and sub-systems;
- In the case of many analytical models certain assumptions have to be made to simplify the task. Often these assumptions are of a doubtful nature. Simulation models can overcome such deficiencies;
- Simulation models are "transparent," in the sense that anyone who wishes to know how they work can see through the model;

Limitations of traffic simulations:

- Simulations are resource limited;
    - Resolution: Level of detail;
    - Fidelity: Degree of realism;
    - System size: The network size to be covered;
    - Simulation speed: Speed of simulation compared to real time;
    - Resources: Computational resources, programming time;

Considering what has been said above is intended to contribute fundamentally to encourage the development and implementation of future projects using this technology for urban planning.

5.2. FUTURE DEVELOPMENTS

With the numerous scientific contributions that have been published in the last decade, we can denote an increasing preoccupation with the planning of transit. It has been recognized the need for continuing research in this area, so we can efficiently benefit from the great potential that the models offer to whole society.

Since not all decision making processes involve the use of these models, it is suggested the implementation of methodologies aimed at the use of traffic models will help to support a decision. This is the availability of time and money to build a team capable of creating networks of transit for the whole island of Madeira, study the movement of people, perceive the needs requested by users, the potential land use, making it possible to characterize the behaviour of the traffic across the island and focus on studies for the most problematic areas, making it possible to respond immediately to any problems encountered.

Apart from these, it is important to continue to develop more and better models able to completely characterize network traffic in order to get cheaper and more accurate models.

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APPENDIX

Macro Simulation for the case studied of Funchal

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ABSTRACT

Mobility, the freedom and ability to travel, has always been an important part of each country lifestyle. However, as more and more vehicles crowd the nation's roadways, traffic congestion is having an increasingly debilitating effect on our quality of life. We still encounter many of the same transport problems of the past: congestion, pollution, accidents and financial deficits. The work done in this paper attempts to demonstrate the importance of using models that can predict and represent the mobility of our society. To answer the proposed challenges, we built a simplified macro simulation model with the intention of understanding the traffic problems in Funchal and in particular the frequency of the bus, responsible for transport in the city of Funchal, and some surrounding areas.

1. INTRODUCTION

The company Horários do Funchal and the Funchal City Hall, proposed to University of Madeira the macroscopic study of Funchal. In partnership with the investigation group of University of Cantabria we studied and developed all models to carry this study.

Macro simulation models evaluate traffic flow as a whole without consideration of the characteristics and features of individual vehicles in the traffic stream. First we did an initial O/D matrix, and the objective was to have a VISUM model with a good approximation to this matrix.

With the creation of macro simulation we intended to project a valid model where we could study in general the traffic behaviour in the city, and determine the frequencies of the busses. Therefore, the global objective is to investigate the cumulative impacts of potential development on the bus networks where the principal aim is the elaboration of a robust evidence data base. This allows the planning of an effective and improved long-term transport infrastructure strategy, with the goal of alleviating the existing problems and the predicted transport capacity issues on Funchal.

2. STUDY ZONE

The study zone is Funchal one of the ten municipalities that compose the island of Madeira. Madeira has an approximated area of 785 km^2, with many slopes that influence the zoning in certain areas. According to the Census of 2011, the Autonomous Region of Madeira has 267.785 habitants with a population density of 334.500 hab/km².

The population of Madeira reflects the geographical constraints that characterize it, where in big part, the population is on the south coast, which led to the definition of two major conurbation: Funchal and Machico. Funchal a predominantly urban district, occupying an area of 73 km^2, 44% of which is built on. The town is composed by 42 parishes with about 104 thousand residents. According to data of 2001 Census, there was a present population in Funchal around 7% superior (over 7.192 individuals), than the residents count, reflecting in part the weight of tourism.

	Zones
5	Imaculado Coração de Maria - Center
7	Imaculado Coração de Maria - North
6	Imaculado Coração de Maria - West
	Imaculado Coração de Maria
32	Monte - North
34	Monte - South
38	Monte - Center
	Monte
1	Santa Luzia - Central Zone
2	Santa Luzia - Center
3	Santa Luzia - North
	Santa Luzia
35	Santa Maria Maior - Central Zone
36	Santa Maria Maior - South
37	Santa Maria Maior - North
42	Santa Maria Maior - Up South
	Santa Maria Maior
29	Santo António - North
30	Santo António - Low Center
31	Santo António - South
33	Santo António - West
40	Santo António - Up Center
	Santo António
13	São Gonçalo - Center
14	São Gonçalo - West
15	São Gonçalo - East
16	São Gonçalo - North
	São Gonçalo
4	São Martinho - Touristic Zone - West
21	São Martinho - Nazaré
22	São Martinho - Tourism - East
23	São Martinho - Center
24	São Martinho - West
25	São Martinho - North
26	São Martinho - South
	São Martinho
19	São Pedro - Central Zone
20	São Pedro - Center
27	São Pedro - West
28	São Pedro - North
39	São Pedro - Av. Luis de Camoes
41	São Pedro - Center B° Moinhos
	São Pedro
8	São Roque - East
9	São Roque - Center
11	São Roque - North
10	São Roque - South
12	São Roque - West
	São Roque
17	Sé - Zona Central - West
18	Sé - Zona Central - East
	Sé

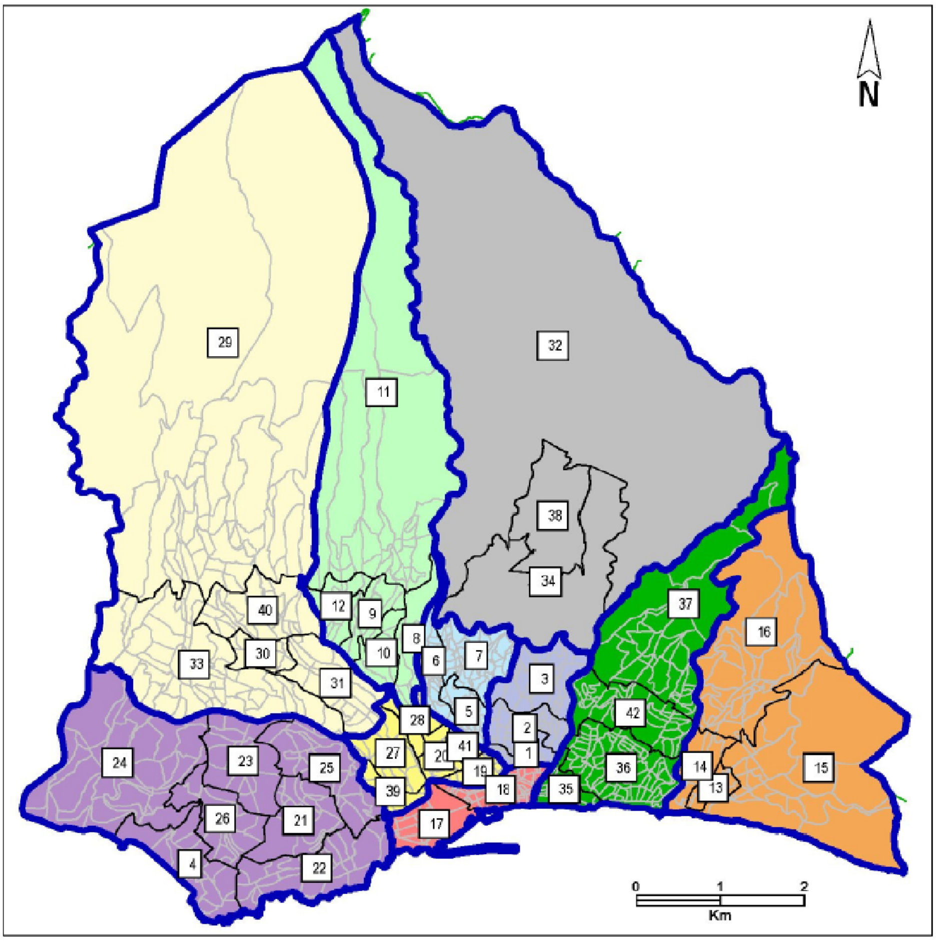

Fig.1 - Zone distribution;

Source: Survey of Mobility in the city of Funchal, 2006/2007.

3. MOBILITY IN FUNCHAL

Based in the summary report of the Study of Mobility in Funchal, of 2006/2007, a survey was made to approximately 82.9 thousand habitants in Funchal. The extrapolation of the survey, allows an estimation that this population performs daily around 144.3 thousand trips, of which about 144.1 thousand begin or end in Funchal.

Based on the results of the counts and surveys done to the non resident population , but who perform activities in the study zone, it is estimated that daily "go in" Funchal approximately 24.6 thousand people, which perform about 60.3 thousand trips with end or start in Funchal. The duration of the trips varies, according to the factors considered. By analyzing the transport mode as function of the travels performed internally to city, or the travels generated from others towns to the study area, was possible determinate the average time of these travels.

Table 1
Average duration of travels: Total and by typology of movement;
Source: Survey of Mobility in the city of Funchal, 2006/2007.

Segment	Travels inside Funchal	Travels to/from Funchal
TI	18,4 min	23,7 min
TC	24,7 min	44,1 min
On Foot	19,7 min	14,0 min
TOTAL	**20,7 min**	**30,7 min**

4. SYSTEM OF COLLECTIVE TRANSPOT

The public transport network of Funchal is based mainly on heavy road passenger transport: city and intercity bus network. The exploration of the road transport service of passengers within the limits of Funchal is the responsibility of a single operator, the company Horários do Funchal.

This is composed by three types of trips:

- Regular journeys , moving generally from the center of Funchal and another destination within the county limits ;
- Journeys of high areas, which serve locations with difficult access through special vehicles to rough terrain ;
- Journeys of the dawn, serving the municipality of Funchal during night period.

In total, the network is composed of 63 routes, of which 55 are regular routes, 5 routes of uplands and 3 night time only routes. In total these routes run a distance with a little over 170 km, and ensure spatial coverage in the territory. Except for the journeys of all the high areas all routes shall commence in the town center.

5. OFFER AND DEMAND

The objective of this first stage is to define the magnitude of total daily travel in the model system, at the household and zonal level. Each trip is separated into a production and an attraction, effectively preventing network performance measures from influencing the frequency of travel. Generation essentially defines total travel in the region.

To this purpose we have compiled social and economic information by census region. Also we have compiled information of other variables like kind of soil in the city.

The information collected for each transport zone is shown in Table 1. With this information we have calibrated a model of travel's productions by area and time, such that with the total travels that we have calculated, they can be disaggregated between generated and attracted with recommended rates in the manual of TRIP GENERATION .

In regard to other land uses (other than residential), we have used the expressions in the manual, which, depending on the selected independent variable, we estimated total trips by period. Below we show the different land uses and the selected independent variable:

Table 2
Funchal Key Data Resume:

KEY DATA	
ID_TRANS	transport area
TYPE_ZONE	type of area (census tract or equipment)
Nº_STUDENTS	students number
m2_BUILDING	built area
m2_PARKING	parking area
EMPLOYEES	employees number
Nº_BEDS	Beds number/ hospital
POB_T	total population
MEN	male population
WOMEN	female population
Nº_BUILDING	Buildings number
TRA_PEOPLE	people traveling daily
NO_TRA_PEOPLE	no people traveling daily
1 TRA_PEOPLE	people who make a daily trip
2 TRA_PEOPLE	people who make two daily trip
OCUPPIED	employed people
STUDENTS_16	Students over 16 who do not work
LOCAL	locals
HOMES	homes number
HOUSING_FAM	number of family households
EQUIP_HEALTH	number of health facilities
EQUIP_EDUCA	number of educational facilities
BUSINESS_PREMISES	number of business premises
OFFICE	office number
INDUSTRIAL_LOCAL	number of local industrial
LOCA _AGRICULTUR	number of local agricultural
1_P	number of properties with 1 floors
2_P	number of properties with 2 floors
3_P	number of properties with 3 floors
4_P	number of properties with 4 floors
5_P	number of properties with 5 floors
6_P	number of properties with 6 floors
7_P	number of properties with 7 floors
8_P	number of properties with 8 floors
9_P	number of properties with 9 floors
10+P	number of properties with 10 or more floors
H_1VEH	households with one vehicle
H_2VEH	households with two vehicle
H_3+VEH	households with three or more vehicle
H_SI_VEHI	households if they have vehicle
H_NO_VEH	households have no vehicle

Therefore with the manual [1], we could calculate the generation and attraction that each zone produces, depending on each zone land use.

5.1 Estimation of Origin-Destination matrix

Based in the data that we obtained for each special area, we determinate the matrix with the follow assumptions:

5.1.1 Estimation of the base matrix: aggregate model

In this phase we used the book [2], and we obtained a base matrix, were travel is defined as a proportion between i and j that can occur k times, which is known as model of modal partition, and it have the next expression:

$$M_{ij}^{kn} = \frac{\exp(-\lambda^n C_{ij}^k)}{\sum_k \exp(-\lambda^n C_{ij}^k)}$$

Where C_{ij}^k is the Generalized Cost to go from zone i to zone j in k mode.

In addition, to develop distribution travel models is need to know the value of compound costs for each pair (i, j).

To calculate these costs compounds $\check{C}_{ij}$ the following expression is used:

$$\check{C}_{ij} = -\frac{1}{\lambda} \times \ln\left(\sum_k exp\left(-\lambda \times \left(C_{ij}^k + \delta^k\right)\right)\right)$$

Where:

k: Modes available in the pair (i, j).

λ: Function´ parameter for estimating user type n.

δ^k: Modal penalty.

C_{ij}^k: Generalized cost of mode k in pair (i, j).

5.1.2 Setting the matrix based on traffic counts

In this step we adjusted the preview calculated matrix, the methodology used here consists of the application of the method of "Maximization of Entropy".

The method defines the following term: P_{ij}^a proportion of trips between origin (i) and destination (j) using the arc (a). It has values between 0 and 1, with 1 indicating that all travel between (i) and (j) are performed by the arc (a).

The expression to determinate flows V_a, with the total travels in each pair (i, j) is:

$$V_a = \sum_{ij} T_{ij} \cdot P_{ij}^a, \quad a \in A_c$$

Where:

V_a: Flow in the arc a.

T_{ij}: Amount of travels between origin (i) and destination (j).

A_c: Set of arc with counts.

6. NETWORK MODELLING – MACRO SIMULATION

Modelling and calibration of the road network in analysis were performed using the program VISUM a traffic modelling *software* belonging to the German company of transport planning and analysis of operation: PTV- Vision. Visum is *software to* model networks that offers the possibility to determine the various impacts or alterations in study zone, in respect of individual or public transport networks.

Due the fact that the license of product, only allows 2000 nodes and 5000 links, it was necessary to simplify the network, without losing information that could compromise the study. The following phases have been carried out to model an acceptable model:

- Trip generation, focused on constructing the traffic zones and recognizing their travel potential, and defining origins of all passengers trips in each traffic zone;
- Trip distribution featured by determination of all passengers trips between any pair of zones. The result of this step is a construction of a complete O/D matrix;
- Route assignment consisting in assigning the distribution of O/D matrix to the transportation network, which results in generating the volume of passengers and vehicles flows on particular links of the network;

Based on those principles, and in the below data collected was construct the macro simulation model to Funchal.

6.1 Survey and Count Post

The collected volumes were obtained with resource to traffic counts, in intersections and main links. Also were made surveys of origins-destinations to householders, residents, and no residents. This led us to this data distribution map.

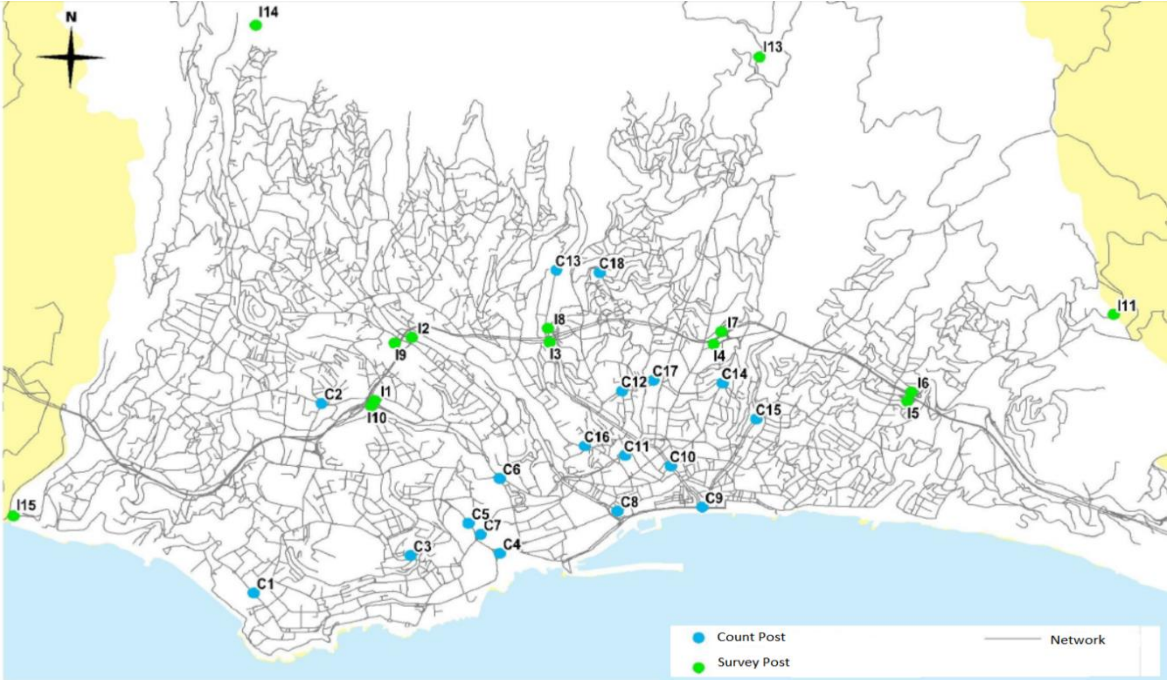

Fig.3 – Data Post Locations;

Source: Survey of Mobility in the city of Funchal, 2006/2007.

6.2 Traffic Count

For analysis of the collected values, we considered three disaggregated periods: in the morning, lunch and afternoon. In the morning peak period were counted, on average, about 43.800 vehicles, while the afternoon peak period corresponds to an average of about 45.600 vehicles. In what concerns the lunch peak period, it was noted that while it is possible to identify a slight increase in car traffic, is not substantially different from what happens throughout the day, with an average of 36.201 vehicles per hour.

Therefore the macro and micro simulations are made for the afternoon peak period, between 18:30 until 19:30.

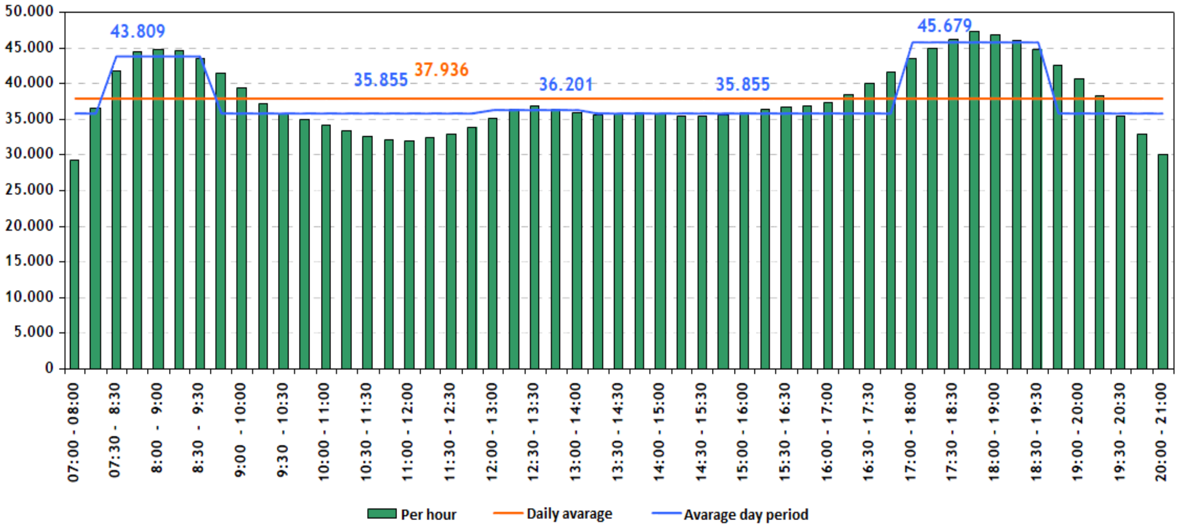

Fig.4 – Progress of traffic in the sum of all the counting stations;
Source: Survey of Mobility in the city of Funchal, 2006/2007.

6.3 Hierarchy of Roads

The objective is to serve people and the economy, so the hierarchy of the road network is established from the importance of links offering, and culminates in the profile type and operating conditions that the route must submit. Contributing to this, the dimension and importance of urban agglomeration, the tourist interest in the area, the economic activities and establishing links with the outside. In this understanding the following levels in the road hierarchy for the municipality of Funchal were set as:

- Level 1 - Structural Network
  Must ensure the main accesses to the city;

- Level 2 - Primary Distribution Network
  Should guarantee the distribution of the largest flows of traffic in the city, as well as average routes and access to 1st level;

- Level 3 - Secondary Distribution Network
  Must ensure the next distribution, as well as the routing of traffic flows to routes of higher education;

- Level 4 - Network Proximity
  Composed of structural pathways of neighborhoods, with some flow capacity;

- Level 5 - Local Access Network
  Need to ensure access to buildings, but gathering privileged conditions for pedestrian circulation.

6.4 Speeds

We measured the road speed practicable in the network by using the GPS technology. This allowed to measure with great accuracy the average velocities practiced in the network. It was observed that the highest speeds were recorded in the arcs of higher hierarchy, and as expected the central area of the city offers reduced speeds of circulation, due to concentration of traffic and others factors.

The velocity of circulation is the indicator commonly used to evaluate the performance of a road network, since it allows a direct comparison between the different arcs that constitute the network. The velocity of circulation is calculated based on the theoretical velocity of circulation, which is influenced by the volume of traffic flowing on the road, with a more significant degradation as the volume approaches the capacity of the circulation route. Observing the velocities we can see it is less than the legal limits of circulation velocity, which implies disturbances to the free circulation of vehicles: parking maneuvers, crosswalks, traffic lights, among others.

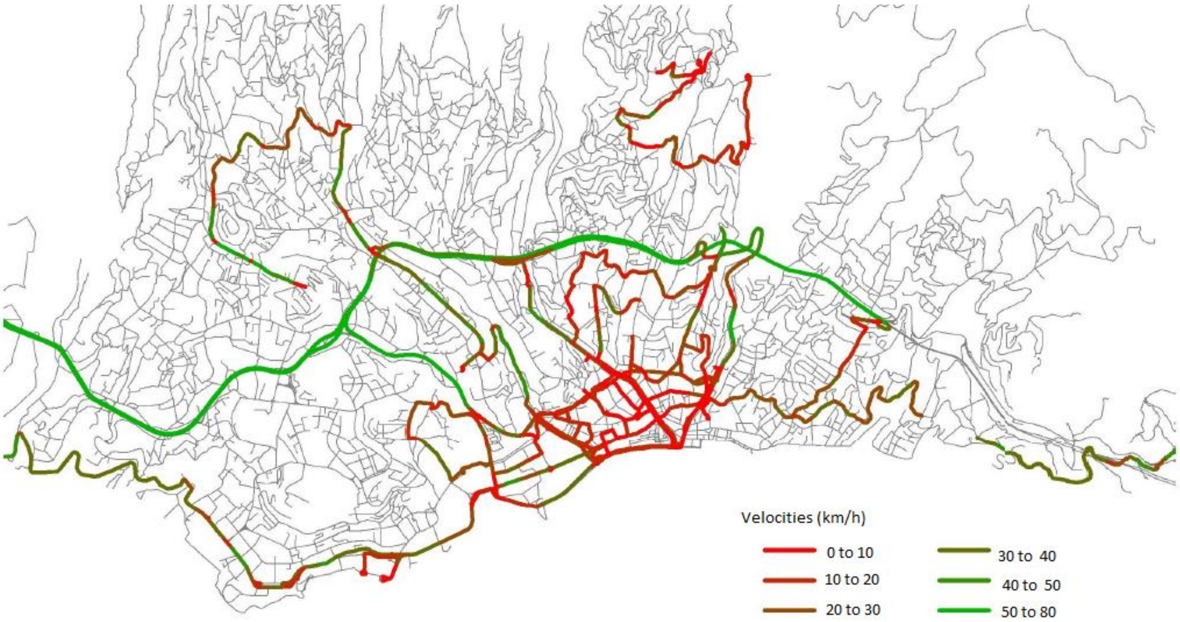

Fig.5 – Average Velocities;
Source: Survey of Mobility in the city of Funchal, 2006/2007.

6.5 Saturation

The configuration and performance of the road network where also measured through the degree of saturation of their arteries. The network saturation occurs when the traffic received is more than can be routed. This is a phenomenon that appears when the number of vehicles received, approaches the maximum capacities the network has. In the peak afternoon hour, we have areas, where traffic exceeds 75% of the maximum capacity of the route. And saturations above 100% corresponding to a conditioned and highly unstable circulation, this means, the volume of traffic exceeds the capacity of the artery causing the formation of queues and stop-start waves.

Fig.6 – Saturation levels (%/direction) in the road network;
Source: Survey of Mobility in the city of Funchal, 2006/2007.

Based on those principles and collected data it was possible to construct the macro simulation model to Funchal, which led us to an O/D matrix with an Alpha level of 0.57 that is considered a good approximation to the initial O/D matrix.

6.6 Performance Indicators

We see daily that about 67.400 trips in public transport take place in Funchal. It appears that virtually all areas with more offers are the areas with most demand: central areas near the sea and the axis of Santo António. The only exception is the zone 4, which shows more demand than there is available supply.

Although they are not segregated, there are about 23.500 trips, one third of the total, with one end/start outside of Funchal, which implies the use of interurban transportation.

6.6.1 Average Waiting Time at Origin

The average time that the customer has to wait to enter the public transport system, in areas where the supply is less, the waiting time increases, as are the cases of the north areas Monte, Santa Maria Maior and São Gonçalo. However in coastal and central areas the waiting time is relatively short, not exceeding 5 minutes, while the upland areas can sometimes exceed 7 minutes.

6.6.2 Average Speed of Movement

Is an indicator that evaluates the relationship between the distance traveled, and the time spent on realization of the trip. The average speed of travel, to the trips started in Funchal is generally 9.0 km/h, presenting a minimum of around 6.5 km/h in central areas of São Roque and Imaculado Coração de Maria.

6.6.3 Average Travel Speed

It matches the speed of the route between the stops, including the times of overflow, which allows the evaluation of the speed of the transport system.

On average moving speed of travel of public transport began in Funchal is 16 km/h. It appears however that the trips started in the city center, have considerably higher average speeds of around 18 km/h, since mostly correspond to long distance trips that split to several axis with commercial speeds. In generally, it is observed that the trips initiated in the western part of the county have higher speeds than trips started in the central and eastern areas.

6.6.4 Average Number of Transshipments

The average number of transshipments allows us to estimate the quality of travel started in determinate area, since the greater the number of transshipments to perform, worse are the levels of network performance and consequently the satisfaction of passenger. The transshipments in the district occur especially in long distance travel that, often, need for transshipment to the network of Horários do Funchal. It occurs between trips from external and internal areas of the region. The practice of transshipments in Funchal is not significant. However, it should be noted that the existence of only one point of transshipment, reduce the average number of transshipments but implies greater travel times.

6.6.5 Percentage of Direct Travel

The percentage of direct travel, allow us to judge, to what extent the current network meets the mobility needs of each zone. In a convenient way, identifying connections where supply system is satisfactory, and calculating to what extent it is justified the introduction of more direct connections between certain areas. The areas with the biggest problems are the zones 1 and 4, where the percentage of direct travel is less than 25%. However, despite the area 4 present a low percentage of direct travel, this area recorded one of the largest volume demand. In overall, it appears that more than half of the areas where the trips started, experience more than 75% of direct travel, and there are even several cases where all journeys started, correspond to a direct travel.

7 CONCLUSIONS

As we seen before the tourism and the geographical position of the city, has an influence in the city traffic, per day there is approximately 23.500 trips, one third of the total, with one end/start outside of Funchal, concluding that the interurban transportation has weigh in the daily trips.

- In Funchal, the areas with the greatest demand are the Estrada Monumental axis. The concentration of demand and offer in these areas is related to the strong concentration of employment: commerce, industry, tourism and services.
- The zone 18 which , in addition to the city center is where is the terminus of the Horários do Funchal, presents a daily demand of over 7 thousand trips of TC, this corresponds to 13% of daily trips of TC with end in Funchal;

- The zones that are at the central core of the city are the ones with lower average waiting times at the origin, between 3 and 5 minutes, while the more remote areas have waiting periods between 5 and 8 minutes;
- The considerable gap between the speed movement and travel speeds, allow conclude, the waiting times are high, which, reflects the low frequency of most journeys of Horários do Funchal;
- The practice of transshipments, of trips started in Funchal is relatively low, of the order of 0.3 transfers per trip. However, the network of urban public transport is strongly radial, even a low index of transshipments brings considerable implications to the average travel time;
- The trips with the greatest number of transshipments are interurban trips, which in several cases, needs transshipment to the company Horários do Funchal. And trips started in one extreme zone of Funchal, where the radial nature of the network means, that the travel with destination to another extreme, needs at least one overflow.
- Areas with better performances in the TC system, are the areas in the center (Zone 17, 18, 22 and 35) since they have high levels of demand and offer. And the travel offers short duration and has low rate of transshipment. In other hand the worst performing areas are dispersed in the region: area 1, 2, 13, 37 and 41.

8 ACKNOWLEDGEMENTS

This study has its roots in 2014, when the University of Madeira disponibilized this theme for dissertation. Therefore this report is a response to the population needs, amelioration of lifestyle, the call for more traffic strategies, and enhanced analysis of data.
The information contained in this paper, is based on Census and in Mobility Study done in Funchal and together with the data gathering was conducted by numerous agencies, developers, and others individuals. This paper is dependent on that collected data, because it enhances the database on which we are based. The magnitude of the database bestows credence on the information contained in the report.

I want to express my gratitude to those many individuals who have contributed data, and who continue to contribute, to this effort.
In particular, the company Horários do Funchal in special Claudio Mantero and Funchal City Hall, for sharing all the data available.
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To University of Madeira, for financial support and in particular to Professor Lino Maia, who made possible this study. Lastly, want to thank all the support gave by family and friends.

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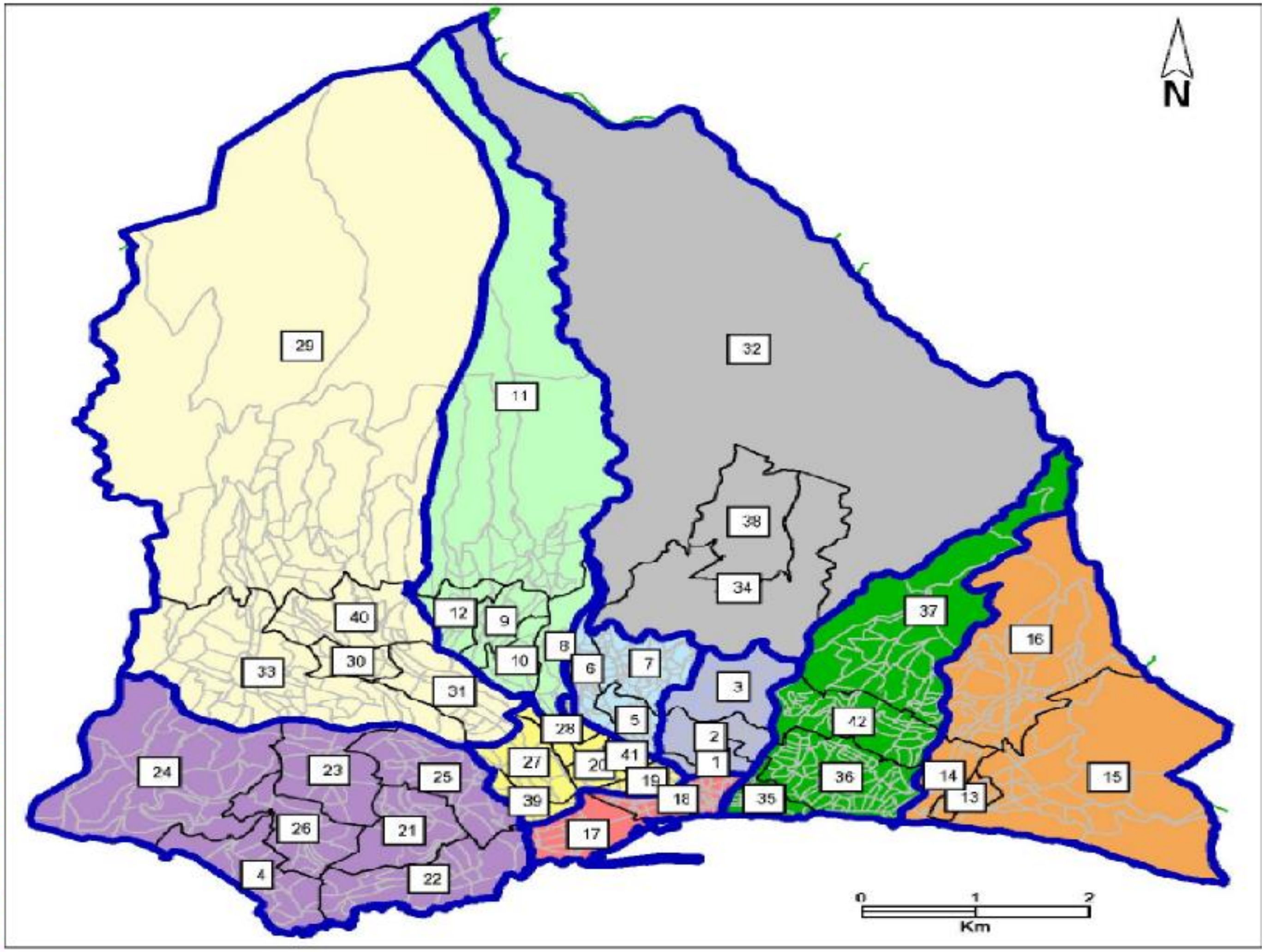
Appendix B – Funchal Zones Description

Zones	
5	Imaculado Coração de Maria - Center
7	Imaculado Coração de Maria - North
6	Imaculado Coração de Maria - West
	Imaculado Coração de Maria
32	Monte - North
34	Monte - South
38	Monte - Center
	Monte
1	Santa Luzia - Central Zone
2	Santa Luzia - Center
3	Santa Luzia - North
	Santa Luzia
35	Santa Maria Maior - Central Zone
36	Santa Maria Maior - South
37	Santa Maria Maior - North
42	Santa Maria Maior - Up South
	Santa Maria Maior
29	Santo António - North
30	Santo António - Low Center
31	Santo António - South
33	Santo António - West
40	Santo António - Up Center
	Santo António
13	São Gonçalo - Center
14	São Gonçalo - West
15	São Gonçalo - East
16	São Gonçalo - North
	São Gonçalo
4	São Martinho - Touristic Zone - West
21	São Martinho - Nazaré
22	São Martinho - Tourism - East
23	São Martinho - Center
24	São Martinho - West
25	São Martinho - North
26	São Martinho - South
	São Martinho
19	São Pedro - Central Zone
20	São Pedro - Center
27	São Pedro - West
28	São Pedro - North
39	São Pedro - Av. Luis de Camoes
41	São Pedro - Center B° Moinhos
	São Pedro
8	São Roque - East
9	São Roque - Center
11	São Roque - North
10	São Roque - South
12	São Roque - West
	São Roque
17	Sé - Zona Central - West
18	Sé - Zona Central - East
	Sé



Appendix C – Results of Case 1

Time Series	Value	Standard Deviation	Units
Average virtual queue waiting for Bus	1,18	ND	vehs
Average virtual queue waiting for Car	7,45	ND	vehs
Average virtual queue waiting for All	8,76	ND	vehs
Average virtual queue waiting for Truck	0,14	ND	vehs
Maximum virtual queue waiting for Bus	6,2	ND	vehs
Maximum virtual queue waiting for Car	29,4	ND	vehs
Maximum virtual queue waiting for All	34	ND	vehs
Maximum virtual queue waiting for Truck	1,2	ND	vehs
Consumption of Combustible Bus	5,89	ND	l
Consumption of Combustible Car	2,89	ND	l
Consumption of Combustible All	3,09	ND	l
Consumption of Combustible Truck	3,21	ND	l
Density Bus	1,24	ND	veh/km
Density Car	10,77	ND	veh/km
Density All	12,42	ND	veh/km
Density Truck	0,42	ND	veh/km
Total distance traveled Bus	142,24	ND	km
Total distance traveled Car	2269,61	ND	km
Total distance traveled All	2486,27	ND	km
Total distance traveled Truck	74,42	ND	km
Flow Bus	157,4	ND	veh/h
Flow Car	2258,2	ND	veh/h
Flow All	2491,8	ND	veh/h
Flow Truck	76,2	ND	veh/h
IEM CO2 Bus	233039,17	ND	g
IEM CO2 Car	743849,9	ND	g
IEM CO2 All	1152154,11	ND	g
IEM CO2 Truck	175265,04	ND	g
IEM CO2_Interurban Bus	60886,18	ND	g/km
IEM CO2_Interurban Car	194345,78	ND	g/km
IEM CO2_Interurban All	301023,48	ND	g/km
IEM CO2_Interurban Truck	45791,53	ND	g/km
IEM NOx Bus	1905,39	ND	g
IEM NOx Car	1134,66	ND	g
IEM NOx All	4259,94	ND	g
IEM NOx Truck	1219,9	ND	g
IEM NOx_Interurban Bus	497,82	ND	g/km
IEM NOx_Interurban Car	296,45	ND	g/km
IEM NOx_Interurban All	1113,00	ND	g/km
IEM NOx_Interurban Truck	318,72	ND	g/km
IEM PM Bus	68,97	ND	g
IEM PM Car	213,4	ND	g
IEM PM All	311,45	ND	g
IEM PM Truck	29,09	ND	g

Time Series	Value	Standard Deviation	Units
IEM PM_Interurban Bus	18,02	ND	g/km
IEM PM_Interurban Car	55,75	ND	g/km
IEM PM_Interurban All	81,37	ND	g/km
IEM PM_Interurban Truck	7,6	ND	g/km
IEM VOC Bus	143,38	ND	g
IEM VOC Car	955,8	ND	g
IEM VOC All	1137,29	ND	g
IEM VOC Truck	38,1	ND	g
IEM VOC_Interurban Bus	37,46	ND	g/km
IEM VOC_Interurban Car	249,72	ND	g/km
IEM VOC_Interurban All	297,14	ND	g/km
IEM VOC_Interurban Truck	9,95	ND	g/km
Average length of queue Bus	1,47	ND	vehs
Average length of queue Car	22,57	ND	vehs
Average length of queue All	16,17	ND	vehs
Average length of queue Truck	1,16	ND	vehs
Number of Stops Bus	0	ND	
Number of Stops Car	11,07	ND	
Number of Stops All	36,95	ND	
Number of Stops Truck	25,88	ND	
Delay Time Bus	191,1	6,83	seg/km
Delay Time Car	78,61	2,87	seg/km
Delay Time All	86,49	2,79	seg/km
Delay Time Truck	103,73	9,41	seg/km
Stop Time Bus	188,1	7,51	seg/km
Stop Time Car	65,41	2,65	seg/km
Stop Time All	73,75	2,52	seg/km
Stop Time Truck	84,57	9,29	seg/km
Time Travel Bus	266	7	seg/km
Time Travel Car	147,52	2,99	seg/km
Time Travel All	155,87	2,92	seg/km
Time Travel Truck	175,57	9,64	seg/km
Total travel time Bus	9,04	ND	h
Total travel time Car	82,96	ND	h
Total travel time All	95,24	ND	h
Total travel time Truck	3,24	ND	h
Inside vehicles Bus	4,6	ND	vehs
Inside vehicles Car	85,8	ND	vehs
Inside vehicles All	91,8	ND	vehs
Inside vehicles Truck	1,4	ND	vehs
Wandering Inside Vehicles Bus	0	ND	vehs
Wandering Inside Vehicles Car	0	ND	vehs
Wandering Inside Vehicles All	0	ND	vehs
Wandering Inside Vehicles Truck	0	ND	vehs

Time Series	Value	Standard Deviation	Units
Wandering Vehicles outside Bus	0	ND	vehs
Wandering Vehicles outside Car	2,2	ND	vehs
Wandering Vehicles outside All	2,6	ND	vehs
Wandering Vehicles outside Truck	0,4	ND	vehs
Vehicles Waiting to Enter Bus	4	ND	vehs
Vehicles Waiting to Enter Car	27,8	ND	vehs
Vehicles Waiting to Enter All	32,2	ND	vehs
Vehicles Waiting to Enter Truck	0,4	ND	vehs
Vehicles Out Bus	157,4	ND	vehs
Vehicles Out Car	2258,2	ND	vehs
Vehicles Out All	2491,8	ND	vehs
Vehicles Out Truck	76,2	ND	vehs
Velocity Bus	16,07	0,28	km/h
Velocity Car	27,88	0,23	km/h
Speed Harmonica Bus	13,57	5,83	km/h
Speed Harmonica Car	24,45	9,16	km/h
Speed Harmonica All	23,14	9,45	km/h
Speed Harmonica Truck	20,53	7,86	km/h
Velocity All	27	0,21	km/h
Velocity Truck	23,54	0,71	km/h

Appendix D – Results of Case 2

Time Series	Value	Standard Deviation	Units
Average virtual queue waiting for Bus	1,18	ND	vehs
Average virtual queue waiting for Car	7,45	ND	vehs
Average virtual queue waiting for All	8,76	ND	vehs
Average virtual queue waiting for Truck	0,14	ND	vehs
Maximum virtual queue waiting for Bus	5,8	ND	vehs
Maximum virtual queue waiting for Car	29,6	ND	vehs
Maximum virtual queue waiting for All	34,2	ND	vehs
Maximum virtual queue waiting for Truck	1,2	ND	vehs
Density Bus	1,34	ND	veh/km
Density Car	12,11	ND	veh/km
Density All	13,9	ND	veh/km
Density Truck	0,44	ND	veh/km
Total distance traveled Bus	143,08	ND	km
Total distance traveled Car	2292,67	ND	km
Total distance traveled All	2507,06	ND	km
Total distance traveled Truck	71,31	ND	km
Flow Bus	157,6	ND	veh/h
Flow Car	2274,4	ND	veh/h
Flow All	2504,6	ND	veh/h
Flow Truck	72,6	ND	veh/h
Average length of queue Bus	1,51	ND	vehs
Average length of queue Car	23,96	ND	vehs
Average length of queue All	15,99	ND	vehs
Average length of queue Truck	1,24	ND	vehs
Number of Stops Bus	6,06	ND	
Number of Stops Car	3,11	ND	
Number of Stops All	3,3	ND	
Number of Stops Truck	3,44	ND	
Delay Time Bus	202,52	11,18	seg/km
Delay Time Car	90,62	5,84	seg/km
Delay Time All	98,41	5,83	seg/km
Delay Time Truck	117,57	7,18	seg/km
Stop Time Bus	198,81	12,46	seg/km
Stop Time Car	76,25	5,64	seg/km
Stop Time All	84,54	5,66	seg/km
Stop Time Truck	97,41	6,5	seg/km
Time Travel Bus	277,1	11,51	seg/km
Time Travel Car	159,33	5,91	seg/km
Time Travel All	167,57	5,88	seg/km
Time Travel Truck	189,07	7,11	seg/km
Total travel time Bus	9,42	ND	h
Total travel time Car	89,12	ND	h
Total travel time All	101,82	ND	h

Time Series	**Value**	**Standard Deviation**	**Units**
Total travel time Truck	3,28	ND	h
Inside vehicles Bus	4,4	ND	vehs
Inside vehicles Car	86,8	ND	vehs
Inside vehicles All	93,4	ND	vehs
Inside vehicles Truck	2,2	ND	vehs
Wandering Inside Vehicles Bus	0	ND	vehs
Wandering Inside Vehicles Car	0	ND	vehs
Wandering Inside Vehicles All	0	ND	vehs
Wandering Inside Vehicles Truck	0	ND	vehs
Wandering Vehicles outside Bus	0	ND	vehs
Wandering Vehicles outside Car	4	ND	vehs
Wandering Vehicles outside All	4,2	ND	vehs
Wandering Vehicles outside Truck	0,2	ND	vehs
Vehicles Waiting to Enter Bus	4	ND	vehs
Vehicles Waiting to Enter Car	27,8	ND	vehs
Vehicles Waiting to Enter All	32,2	ND	vehs
Vehicles Waiting to Enter Truck	0,4	ND	vehs
Vehicles Out Bus	157,6	ND	vehs
Vehicles Out Car	2274,4	ND	vehs
Vehicles Out All	2504,6	ND	vehs
Vehicles Out Truck	72,6	ND	vehs
Velocity Bus	15,69	0,26	km/h
Velocity Car	26,46	0,33	km/h
Speed Harmonica Bus	13,02	5,89	km/h
Speed Harmonica Car	22,63	9,31	km/h
Speed Harmonica All	21,52	9,44	km/h
Speed Harmonica Truck	19,07	7,88	km/h
Velocity All	25,67	0,31	km/h
Velocity Truck	22,33	0,42	km/h

Appendix E – Results of Case 3

Time Series	Value	Standard Deviation	Units
Average virtual queue waiting for Bus	1,18	ND	vehs
Average virtual queue waiting for Car	7,45	ND	vehs
Average virtual queue waiting for All	8,77	ND	vehs
Average virtual queue waiting for Truck	0,14	ND	vehs
Maximum virtual queue waiting for Bus	5,80	ND	vehs
Maximum virtual queue waiting for Car	29,80	ND	vehs
Maximum virtual queue waiting for All	34,40	ND	vehs
Maximum virtual queue waiting for Truck	1,20	ND	vehs
Consumption of Combustible Bus	6	ND	l
Consumption of Combustible Car	2,94	ND	l
Consumption of Combustible All	3,15	ND	l
Consumption of Combustible Truck	3,27	ND	l
Density Bus	1,21	ND	veh/km
Density Car	11,03	ND	veh/km
Density All	12,65	ND	veh/km
Density Truck	0,41	ND	veh/km
Total distance traveled Bus	143,83	ND	km
Total distance traveled Car	2291,44	ND	km
Total distance traveled All	2507,56	ND	km
Total distance traveled Truck	72,29	ND	km
Flow Bus	158,20	ND	veh/h
Flow Car	2261,40	ND	veh/h
Flow All	2494	ND	veh/h
Flow Truck	74,40	ND	veh/h
IEM CO2 Bus	233966,23	ND	g
IEM CO2 Car	760837,91	ND	g
IEM CO2 All	1164829,69	ND	g
IEM CO2 Truck	170025,55	ND	g
IEM CO2_Interurban Bus	61133,97	ND	g/km
IEM CO2_Interurban Car	198802,38	ND	g/km
IEM CO2_Interurban All	304363,01	ND	g/km
IEM CO2_Interurban Truck	44426,66	ND	g/km
IEM NOx Bus	1895,31	ND	g
IEM NOx Car	1161,57	ND	g
IEM NOx All	4240,79	ND	g
IEM NOx Truck	1183,91	ND	g
IEM NOx_Interurban Bus	495,23	ND	g/km
IEM NOx_Interurban Car	303,51	ND	g/km
IEM NOx_Interurban All	1108,09	ND	g/km
IEM NOx_Interurban Truck	309,35	ND	g/km
IEM PM Bus	69,49	ND	g
IEM PM Car	221,97	ND	g
IEM PM All	319,70	ND	g

Time Series	Value	Standard Deviation	Units
IEM PM Truck	28,24	ND	g
IEM PM_Interurban Bus	18,16	ND	g/km
IEM PM_Interurban Car	58	ND	g/km
IEM PM_Interurban All	83,54	ND	g/km
IEM PM_Interurban Truck	7,38	ND	g/km
IEM VOC Bus	142,88	ND	g
IEM VOC Car	972,95	ND	g
IEM VOC All	1152,88	ND	g
IEM VOC Truck	37,05	ND	g
IEM VOC_Interurban Bus	37,33	ND	g/km
IEM VOC_Interurban Car	254,23	ND	g/km
IEM VOC_Interurban All	301,24	ND	g/km
IEM VOC_Interurban Truck	9,68	ND	g/km
Average length of queue Bus	1,44	ND	vehs
Average length of queue Car	22,60	ND	vehs
Average length of queue All	16,23	ND	vehs
Average length of queue Truck	1,14	ND	vehs
Number of Stops Bus	201,74	ND	
Number of Stops Car	0	ND	
Number of Stops All	212,50	ND	
Number of Stops Truck	10,76	ND	
Delay Time Bus	183,35	5,86	seg/km
Delay Time Car	80,97	5,89	seg/km
Delay Time All	88,14	5,63	seg/km
Delay Time Truck	103,32	8,34	seg/km
Stop Time Bus	179,91	7,18	seg/km
Stop Time Car	67,14	5,54	seg/km
Stop Time All	74,80	5,33	seg/km
Stop Time Truck	83,92	7,77	seg/km
Time Travel Bus	258,32	5,83	seg/km
Time Travel Car	149,83	5,81	seg/km
Time Travel All	157,47	5,53	seg/km
Time Travel Truck	174,94	8,40	seg/km
Total travel time Bus	8,96	ND	h
Total travel time Car	85,48	ND	h
Total travel time All	97,61	ND	h
Total travel time Truck	3,17	ND	h
Inside vehicles Bus	3,80	ND	vehs
Inside vehicles Car	78,20	ND	vehs
Inside vehicles All	83,80	ND	vehs
Inside vehicles Truck	1,80	ND	vehs
Wandering Inside Vehicles Bus	0	ND	vehs
Wandering Inside Vehicles Car	0	ND	vehs

Time Series	**Value**	**Standard Deviation**	**Units**
Wandering Inside Vehicles All	0	ND	vehs
Wandering Inside Vehicles Truck	0	ND	vehs
Wandering Vehicles outside Bus	0	ND	vehs
Wandering Vehicles outside Car	0	ND	vehs
Wandering Vehicles outside All	0,20	ND	vehs
Wandering Vehicles outside Truck	0,20	ND	vehs
Vehicles Waiting to Enter Bus	4	ND	vehs
Vehicles Waiting to Enter Car	27,80	ND	vehs
Vehicles Waiting to Enter All	32,20	ND	vehs
Vehicles Waiting to Enter Truck	0,40	ND	vehs
Vehicles Out Bus	158,20	ND	vehs
Vehicles Out Car	2261,40	ND	vehs
Vehicles Out All	2494	ND	vehs
Vehicles Out Truck	74,40	ND	vehs
Velocity Bus	16,24	0,14	km/h
Velocity Car	27,39	0,69	km/h
Speed Harmonica Bus	13,97	5,63	km/h
Speed Harmonica Car	24,07	8,94	km/h
Speed Harmonica All	22,91	9,15	km/h
Speed Harmonica Truck	20,61	7,56	km/h
Velocity All	26,56	0,62	km/h
Velocity Truck	23,39	0,64	km/h

Appendix F – Results of Case 4

Time Series	Value	Standard Deviation	Units
Average virtual queue waiting for Bus	2,35	ND	vehs
Average virtual queue waiting for Car	29,11	ND	vehs
Average virtual queue waiting for All	32,34	ND	vehs
Average virtual queue waiting for Truck	0,88	ND	vehs
Maximum virtual queue waiting for Bus	9	ND	vehs
Maximum virtual queue waiting for Car	95,2	ND	vehs
Maximum virtual queue waiting for All	105,2	ND	vehs
Maximum virtual queue waiting for Truck	4,4	ND	vehs
Density Bus	1,5	ND	veh/km
Density Car	21,81	ND	veh/km
Density All	24,02	ND	veh/km
Density Truck	0,72	ND	veh/km
Total distance traveled Bus	142,23	ND	km
Total distance traveled Car	2124,99	ND	km
Total distance traveled All	2337,83	ND	km
Total distance traveled Truck	70,61	ND	km
Flow Bus	153,8	ND	veh/h
Flow Car	2111	ND	veh/h
Flow All	2337,4	ND	veh/h
Flow Truck	72,6	ND	veh/h
Average length of queue Bus	1,19	ND	vehs
Average length of queue Car	75,22	ND	vehs
Average length of queue All	22,66	ND	vehs
Average length of queue Truck	2,87	ND	vehs
Number of Stops Bus	6,56	ND	
Number of Stops Car	5,34	ND	
Number of Stops All	5,4	ND	
Number of Stops Truck	4,81	ND	
Delay Time Bus	268,97	55,6	seg/km
Delay Time Car	229,44	64,99	seg/km
Delay Time All	231,82	63,68	seg/km
Delay Time Truck	221,11	58,2	seg/km
Stop Time Bus	268,08	54,06	seg/km
Stop Time Car	206,43	63,96	seg/km
Stop Time All	210,25	62,58	seg/km
Stop Time Truck	197,77	56,29	seg/km
Time Travel Bus	344,11	55,4	seg/km
Time Travel Car	298,3	64,9	seg/km
Time Travel All	301,18	63,58	seg/km
Time Travel Truck	292,91	58,13	seg/km
Total travel time Bus	10,71	ND	h
Total travel time Car	153,59	ND	h
Total travel time All	169,3	ND	h
Total travel time Truck	5	ND	h
Inside vehicles Bus	5	ND	vehs

Time Series	Value	Standard Deviation	Units
Inside vehicles Car	184,8	ND	vehs
Inside vehicles All	195,2	ND	vehs
Inside vehicles Truck	5,4	ND	vehs
Wandering Inside Vehicles Bus	0	ND	vehs
Wandering Inside Vehicles Car	0	ND	vehs
Wandering Inside Vehicles All	0	ND	vehs
Wandering Inside Vehicles Truck	0	ND	vehs
Wandering Vehicles outside Bus	0	ND	vehs
Wandering Vehicles outside Car	85,8	ND	vehs
Wandering Vehicles outside All	88,4	ND	vehs
Wandering Vehicles outside Truck	2,6	ND	vehs
Vehicles Waiting to Enter Bus	7,2	ND	vehs
Vehicles Waiting to Enter Car	91,2	ND	vehs
Vehicles Waiting to Enter All	101	ND	vehs
Vehicles Waiting to Enter Truck	2,6	ND	vehs
Vehicles Out Bus	153,8	ND	vehs
Vehicles Out Car	2111	ND	vehs
Vehicles Out All	2337,4	ND	vehs
Vehicles Out Truck	72,6	ND	vehs
Velocity Bus	15,57	0,35	km/h
Velocity Car	20,05	1,07	km/h
Speed Harmonica Bus	11,36	6,92	km/h
Speed Harmonica Car	13,4	9,44	km/h
Speed Harmonica All	13,24	9,26	km/h
Speed Harmonica Truck	13,19	8,78	km/h
Velocity All	19,72	0,99	km/h
Velocity Truck	19,04	1,48	km/h