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FACULDADE DE LETRAS

The Application of GIS in the definition of DRT System
Case Study of Vila do Conde

Isabel Maria dos Santos Cruz

Thesis for the degree of Master of Sistemas de Informação Geográfica e Ordenamento do Território

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ABSTRACT

A new emerging model of mobility, which is more extended in time and space and closer to life rhythms, has generated a new demand of transport, with new needs to which conventional transports systems do not adjust. The Demand Responsive Transports have evolved from the need to attend these changing mobility demands. Due to its flexibility, the design of DRT services and the development of its system architecture is a complex process.

The application of GIS technologies in transportation studies is increasing due to its powerful capacity to store, manage and analyze spatial and non-spatial information, as well to model transportation networks.

This work aims to study how GIS technologies can be applied in the definition of DRT systems. An analysis methodology in the context of the User's Needs Analysis of DRT services, applying GIS tools and analysis techniques, is proposed in this research study. Its main objective is to identify mobility requirements and constraints of travelers to evaluate feasibility of implementation of DRT within a municipality. A *Spatial DRT Need Index* is proposed in order to summarize the results of analysed indicators. The methodology is applied and validated in a case study, namely the Municipality of Vila do Conde.

Keywords: Demand Responsive Transports (DRT), Geographic Information Systems (GIS), Intelligent Transportation Systems (ITS), Users Needs Analysis

RESUMO

O emergir dum novo modelo de mobilidade, mais alongado no tempo e no espaço e, também mais próximo dos actuais ritmos de vida, gera um novo modelo de procura de transportes, com novas necessidades e às quais os tradicionais sistemas de transporte não se ajustam. Os Sistemas de Transportes Flexíveis (STF) evoluíram da necessidade de dar resposta a essa procura em transformação. Devido à sua flexibilidade, o planeamento de STF e o desenvolvimento da arquitectura do sistema é um processo complexo.

É crescente a aplicação de Sistemas de Informação Geográfica (SIG) nos estudos de transporte devido às suas notáveis capacidades de armazenar, manusear e analisar informação espacial, assim como de modelação de redes de transportes.

Este trabalho tem como objectivo estudar como os Sistemas de Informação Geográfica podem ser aplicados na definição de Sistemas de Transportes Flexíveis. No seu contexto, é proposta uma metodologia de análise no âmbito da análise de requisitos dos utilizadores de STF com a aplicação técnicas e ferramentas SIG. Esta metodologia visa nomeadamente identificar os requisitos de mobilidade e dificuldades dos utilizadores, para avaliar a viabilidade de implementação dum STF num município. É proposto um índice espacial designado por *Spatial DRT Need Index* que visa sumariar os resultados obtidos para os diversos indicadores analisados. Esta metodologia é aplicada e validada no caso de estudo do município de Vila do Conde

Palavras-chave: Sistemas de Transportes Flexíveis (STF), Sistemas de Informação Geográfica (SIG), Sistemas Inteligentes de Transportes, Análise de Requisitos dos Utilizadores

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List of Acronyms

BGRI – Base Geográfica de Referenciação de Informação

CAOP – Carta Administrativa Oficial de Portugal

DRT – Demand Responsive Transport

ESRI – Environmental Systems Research Institute

GPS – Global Positioning System

IGOE – Instituto Geográfico do Exército

IGP – Instituto Geográfico de Portugal

INE – Instituto Nacional de Estatística

ITS – Intelligent Transportation Systems

TDC – Travel Dispatch Center

1. INTRODUCTION

1.1. Problem Definition

At the present time we assist to changing mobility behavior and needs. On the one hand, this is due to the sprawling of the cities and, on the other hand, due to the changing rhythms of life and associated human habits.

This new emerging model of mobility has generated a new demand of transport. Conventional transports systems do not adjust to these new mobility needs which, together with other factors, such as land use fragmentation, for example, are contributing to the social exclusion of some sectors of the population and also to the increasing use of the private vehicle and it's well known traffic and pollution effects.

In response to these problems, some countries are developing new transportation services, more responsive to the mobility demands of the population. Actually, in most economically developed countries, statutory authorities are charged with ensuring that adequate transport is provided for members of the general public to reach their desired destinations- whether for work, health or leisure purposes (Brake et al, 2004). The alternative solution to traditional public transport is the Flexible Transport Service (FTS) more commonly known as Demand Responsive Transport in Europe, and Paratransit in the USA.

Due to its flexibility the planning, implementation and operation of this type of transport service is much more complex than the traditional fixed route service.

In the planning of traditional transport there has been a spread in the use GIS technologies because they offer extremely significant power in transport modeling (Arampatzis et al, 2004). It has been acknowledged that GIS is a useful tool, which provides capabilities for data collection, data management and manipulation, spatial analysis, network analysis and cartographical presentation of results (Zhu and Liu, 2004)

How are these technologies being used by DRT services? How are they applied In the planning and operational phase of DRT systems? What geographic information is necessary? These are some of the questions this research aims to address.

1.1.1. Demand Responsive Transport

The Demand Responsive Transport (DRT) is an alternative form of transport that fills the gap between individual transport and scheduled conventional public transport (Ambrosino et al, 2004).

Brake et al (2007) affirms that it is appropriate to consider the services promoted as DRT, being a subset of Flexible Transport Service, which he defines:

"an emerging term which covers services provided for passengers (and freight) that are flexible in terms of route, vehicle allocation, vehicle operator, type of payment and passenger category. The flexibility of each element can vary along a continuum of demand responsiveness from services where all variables are fixed a considerable time before operation to services whose constituent variables are determined close to the time of operation."

The more demand responsive is the established service, the more complex becomes the architecture of the DRT system and its management, increasing also the level of telematics required in order to cope with these demands (Brake 2007).

Due to these characteristics the planning and implementation of this type of transport service is much more complex than the traditional fixed route service.

In the planning stage the User Needs Analysis is a fundamental study at the basis of projects concerned with the provision of DRT services, as it allows the project team to understand their users and, with this knowledge, design a system that meets their needs. The results of this study should be the identification of key markets, as well as the services and features that they need, and requirements for communication and information after services are implemented (Finn et al, 2004)

User Needs Analysis first helps identify who are all of the users that will be involved, and secondly what are the needs of each of the different types of user. In the transportation domain, these outcomes are used for the development of various features of the project. Among others is the design of transport network and specific services, as well as the development of special services where the standard network is insufficient.

On the other hand, in the operation stage, an efficient DRT system requires the definition of a system with a complex physical, functional, information and communication architecture, involving the employment of ITS technologies, being GIS an essential technology, especially for the most flexible scenarios.

In these stages of the process, information of geographical nature is used and produced, helping decision-making and promoting a good service.

1.1.2. GIS for Transportation

In any study area that involves geographic information, GIS is a useful tool, which provides capabilities for data collection, data management and manipulation, spatial analysis, network analysis and cartographical presentation of results (Zhu and Liu, 2004)

The study of transportation has necessarily a geographic approach, due to its strong spatial component.

As stated by Rodrigue et al, 2006 *“the fundamental purpose of transportation is to overcome space, which is shaped by a variety of human and physical constraints such as distance, time, administrative divisions and topography”.*

To facilitate movements between different locations, a public transport service must be designed depending on various spatial factors, but on the other hand transport plays a role in the structure and organization of space, shaping territories (Rodrigue et al, 2006)

Thus, to study transportation problems it is necessary to model the transport network and the spatial data that influences it and, because this relationship is becoming more complex, the range of models that needs to be employed has expanded rapidly, making the integration of transport models and technologies such as GIS, a major requirement in any process of transport planning due to its significant power in transport modeling (Dueker, K., Ton, T.,2000 and Arampatzis et al, 2004)

GIS-T has emerged, a branch of GIS, which refers to the principles and applications of applying geographic information technologies to transportation problems. It adapts the four components of GIS – encoding, management, analysis and reporting – to specific needs of transportation studies (Rodrigue et al, 2006).

There is much research on how GIS can be further developed and improved in order to meet the needs of transportation applications as well as research on how GIS can be used to facilitate and improve transportation studies, making possible the spread of GIS use in transportation studies (Rodrigue et al, 2006). This GIS-T research can be grouped in 3 main topics that represent the key areas where GIS assists transportation studies.

- GIS-T data representation
- GIS-T analysis and modeling,
- GIS-T applications

1.1.3 - Application of GIS on DRT Systems

Transport problems are becoming more dynamic due to the complex changes in our world, of social, economical, and physical nature, implicating the use of a wide range of models and making the integration of transport models and GIS technologies become a major requirement in any process of transport planning (Dueker, K. J., Ton, T. (2000).

DRT services are not an exception. GIS can be a major tool in the various stages of the transportation decision process: service design, operation and evaluation.

The study of existing DRT transport services in Europe and USA demonstrate that there is a wide use of GIS technologies, mainly in the operation stage, as a tool for managing the network, scheduling and mapping the location of the vehicle in real-time.

GIS technologies can also be useful in the initial stages of the planning process, but this issue is rarely referred to in the DRT literature. The Users Needs Analysis, which is at the basis of service design involves the organization and analysis of diverse geographic information that can be better accommodated and processed with GIS technologies to help identify key markets, as well as the services and features that they need, and design of transport network.

1.2. Research Objectives

The general challenge of this research is to understand DRT services and identify how GIS technologies are applied in the development and operation of DRT services.

But the main objective is to develop an analysis methodology in the context of the User's Needs Analysis of DRT services, using GIS technologies, aiming to evaluate the feasibility of implementing a DRT system within a municipality. This methodology is to help identify key market, geographic areas where the implementation of DRT services is feasible and define some possible route concepts. The proposed methodology is then applied for evaluation to the case study of the municipality of Vila do Conde.

1.3. Research Questions

To meet the objectives of the study the following research questions need to be addressed:

- How are GIS technologies applied in the service design and operation phases of DRT services? What are the advantages? What geographic information is required?

- In the service design phase of a DRT system, how can GIS technologies contribute to the development of Users Need Analysis and what are the resulting advantages? What geographic information is necessary to collect for its development? What information does the developed analysis with GIS provide to the decision process?

1.4. The case study

The municipality of Vila do Conde is the chosen area to develop the case study. It is integrated in the Metropolitan Area of Porto and is distanced 30 Km North from Porto. In 2001 the total resident population was 74391. Its territory covers 149 Km2 and has an extensive rural area.

The case study aims to test the proposed Users Needs Analysis methodology to study the viability of introducing a DRT system in Vila do Conde, particularly in the rural areas. The resulting information will help identify areas of the territory where the operation of DRT services are necessary as well as to define possible service typologies.

1.5. Structure of the document

The present research is divided in 7 chapters. Chapter 1 deals with the basic reason behind this research, its objectives and research questions. Chapter 2 explores the concepts, goals, service typologies and architecture of Demand responsive Transport systems. Chapter 3 deals with the application of GIS technologies to transportation problems. First, how information related to a transport system is represented, secondly, which capacities and tools of GIS support the modeling and analysis of transport problems and, finally, a reference to the main applications of GIS related to transport problems. Chapter 4 is an approach to the application of GIS technologies in the operation phase of a DRT service. In Chapter 5 is where the analysis methodology for the Users Needs Analysis, using GIS tools, is developed. Chapter 6 focuses on the development of the case study of Vila Conde which is an application of the proposed methodology and, finally, Chapter 7 describes the conclusions related to the experienced advantages and difficulties in the application of GIS technologies to DRT services.

2. DEMAND RESPONSIVE TRANSPORTS

This chapter aims to define Demand responsive Transport services (DRT), to understand how this innovative form of transport evolved, and which goals are at the basis of its implementation. In the context of this research, the application of GIS in defining DRT services, it is also very important to understand the possible typologies, the architecture, the components and technologies that are at the foundation of the system that supports the organization of DRT services. Only then it is possible to understand where and how GIS technologies can be applied.

2.1. Introduction

2.1.1. Definition

When doing research on flexible transport, the concept of DRT is the most used and generally the implemented experiences in Europe are designated as DRT projects, reason why it was chosen to use this designation.

In fact, we can find a variety of definitions of DRT:

> "*transportation options that fall between private car and conventional public bus services. It is usually considered to be an option for less developed countries and for niches like elderly and disabled people*" (Bakker - 1999)
>
> "*a specialized transportation for older persons and persons with disabilities, is also provided to the general public, particularly in areas with lower population densities or lower levels of demand"* (Schofer et al 2003)
>
> "*an advanced, user-oriented form of public transport characterized by flexible routing and scheduling of small/medium vehicles operating in shared-ride mode between pick-up and drop-off locations according to passengers needs*" (Directorate-General of Energy and Transport of European Commission (2009).

Brake et al (2007) state that it is appropriate to consider the services promoted as DRT, being a subset of Flexible Transport Service, which he defines very clearly:

> *"an emerging term which covers services provided for passengers (and freight) that are flexible in terms of route, vehicle allocation, vehicle operator, type of payment and passenger category. The flexibility of each element can vary along a*

continuum of demand responsiveness from services where all variables are fixed a considerable time before operation to services whose constituent variables are determined close to the time of operation."

Figure 2.1 illustrates the possible levels of demand responsiveness of the public transport service in its various elements. The articulation of the various levels of flexibility of these different elements produces a composite transport system, creating many different possibilities of service typologies and scenarios.

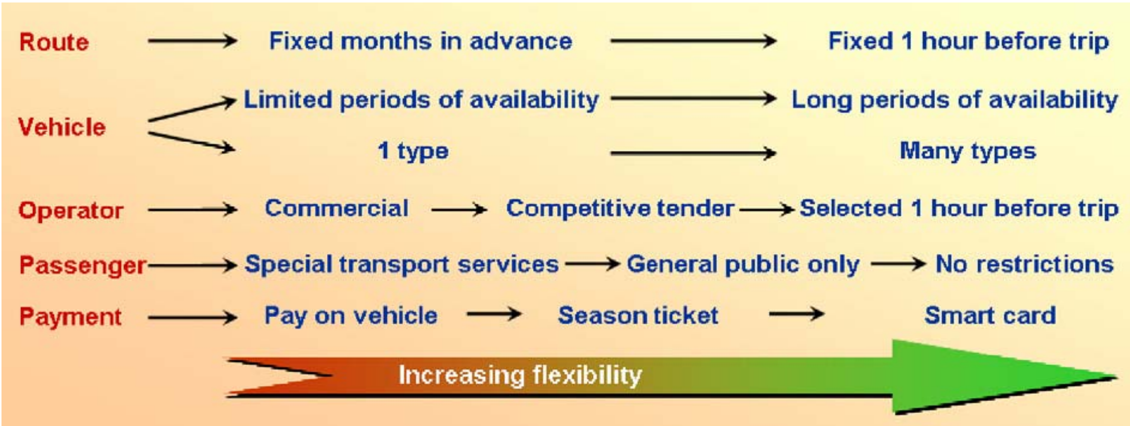


Figure 2.1 - The demand responsiveness of public transport (source: J. Brake et al /Transport Policy 14 (2007) p. 459)

2.1.2. Main Goals

To approach the goals of Demand Responsive Transport it is important to understand how it has evolved.

Engels, D., and Ambrosino, G., (2004) present a scheme that summarizes the evolution of this innovative transport concept (see Figure 2.2). They explain that demand responsive services are a result of the combination of the taxi and conventional transport concept, taking into account the objectives of operators and authorities and as well as the new requirements of costumers.

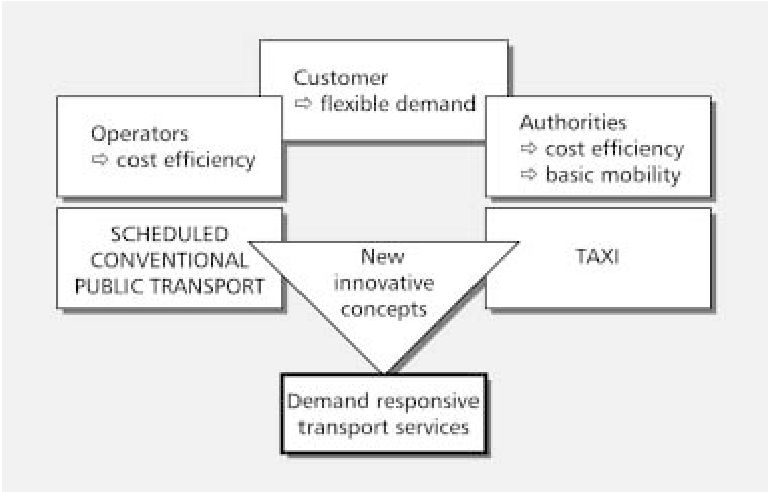


Figure 2.2: From conventional transport and taxi services to innovative schemes (source: Engels, D., Ambrosino, G., (2004) Demand Responsive Transport Services: Towards the Flexible Mobility Agency)

The need to attend the changing demands of costumers, along with the need to rationalize the organization of traditional scheduled public transport, making it economically more efficient, and finally the need of public policy to guarantee basic mobility for the population and create alternatives for the use of car to reduce congestion and pollution, are together at the basis of the Demand Responsive Transport services (Engels, D., and Ambrosino, G., 2004)

In terms of customer's demands, we assist to changing mobility behavior and needs. On the one hand, this is due to the sprawling of the cities and, on the other hand, due to the changing rhythms of life and associated human habits.

Bolot J. et al (2002), support that the development of mobilities in the last years has changed according to social, economic and cultural evolutions and identified 3 effects on mobility:

- more extended in time (off peak hours are decreasing)
- more extended over the space
- closer to life rhythms (costumers want to be able to go everywhere, at any time, from any point)

This new emerging model of mobility has generated a new demand of transport, with new needs to which conventional transports systems do not adjust and, together with other factors, such as land use fragmentation, for example, are contributing to the social exclusion[1] of some sectors of the population and also to the increasing use of the private vehicle along with the well known traffic and pollution effects.

Due to these factors, transport operators are facing new challenges, needing to rationalize the organization. As the number of origins and destinations are increasing enormously, the number of operating services need also to increase, but frequently the fare incomes does not cover the operation costs, compromising cost-efficiency (Engels, D., Ambrosino, G., 2004)

On the other hand, public authorities, in response to the consequent problems, such as social exclusion of some sectors of the population and the traffic and pollution effects due to the increasing use of the private vehicle, are charged with ensuring that adequate transport is provided for members of the general public to reach their desired destinations- whether for work, health or leisure purposes, and are also seeking for measures to reduce the use of private car, incentivizing alternative solutions to traditional public transport (Brake et al, 2004).

In form of conclusion, the provision of DRT services has 3 main goals:

1. Ensure mobility and social inclusion to people without access to private vehicle, that depend on public transport
2. Optimize economic efficiency of public transport service provided in areas of low passenger demand, where a regular bus service may not be as viable, most frequently in rural areas
3. Reduce the use of private vehicles and consequently of associated traffic congestion and pollution effects.

2.2. Key Issues for Implementation of DRT systems

Due to the complexity of the DRT service and the supporting system behind it, a variety of decisions need to be made when setting up a DRT for the first time. Among various authors that discuss this issue, Brake et al (2007) clearly points out five key areas considered relevant for the implementation of a successful DRT service:

[1] Social exclusion is a process that limits the participation of individuals in civil society, due to having lack of access to social opportunities such as healthcare, shops, leisure facilities, which is strongly transport-dependent (Preston and Rajé, 2006)

1. **Identifying viability**

In general, a service is economically viable if the costs and revenues are, at least, balanced. If this is not the case, a public subsidy is required. A decision-making framework for the assessment of viability of flexible service provision is necessary to help identify which costs and revenues are appropriate to the decision as whether a service is viable. It is necessary to identify the link between viability and fares, considering that these should be set by reference to the need to cover avoidable costs, as a way of ensuring better viability and long run sustainability.

2. **Technologies employed in operation**

In this context the main issue is making the appropriate choice between levels of technology that are available and appropriate for the case in question, thus a balance between complexity and cost. Because the level of telematics conditions the parameters of operation, such as booking and scheduling, this decision must be appropriate to the objectives and long-term strategy.

3. **Issues of service design**

For an appropriate service and system design the objectives of the flexible service must first be clearly defined and adjusted to external constraints, such as political, legal, geographical and communication constraints, and be completed in collaboration with key stakeholders, including travelling public, transport operators, the local authority and the dispatch centre manager. An efficient service design requires the study of user requirements, to identify the needs of potential users, to help define appropriate routes, service levels and booking characteristics.

The appropriate route design, implies defining the type of route (totally flexible or semi-flexible), choosing the geographical coverage of transport, deciding for a freestanding mode or the integration with other modes. It also depends of the telematics options and selected booking criteria.

4. **Managing multiple services and need for partnership working**

When compared to fixed route services, flexible services require a new level of management, being predictable that as the management requirements become more complex, the level of telematics used, to handle these demands, will increase. The level of complexity is determined by a range of interacting management decisions, which depend on two critical factors: existence and availability of management resources and the long term strategy for the development of the service, while both depend strongly upon the level of cooperation between stakeholders.

The emergence of several types of partnerships in the movement towards multiple services is an apparent trend in recent evolution of flexible services.

The major purpose of developing a partnership is to ensure that the interests of all stakeholders are met and understood. However there are other advantages, such as helping break down suspicions about new forms of transport service in the perspective of the provider and the end-user, being also an opportunity to reduce marginal and operating costs for everyone involved, for instance through the pooling of education, social services and public transport passengers, as well as making possible the centralization of funds that are distributed, improving its management.

5. Marketing and promotion

To increase the use of the service and its viability it is extremely important to communicate with the public making use of branding techniques, and distribution of timetables, posters and letters. First, to make users aware of the DRT service and, secondly, because the more flexible the service is, the less visible it is to the end-user in terms of route and vehicle used, making difficult its use.

2.3. Designing a DRT System

Due to its flexibility, the planning and implementation of a DRT system when compared to traditional transport system, is much more complex.

The booking procedures and the real time optimization of a DRT service are two important elements that distinguish it from a traditional service that is fully planned in advance (Engels, D., Iacometti, A., (2004).

The traditional regular services have a well defined route, stop points, and timetable, which are previously planned and normally remain unaltered during an operation period. On the contrary, these features in the DRT services are generally flexible, so the organization of services is defined mainly during the operational period, as it adjusts to individual requests (European Commission – DGXIII, 2000).

The design of a system to support the organization of DRT services requires the following stages:

- Users needs analysis
- Definition of Service Typology
- Definition of the architecture of the system
- Choosing technological solutions

2.3.1. Users Needs Analysis

User Needs Analysis is a fundamental research phase at the basis of projects concerned with the provision of transport services, as it allows the project team to understand their users and, with this knowledge, design a system that meets their needs. The results of this study should be the identification of key markets, as well as the services and features that they need, and requirements for communication and information after services are implemented (Finn et al, 2004)

User Needs Analysis first helps identify who are all of the users that will be involved, and secondly what are the needs of each of the different types of user. In the transportation domain, these outcomes are used for the development of various features of the project. Among others is the design of transport network and specific services, as well as the development of special services where the standard network is insufficient.

Finn et al (2004) refer that a set of guidelines for identifying the different users and their needs was developed within the Samplus project, and resume them as a six step approach:

I. **Define the objective of the User Needs Analysis**

Before starting the user's needs analysis, the key objectives must be clearly defined. Some possible objectives are:

• *determine mobility requirements and constraints of travelers*

• *determine perception and probable response of users to new transport services*

• *determine perception and probable response of users to new (automated) technologies*

• *determine users' value sets, trade-offs, and willingness to pay*

• *understand the key motivations, constraints and interests of operators*

• *determine the main functional requirements of TDC operators, drivers etc.*

• assess the potential market and usage levels by different categories of user.

II. Identify the relevant Users

It is very important to identify who are the relevant users within the demonstration. They can be end-users and other interested parties who have a direct interest in the commercial, social, infrastructural or transport impacts of the service (Finn et al, 2004).

A concept of User Groupings was developed within the SAMPO project making clear what different actors exist within a transport project, and demonstrates they have weight within the design and assessment processes. Finn et al, (2004) define them:

"a) End Users: The End-User is a direct customer, or potential customer of the transport service provided. (S)he can also be described as the "passenger" or "consumer".

b) Operators: The Operator is directly involved in the provision of the transport service to the End-User by providing some or all of the elements of the vehicle, driver and support services.

c) Authorities: The Authority has statutory or delegated responsibility for the provision or regulation of transport services in the target area.

d) Active Destinations: Certain destinations may play an active role in the organisation of transport. For example, they may supply information to the operator about trips to the destination, they may act as a travel broker, they may assist the operator in planning the services, or they may co-operate with the operator to provide an inclusive price for the travel and the destination activity. "

Within this context, each of the identified User Groupings has a range of User Categories, which are summarized in Table 1.1

End-Users	Operator	Authorities	Active Destinations
School children	Association	European	Healthcare
Students	Co-operative	National	Education
Disabled	Municipality	Regional	Day-care
Elderly	Company	Local	Shopping centre
Healthcare patients	Sole operator	Community	Leisure/cultural
Accompanied person	Foreign operator	Politicians	Administrations
Companion	Drivers/personnel	Legislature	Other transport modes/
Workers	Dispatch centre	Police	interchange points
Shift workers	Administration	Traffic authorities	Workplace
Leisure/cultural	Planning	Funding Agencies	Tourist centre
Shoppers	Management	Manufacturers	

Groups Tourists Sports Non-driver Car-driver(choice user) Administrative	Owner		

Table 1.1 - User Groupings and User Categories (after SAMPO Project) (source: Finn et al (2004) Goals, Requirements and Needs of Users, p.40)

In the Users Needs Analysis each of these categories should be analyzed to determine if it is relevant, or not, to the project.

III. Analyze previous work in the domain

All previous studies of the transportation and mobility context, as well as other previous user's needs analysis, and additional relevant work from non-transport domains, should be analyzed carefully before advancing further in the analysis process.

IV. Determine the data requirements

Before developing field work, it is important to make an explicit listing of the data which is required, which further more will help to determine the methodology needed for data collection.

The objective and subjective data requirements, as well as the users from which the data will be obtained should be summarized/aggregated in a matrix, identifying any requirements for minimum sample sizes, for statistical significance, and for distribution within the sample

V. Design and implement the appropriate methodology

The design of the methodology used is strongly dependant of the nature of the target users, the data that is to be collected, and the existing previous work. Some of the successful data collection methods used within the DRT Users Needs Analysis are: postal and telephone surveys, questionnaires, direct interview with end-users and organizations, and focus and discussion groups.

VI. Analyze and use the results

The analysis of the data should be preset by the objectives and data requirements. In this context some recommendations are made to make the best use of the results obtained:

i. the end-users of the data should be involved throughout the whole process;

ii. note and discuss any anomaly, negative comments, apparent contradictions, etc with the demonstration team.

iii. the results should be presented to a cross-section of people and organizations involved in the demonstration, helping them in focusing their work;

iv. presenting results to a discussion group that participated in the user needs work, can be useful for further clarifying of obtained results.

v. the data should be filled in an accessible format to the design and the demonstration teams, because reviewing the material later in the project could prove very valuable.

2.3.2. Service Typologies and Scenarios Concepts

In the organization of DRT services the flexibility can vary a lot, therefore previous to designing the system that supports the organization of DRT services, the operator has to offer a well defined type of service with well defined rules and flexibility (European Commission – DGXIII - 2000).

According to Engels and Ambrosino (2004), setting up a flexible transport service requires a previous discussion and decision about different aspects of the service, which they believe to be the conceptual building blocks of the resulting service scheme. They consider the next four concepts the most important:

I. Route and time concepts

II. Booking concepts

III. General Intermodal (Network) concepts

IV. Vehicle allocation concepts

2.3.2.1. Route and time concepts

"The route of a service is the list of stops that will be served in a specific order. The flexibility in the timetable is seen as a part of the concept." (Engels, D., Ambrosino, G., 2004)

A wide range of different concepts in relation to route and time options are possible when organizing DRT services, starting from a fully preset route and timetable to a service for which stops and passing time is fully determined just before operation or even during operation (Engels, D., Ambrosino, G., 2004)

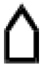
In this context, the Samplus research considered 4 possible scenarios, but Engels and Ambrosino (2004) proposed a wider array of service schemes that include the former four, in which, as level of flexibility increases fewer elements are predefined in advance.

The concepts were built using the following types of stops:

 a fixed, predefined stop with a predefined passing time and which is always served;

 a predefined stop with a predefined passing time which is only served on request (for end stops a predefined departure or arrival time);

 a predefined stop which is only served on request;

 a stop point anywhere in the region indicated by the address (e.g. for a house) or the name of the place (e.g. an important building).

Scenario I – Predefined route and time table which is partly fixed

The service is partly coincident with a conventional scheduled service, which has previously defined a list of stops to be served, the route and timetable. The flexibility of the service consists in making possible the inclusion of some additional stops along a predefined route extending it, in case of customer demand.

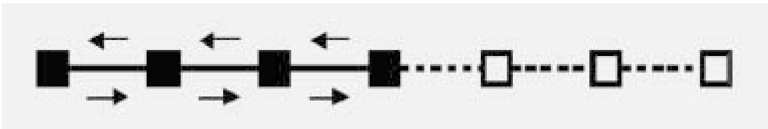


Figure 2.3: Scenario 1 - Extension of a scheduled service with a predefined route and timetable **(source**: Engels, D., Ambrosino, G.,2004)

Scenario 2 – Deviations on a scheduled service to predefined routes in a corridor

In this scenario basically there is a scheduled service with fixed stops and predefined passing times, allowing the vehicle to make short deviations from the route to serve other predefined stops on request that are located within a corridor around the basic route. The vehicle only leaves the main route if requested.

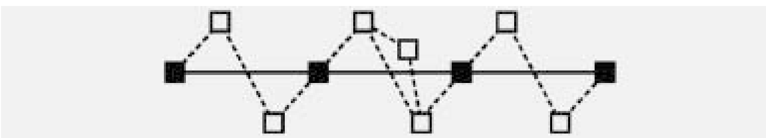


Figure 2.4: Scenario 2 - Deviations on a scheduled service to predefined routes in a corridor **source**: Engels, D., Ambrosino, G.,2004)

Scenario 3 – Predefined stops on a corridor

This concept also covers a corridor service with predefined stops, whereas some of the intermediate stops have predefined passing times (with margins) to structure the service and allow serving more non-fixed predefined stops. The scheduling of the predefined passing times is a very important aspect, which will condition the level of flexibility as well as the efficiency of the service, where a balance must be achieved.

Usually there is one or two end stops that are defined as fixed stops with predefined departure or/and arriving time. In some cases, any fixed stop is completely excluded and timetable is totally based on request.

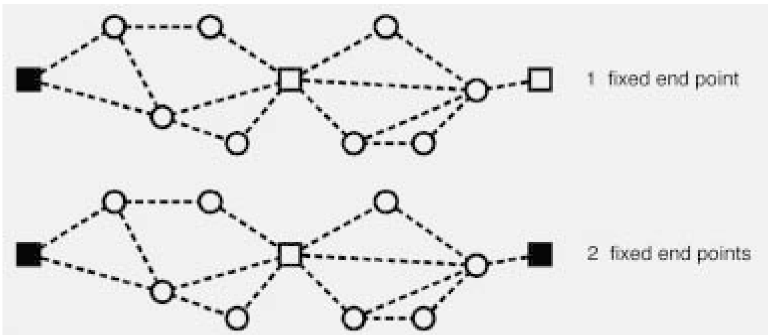


Figure 2.5: **Scenario 3 - Predefined stops in a corridor (source**: Engels, D., Ambrosino, G.,2004)

Scenario 4 - Predefined stops in an area

This scenario covers service schemes in which predefined stops are distributed within an area (not a corridor) and generally only one stop will have a predefined passing time to make the organization of the service feasible. Only stops on demand will be served and the structure of the service will be completely defined by the requests. In some cases no predefined passing time is determined for any stop, making the service similar to a taxi service.

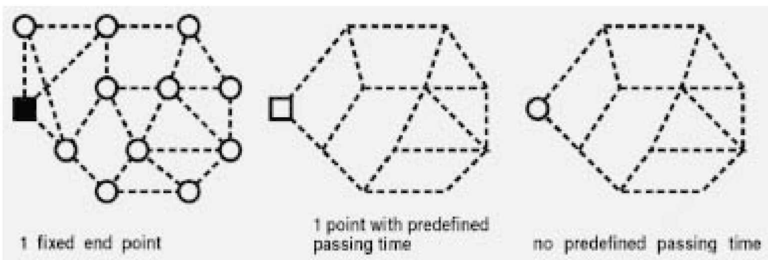


Figure 2.6: **Scenario 4 - Predefined stops in an area (source**: Engels, D., Ambrosino, G.,2004)

Scenario 5 – Points in an area

This concept corresponds to an evolution of the previous scenario of predefined stops in an area. In this case the served points in the area can be any point (the address of a house or building) instead of fixed stops.

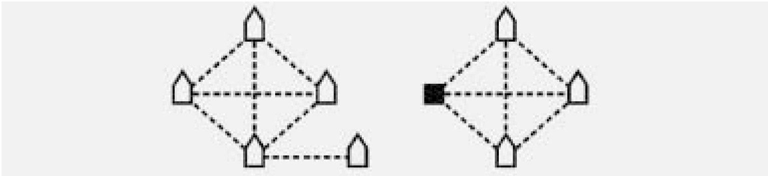


Figure 2.7: **Scenario 5 - Points in an area (source**: Engels, D., Ambrosino, G.,2004)

It is also possible to combine the some of the previous 5 scenarios.

The five basic DRT scenarios previously outlined can also be combined to give the best transport scheme offer for a specific operational environment. Figure 2.8 illustrates a possible combination of a fixed route and stops in the city centre with an area-wide service on request in the suburbs, allowing the customers to board at the fixed stops and request for a destination stop.

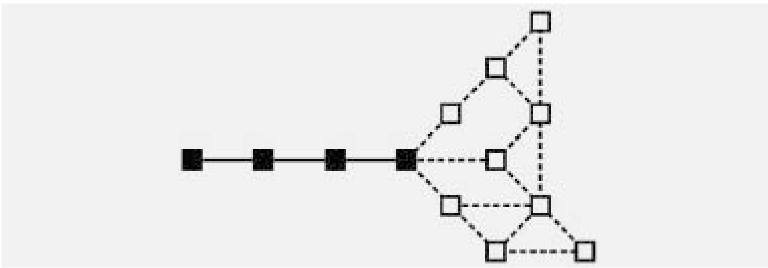


Figure 2.8: **Combined DRT scenario combination of predefined routes and timetable with an area-wide service (source**: Engels, D., Ambrosino, G.,2004)

2.3.2.2. Booking Concepts

A central element for DRT Services is the booking of the trip, and basically three phases can be distinguished:

Phase 1. Costumer requests to make a trip with a particular origin and destination (stop or address) giving an arrival or departure time.

Phase 2. Service operator proposes a feasible service.

Phase 3. Customer confirms or refuses proposed service.

The different service booking scenarios that are pointed out by Engels and Ambrosino (2004) are next briefly discussed:

Scenario 1: Non-pre-booked trips

This is called on-board booking. In practice, the customers do not pre-book trips, they notify driver directly at the boarding stop, and the driver decides to allow or not the passenger too board the vehicle. In general, service operators do not like such a situation because it diverges from the central idea of DRT services, which is combining booking request in the most optimal way into service routes.

Scenario 2: Direct booking

In this scenario the customer issues a request to the operator, normally up to one or two hours before departure time, receives one or more detailed service proposals, decides and confirms the booking. In this scenario the operator has time to organize the services, informing the driver on the service journey pattern and driving to the departure stop of the customer.

Scenario 3: Wide time window - trip notification

After receiving the customer's request, the operator makes a proposal with rather wide time margins on departure and arrival times. After obtaining this information, the customer can confirm, or not, the booking. When confirmed, the operator will call back a short time before departure time to inform the customer more precisely about the scheduled departure time.

This scenario allows the operator to apply route and vehicle allocation optimization, due to the wider flexibility on departure and arrival times, and to communicate to the customers the actual scheduled departure or arrival times if service planning is refined.

Scenario 4: Collecting requests – defining service

In this scenario the operator first collects all requests of the customers, to next calculate the most optimal route, considering optimization criteria chosen in advance. After defining the route the customer is informed in detail about the service he can use, based on his travel requirements, to decide the booking or not.

Generally this procedure for organizational reasons is done well in advance of the travel planning horizon, usually the day before, and after the planning is completed the customer is contacted, normally in the evening.

In order to implement the various booking procedures described in previous sections, a wide range of technologies are available to manage the communication with the customer and the booking process. In the first DRT implementations a human dispatcher was the direct interface between the customers and the booking component, as for now a day's new ICT technologies enable a higher degree of automation of the booking process.

2.3.2.3. Network concepts

Engels, D., Ambrosino, G., 2004 considered 3 possible network concepts that aim to classify the different roles of DRT services in the general public transport offer:

1- Stand-alone DRT service

DRT service has no time or spatial relation with other transport services, operating independently. The definition of the service can be mainly determined by opening hours and location of the community or health services.

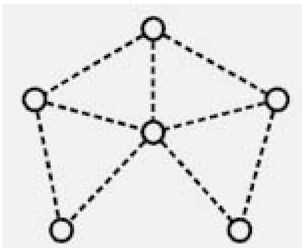


Figure 2.9: Stand-alone DRT service
(source: Engels, D., Ambrosino, G.,2004)

2- DRT feeder service

This DRT service operates for almost all costumers as a feeder service to another bus service which completes the rest of the trip. In this case the stop of the connecting vehicle is the main stop point of the DRT service.

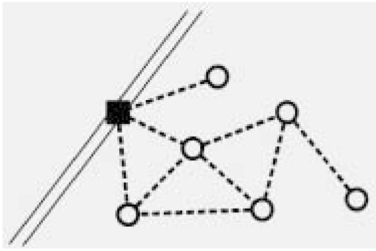


Figure 2.10: DRT feeder service
(source: Engels, D., Ambrosino, G.,2004)

3- DRT with multiple service roles

This DRT service serves an important center giving passengers access to other public transport systems (railway for example) as well as taking them to their shopping, service, work and school destinations.

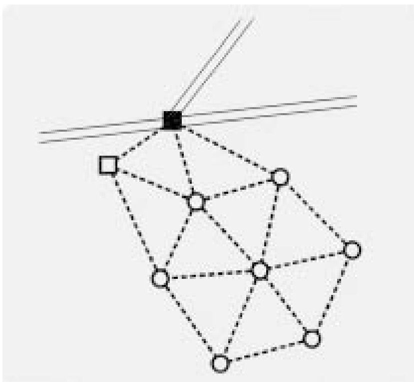


Figure 2.11: DRT with multiple service roles
(source: Engels, D., Ambrosino, G.,2004)

2.3.2.4. Vehicle allocation concepts

According to Engels and Ambrosino (2004), a final important choice in the definition of the DRT service is the way vehicles are allocated to each service, making possible different solutions:

i. *Fixed vehicle allocation* - DRT service has only one vehicle which strongly determines the type of DRT service that is defined.
ii. *Extendable vehicle allocation* - DRT service is defined for one vehicle, but the use of an extra vehicle can be foreseen within certain limits.

iii. *Dynamic allocation of vehicles* - DRT service has at its disposal a pool of vehicles with different characteristics in terms of capacity, accessibility and special facilities. The vehicles are allocated to the services taking into account optimization aspects and the specific requirements of the requests.

The choices that are made for each concept, can determine decisions about the other concepts.

Choosing the right DRT typology for the right place, requires a number of design decisions and operational choices that must also take into account:

1. The typology of the region
2. The objectives of the operator/authority
3. The characteristics of the users groups
4. The type of demands

After deciding in detail what type of service to implement, it is possible to define the functional system architecture that is behind the complex system supporting the DRT service scheme (European Commission – DGXIII, 2000).

2.3.3. Architecture, Components and Technologies of a DRT System

When reading about DRT experiences it is clear that there are many types of solutions. Some DRT agencies resort to manual scheduling and dispatching, while others use automatic systems. The booking criterion also varies as some agencies require pre-booking and others accept requests close to the time of travel.

One the other hand, more mature DRT systems involve interacting agencies or travel dispatch centers, creating partnerships, which enables the optimization of modes and services between several transport agencies, giving access to a greater range of vehicles and creating more opportunities for passengers to travel when it is most convenient for them in a larger geographical network (Brake et al, 2006)

The same author illustrates in Fig 2.12 a model that demonstrates how DRT services can be provided and how they may link with key factors, such as booking and dispatching, which in turn also affects the required level of telematics.

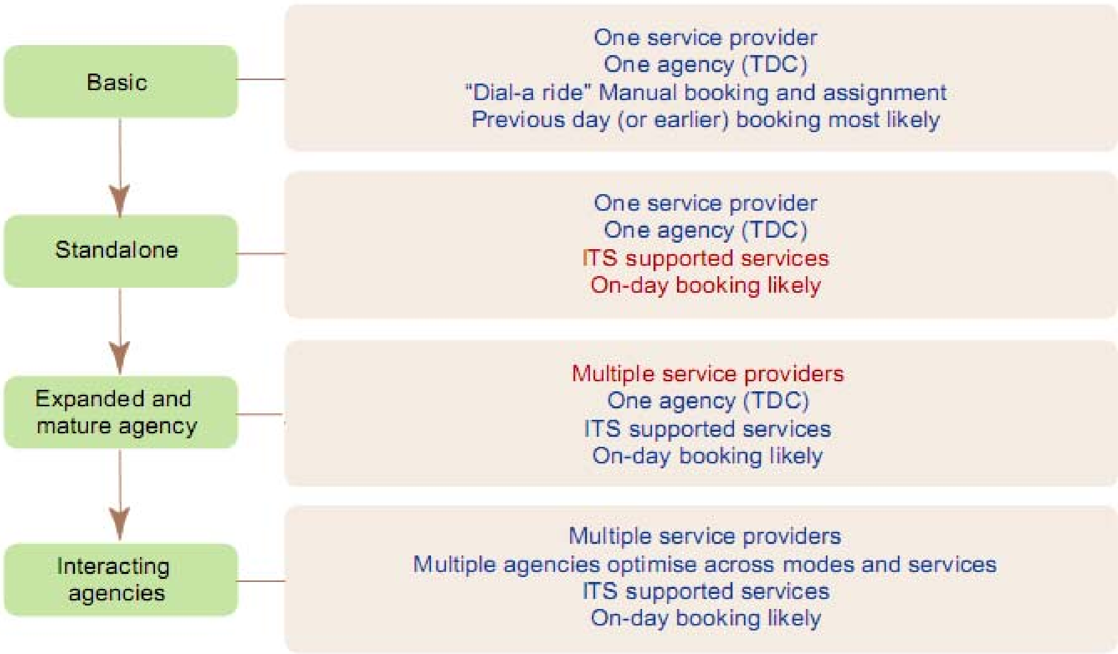


Figure 2.12 The layered model of service provision (adapted from Brake et al, 2006)

Therefore, behind different solutions are different system architectures as well as the related components and technologies. Ambrosino et al, (2004), Brake et al, (2006) and the Samplus experience (European Commission – DGXIII, 2000), making reference to existing projects, describe different system architectures, components and technologies of DRT systems.

2.3.3.1. Architecture of the system

The organization of DRT services on a reasonably large scale is only possible if accompanied by a well performing supporting system (Engels, D., Iacometti, A., (2004)

However, in order to design of a good working system it is necessary to have a complete description of the architecture of the system, which is developed based on assumptions made about the environment in which the system will work. The importance of the system architecture is that it defines the structure around which the system is developed, providing it with form and style as well as attributes about functionality, size, performance, etc.

As illustrated in figure 2.13, in the DRT context, the developed system architecture must address the system requirements that respond to the user's needs analysis.

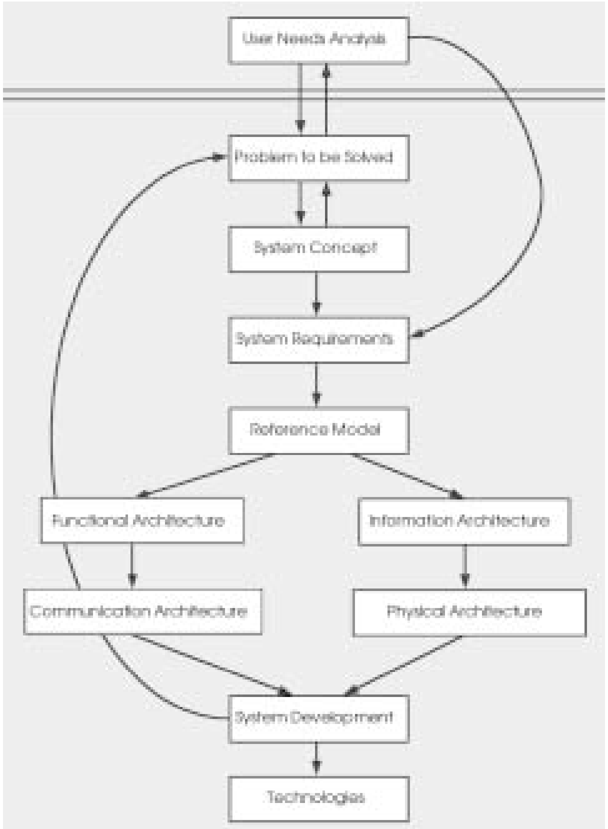


Figure 2.13 - Phases in the design of a system (source: Engels, D., Iacometti, A., (2004) System Architecture)

According to Engels, D., Iacometti, A., (2004) the system architecture for DRT services are structured in 4 points of views:

1. *Functional Architecture* which describes the sub-functions of the system and the data flow between them. Seven main functional areas are identified:
   i. Management of DRT services
   ii. Resource Management
   iii. Operations Control
   iv. Customer Information
   v. Communication Management - Vehicle
   vi. Data Maintenance
   vii. Fare Collection

2. *Information Architecture* which indicates the various data models that embed the sets of data that have been identified, complementing the functional model. It defines the relevant concepts of the real environment and describes the relationship between them. In the context of the conceptual model, four main sets of data are identified:
   i. Road network (in which the DRT services are operated)
   ii. DRT resources (f.e. drt vehicles)
   iii. Costumers orders
   iv. DRT journeys

3. *Physical Architecture* which identifies the physical units that will perform the functions described in the functional structure and the communication paths between them, describing the conceptual structure of the hardware and software environment of the sub-systems in the application to be designed.
4. *Communication Architecture* describes schematically the communication procedures between the different physical units and applications, focusing on the physical transmission of data, representing the communication means and characteristics.

Once these four structures are conceptualized, the next step is to materialize them.

2.3.3.2. Architecture Components and Technologies

A DRT system is composed of various architectural components and associated technological solutions.

In DRT's recent history many innovative solutions have been enabled by the development of transport telematics, particularly in terms of when booking can be made and route taken by the vehicle. But to make the appropriate decision in this matter, it is necessary to balance between the available levels of technology and the appropriate one for the chosen solution (Brake et al. 2007)

The present Information and Communication Technologies (ICT) offer a wide range of possible technological options for the development of DRT system modules such as localization and navigation systems (GPS, …), internet network, wireless communication systems (GPRS…), on-board units, mobile terminals, real-time booking systems, GIS, etc. The choosing of these technological products within DRT systems can vary a lot, mainly due to cost factors, specific requirements of the service architecture, and integration with existing transport services (Iacometti et al 2004)

According to Iacometti et al (2004) the main architectural components and related technologies of the system are:

i. *Travel Dispatch Center* – is where main DRT service functionalities are managed: order handling, reservation scheduling, travel planning and service monitoring. It´s architecture involves hardware and software platforms described below:

   - Dispatcher Server – workstation that has the function of managing requests (trip reservation and modification) as well as travel planning (optimal routes search, vehicle assignment, scheduling, etc)

   - Database Server – a relational database where all information related to passengers, demands and trips and DRT vehicles and drivers, are stored. Also manages statistics and historical data as well as controls access to shared resources.

   - DRTS operator terminal – it is composed of a monitor to manage order and check vehicle position and status, a radio communications terminal to communicate with drivers and a costumer interface device (automatic or manual)

ii. *Customer Devices* – are the front-end technologies that users adopt to contact the TDC, that can be accomplished in different ways:

   - Public telephone network
   - GSM/SMS
   - Internet
   - Magnetic card reader-terminal

iii. *On-board units* – are technological components that perform the following main functionalities:

   - bi-directional voice/data communication with the TDC
   - on-board loading management of the DRTS network topological data and service
   - data
   - acquisition and presentation of up-to-date service data

- vehicle localization
- advance/delay status monitoring with respect to the planned service
- new trip order management
- send/receive messages to/from the service centre.

To make possible these functionalities, the in vehicle units include the following components:

- In-Vehicle Terminal (IVT)
- Location system
- Communication system
- Passenger device
- On-board communication network

iv. *Communication network* - The long-range communication network makes possible:

- bi-directional voice communication between the TDC operators and the DRTS drivers
- pre-coded message exchange between the TDC and the vehicles
- automatic data exchange between the TDC and the vehicles (for example next trip description, vehicle position and status ...)

The most frequently used systems are:

- PRN - Private Radio Network
- GSM - mobile phone network.

2.4. Conclusion

The DRT has evolved from the need to rationalize the organization of traditional scheduled public transport, fight social exclusion and to develop an alternative transport to car use aiming to reduce congestion and pollution.

In nature, due to their flexibility, DRT's are complex transport systems. The possible levels of demand responsiveness of this public transport service can occur in its various elements, such as route, vehicle, operator, passenger and payment mode. The articulation of the various levels of flexibility of these different elements produces a composite transport system, creating many different possibilities of service typologies and scenarios.

DRT systems can be more or less complex depending mainly on project dimension and chosen service typologies. The more demand responsive is the service, the more complex is the architecture of the system and more strongly dependent of ITS technologies. It is in this context, that GIS has an important role in the development of this innovative transport system.

The next chapter focuses on the application of GIS tools to transportation problems, pointing out its developments and potentials.

3. GIS FOR TRANSPORTATION

This chapter approaches issues related to the application of GIS technologies to transportation problems. First, how information related to a transport system is represented, secondly, which capacities and tools of GIS support the modeling and analysis of transport problems and, finally, a reference to the main applications of GIS related to transport problems, giving more attention to the travel demand analysis and to ITS applications which have great interest in the development of a DRT system, a therefore to this study. On the one hand, the travel demand analysis is a central feature of viability studies and planning of a DRT system, and on the other, in the operational context, generally DRT's are generally dependent of ITS technologies for greater efficiency.

3.1. Introduction

In any study area that involves geographic information, it is known that GIS is a useful tool, which provides capabilities for data collection, data management and manipulation, spatial analysis, network analysis and cartographical presentation of results (Zhu and Liu, 2004)

In particular, the transportation studies necessarily have a geographic approach due to its strong spatial component. As stated by (Rodrigue et al, 2006), *"the fundamental purpose of transportation is to overcome space, which is shaped by a variety of human and physical constraints such as distance, time, administrative divisions and topography".*

To facilitate movements between different locations, a public transport service must be designed depending on various spatial factors, but at the same time transport systems also play a role in the structure and organization of space, shaping territories (Rodrigue et al, 2006).Therefore, to study transportation problems it is necessary to model the transport network and the spatial data that influences it and, because this relationship is becoming more complex, the range of models that need to be employed has expanded rapidly, making the integration of transport models and technologies such as GIS, a major requirement in any process of transport planning due to its significant power in transport modeling (Dueker, K., Ton, T.,2000 and Arampatzis et al, 2004)

According to Rodrigue et al (2006) GIS-T has emerged as a branch of GIS, which refers to the principles and applications of applying geographic information technologies to transportation problems, adapting the four components of GIS – encoding, management, analysis and reporting – to specific needs of transportation studies:

- Encoding – concerns the representation of a transport system and its spatial components. To be correctly encoded in a GIS, a transport network must be represented graphically with nodes and edges that are connected by a functional topology[2], and have associated to these spatial elements relevant qualitative and quantitative data.

- Management - The encoded information that supports the various transportation applications normally is organized by spatial, thematic, or temporal considerations and stored in a database. Therefore GIS normally implies the organization of a large amount of heterogeneous data, and to be easily accessed, implies an efficient design of the GIS database.

- Analysis – GIS has a wide range of tools and methodologies available for transport issues. They can vary from a simple query over an element of a transport system to a complex model that inquires the relationships between its elements.

- Reporting – The visualization and data reporting capabilities for both spatial and non-spatial data, is a particularly important component of GIS as it offers interactive tools to express complex information in a map format, easily informing people who otherwise may not be able to visualize the hidden patterns and relationships embedded in the datasets.

The particular type of information stored and analysed by GIS-T are transportation systems and geographic regions that shape or are affected by those systems.

In a GIS the information is often stored and represented as layers, which are a set of geographical features linked with their attributes. Figure 3.1 is an example of a representation of a transport system in three layers, related to land use, flows (spatial interactions) and the network.

[2] In digital data, topology embodies the relative location of geographic phenomena independent of their exact position, expressing relationships such as connectivity, adjacency, and relative positions between nodes, links and polygons (Smith et al, 2007)

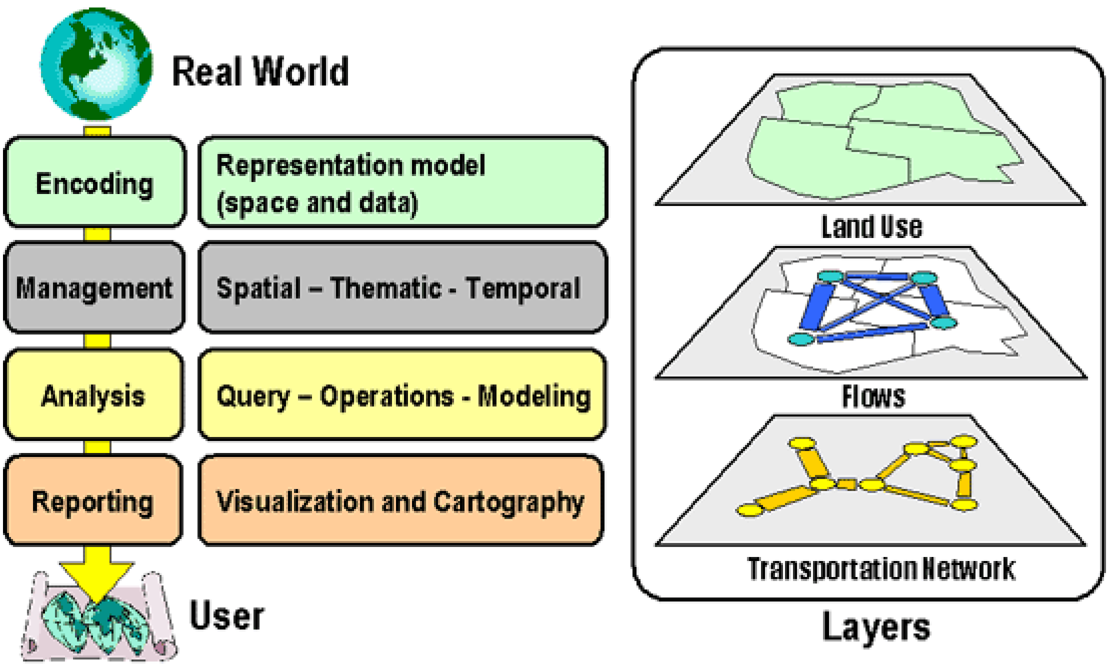


Figure 3.1 – Geographic Information System and Transportation (source: Rodrigue, J.P., Comtois, C., Slack, B. 2006 The Geography of Transport Systems p. 33)

The application of GIS to transportation problems aids as well as encourages the development of GIS-T research, which can be grouped in 3 main topics that represent the key areas where GIS assists transportation.

1. GIS-T data representation – studies how to represent various components of transport system
2. GIS-T analysis and modeling – studies how can transport methodologies be integrated in GIS
3. GIS-T applications – research about what applications are particularly suitable for GIS

3.2. GIS Data Representation for Transportation

Modeling the world in a GIS signifies representing real world data properly in a digital computing environment. In GIS two basic data models have been developed (see Figure 3.2):

Raster data model –a field-based data model which divides space in cell units, generally with similar sizes. Features are divided into cellular arrays, being grid cells the most common raster representation. A value and a coordinate are assigned to each cell. (Rodrigue et al, 2006; Dueker, K. J., Ton, T.,2000)

Vector data model –an object-based data model, where representation of the real world is composed of three main elements: points, lines and polygons. Points are spatial objects with no area and a single set of coordinates. Lines are spatial objects that result from connecting points and have no width. Polygons are closed areas, limited by a circuit of line segments.

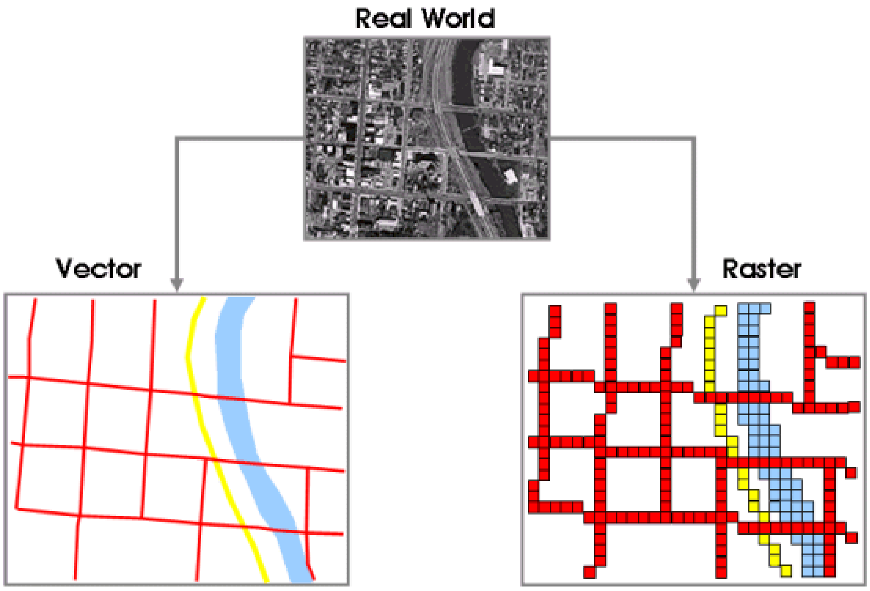


Figure 3.2 - GIS Data Models - Dr. Jean-Paul Rodrigue, 2006, Source : http://people.hofstra.edu/geotrans/eng/ch1en/meth1en/ch1m4en.html

Although GIS-T applies both these models, generally it is the vector data model that better adjusts to the transportation problems, because its properties allow modeling the transportation system for network analysis purposes.

It is the node-arc topological data model, a specific vector model, which is mostly used in GIS software to represent the network of a transportation system. Networks are modeled as connecting nodes (points) and arcs (lines), where topological relationship between all features is defined (Gutiérrez, J., 2007; Longley et al, 2005; Miller et al 2001). Furthermore, for network analysis purposes, particularly to model flows in the system, directional flow properties are defined, as well as impedance – resistance to movement – values are attributed to nodes and arcs, to model the rate of the flow. Impedance can be expressed in distance, time and transportation cost.

Despite these qualities, Miller et al (2001) points out 3 main weaknesses of the node-arc model:

i. The planar embedding requirement forces nodes to exist at all arc intersections, which does not always represent accurately the real world properties of transportation networks that can contain, for example, underpasses and overpasses.
ii. Assumes that the characteristics along the whole arc, between end nodes, are homogeneous, which is not always valid. A good example of this is the pavement quality of a street segment that can vary considerably along its extent.
iii. Has difficulty supporting one-to-many relationships among transportation entities, which in the real/physical transportation network frequently exist.

Dueker and Ton (2000) regards 3 special representation requirements of GIS for transport applications:

1. Have a complex and flexible data-structure-handling capability to represent realistic transport network, as to model:
    a. Directional flows
    b. Underpasses and overpasses
    c. Turning movements at intersections
    d. Public transport route system
2. Needs to accommodate large amount of transportation data in a linear referencing system[3] (LRS) requiring the use of dynamic segmentation techniques, as to support one-to-many relationships.
3. Capability of conversion of database tables into matrices, which are used in most transport modelling tools, as this will help in the tasks of data handling and algorithms evaluation in a more efficient way.

According to Miller, H.J., Shaw, S (2001), a LRS model, in a GIS-T context, is used for the storage and maintenance of information about events that occur within the transportation network and consist mainly of 3 components:

1. *Transportation network*, that consists of traditional node-arc topological network
2. *Location referencing method (LRM)*, that determines the localization of an event in a defined path within the transportation network, using an offset distance along the path from some known origin

[3] LRS is a *method for storing geographic data by using a relative position along an already existing line feature; the ability to uniquely identify positions along lines without explicit x,y coordinates. In linear referencing, location is given in terms of a known line feature and a position, or measure, along the feature. Linear referencing is an intuitive way to associate multiple sets of attributes to portions of linear features" (ESRI).*

3. *Datum,* a set of objects with known, measured, georeferenced locations, that model the earth's shape. The datum ties the LRS to the real world.

Currently one of the most popular LRM is dynamic segmentation[4], a type of linear referencing where event data values are stored as linear distances or offsets, separately from the network route in database tables, and then can be dynamically added to the route, every time the user queries the database (Longley et al, 2005).

Due to the long life of transportation infrastructure and the dynamic nature of traffic flows, the representation of the temporal dimension of transportation phenomena has also been identified as a key issue in GIS-T. Miller and Shaw (2001) pointed out some existing temporal GIS data models, such as the *amendment model*, *space-time composite model* and the *event based spatio-temporal data model,* referring them to be inadequate to handling dynamic phenomena such as traffic flows and vehicle routing. More research has been developed in time-geographic approaches, by various authors, such as Ahamed and Miller (2007) and Shaw and Yu (2009).

3.3. GIS Spatial Analysis and Modeling in Transportation

In a GIS-T context, GIS functions can be used in three levels. At the lowest level, GIS is used to retrieve and store land use and network data. At the next level, GIS is used for information manipulation to model transportation data, and at the highest level, transportation analyst uses GIS as an analysis tool, scrutinizing existing geographic data that leads to the creation of new additional geographic information (Miller, H.J., Shaw, S, 2001) – see examples of Figure 3.3 and 3.4.

[4] Dynamic segmentation is *"the process of computing the map locations of linearly referenced data (for example, attributes stored in a table) at run time so they can be displayed on a map, queried, and analyzed using a GIS. The dynamic segmentation process enables multiple sets of attributes to be associated with any portion of a line feature without segmenting the underlying feature. In the transportation field, examples of such linearly referenced data might include accident sites, road quality, and traffic volume" (ESRI)*

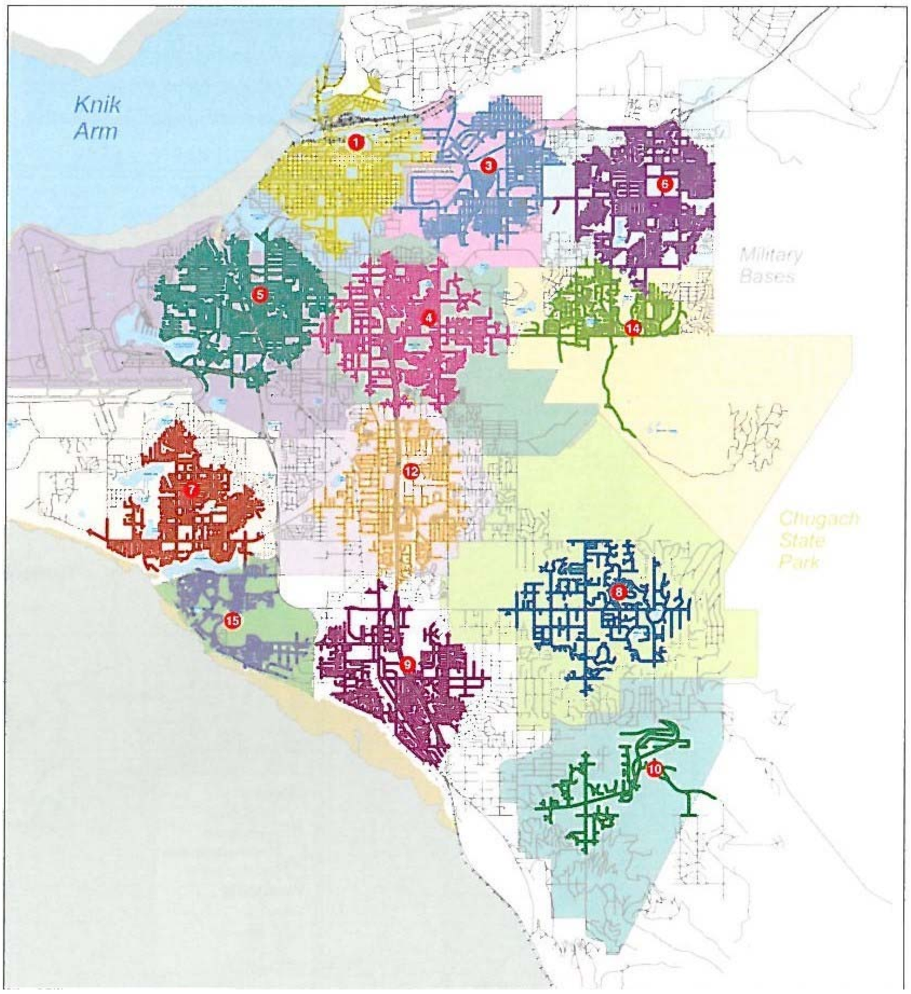


Figure 3.3 – Example of GIS analysis operations – Mile Driving Distances from Fire Stations
Source :ESRI Map Books - Volume 20

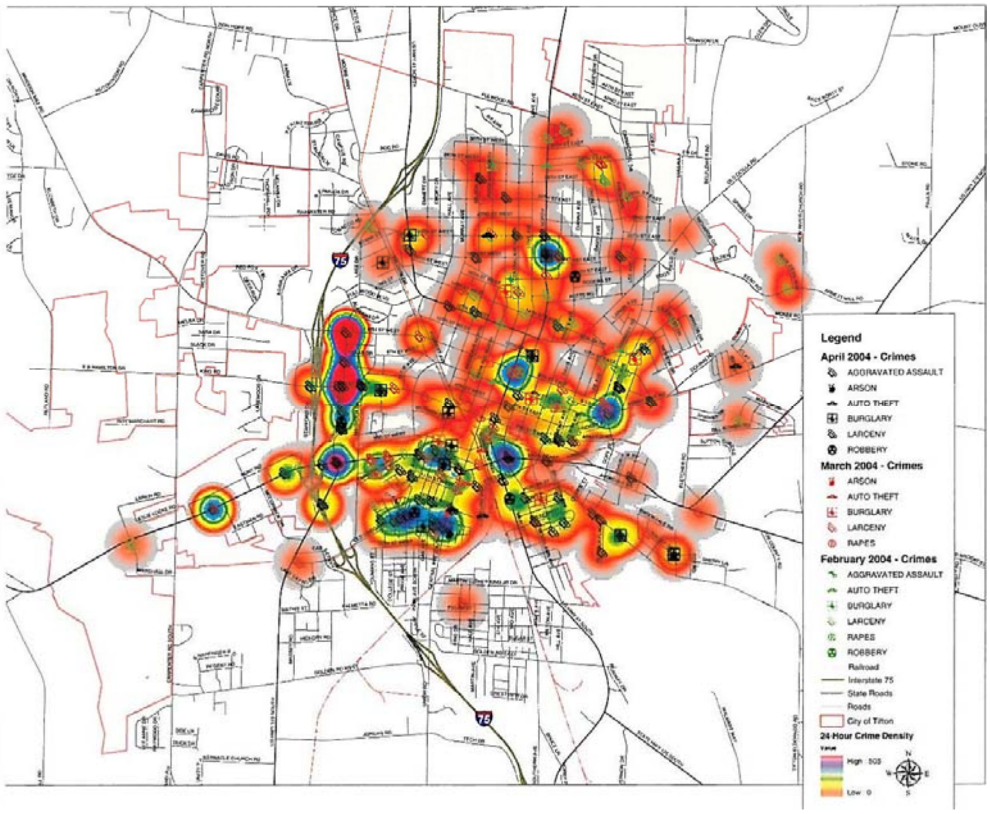


Figure 3.4 – Example of GIS analysis operations – Hour Crime Density for a 3 month period. Source :ESRI Map Books - Volume 20

The data management, analysis and visualization needs of GIS-T applications benefits from standard GIS functions, such as query, buffer, overlay[5], geocoding, etc[6].

However, transportation has its specific analysis methods and models, being most of them based on network analysis procedures (Miller, H.J., Shaw, S, 2001, Rodrigue et al. 2006, Ying, J. 2007) :

- *Shortest path algorithms* – computes the shortest path from an origin node to a destination node in a network, taking into account the constraints and penalties associated to turn movements, which are embedded in the node-arc topological data model.

- *Routing algorithms* – defines a route for a fixed number of delivery or pickup vehicles, through a number of demand locations, in which total costs are minimized and capacity

[5] Includes operations of Union, Intersect and Clip

[6] See Appendix

constraints of the vehicles are not violated. Typically the starting point is the end point, and time windows for pickup and delivery and driver work hours can be established.

- *Spatial interaction models* – estimate the amount of interaction between geographic locations, relating to the movement of people, material, information, or energy. These models, that are central to trip distribution forecasting, consider trip generation factors at the origin, destination attractiveness, and the cost of traveling between origin-destination pairs, representing data in a flow matrix. They are also integrated in more comprehensive travel demand and land use/transportation models.

- *Network flow problems* – models that analyze the flow in congested networks, applied to model traffic flow problems, and uncongested networks, mostly used to solve problems associated to transportation logistics applications.

- *Facility location problems* – computing models that attempt to find optimal locations within the transportation network for activities that service some type of demand distributed in space, such as retail stores, public facilities and emergency facilities. Determines the number of facilities, their locations and the allocation of demands among facilities.

- *Travel demand models* – compute the travel pattern in a study area, aiming to evaluate effectiveness of transportation systems serving the area. Involves estimating some or all of four basic travel demand components: trip generation, trip distribution, modal split and network assignment.

- *Land use-transportation interaction models* – taking into account that land use influences the level and pattern of travel demand and that travel demand also influences future land uses, these models are used to evaluate interactions between land use and travel demand, considering land-use as a fifth component in travel demand analysis, as well as to evaluate further development of transportation systems. In general, these models are composed of a land use sub-model and a transportation network sub-model, with the outputs of one sub-model transformed into inputs for the other.

Rodrigue et al, 2006 states that only a few of these models are available in GIS software packages but does not indicate which of them. When researching the internet for GIS transportation software the most popular professional solutions are *Transcad* and *TransModeler* (for more information consult http://www.caliper.com/)

Some other popular GIS enterprises, like Intergraph and ESRI, have desktop solutions, such as *Geomedia Transportation Analyst*, *Geomedia Transportation Manager* and *Network Analyst* (for more information consult http://www.intergraph.com/sgi/products/default.aspx and http://www.esri.com/software/arcgis/extensions/networkanalyst/index.html)

The *Network Analyst*, which will be applied in the case study presented and discussed in this work, is used for network-based spatial analysis. It includes various analysis tools that provide drive-time analysis, point-to-point routing, route directions, service area definition, shortest path, optimum route, closest facility, origin-destination analysis and the vehicle routing problem (VRP).

3.4. GIS Applications in Transportation

GIS-T applications have been implemented in the last two decades in various transportation agencies, covering much of the broad scope of transportation.

GIS-T is currently applied in different components of transportation studies. In the context of planning and operating transport systems, some of the main applications are:

- Infrastructure planning, design and management
- Travel demand analysis
- Public transit planning and operations
- Intelligent Transportation Systems (ITS)

Each of these applications has its specific data and analysis requirements.

According to Dueker and Ton (2000) the planning applications require a low level of spatial accuracy and data needs to be updated or forecasted occasionally, whereas operational applications have real-time data needs and high level of spatial accuracy so that vehicles can be correctly and quickly guided. The role of GIS-T in planning applications is to support travel-demand modeling, which consists of processing and validating input data, such as small-area and network data, and in processing and visualization of output data. The role of GIS-T in operational applications is usually real-time oriented and more integrated with other systems, having to be very effective and efficient in the support of operational decisions, rather than suppositional.

In the perspective of the applying GIS tools in the definition of DRT systems, it is of interest to further investigate travel demand analysis applications and in the operational context, the ITS applications.

3.4.1. The role of GIS in travel demand analysis

Traditionally, transport planning consisted of predicting future traffic flows which led to the creation of new infrastructures to adjust capacity to future demand, instigating the expansion of highways and car use and inducing demand. As it became clear that forecasting and building capacity was not a solution, as it only generated more traffic, the transport planners increasingly attempted to manage both demand and transport systems, seeking to reduce car use and favor the use of alternative modes of transport (Miller and Shaw, 2001; Rodrigue et al, 2006; Gutiérrez, 2007)

Travel demand analysis is an important component of the transport planning process. When planners seek to evaluate the effect of proposed changes in transportation infrastructure, service or policy on different parts of a transportation system, travel demand analysis is generally required, involving the study of transport supply and demand, particularly estimating some or all of 4 demand components in a study area (Miller and Shaw, 2001):

1. Trip generation – where trips are coming from
2. Trip distribution – where trips are going to
3. Modal split – which modes are used
4. Network assignment – which routes are used within each mode.

There are two traditional models for estimating travel demand, the *four-step approach*, that conceptually separates the four travel demand components and the *equilibrium approach* which views the transportation system as a market that tends to achieve a balance between the demand for travel and the supply of transportation services. It has been proved that these two models suffer from some weaknesses.

In the *four step approach* each component's model has been proven viable as an independent "snapshot" of one travel demand facet, but the linkage of the 4 models to derive the overall travel demand has flaws. On the other hand, the *equilibrium approach* that is a substantial improvement over the sequential approach, assumes that a balance between supply and demand is achieved in transportation systems, which is, in reality, debatable.

These weaknesses have led to emerging alternatives such as *activity-based analysis*, *computational intelligence approaches* (neural networks) and *accessibility modeling* that complements, but does not replace, travel demand forecasting. All these travel demand analysis approaches, depend on data about movement and activity in geographic space, and therefore are greatly enhanced by GIS tools and software (for further information consult Miller and Shaw, 2001)

GIS has much to offer to the transportation planning process and potentially enhances the course of decision-making within it. GIS supports the front end of the planning process as a spatial database management system, also the back-end producing graphic and cartographic visualizations of present and future scenarios, and in the middle as a spatial analysis tool for processing geographic data into geographic information.

In the GIS environment, *network analysis* is an important and the most specific analysis tool applied to transport planning. It's used to simulate movements of people and vehicles on transport networks, such as streets, metro, buses, pedestrian, with many applications, such as travel demand analysis in particular (Gutiérrez,2007)

An agency involved in public transport planning must have georeferenced data related to the supply - bus routes, schedules, bus stops and stations - and demand of public transport - localization of potential demand population and activity centers. The consultation and cartographic visualization of this geographic information is fundamental for decision making.

A frequently used approach to travel demand analysis, often applied to evaluate transportation system performance, is measuring access to the transportation system as well as to measure accessibility provided to individuals. It is assumed that the more individuals have access to the transportation system and the more accessible the system is, the more it benefits individuals. Access and accessibility analyses are key elements in transport geography and planning. Access greatly impacts the public transportation system and complements service accessibility and furthermore access and accessibility are dependent upon each other if the public transport system is to be successful and well utilized (Murray et al, 1998)

Rodrigue et al, 2006 and Murray et al, 1998 define these concepts making a clear distinction between access to public transportation and the accessibility of the public transport system: In a simple manner, Rodrigue et al (2006) defines “Access” as being the capacity to use a transport system, entering or exiting it and considers it to be an absolute term in the sense that a location or has access or does not. In turn, Murray et al (1998) has a more detailed definition, considering “Access” as the opportunity to use the transport system, which depends on proximity to the service or its cost. If the trip origin/destination is too distant or the cost of the service is unaffordable, it is unlikely that the transport mode will be utilized.

On the other hand, “Accessibility”, according to Rodrigue et al (2006), is a relative term that measures the capacity of a transport mode to reach a location or various locations. Murray et al (1998) considers that the measure of this capacity is time units, to evaluate the suitability of a public transport to take individuals from the entry point of the network to the exit location.

To conclude, “Access” is a measure to use the transport system as where “Accessibility” is a measure of the capacity of the transport system to reach places.

Several authors have applied GIS tools for measuring access to the transportation system and accessibility of public transport, to determine potential demand and evaluate how well a transport system is serving the area.

An example of this approach is the study developed by Silva and Julião (2006), which evaluated the supply and potential demand of the transportation system of Guimarães, measuring access to the system and accessibility of system.

First, the analysis of access to the system was based on distance cost, and the used methodology consisted of calculating Euclidian distance *buffers* around the stops to determine area and population coverage of the public transport system, process which is generally designated as coverage analysis.

In GIS systems the analysis of the access to the transport network, based on proximity, is supported by c*overage analysis* which enables one to evaluate pedestrian accessibility to the bus stops or stations on the network. This measure is a tool for determining potential demand, allowing calculating the amount of population or employment within a certain distance threshold with respect to one or several access points (Murray et al, 1998)

According to (Gutiérrez, 2007), network coverage analysis has various applications in transport planning:

1. Diagnostic – identify locations and population that falls into the coverage area of public transport as well as falls out. Give attention to locations with no or little coverage, which eventually should have new services.
2. Evaluation of alternatives – compare the potential demand for each possible bus stop or station, choosing locations that capture more demand.
3. Plan evaluation – Evaluate the differences in terms of covered population, resulting from the enlargement of the pt network, and study the contribution that each new bus stop brings to the whole network in terms of pedestrian access to the network (population and employment coverage)

Secondly, the adopted approach to measure the accessibility of the system, which evaluates the capacity of system to transport people from origin to destiny within a reasonable time, was to account for service frequency and develop an isochrone-based analysis to map the travel time of the system (see Figure 3.5 example of isochrone map)

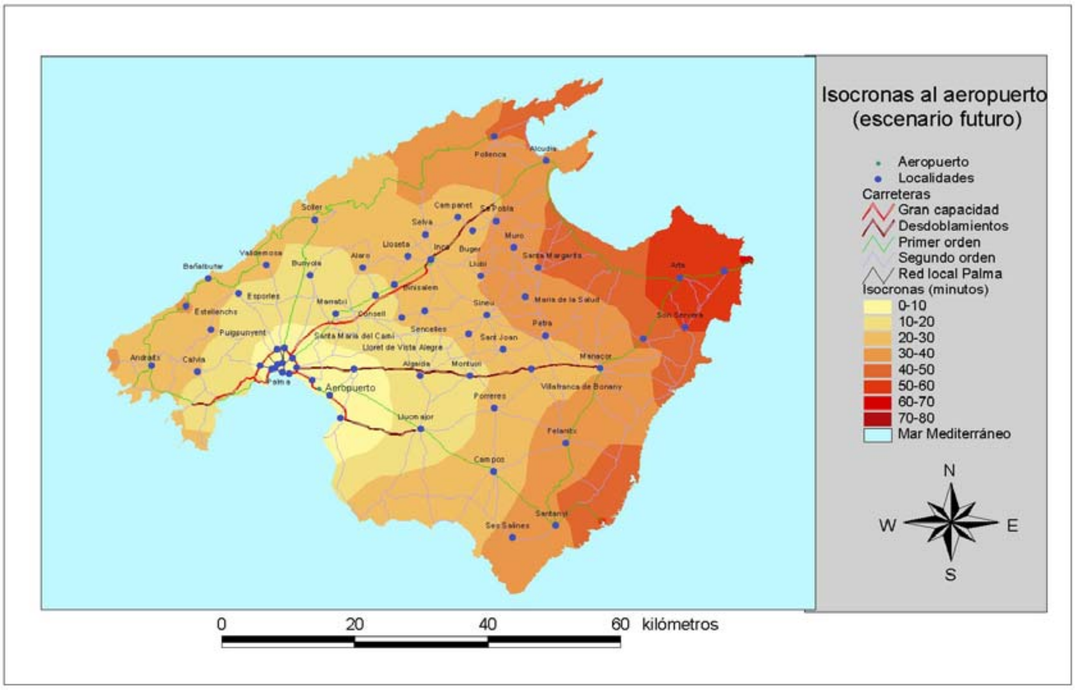


Figure 3.5 : Isochrone Map of time cost to access city of Palma de Majorca along roads
Source : GUTIÉRREZ, J. 2007

Isochrones are a general tool frequently used in accessibility analysis, to measure the effectiveness of a transport system in delivering people to facilities they wish to use, and consist of a line joining a set of points at equal travel time from a specified location. Isochrone areas are mostly used in a GIS environment, referring to a set of all points contained within an isochrone that are reachable in specified time or less, yielding the immediate benefit that they may be re-used in various other analyses (O'Sullivan et al, 2000).

A second example of GIS application to measure access to transport network is Gutiérrez and Palomares' work (2008), in which they analyze the access coverage of 4 public transport networks of the Region of Madrid: metro, suburban rail, urban buses, and interurban buses, where access is perceived as physical proximity to transit stops or stations. The authors use two methodologies to measure service areas, the Euclidian distance and network distance, proving the last to be a more accurate method (Figure 3.6).

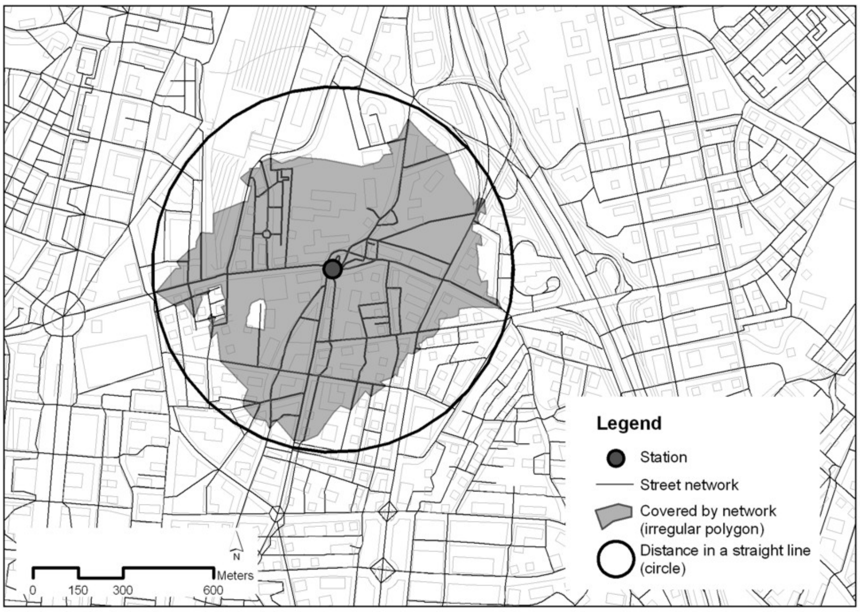


Figure 3.6 : Defining service areas around a station using the Euclidian distance and network distance methodology Source : GUTIÉRREZ, J. 2007

One the other hand, Gutiérrez (2007) illustrates an example of applying GIS tools to measure accessibility of road network of Palma de Majorca, aiming to evaluate accessibility before and after the implementation of new transport plans. To achieve this, the author calculated isochrone areas of mobility time costs between cities before and after the construction of the new infrastructure which, as would be expected, changed accessibility conditions.

3.4.2. The role of GIS in Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) is an approach to tackle problems of transportation congestion, aiming to make transportation systems efficient, safer, and environmentally friendly.

It is the use of advanced computing, real-time data sensors and communication technologies that improves system efficiency (Miller, H.J., Shaw, S, 2001).

ITS applications can be classified in seven categories. Three of them can be applied in the implementation of DRT systems:

1. *Travel demand management* – attempts to decrease travel single occupancy vehicles, by supporting programs of carpooling, and providing information to support traveler's trip planning;
2. *Public transportation operations* – intends to improve public transportation systems, resorting to technologies that monitor trip demand and vehicle location, being *automatic vehicle location* (AVL) the most common ITS application;
3. *Electronic payment systems* – the use of "smart cards", wireless transmission and other automated fee collection devices makes paying fares easier for travelers, representing also increased revenues for transport systems.

Some of these ITS applications entail capturing and transmitting, between different subsystems, real-time or near real-time geographic information based on unambiguous location reference. Clearly, these tasks are central to ITS architecture, and involve the use of GIS technologies.

The in-vehicle navigation systems and internet-based transportation information systems are particular examples of the integration of GIS in ITS user services, respectively for public transportation operations and travel demand management.

In-vehicle navigation system provides guidance to drivers along a route from trip origin to trip destination, using 3 crucial components:

1. Determines the real-world location of a vehicle and matches it to a location in a geographic database, being the global positioning systems (GPS) the mostly used method.
2. Provides route guidance to driver, requiring the use of GIS tools to identify trip ends and to find best route. Geocoding functions are used to identify the trip origin and trip destination in geographic database, generally finding a map coordinate location through matching street addresses. Then a minimum cost path algorithm is applied to find best route, along street network, between the two identified points, requiring a GIS map database with topology.
3. Effectively communicate the route guidance information to the user in real-time, through a map display interface with voice instructions, to minimize distraction of driver.

A correct route guidance requires high quality digital geographic data, that includes positional accuracy, actual and precise street address data, correct representation of street network (topologically correct), operational restrictions data associated to network (one-way, etc) .

On the other hand, the internet-based transportation information systems for travel demand management purposes are also ITS services that require GIS applications to support them.

Two main strategies for distributing geographic information on the internet can be identified: simple data download of static map display, or dynamic map display with interactive GIS query and analysis. In the first case, mostly used for maps of fixed transit routes, the system converts cartographic output from GIS software into a static image (JPG or GIFF), that is then displayed on a web page for user to view and download. Further requests of other map displays are not possible. The static map display is not very useful for real-time ITS applications, due to the dynamic nature of associated data. In this case it is necessary to make available, to the user, a map of the current operational status of transportation system. This is possible using dynamic map displays that allow the client to define the map parameters on his computer and send the request to the web-server, where it will be processed by GIS software and return the requested map display to the client's computer. An example of dynamic map display is the Google Map site.

Advanced internet-based GIS applications include query and analysis capabilities, requiring a user interface on the client to formulate these requests and a GIS interface program on the server to execute the requests and send back the resulting map to the client.

3.5. Conclusions

The need to model the transport network and the spatial data that influences transportation problems has led to the integration of transport models and GIS technologies, emerging a new branch of GIS, called GIS-T.

In this context, GIS functions can be used in three levels. At the lowest level, GIS is used to represent and store land use and network data. At the next level, GIS is used for information manipulation to model transportation data, and at the highest level, used as an analysis tool.

To represent real world data, GIS-T can apply two general models, both the raster and vector model, but commonly it is the vector data model that better adjusts to the transportation problems, particularly for network analysis.

However, various specific transport models have been developed in the GIS-T context. To represent the network of a transportation system, in particular, there are two models. The node-arc topological data model is the most widely used, although its weaknesses which led to the development of the LRS model. The need to represent the temporal dimension of transportation phenomena has also led to the development of temporal GIS data models.

The transportation analyst also uses GIS as an analysis tool, scrutinizing existing geographic data that leads to the creation of new additional geographic information. Besides using standard GIS functions, such as query, buffer, overlay, geocoding, etc, transportation has several specific analysis methods and models, being most of them based on network analysis procedures, such as shortest path and routing algorithms, network flow models, etc.

Many specific GIS-T applications have been developed and applied in various components of transportation studies such as infrastructure planning, design and management, travel demand analysis, ITS, among others.

In the next chapter, we will approach how GIS technologies can be useful and applied in the operation of DRT services, contributing for better service. Also, we will propose, a methodology, using GIS tools, to evaluate the existing transport system and to plan the development of a DRT system.

4. APPLICATION OF GIS TECHNOLOGIES TO THE DEFINITION OF DRT SYSTEMS

When researching the application of GIS to DRT systems, all literature and studies found about existing projects reference the use of GIS applications in the operation phase. No literature was found about the application of GIS in the study and planning of a DRT system.

In the operational context, it is mostly the advantages that are referenced. Which GIS tools are used and what information is necessary is scarcely referred.

This chapter first aims to analyze the functional areas in the operation phase of the DRT system in which GIS technologies can be supportive, how they can contribute to the efficiency of the system, in which components of the system can they be installed and which GIS tools and geographic information is necessary.

DRT systems, due to their flexibility, are complex transportations systems, both in terms of system architecture and operational requirements. Generally, for greater operative efficiency, DRT are dependent of ITS technologies and computer scheduling and dispatching software, which can integrate GIS technologies also.

4.1 Operations Management, Data Maintenance and Costumer Information

Among the seven main functional areas identified in Chapter 2, it is in the management of DRT services, namely in operations control, customer information and data maintenance where GIS may play an important role.

The core operations of a DRT system are the trip reservation, routing and scheduling, dispatch control, financial reporting and the management of statistics and reports.

However, it is the complex scheduling[7] and dispatching[8] operations that most critically affect the daily service performance. Therefore, at present most DRT agencies, with some exceptions, implement these operations using customized software.

[7] Giving a request for a trip an estimated time of pickup and/or drop-off (Kessler, D. (2004)

A historical review developed by the Transportation Research Board of Washington D.C. (Resource Requirements for Demand-Responsive Transportation Services, 2003) about the development, procurement, implementation and operation of computer aided scheduling and dispatch systems in DRT services in the USA, reveals that traditionally, the first small DRT systems, developed in the early 70's, used to control their reservations, trips and vehicles manually but, as the demand for DRT services grew, it became evident to the agencies that it was necessary to automate operations.

The main reasons for implementing computer aided scheduling and dispatch software was the need to manage and monitor large volumes of data and the desire to improve scheduling and dispatching (including the production of optimized schedules in a timely manner), as well as to increase productivity and client satisfaction.

In the context of customized scheduling and dispatching software for DRT systems, there has been the development of applications based on digital maps and GIS technology that improve routing, scheduling and vehicle tracking, contributing to service performance and productivity. Some applications also supply tools to better collect and understand provided statistical data, helping to measure performance and to produce reports, which are very useful for service monitoring and evaluation (Terrey and Harp, 2006), (Iacometti et al, 2004).

(Sullia and Grenney, 2005), who developed a framework for enhancing scheduling software for small to medium-sized agencies, also confirm, in their study, the need of DRT agencies for computer technology to better address complex scheduling and reporting requirements, referring that the adopted software solutions varies from basic spreadsheet type applications to advanced GIS with automatic trip scheduling.

Typical software used is generally composed of a database (backend), where data is stored and an interface (frontend) to access data, providing the convenient usability. Most advanced products use GIS as an interface.

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[8] In DRT systems, the process of assigning a sequence of trips to a vehicle; relaying service instructions to drivers (Kessler, D. (2004)

As described in section 3.4.1, there are two main strategies for distributing geographic information on web portals: simple data download of static map display, or dynamic map display with interactive GIS query and analysis.

(Terrey and Harp, 2006) point out some examples of software that support routing, scheduling and dispatching functions of DRT systems, incorporating GIS functions, such as *Arclogistics Route* (http://www.vehiclelocationsystem.com/ArcLogistics%20Route.htm), *RouteMatch* (http://www.routematch.com) and *Trapeze* (http://europe.trapezegroup.com/index.php).

The Mascara Project (INTERREG IIIC WEST, 2007) also makes reference to the use of *MobiRouter* software (http://www.mobisoft.fi/www_english/index.php) in the pilot project of Angus, Scotland, and to *PersonalBus* (http://www.softeco.it/softeco/en/pbus.html), installed in the Empoli pilot project in Italy.

Besides the application to improve dispatching, scheduling and monitoring functions, GIS technologies can also applied in the operation phase to communicate with the customers. The development of internet-based DRT information systems, based on GIS technologies, provide mapped information (in some cases, real-time information) to costumers.

4.2. Installation of GIS software in System Components

It is in the Travel Dispatch Center (TDC) servers where main DRT service functionalities are managed, such as order handling, reservation scheduling, travel planning and service monitoring, and therefore, where the core GIS based applications are installed. They improve these operations, allowing a more accurate determination of customer origin/destination in large areas and a more intuitive presentation of travel data. The TDC operators generally have access to an interface with graphical and geographical information tools, used to access and manage the planning and execution of the DRT system, using the geographical and DRT network data, stops and routes stored in the servers (Iacometti et al, 2004).

Complementarily, the vehicles, when equipped with a location system and In-Vehicle Terminal (IVT), provide additional information to the TDC, such as vehicle position and status, contributing to greater efficiency of service performance. In these cases, the vehicle has a graphical GIS interface where automatic data exchange between the TDC and the vehicles occurs, both visualizing on a digital map the location of the vehicle, next route and passengers to pick up, and allowing a better communication with the TDC (Iacometti et al, 2004), (Terrey and Harp, 2006).

The use of advanced internet-based GIS information systems that include query and analysis capabilities to provide service information to costumers requires a user interface on the client to formulate these requests and a GIS interface program on the server to execute the requests and send back the resulting map to the client (Miller and Shaw, 2001).

4.3 GIS Tools

When researching the application of GIS in operating and managing DRT systems, most literature found, including those that describe existing projects, refer the use of GIS applications and its advantages, but practically never explain which GIS tools are used and scarcely refer to the information that is necessary.

However, (Sullia and Grenney, 2005) in the context of their research make reference to the GIS tools they consider necessary for DRT agencies, concluding that these GIS features fall into two categories:

1. Features that are necessary prior and during trips for the purpose of improving scheduling and dispatching performance, having similar characteristics among all costumer site, which include:
    a. Map display on screen with pan and zoom
    b. Geocode and display location of addresses on map (geocoding tool)
    c. Determine the best path for a vehicle between 2 addresses based on distance or travel time and provide the calculated distance and travel time to help decide about the viability of the trip that is demanded (shortest path and routing algorithms)
    d. Provide turn-by-turn directions for travel path
    e. Display the path on the map
    f. Provide tools for delineating geographical areas, sites and zones, on the map (basic GIS tools)
2. Features that are useful for analyzing data after trips have been taken, which vary widely among costumer sites.

The authors do not develop this last point, but most certainly are referring to GIS tools that help evaluate the DRT service. It is acknowledged that, besides being helpful for the optimization of DRT services, the use of georeferenced maps and GIS technologies also enables service monitoring and the collection of useful planning and balance data for service management, which contributes to the further improvement of service performance (Iacometti et al, 2004).

A good GIS-based routing software provides reports detailing miles driven, driving time and time per passenger on the vehicle, as well as trips per hour, trips per route, miles per trip by route and other indicators (Terrey and Harp, 2006).

4.4 Geographic Data

The use of GIS technologies to operate and manage transport systems requires, in general, geographic information that models the transportation system and the real world environment where it operates.

Reading about several existing DRT projects, such as the Delaware case and others developed in the Samplus and Mascara studies (Scott, M and Tuttle, D, 2007; European Commission – DGXIII, 2000; INTERREG IIIC WEST, 2007) and other authors like (Terrey and Harp, 2006) and (Sullia and Grenney, 2005), leads to the conclusion that the basic information needed in the operational context of a DRT service is fundamentally the same as required for traditional transports systems:

- Street network - includes detailed attributes related to one-way streets, physical turn restrictions, improved ramp structures and calculated speed information, street names.
- Transportation network – bus stops, bus routes, train/metro stations, railway
- Geographical location of active destinations such as places of employment, hospitals and health centers, shopping centers, schools, civic services, etc
- Geographical location of clients address (in the case of DRT services with door to door schemes)
- Geographical site boundaries and administrative boundaries

However, in the case of DRT services, which frequently have flexible routes, additional real-time information is extremely useful for greater service efficiency.

As (Dueker and Ton, 2000) point out, the operation of more advanced transport systems, have real-time data needs and a high level of spatial accuracy information, so that vehicles can be correctly and quickly guided.

The developing correlation between ITS and GIS technologies allows to obtain real-time information and update traditional base maps in real-time with information on lane closures, traffic levels, weather, emergency service data, providing it to traffic operators and emergency teams (Lang, 1999), (Terrey and Harp, 2006).

The real-time data that is mostly referred for operating DRT systems is:

- Real time location of operating vehicles
- Real-time traffic data

Knowing precisely where vehicles are at all times is becoming essential. This is called vehicle tracking and is done using GPS technology, making service more efficient and acts, as well, as a security device for drivers, passengers and vehicles. GPS data, when combined with a vehicle routing and scheduling system, can be very valuable, as it allows dispatchers to assure that a driver stays on the route and that he meets time obligations. GPS data also allows to update, in real time, estimated arrival times, producing more accurate information to clients, thus narrowing pickup and delivery windows.

Furthermore, real-time traffic data allows identifying congested areas in real time. In the context of showing how real-time traffic data is useful, (Terrey and Harp (2006) give an example of a system that shows the latest traffic information, usually less than 10 minutes old, accessing the Washington Department of Transportation's Web site. It pulls raw traffic data and plots it on the map with colour-coded bands that represent congestion levels on the highways, which help the drivers, decide which highways to take or to avoid.

4.5 Conclusions

The literature about the use of GIS technologies in existing DRT systems is mostly oriented to its application in the operational phase. Generally, for greater operative efficiency DRT are dependent of ITS technologies and computer scheduling and dispatching software, which integrate GIS technologies also.

It is the complex scheduling and dispatching operations that most critically affect the daily service performance, therefore most DRT agencies implement these operations using customized software, and many integrate GIS technologies, increasing productivity and client satisfaction.

5. A METHODOLOGY FOR THE APPLICATION OF GIS IN THE USERS NEEDS ANALYSIS FOR THE IMPLEMENTATION OF DRT SERVICES

5.1. Introduction

In this chapter we propose an analysis methodology in the context of the User's Needs Analysis of DRT services, applying GIS tools and analysis techniques. Although the feasibility studies developed by the Mascara project (INTERREG IIIC WEST, 2007) were also an important practical reference, this methodology is essentially based on the theoretical concepts that were developed in Chapters 2 and 3 of the present research. In fact, when researching literature to study how existing projects developed the planning phase of a DRT system, no studies were found, with the exception of the Mascara Project (INTERREG IIIC WEST, 2007). Also, for the application of GIS to the planning of DRT systems, no literature was encountered.

As explained in Chapter 2, the design of a DRT system requires the following stages:

- Users Needs Analysis
- Definition of Service Typology
- Definition of the architecture of the system
- Choosing technological solutions

Therefore, before defining the service typology, the architecture of the system and the technological solutions, it is necessary to develop the User Needs Analysis (UNA) which is the basis of the whole planning process. It helps identify who are all of the users that will be involved, and which are the needs of each of the different types of user. In the transportation domain, these outcomes are used for the development of various features of the project. Among others, the design of transport network as well as the development of special services where the standard network is insufficient.

(Finn et al, 2004) refer a set of guidelines for the Users Need Analysis that is resumed as a six step approach:

Step 1: Identify the objective

Step 2: Identify the relevant users

Step 3: Analyze previous work in the domain

Step 4: Determine the data requirements

Step 5: Design and implement the appropriate methodology to collect data

Step 6: Analyze and use the results

The objective of the UNA (Step 1) primarily defines the subsequent options. The UNA can have different key objectives and, therefore, focus on the needs of different user groups (operators, authorities, active destinations, end users) as well as on the common needs of all of them.

The analysis of previous transport studies is important to know what information is already available making it possible to narrow the data requirements, as well as it is important to analyze data from non-transport domains for better social economic portrayal of the territory.

The data requirements are reliant of the defined objectives and the adopted methodology to collect data is dependent on the nature of the relevant users and on the data that needs to be compiled.

The analysis procedures of data are also conditioned by the objectives of the UNA and by the nature of the collected data.

The proposed methodology follows this set of generic guidelines, but it is mainly focused on the last three steps, namely the data requirements, the methodology to collect data, and, finally, the data analysis.

Identification of the objective of UNA: to determine mobility requirements and constraints of travelers in order to evaluate the implementation feasibility of DRT within a municipality.

Identification of the relevant users: although other users can be involved, the proposed methodology is mainly focused on end users

Analysis of previous work: the proposed methodology is based on existing works about mobility and transport system on the study area and also socio-economical studies.

5.2 Data requirements

When seeking to understand mobility requirements and constraints of travelers, the UNA of a DRT system involves the study of the demand needs of end users, the evaluation of the existing transport system, and the identification of the deficiencies of the service (in particular, which demands are not met by public transport and supply shortages). To achieve these purposes using GIS technologies, the data requirements are the following:

Spatial Data:

1. Polygon feature class of **BGRI**[9] with demographic census data related to study area

2. Polygon feature class of **CAOP**[10]**,** the administrative boundaries of study area

3. Polygon feature class of **urban perimeters** of villages

4. Point feature class of **civic centers** of villages

5. Point feature class of **active destinations** (such as public services, schools, health centers, shopping centers, working places, etc)

6. Polygon feature class of **areas of influence of active destinations,** when applied.

7. Polyline feature class of **street centerlines** with topology and quantitative and qualitative attributes related to street names, impedance values (one-way restrictions, circulating speed and associated time) and directional flow properties, assigned to arcs.

8. Polyline feature class of **bus, metro and train routes** with topology and attributes related to name of route, origin and destiny, number of daily trips and impedance values (one-way restrictions, circulating speed and associated time) and directional flow properties, assigned to arcs.

9. Point feature class of **bus stops, metro and train stations** with name attributes and route stop frequencies

Non-spatial data:

10. Bus, Metro and train schedules

11. Statistical data about population age structure and mobility

12. Statistical information about end user's needs, difficulties and preferences

5.3 Methodology for data collection

The ideal strategy to acquire the data related to demand needs and constraints of end users is to develop a public survey that questions them about their mobility needs and preferences, trying to identify which difficulties they face when using the existing public transport system. The obtained information can later be processed to statistical data and, in some cases, related to spatial features, being stored and represented in a geographical feature class. However, in most small studies it is financially impossible to implement such a survey and therefore, a

[9] Base Geográfica de Referenciação Informação - Geographic Base of Referencing Information, a polygonal feature class with the statistical information obtained in the Census operations. It is divides the territory into polygonal sections and subsections having population data associated to polygons that cover both habited and unhabited areas.

[10] Carta Administrativa Oficial de Portugal - Oficial Administrative Map of Portugal

potential demand analysis is developed using census population data (total or specific ages, classes, etc.), analyzing its territorial distribution and relating it to the transport system and to the active destinations.

Concerning the public transport system, the best methodology to collect data is to contact the companies who provide the service and request route descriptions and schedules. These data is then converted to GIS polyline (routes) and point (stops) feature classes using the street centerlines as a spatial reference.

The polygon feature class of BGRI and other statistical data is requested to the national statistic entity that is responsible for Census operations.

The basic spatial data representing the territory under analysis, such as administrative boundaries, cartography, urban perimeters, street centerlines and active destinations should be requested to the entities that govern the studied area, such as the municipal City Hall, the executive bodies of metropolitan areas, etc., as applied. Another particular entity to which it is possible to request basic cartographic data is the national entity that produces cartography (IGP and IGOE).

In the particular case of active destinations, some additional descriptive and statistical data can be useful for the analysis. If this is the case, it is necessary to contact the administrative services of these active destinations to request the information needed and load it into the GIS system.

Generally, if the needed spatial data is not available in the format of geographical feature classes, and is provided as descriptive information, it can be edited into a GIS feature class, using the cartography and street centerlines as a spatial reference. In case of not having this basis spatial reference information, the spatial data acquisition can be done with a GPS.

After collecting all the spatial data, it is stored into a GIS and represented as layers, a set of geographical features linked with their attributes, which are later managed according to analysis requirements. However, for *network analysis* purposes, the transportation data (street centerlines, bus and metro routes, bus stops and stations) must be modeled into a multimodal transportation network which, representing the real-world transport system, models flows in the system and connections between different modes at modal junction points (stations and bus stops). Before proceeding to build the multimodal transportation network it is necessary to assure that all features classes fulfill topology requirements.

5.4 Analysis Procedures

After storing and organizing the data, we can also use GIS as an analysis tool, which scrutinizes existing geographic data leading to the creation of new additional geographic information. GIS has a wide range of tools for the analysis of transport issues that can vary from a simple query over an element of the transport system to simulating movements on a modeled network.

To address the UNA objective of determining mobility requirements and constraints of travelers, the developed analysis aims, on one hand, to identify supply deficiencies and weaknesses in existing public transport services and which geographic areas are most affected: inadequate access and accessibility, low frequencies, deficient connections between places or between transport modes. On the other hand, it aims to study potential demand analyzing the geographic distribution of end-users, identifying their active destinations, their schedule needs, and relating them to the existing supply.

The proposed GIS based analysis methodology is based on some of the GIS travel demand analysis procedures referenced in Chapter 3, usually applied in the evaluation of supply and potential demand of traditional transportation systems: access/coverage analysis and accessibility analysis of transportation network. To enrich the analysis, some complementary procedures are suggested such as analyzing the spatial behavior of bus line and metro/train frequencies to identify villages with low transport supply. The study of the conveyance between transport modes, as well as quantifying available transport connections between important centers/active destinations was also approached, as it helps to identify villages where the connecting transport system is insufficient, what makes them potential areas in need of complementary DRT services.

5.4.1 Access Analysis

5.4.1.1 Coverage analysis

The objective of the coverage analysis is to measure the opportunity to use the public transport system based on proximity to the service. If the trip to the bus stop is too distant, it is unlikely that the transport mode will be utilized. This analysis is used to help evaluating the capacity of transport system to serve an area. It identifies the territorial area and resident population (or subclasses of population) that is covered by the transport system, as well as determines the potential demand for DRT services since it indirectly helps to calculate the population that is not covered.

Spatial data used: census data (BGRI), urban perimeters, bus stops and stations, and street centerlines making buffers of walking distances to stops along streets.

Suggested procedure: Since the transportation system is expected to serve the whole population, including the old aged who generally has walking constraints, we propose an ideal walking distance of 150 meters, as well as a more realistic class of 300 meters (obviously, these values may change according to each particular situation). The polygonal population data of BGRI is converted into centroids and integrated in urban perimeters. The walking distance buffers are related to urban perimeter centroids to identify covered population.

Results: Calculation of covered area and population of territory, producing indicators of low transport coverage associated to geographic areas.

5.4.1.2 Analysis of the regularity of the Public Transport Service

The objective of this analysis is to identify the number of daily bus and metro/train services associated to each stop which also measures the opportunity to use the transport system – the more bus lines or metro trips that pass at a bus stop or station, the greater the opportunity to use the transport system. This analysis also helps to identify areas with low transport services in order to evaluate the need of a DRT service. Bus stops with very low frequency can be considered to integrate a DRT service typology with predefined stops.

Spatial data used: bus stops/stations and transport routes.

Suggested procedure: Select and relate all stops/stations that intersect each bus/metro route, creating a new feature class of stops with the frequency attributes of each routes connected to them.

Results: Produce indicators of low service frequency of transport associated to geographic areas.

5.4.1.3 Connection Analysis

The connection analysis may be divided into two phases: an analysis between Geographic Centers or/and Active Destinations, and an intermodal connection analysis.

Connection Analysis between Geographic Centers or/and Active Destinations

The objective of this analysis is to measure the opportunity to use the public transport system from a specific origin towards an active destination or geographic center. It also intends to evaluate if the access to specific centers is possible and at what frequency, hence helping to identify weak transport connections between important centers.

Spatial data used: civic centers or active destinations, transport routes and administrative boundaries.

Suggested procedure: Identify all transport lines that establish connections between specific geographic centers or/and active destinations and quantify their frequency.

Results: Identify villages where residing population has constraints using public transport system to travel towards important centers, producing indicators of difficulty levels.

Intermodal Connection Analysis

The objective of an intermodal connection analysis is to analyze connectivity of transport system, identifying intermodal junctions and which villages these junctions serve. It measures the opportunity of a population of certain villages to get to further regional destinations, when modal change is required. It also helps to identify villages that are poorly served.

Spatial data used: Bus stops/stations, transport routes and administrative boundaries.

Suggested procedure: Identify all bus lines that establish connections, at intermodal junctions, with other existing modes of transport and quantify their frequency.

Results: indicators of low access to other transport modes and further destinations associated to geographic areas.

5.4.2 Accessibility Analysis

The objective of an accessibility analysis is to measure, in time units, the capacity of a transport system to take individuals from the entry point of the network to the exit location. It helps to identify areas that, although not far in distance, are in time cost generally explained by lack of direct transport or involving long walking distance to origin or to destination bus stop/station. It also helps to identify weak transport connections between important centers.

Spatial data used: Civil centers or active destinations and the multimodal transport network.

Suggested procedure: Process a network analysis (using GIS technology) on the multimodal transport network from civil centers towards, or away from, active destination in order to calculate the time service area, for different time classes (for example, 20, 40, 60, 80 minutes).

Results: An Isochrone map that illustrates the time cost to travel towards or away from active destinations. It produces spatial indicators of low accessibility, when travelling towards or away from identified centers.

5.5 Analysis of the Results: Spatial DRT Need Index

The resulting indicators of the access and accessibility analysis classify the level of transport service available in each village in its various aspects, namely, coverage, frequency, connections and accessibility. It allows identifying areas that do not have access to public transport, have low frequency of services, are poorly connected to important centers or other modes of transport, or are unreasonably distant in time cost from important centers. All these indicators of supply deficiencies and weaknesses in existing public transport services can be minimized or resolved with the implementation of DRT services.

In order summarize the analysis results, the development of a *Spatial DRT Need Index* is proposed.

The *Spatial DRT Need Index* is based on 5 indicators, each of them helping to measure the need of a DRT service. The value of each indicator is classified into three levels: 3- High, 2- Medium and 1-Low. The values within each level can be adjusted to the specific features of the studied area. In the following, the 5 indicators and examples of values for the three levels are provided:

i. Coverage area:

Level 3: less than 20% area;
Level 2: between 21%-30%;
Level 1: more than 31%

ii. Nº of public transport lines connecting identified geographic centers:

Level 3: 0 to 6 lines;
Level 2: between 7 and 15 lines;
Level 1: more than 16 lines

iii. Nº of bus lines connecting identified centers to other modes of transport such as metro/train:

Level 3: between 2 to 6 lines;
Level 2: between 7 to 15 lines;
Level 1: more than 16 lines.

iv. Accessibility from villages to main geographic center of municipality:

Level 3: more than 50% of village area is more than 60 minutes distance
Level 2: more than 50% of village area is between 40 and 60 minutes distance
Level 1: others.

v. Accessibility from villages to disperse active destinations:

Level 3: more than 50% of village area is more than 40 minutes distance;

Level 2: more than 50% of village area is between 20 and 40 minutes distance;
Level 1: others.

Calculating the average value of all indicators for each geographic area studied, and considering that these indicators all have identical weight, we can define the *Spatial DRT Need Index,* an indicator that measures the need for DRT services for that geographic area. Mapping these values in GIST will help to identify broader focus areas and give possible indications of required route and network DRT typologies to implement, when layers of existing transport system is added to map.

5.5 Conclusions

A Users Need Analysis methodology, using GIS tools, to evaluate the existing transport system and to plan the development of a DRT system, was proposed.

After defining the data requirements and methodology to collect data, an analysis procedure is developed aiming to identify the supply deficiencies and weaknesses in existing public transport services as well as the geographic areas that are most affected, focusing on inadequate access and accessibility, low frequencies, deficient connections between places, or between transport modes. On the other hand, the analysis procedure also aims to study demand, analyzing the geographic distribution of end-users, identifying their active destinations, their schedule needs, and relating them to existing supply.

Finally, the development of a Spatial DRT Need Index helps summarize the analysis results for each indicator. Mapping these values help identify broader focus areas and give possible indications of required route and network DRT typologies to implement, when layers of existing transport system are added to map.

6. A CASE STUDY: Municipality of Vila do Conde

6.1. Introduction to Users Needs Analysis

The case study aims to develop a UNA to study the viability of introducing a DRT system in Vila do Conde, particularly in the rural areas, addressing general mobility problems and also those associated to health issues. The UNA methodology developed in Chapter 5 is applied in this case, aiming to identify areas of the territory where the operation of DRT services are necessary as well as to identify possible service typologies to implement.

Since the study aims to identify the weaknesses of existing transport system and, in particular, the mobility associated to the seven public health centers in the studied area, the end user´s in this case are the transport users, particularly, the health center users.

The data requirements of this UNA are basically those necessary to represent and characterize the municipality environment, to build the public transport network, to identify active destinations and to identify users' constraints.

The ideal methodology to identify needs and constraints of end users is to develop a public survey that essentially identifies their mobility needs and which are the felt deficiencies of the existing transport system. However, in the case study of Vila Conde it was not possible to implement this survey, so the demand analysis is based only on population census data, used to identify potential demand.

The collected data for the case study was:

Spatial Information:

13. Polygon *shapefile* of BGRI[11] of the municipality of Vila do Conde with demographic attribute of total population.

14. Polygon *shapefile* of CAOP[12] v.6, which defines administrative boundaries of the municipality of Vila do Conde and villages

15. Polygon *shapefile* of urban perimeters of villages

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[11] Base Geográfica de Referenciação Informação - Geographic Base of Referencing Information, a polygonal shapefile with the statistical information obtained in the Census operations of year 2001.

[12] Carta Administrativa Oficial de Portugal - Oficial Administrative Map of Portugal

16. Point *shapefile* of civic centers of villages

17. Polygon and Polyline *shapefile* of cartography

18. Point *shapefile* of health centers

19. Polygon *shapefile* of areas of influence of health centers

20. Polyline *shapefile* of street centerlines with attributes related to names of streets, one way restrictions and circulating speed

21. Polyline *shapefile* of bus routes with attributes related to direction of route, origin and destiny, number of daily bus lines

22. Point *shapefile* of bus stops, with name attributes

23. Polyline *shapefile* of Metro line with attributes related number of daily trips

24. Point *shapefile* of Metro stations with name attributes and number of trips that stop on it

Non spatial information:

25. Bus and Metro schedules

26. Statistical data about population age structure

The collection of data related to bus transport system was based on an inquiry sent to the 4 bus companies that operate within the municipality territory, asking for bus route descriptions and schedules. Only 3 companies answered and one of them, Arriva, conceded their bus routes and bus stops in *shapefile* format. The 4th company, which has a small concession area providing transport to two villages (Retorta and Tougues), did not answer the inquiry so no data was obtained for this area leaving it uncovered. In the development of the study this area was not considered.

The *shapefiles* of the Metro line and stations were obtained at the City Hall's GIS Service and the schedules were obtained from the company's website.

The polygon *shapefile* of BGRI and other statistical data was obtained from INE, the national statistic entity that is responsible for Census operations.

The geographic data representing Vila Conde's territory, such as administrative boundaries, cartography, urban perimeters, street centerlines, civil centers and public health centers was obtained at the City Hall's GIS Service. However, impedance attributes had to be added later to the street centerlines.

Descriptive data about the areas of influence of public health centers was obtained at the Health Delegation of Vila do Conde by inquiry, and was processed and stored into a polygon *shapefile* that represented these areas. The basis *shapefile* used was the CAOP.

After collecting the spatial data, it was stored and organized in a GIS database.

The geographic data for demand analysis purposes, such as polygonal census/population data, urban perimeters, public health centers and their areas of influence were organized in layers as well as the administrative boundaries, cartography and civil centers.

In the particular case of the transportation data (street centerlines, bus and metro routes, bus stops and stations), it was loaded into a *network dataset* and used to model a multimodal transportation network, which is required for network analysis purposes. Before modeling the network, the topology of all line features was verified and corrected whenever necessary. Impedance values (one-way restrictions, circulating speed and associated time) and directional flow properties were also assigned to nodes and arcs. It should be stressed that the topological corrections and the network modeling was a very lengthy process.

The network modeling and analysis procedures were developed with resource to ESRI software, in particular *ArcEditor 9.3*. and *Network Analyst* extension.

6.2 Characterization of the Municipality of Vila do Conde

6.2.1. Demography

The municipality of Vila do Conde is integrated in the Metropolitan Area of Porto and is distanced 30 Km North from Porto. Its territory covers 149 Km2 and is divided in 30 villages, with one city, called Vila do Conde, and 29 rural villages (Fig 6.1)

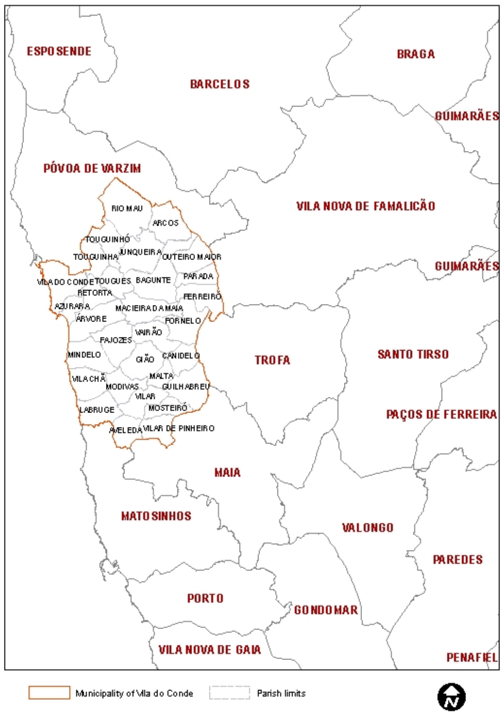


Figure 6.1 – Administrative boundaries of the municipality of Vila do Conde

In the context of the Metropolitan Area of Porto it is one of the less populated municipalities. In 2001[13] the total population was 74391 habitants. The territorial distribution of the population is not homogeneous (Figure 6.2). The most populated areas of Vila do Conde are the city and coastal areas. In the city of Vila do Conde resided 35% of the total population, 20% of the population was in the 5 coastal villages and the rest of the population was distributed among the other 24 villages.

[13] Last Population Census (INE)

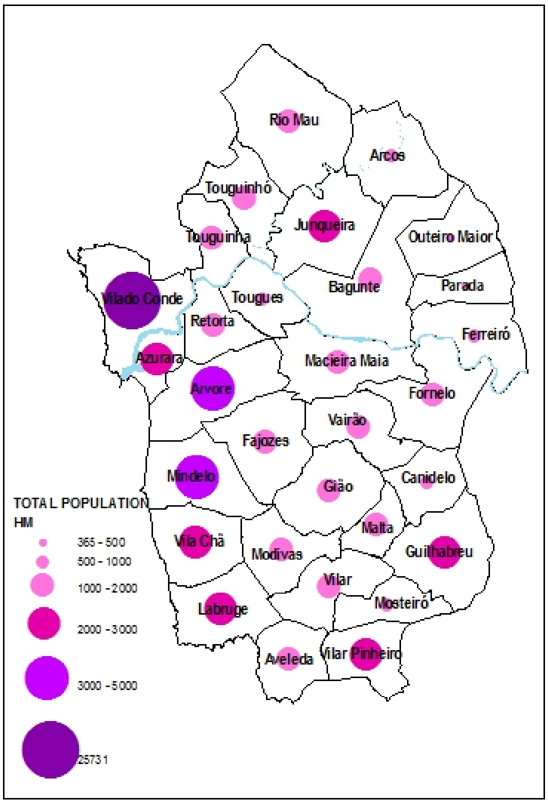


Figure 6.2 – Territorial distribution of resident population – 2001

The average population density is 499 hab./Km2. But when analyzing this parameter for the city and coastal villages this value rises to 828 hab./Km2 and 624 hab./Km2, respectively. In contrast, in the east interior of the territory, with more rural characteristics, the density reduces to 283 hab./Km2. In the South, though, it is visible that there are some important population centers (Fig 6.3).

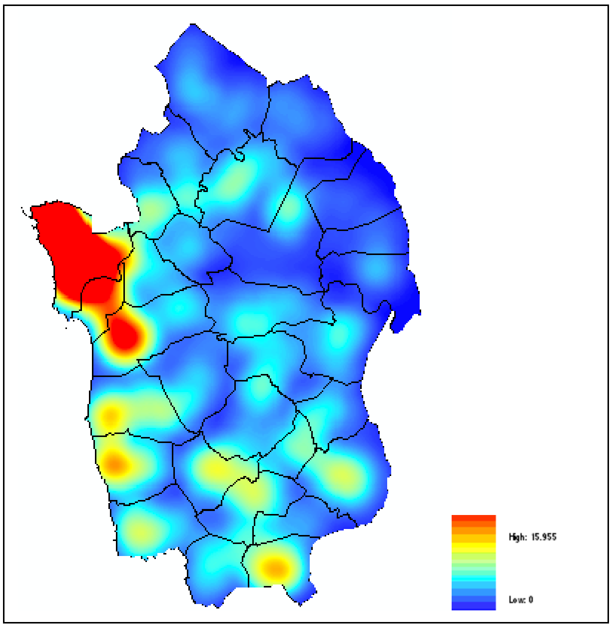
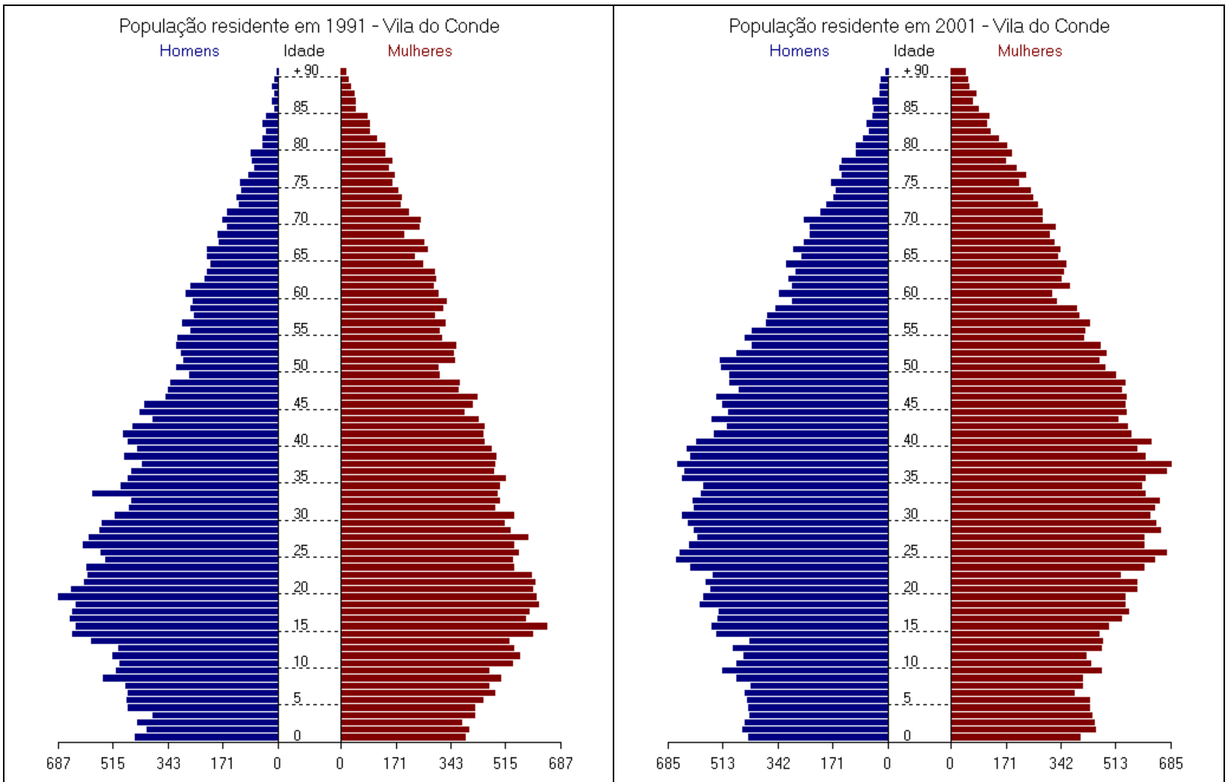


Fig 6.3 – Kernel population density map of the municipality of Vila do Conde

In the last decades the population has grown continuously. The period between 1991 and 2001 was characterized by a strong demographic expansion, increasing 9555 individuals, which represents an increase of population of 14,7%. This period was also characterized by the phenomenon of population ageing.

The ageing of the population in the municipality was verified both at the top and on the basis of the age structure. The weight of children (0 - 14 years) decreased from 22.3% to 18.1% between 1991 and 2001, representing a decrease of 7.6%. Similarly, the weight of the population (15–24) decreased from 18.7% to 15,2%, representing a decrease of 7.1%.



Source: INE, 1991 e 2001

Fig 6.4 – Age Pyramids of Population in 1991 and 2001

Comparing the age pyramids of population in 1991 and 2001 we confirm the ageing of the general population during this period, by increasing the number of persons above 25 years of age (Fig 6.4). However, although the population is aging strongly, in 2001 the younger population class continued to have more expression than the old aged classes (see Table A1 in Appendix)

6.2.2. Public Health Centers

In the municipality of Vila do Conde there are 7 public health centers, 2 of them located in the city and 5 in the rural villages of Junqueira, Vairão, Modivas, Malta and Labruge. These health units are designed to provide preventive and curative health care to the population of the municipality.

Each health center has a defined area of influence (Fig 6.5.) The health centers of Vila do Conde and Junqueira have the most extensive areas.

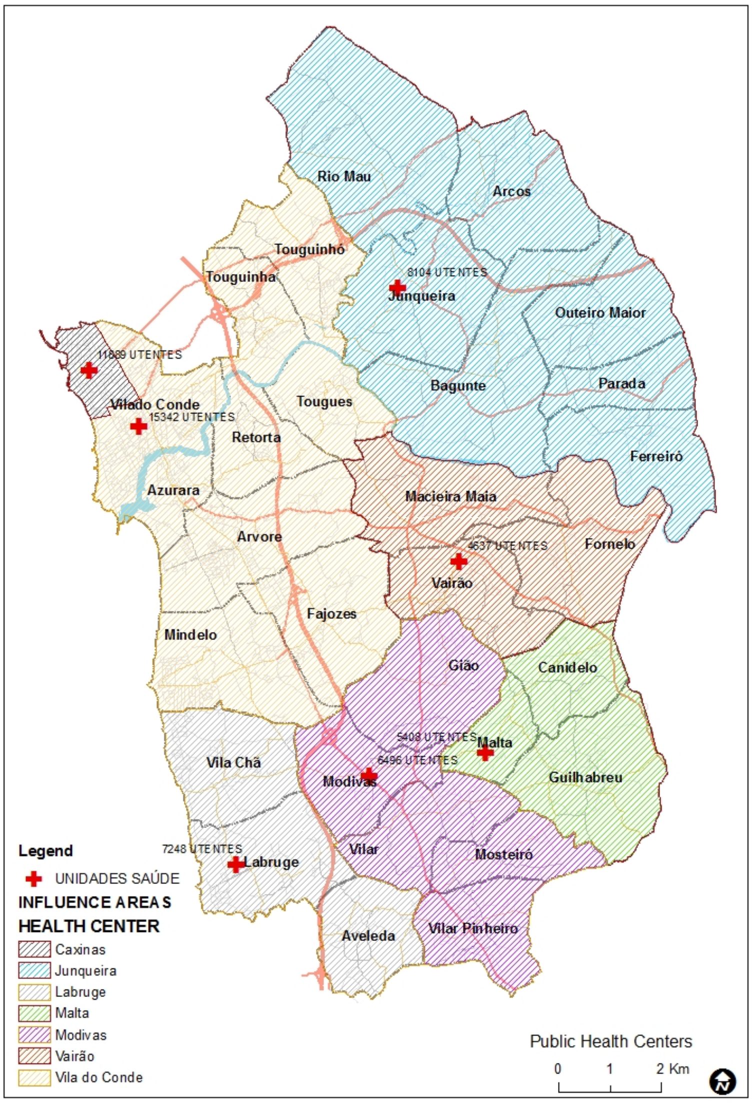


Fig 6.5- Area of Influence of Health Centers

The number of total medical consultations is an indicator of the users demand needs for health service and also for the required trips to the health center. In 2008, 161190 medical consultations were provided, which can be assumed to be trips made to the health center. After the city health centers, it is the center of Junqueira and Modivas that provide a greater number of health services (Table 6.1).

Table 6.1 – Health Centers Statistics for 2008

NAME	VILLAGE	USERS	PRE-SCH MEDICAL CONSULTATION	UNPREDICTED MEDICAL CONSULTATION	TOTAL MEDICAL CONSULTATION
Health Center of Junqueira	Junqueira	8104	20342	1181	21523
Health Center of Labruge	Labruge	7248	20337	567	20904
Health Center of Malta	Malta	5408	13234	1237	14471
Health Center of Modivas	Modivas	6496	18020	7262	25282
Health Center of Vairão	Vairão	4637	14385	695	15080
Health Center of Vila Conde	Vila do Conde	15342	35277	5063	40340
Health Center of Caxinas	Vila do Conde	11889	22680	910	23590
TOTAL		59124	144275	16915	161190

6.2.3. Transport System of the Municipality of Vila do Conde

The existing public transport system of Vila do Conde is mainly composed of fixed bus route services and Metro system (Line B-Porto/P. Varzim).

6.2.3.1. Bus Service

The existing bus services within the municipality are mainly operated by 3 bus companies: Arriva Portugal, Litoral Norte and Castro Linhares. The total bus network has a total of 32 bus lines with an extension of 442 km and 352 bus stops to access the network (Table 6.2).

Table 6.2 - Caracterization of Bus Network

Company	Nº Bus Lines	Urban Lines	Rural Lines	Network Extension (Km)	%
C LINHARES	7	2	5	84,4	19,1%
L NORTE	2	2	0	6,5	1,5%
ARRIVA	23	2	21	351,3	79,4%
Total	32	6	26	442,2	100,0%

The urban routes are provided by Litoral Norte and Castro Linhares and the rural routes are mainly held by Arriva Portugal which connects most of the villages with the city and, at some degree, also by Castro Linhares which provides some bus lines that connect the city to other municipalities

The Arriva's network is the most extensive, representing 79.4% of the total bus network (Fig 6.6). This company has a bus line passing through almost every village (28), except Retorta and Tougues that is served by another small company that did not respond to the inquiry made. Most of the bus lines and their schedules are organized to serve the secondary schools of the municipality. Some of them only exist in the school period being suspended in the summer vacations.

The Castro Linhares' network is the next most extensive, operating 19.1% of the network. Its interurban bus lines connect Vila do Conde to Porto and also to Sanfins and Santo Tirso (Fig 6.7). The NW/SE bus lines serve 8 villages and the E/W bus lines serve 5 villages.

The Linha Norte provides an urban bus service connecting Vila do Conde and Azurara to Póvoa de Varzim (Fig 6.8). Its extension is 1.5% of the total public transport network.

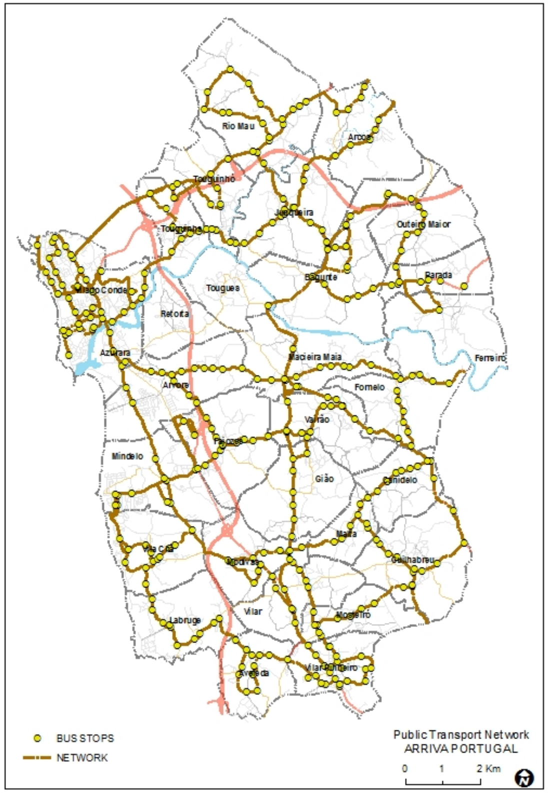


Figure 6.6 – Map of Arriva's Bus Network

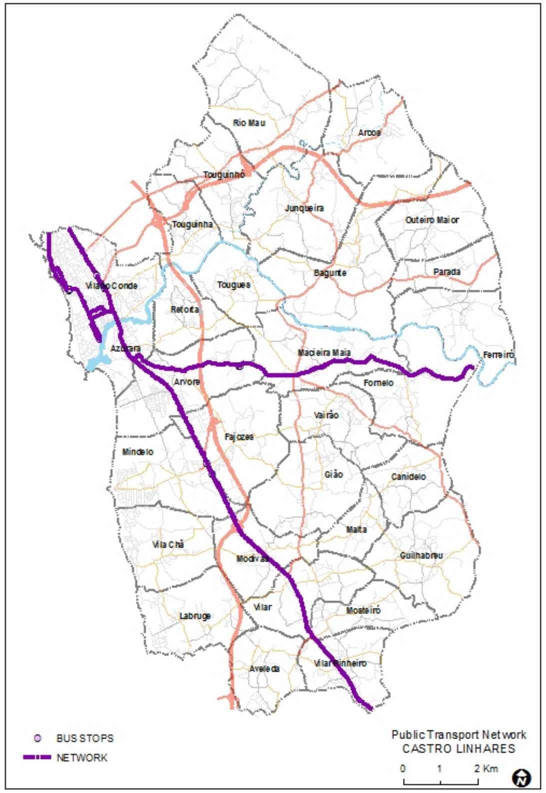


Figure 6.7 – Map of Castro Linhares's Bus Network

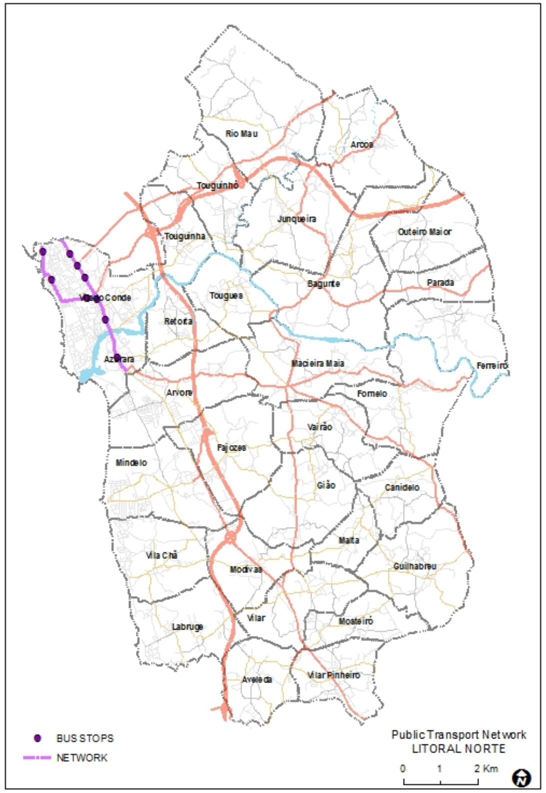


Figure 6.8 – Map of Litoral Norte's Bus Network

When analysing the daily schedules of all bus lines it is clear that a higher number operate on weekdays, and decrease substantially on Saturdays, being almost inexistent on Sundays (Chart 6.1). Along the day, the higher frequencies occur at the peak hours, from 6h to 18h, while after 21h there are no bus services.

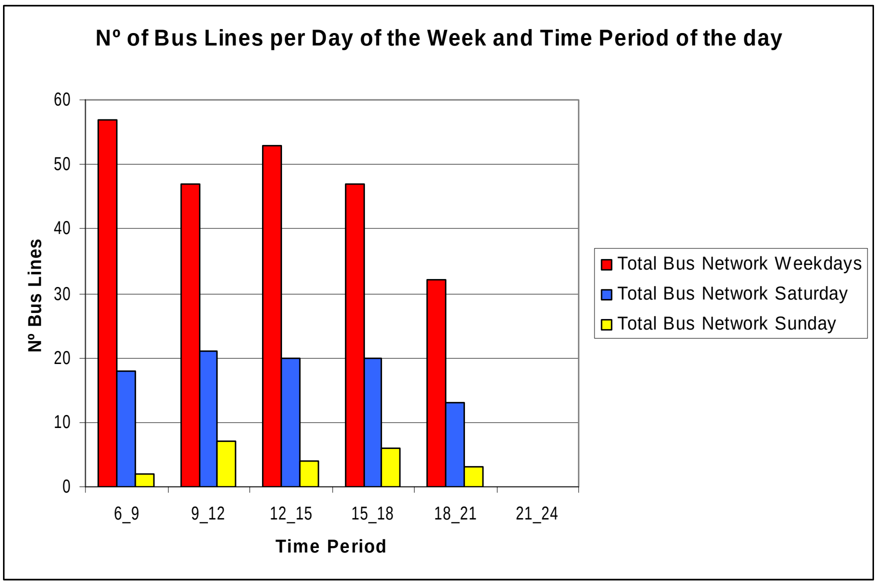


Chart 6.1 – Nº of Total Bus Lines per Day of the Week and Time Period

The analysis of the schedules of each company, allows identifying some differences among them (Chart 6.2)

When compared to other companies, Arriva has a high number of bus lines, but this is the result of having 23 bus lines and mostly rural services. During the weekdays, bus line frequency is very high, reducing abruptly on weekend days. The number of bus lines on weekdays is especially higher from 6h to 9h period as well as from 12h to 15h, which is related to school starting schedules that occur in these periods.

The number of bus lines of Linha Norte, which circulate basically in the city area, is high on week days, reducing almost to half on Saturdays, and becoming inexistent on Sundays. Along the day they have a constant frequency between 9h and 18h (12 bus lines on week days and 6 on Saturdays).

For Castro Linhares, which has urban and interurban bus routes, the bus line frequency on weekdays is relatively high due to the urban routes. On the weekend all bus lines are reduced. Along the day some irregularity of bus frequencies is verified.

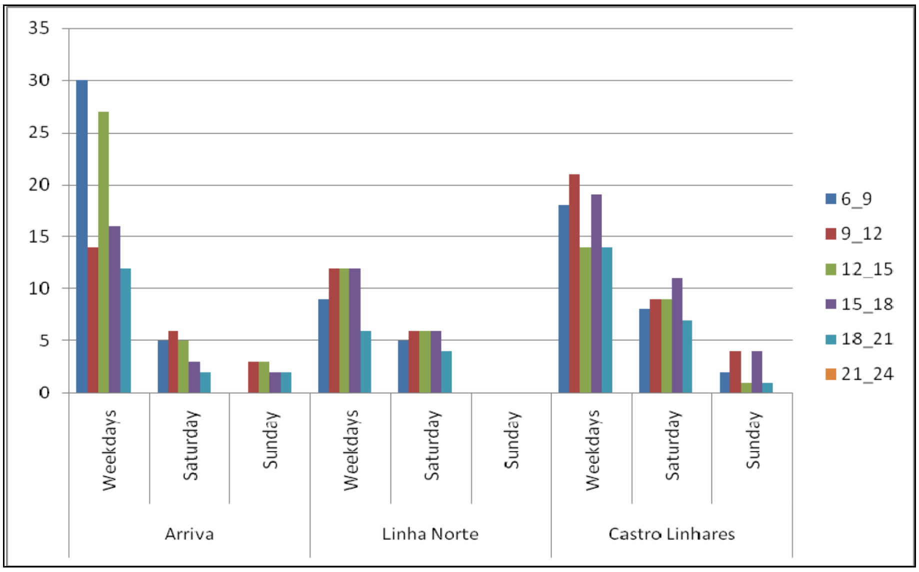


Chart 6.2 – Nº of Bus Lines per Company, Day of the Week and Time Period

The comparison of urban and interurban bus line schedules allows to conclude that the urban bus lines are more regularly distributed along the day, having almost constant fequencies on weekdays and Saturdays. On Sundays, the bus service is very low and, at some hours, inexistent (Chart 6.3)

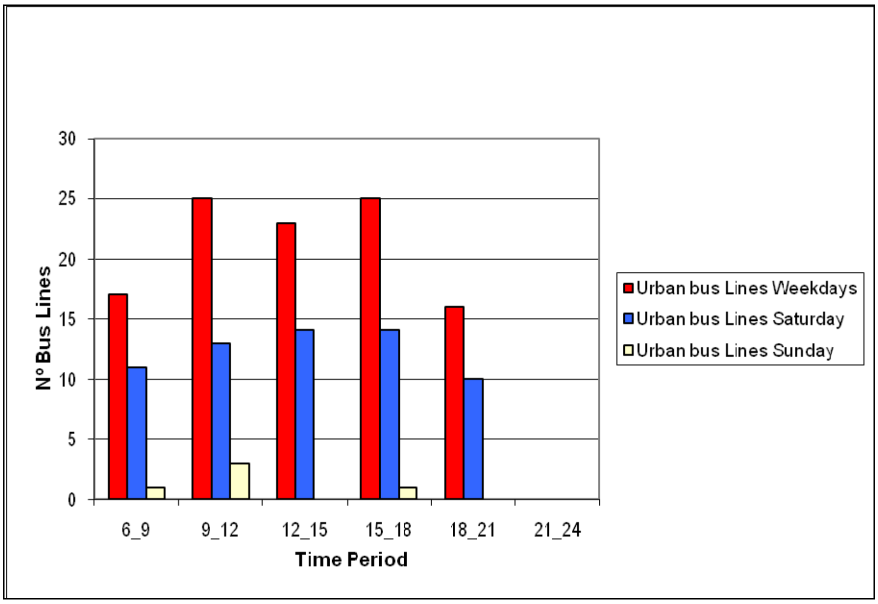


Chart 6.3 – Nº of Urban Bus Lines per Day of the Week and Time Period

For the rural bus lines, there is a high number on weekdays reducing considerably on weekends. On weekdays the bus line frequencies tend to reduce linearly througout the day. The high peak services occur between 6h and 9h and between 12h and 15h time periods, wich is related to the fact of most rural bus lines belong to Arriva which as already refered, is generally adjusted to school schedules (Chart 6.4).

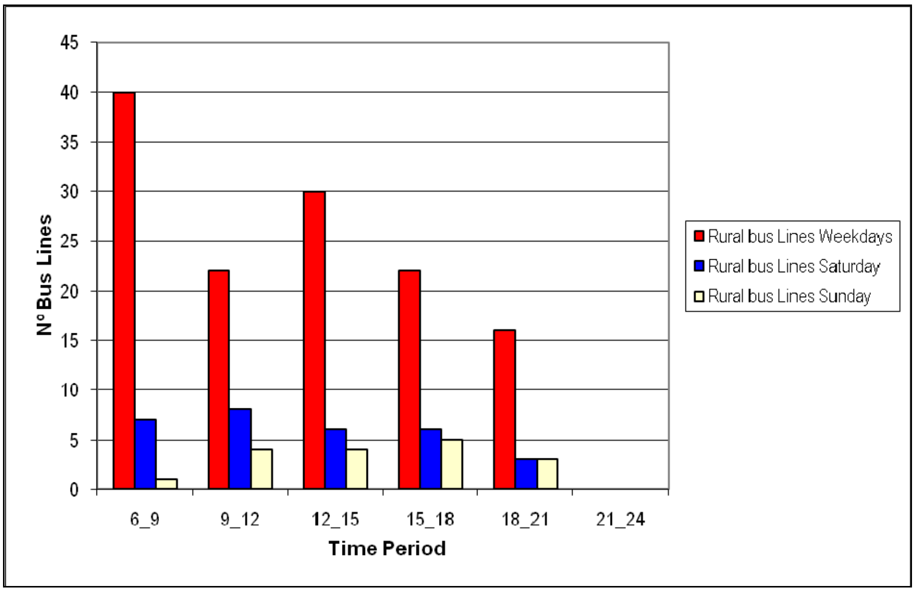


Chart 6.4 – Nº of Rural Bus Lines per Day of the Week and Time Period

But most of the rural bus lines have a daily bus line frequency inferior to 5 trips (Table A3 and Chart A1 in Appendix A).

56.2.3.2. The Metro Line

The Metro line connects a neighbor city of Vila do Conde, Póvoa de Varzim, to Porto. It has a double line with 14.8 Km of extension and 13 stations (Figure 6.9). Located in the coastal area of Vila do Conde with a NW/SE orientation, it serves mostly the city and coast villages. It provides two types of services a normal service that stops at all stations and an express service that only stops in 4 stations.

The transport service provided by the Metro is daily and almost a 24 hour service. On weekdays 60 trips (38 normal and 22 express) are provided, on Saturdays, 56 (38 normal and 18 express) and on Sundays, 38.

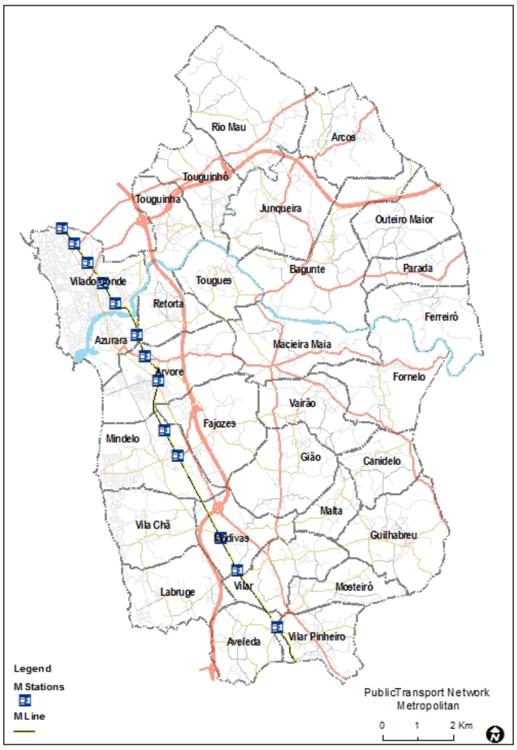


Fig 6.9 – Map of Metro Line and Stations

Along the day on weekdays the higher frequencies occur between 9h and 21h (Chart 6.5). The operating time window is large, including trips after midnight offering 3 trips between 0h and 6h.

On Saturdays, although lesser trips are provided, between 9h-15h occur higher frequencies than on weekdays, because more express trips are concentrated in this time period, and only circulate until 18h. On Sundays, the frequency is constant between 9h-24h.

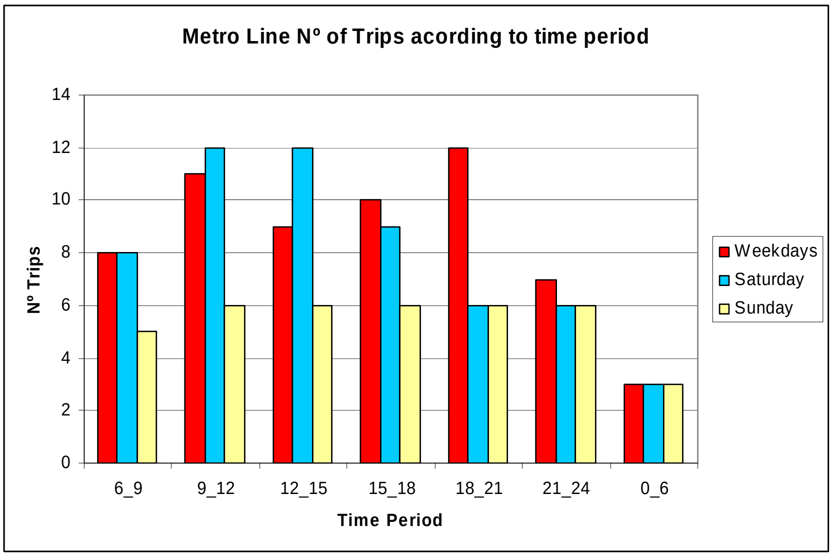


Chart 6.5 – Nº of Trips according to Day of the Week and Time Period

6.2.4. Summary

The municipality of Vila Conde, besides having a growing population, also has an aging population. Its territory covers an extensive rural area, with low population densities. The spatial distribution of the resident population is not homogeneous, concentrated mainly in the city and in coastal villages.

Vila do Conde has 7 public health centers that in 2008 served a total of 59124 users and 161190 medical consultations were provided, which can be assumed to be trips made to the health center. The health centers of Vila do Conde and Junqueira have the most extensive service areas.

The transport system of Vila do Conde is composed of bus and metro services. The metro has one service line while the bus network is very extensive with 6 urban and 26 rural lines.

The metro service when compared to the bus network provides a large time window service. It operates every day of the week connecting Vila do Conde and in-between villages to Porto, and almost throughout the whole day. On weekdays it has a very high frequency, which reduces slightly on Saturdays. Although on Sundays there is a significant reduction of trips, it still has a very high frequency when compared to bus lines.

As for bus services, the weekend schedules, when compared to weekdays, reduce significantly, being almost inexistant on Sundays, especially the rural services. In the night period, after 21h, no urban or rural bus services are provided.

However, urban bus lines have high frequencies when compared to the rural services. These routes and schedules are generally adjusted to school requirements and most of the bus lines (61%) make 5 or less daily trips on weekdays.

6.3. Transport Demand and Supply Analysis

The present study was developed focusing on weekday schedules, because it became clear in the previous data analysis that the access to public bus services in the rural areas is very low on weekends (see Table A3 in Appendix A)

6.3.1. Access to Transport System

6.3.1.1. Coverage Analysis

The coverage analysis of the population and area of the transport network consisted of creating walking distance buffers around the 352 bus stops and 13 Metro stations using the multimodal transport network. Two classes of walking distances were considered, an ideal distance of 150 m and a more practical distance of 300m (Fig 6.10).

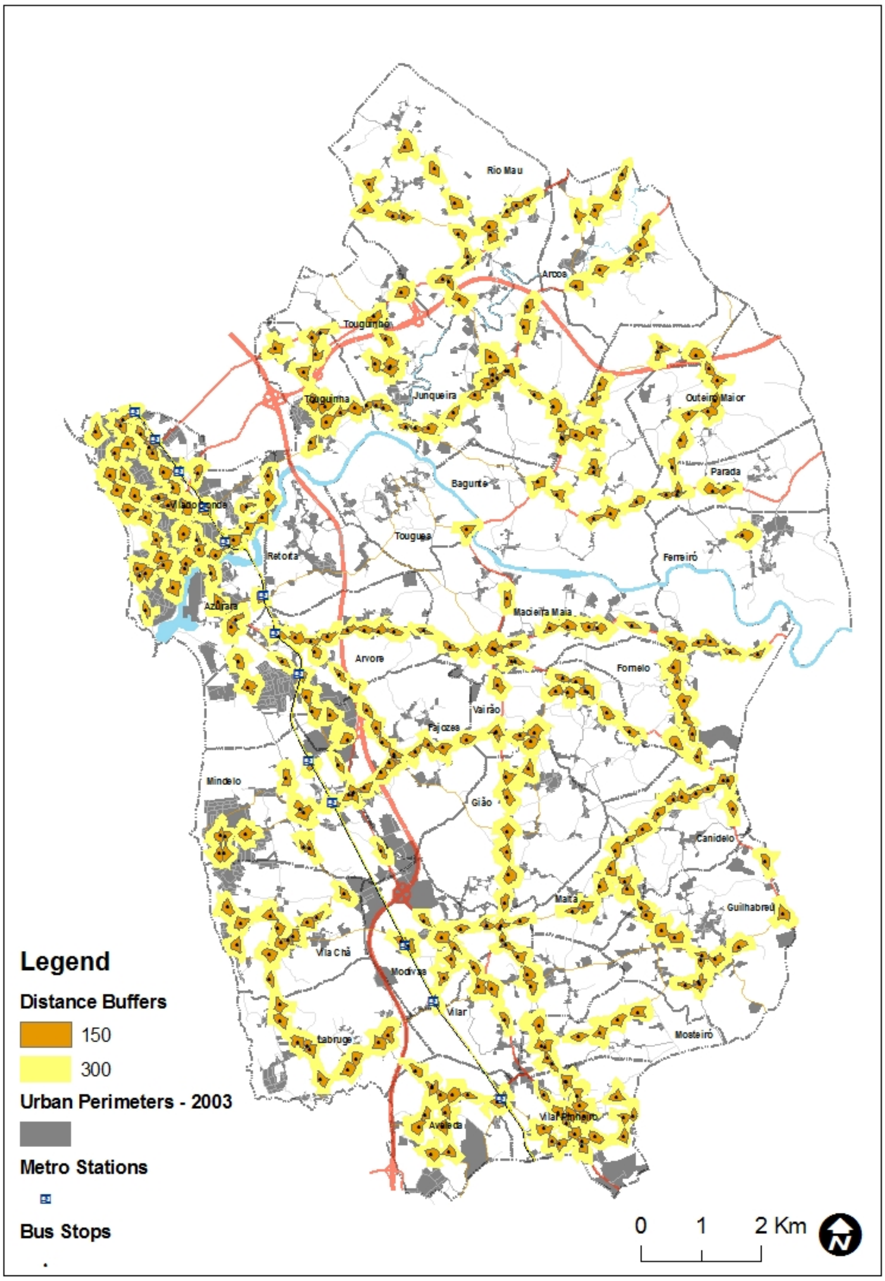


Figure 6.10: Coverage analysis of Bus Stops and Metro Stations

Observing the resulting map, it is clear there is a great dispersion of bus stops throughout the territory and a significant concentration in the city area. The larger villages, with very disperse population, have bus stops along main roads leaving other habited areas uncovered, such as Labruge, Mindelo and Árvore in the coastal area, Fajozes, Canidelo, Gião, Guilhabreu and Modivas in the south interior area, and Arcos, Bagunte, Junqueira, Outeiro, Parada, Rio Mau and Ferreiró in the north area. This last village outstands for having only one bus stop.

The resulting coverage for the 150 m class is very low, as only 7, 7% of the territory and 14% of the population is covered by transport service (Tables 6.3 and 6.4). If analyzing exclusively the rural areas, the population coverage values reduce to 10% of the population living in those villages (Tables 6.5 and 6.6).

Table 6.3: Area Coverage of Transport System - Municipality of Vila Conde

Buffer class (m)	km2	%
150	11,4	7,7%
300	62,3	41,8%

The analysis results for the 300 m buffer class demonstrate that population and area coverage values increase significantly, more than three times. In this case, the transport network covers 42% of the territory and 51% of the population (for more detailed information see Table A4 of Appendix A).

Performing a distinct analysis for urban and rural areas, it is possible to verify that in the city almost 85% of the residing population is covered and in the rural areas, generally characterized by disperse population, only 50% of the population has access to the transport network. In terms of absolute values, the covered population is very similar, 21540 habitants in the city (6,7km) and 24211 individuals in the rest of the territory (142.3 km2). These values demonstrate the unbalanced opportunity to access transport between city and rural villages (Tables: 6.5 and 6.6).

Table 6.4: Population Coverage of Transport System – Municipality of Vila Conde

Buffer class (m)	Population	%	HM 0-14	HM15-24	HM25-64	HM 65+
150	10685	14,4%	1917	1680	5850	1238
300	45751	61,5%	8345	7049	25124	5233

Table 6.5: Population Coverage of Transport System – City of Vila Conde (total pop. 25731)

Buffer class (m)	Population	%	HM 0-14	HM15-24	HM25-64	HM 65+
150	5749	22,3%	1046	915	3175	613
300	21540	83,7%	4092	3474	11791	2183

Table 6.6: Population Coverage of Transport System– Rural area of Vila Conde

(total pop. 48660)

Buffer class (m)	Population	%	HM 0-14	HM15-24	HM25-64	HM 65+
150	4936	10,1%	871	765	2675	625
300	24211	49,8%	4253	3575	13333	3050

6.3.1.2. Frequency of Transport Service

6.3.1.2.1. Bus Lines Frequencies

The bus lines frequencies are higher in the city area and along main roads. The rural villages of Touguinhó, Rio Mau, Árvore, Macieira, Fornelo, Modivas, Vilar and Vilar Pinheiro, wich are crossed by major roads, have access to a greater number of buses. The rest of the other rural villages have all less than 12 daily buses on weekdays, while Arcos, Outeiro, Ferreiró and Aveleda are poorly served with less than 6 daily buses (see Figure 6.11 and Table A5 of Appendix).

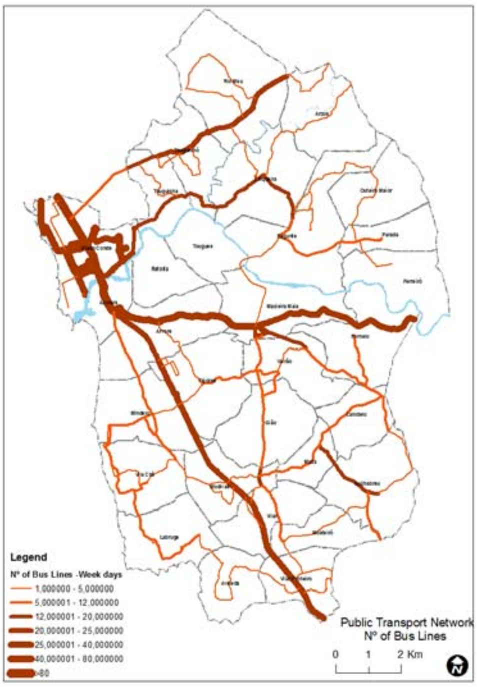


Figure 6.11: Number of Bus Lines

However, even for the better served villages, it is not certain that they are well served, since this analysis only quantifies the number of buses passing through the village territory, and they may not be taking potential users where they want to go.

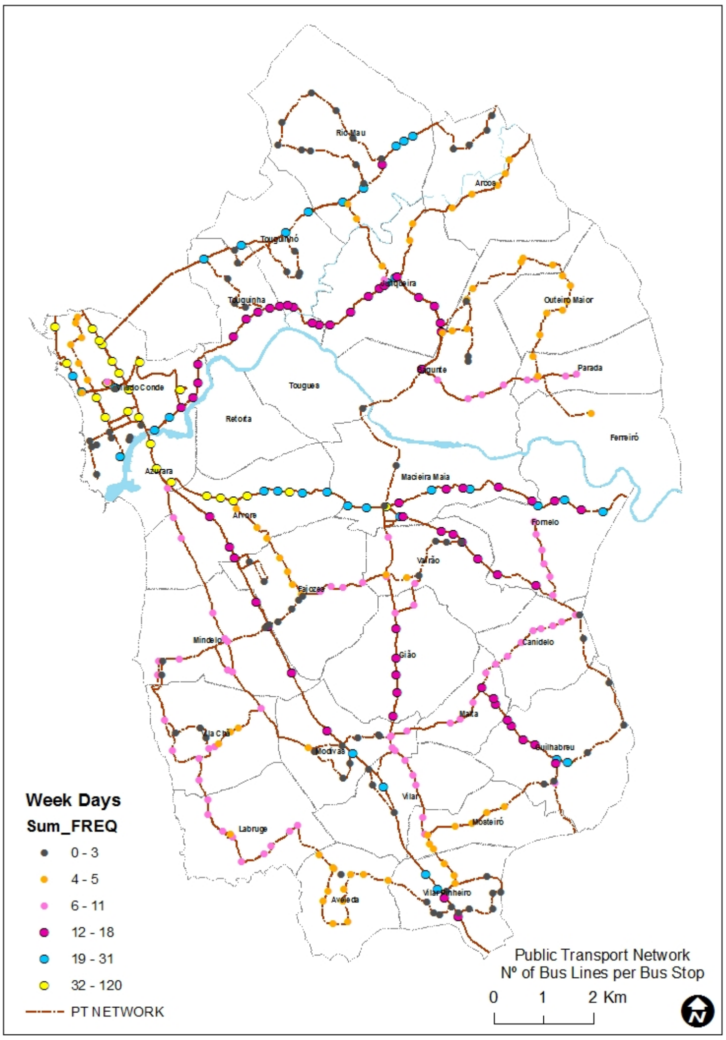


Figure 6.12: Number of Bus Lines per Bus Stop

There are 85 bus stops (24% of total bus stops) with 3 or less buses passing by and 155 stops (44% of total bus stops) with 5 or less buses. An extensive continuous geographic area in the North interior, affecting the villages of Arcos, Ferreiró, Outeiro, Bagunte and Rio Mau, have these low frequencies (Figure 6.12). In the South, area a similar situation is identified for the Mosteiró, Aveleda e Vilar do Pinheiro. These bus stops could be leveraged for the development of a DRT service typologie with predefined stops.

6.3.1.2.2. Metro Line Frequency

The number of the trips provided by the Metro system is constant along the line, being 60 on weekdays. But, because it provides two types of services, some of the lines do not stop at all stations. The normal service stops at all stations although the express services only stops at 4 stations. So the population residing close to the metro stations of Árvore, Mindelo and Vila do Conde have greater access to this transport mode (Figure 6.13)

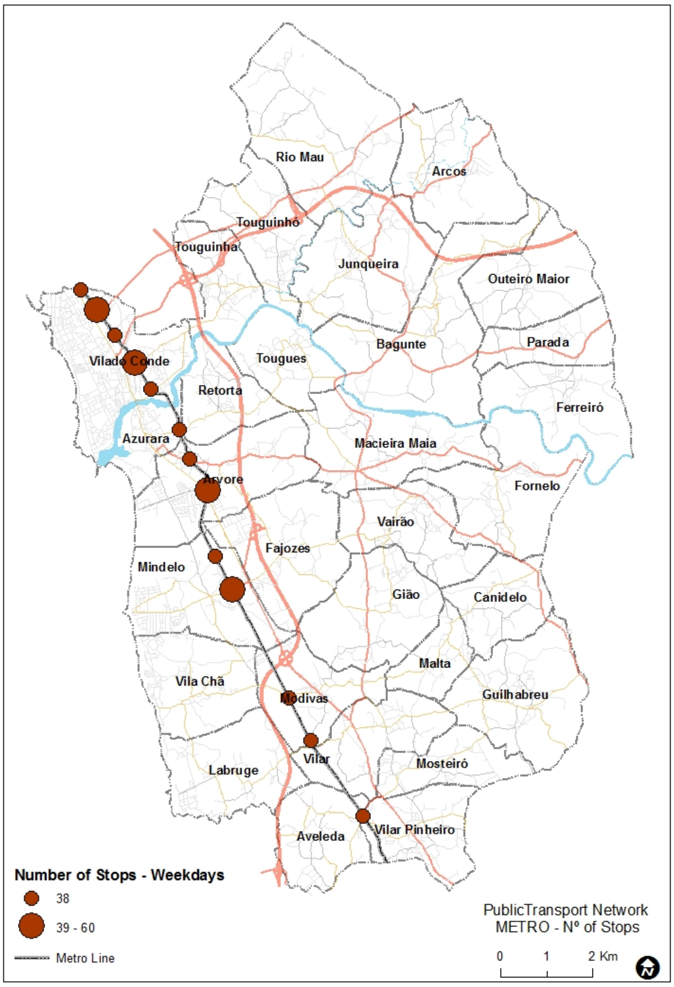


Figure 6.13: Number of Metro Stops

6.3.1.3. Connection Analysis

6.3.1.3.1. Connections between City and Villages

The city of Vila do Conde is the most important commercial and service center of the municipality, where most of the public services are concentrated. The population residing in rural villages necessarily has to travel there with frequency, so an efficient connecting public transport system is essential.

The villages with greater access to public transport towards the city are the near villages of Azurara and Árvore. In the North region of Vila do Conde the most north/eastern villages of Rio Mau, Arcos, Outeiro Maior and Ferreiró have very low access to the city, while in the south Mosteiró and Aveleda are strongly evidenced (Figure 6.14,Table A5 in Appendix)

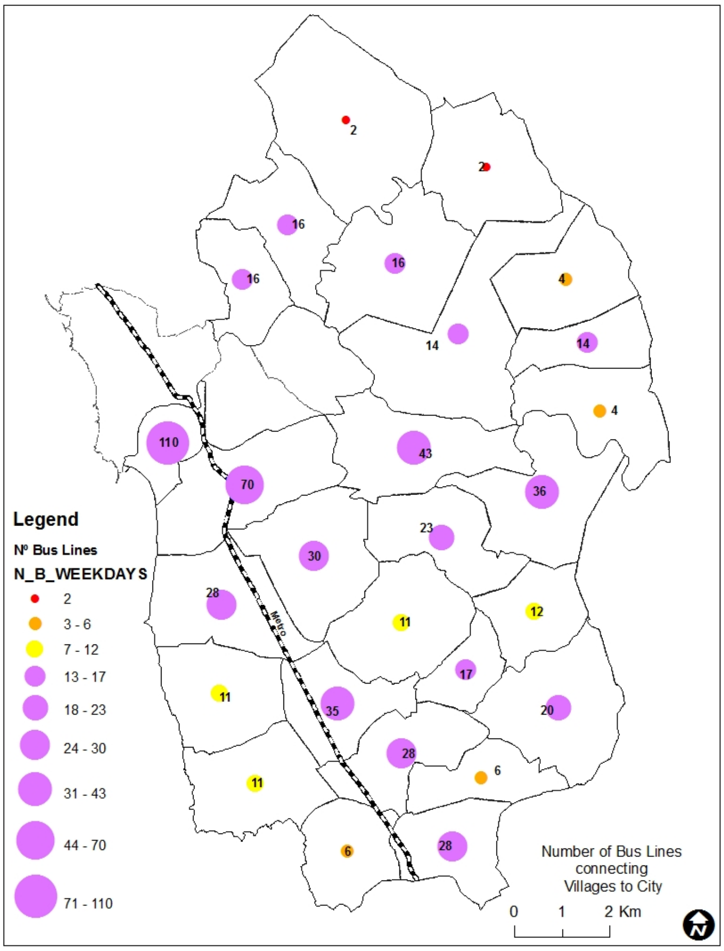


Figure 6.14: Number of Bus Lines connecting Villages to City

6.3.1.3.2. Connections between Villages and Health Centers

The areas of influence of the 7 health centers define which villages and resident population they serve (Figure 6.15). Therefore, the public transport connections between the villages and the respective health center are fundamental. Because the health center of Caxinas has a very small area of influence, with very short trip distances, it was not considered in the study.

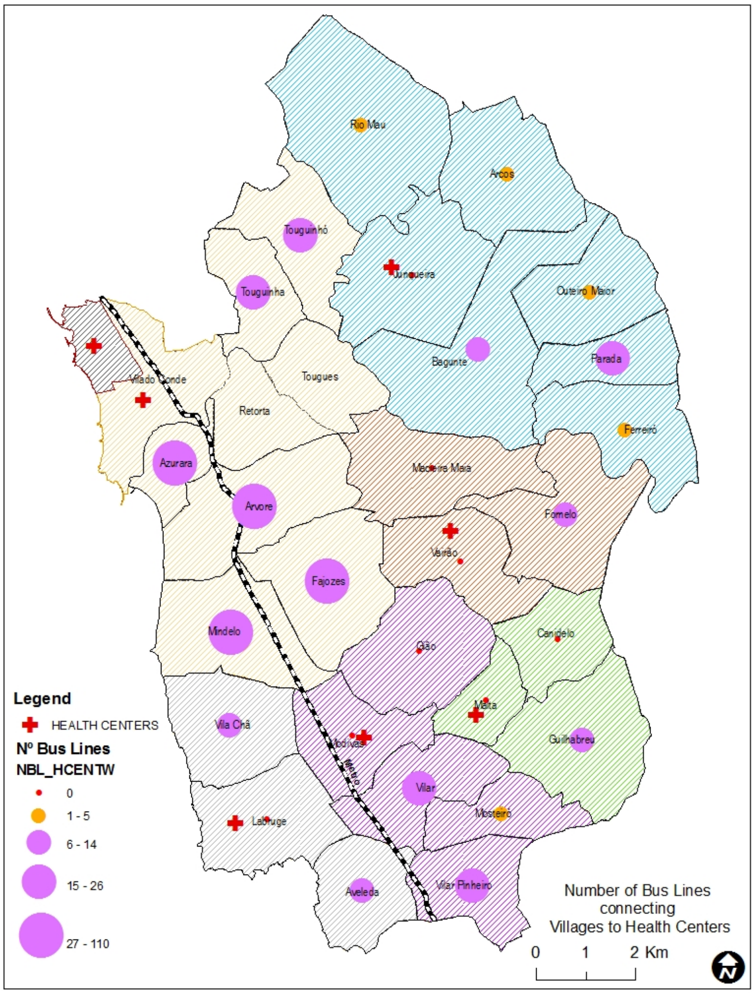


Figure 6.15: Number of Bus Lines connecting Villages to Health Centers

The villages influenced by the health center of Vila do Conde, which has the most extensive area of influence, are those that have most efficient connecting transport service. On the contrary, the villages served by the health center of Junqueira are generally poorly served of connecting transport, as four of the 6 villages have 5 or less daily buses (see Table A6 of Appendix).

Canidelo, Gião and Macieira da Maia, although having bus connections to villages where the respective health center is located, these are very inadequate. In the case of Canidelo, the destination bus stop in Malta is 1 km away from health center. As for Gião, the destination bus stop in Modivas is more than 1 km away from the health center and finally, the origin bus stops in Macieira are spatially concentrated, leaving almost whole territory of the village uncovered. Therefore, these 3 villages were considered as not having connecting transport system to health centers.

6.3.1.3.3. Intermodal Connections

The Metro Line connects the municipality of Vila do Conde to neighbor municipalities and in particular to a very important city center, Porto, where many local habitants work and study. The intermodal connection between the bus lines and the metro line is of great importance. This section aims to evaluate if all rural villages have bus connections to the metro line and with what frequency.

When analyzing the bus lines, excluding the urban lines, which pass less than 100 meters away from a metro station, 15 rural bus lines are identified (Figure 6.16 and Table 6.7).

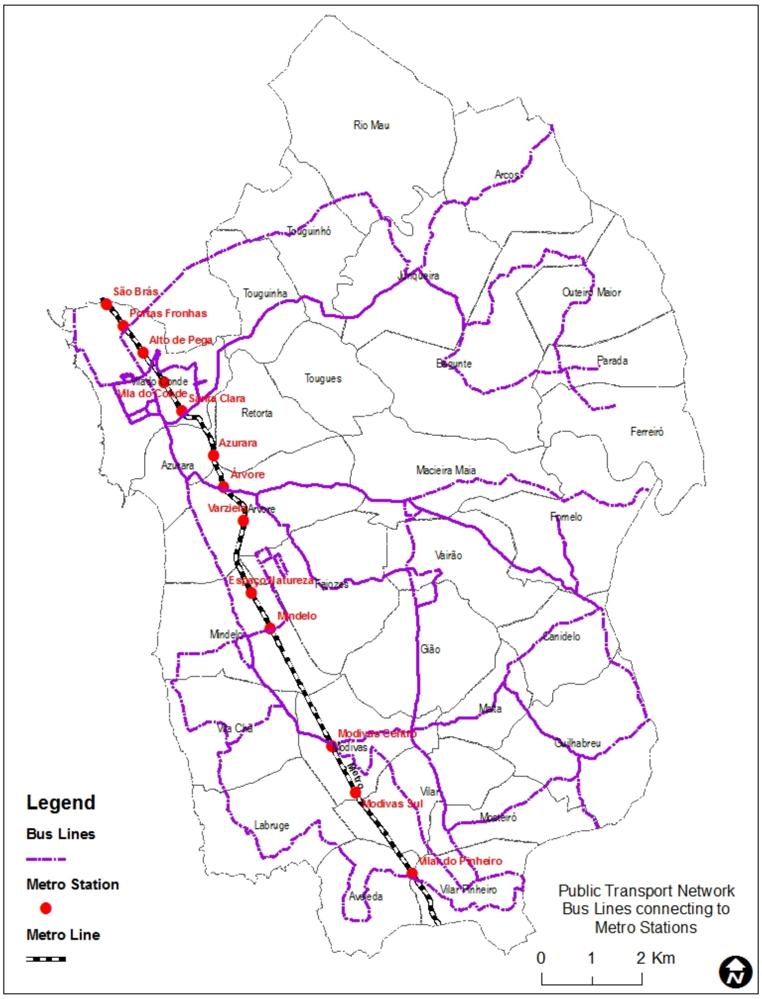


Figure 6.16: Map of Bus Lines connecting Villages to Metro Stations

Observing the map, it is possible to identify 6 metro stations with bus lines passing close, which are Portas Fronhas and Santa Clara, both in the city, and Árvore, Mindelo, Modivas Centro and Vilar Pinheiro. However, when selecting bus stops within a distance of 100 m from metro station only 3 bus stops are identified, situated near to the Árvore, Modivas Centro and Vilar Pinheiro stations. For a 200 m buffer, 5 stations are identified to be served of a near bus stop – Portas Fronhas and Santa Clara, in addition to the 3 stations before referenced. Although there is a bus line passing next to Mindelo's station, the nearest bus stop is more than 350 m away.

Table 6.7: Metro Stations and Connecting Bus Lines

METRO STATION	VILLAGE	Nº METRO TRIPS	Nº BUS LINES	FREQ B LINES	NAME BUS LINES
Varziela	Arvore	60			
Arvore	Arvore	38	8	49	206, 207, 208, 210, 211, 740, PV_SAN, PV_ST
Azurara	Azurara	38			
Mindelo	Mindelo	60	1	2	203
Espaço Natureza	Mindelo	38			
Modivas Centro	Modivas	38	1	2	201
Modivas Sul	Modivas	38			
Alto de Pega	Vila do Conde	38			
Portas Fronhas	Vila do Conde	60	1	2	215
Santa Clara	Vila do Conde	38	2	14	213, 214
São Brás	Vila do Conde	38			
Vila do Conde	Vila do Conde	60			
Vilar do Pinheiro	Vilar do Pinheiro	38	2	8	202, 205

metro station with a bus stop within a 100 meters distance

Relating the bus lines to metro stations and villages we verify that all rural villages have a bus line connecting it to a metro station, but some with very low service frequencies and some with distant metro stations (Figure 6.17; Table A7 of Appendix).

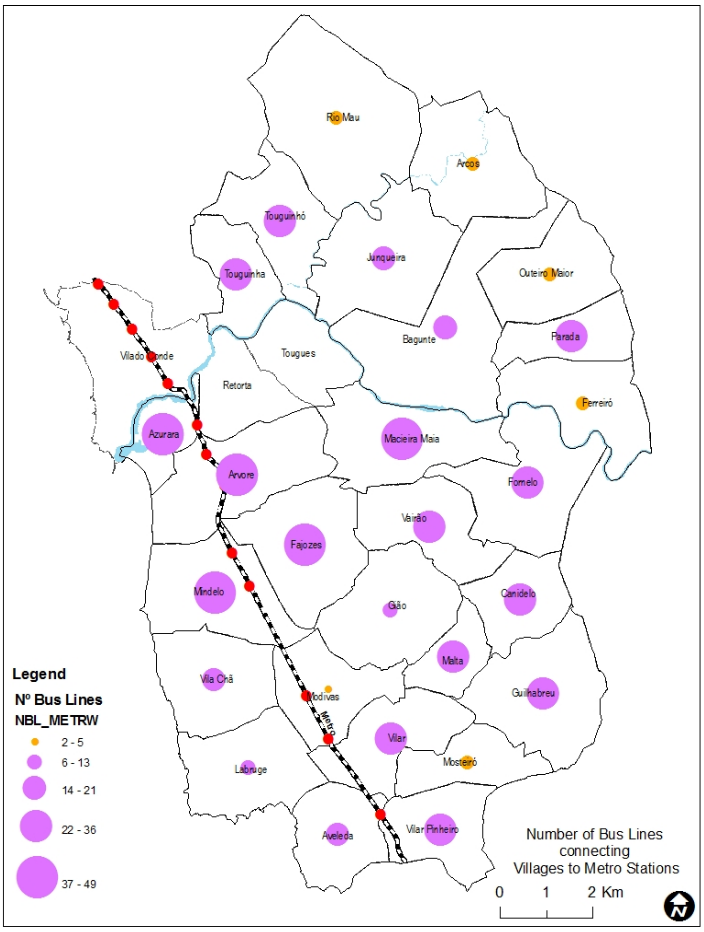


Figure 6.17: Number of Bus Lines connecting Villages to Metro Stations

All northern villages connect to city metro stations, but Rio Mau, Arcos, Outeiro Maior and Ferreiró have 5, or less, daily connecting buses. The south villages connect to the various existing stations. However, strangely, the villages of Canidelo, Guilhabreu and Malta only have connecting bus service to the station of Árvore, when the closest stations are Modivas or Vilar do Pinheiro.

6.3.2. Accessibility Analysis

The accessibility analysis aims to measure, in time units, the capacity of the public transport system of Vila do Conde to take individuals from residing villages to important centers, in particular the city and health centers. The isochrone map allows to identify areas that although are not far in distance are time expensive, which generally is explained by lack of direct transport or involving long walking distance to origin or destination bus stop/station.

This analysis was developed using the modeled multimodal transport network (pedestrian, metro and bus). The assumed impedance values relative to modal speed and stopping time were: bus[14]: 25 Km/hour; metro[15]: 28 km/hour; walking[16]: 1m/second;

The resulting isochrone maps use the 3 transport modes when necessary, always choosing the shortest path, and illustrates the ideal performing time of the system because, in case of modal change, it supposes there is always a connecting bus/metro at that moment passing by at modal change points. In practice this is very improbable, therefore the simulated map results for time cost have probably, when compared to reality, improved values.

6.3.2.1. Accessibility from Villages to City

Only 56% of the territory is less than a hour away from the city center. The areas that are less than 40 minutes away are those that are near main roads and metro line, where there are closer bus stops and metro stations.

In the north interior region, some of the most distant villages such as Arcos, Ferreiró and Outeiro have their whole territory completely outside the 60 minute isochrone, wich means they are more than an hour away from the center of Vila do Conde using the actual transport system.

Next, it is the villages of Rio Mau, Guilhabreu and Aveleda that are noticed for having almost the entire area more than a hour away from the city (Figure 6.18).

Making a shortest path matrix between the villages and city, it is possible to analyse travel distance versus time distance and verify that traveling time is not linearly dependent of distance. Not always are the most distant villages those with longer time travel distances (see table A8 of Appendix). Aveleda, wich is 13 300 m away from city center, takes 71 minutes to make that trip, as for Guilhabreu, wich is 15700 m of distance, only takes 65 minutes. This is explained by the inexistence of bus stops in Aveleda’s village center, so the calculated trip includes the necessary walking distance from the civic center to the closest bus stop.

[14] commercial speed of Arriva;

[15] average of speed values found in studies (see FEUP; Metro do Porto, 2007)

[16] empirical estimation

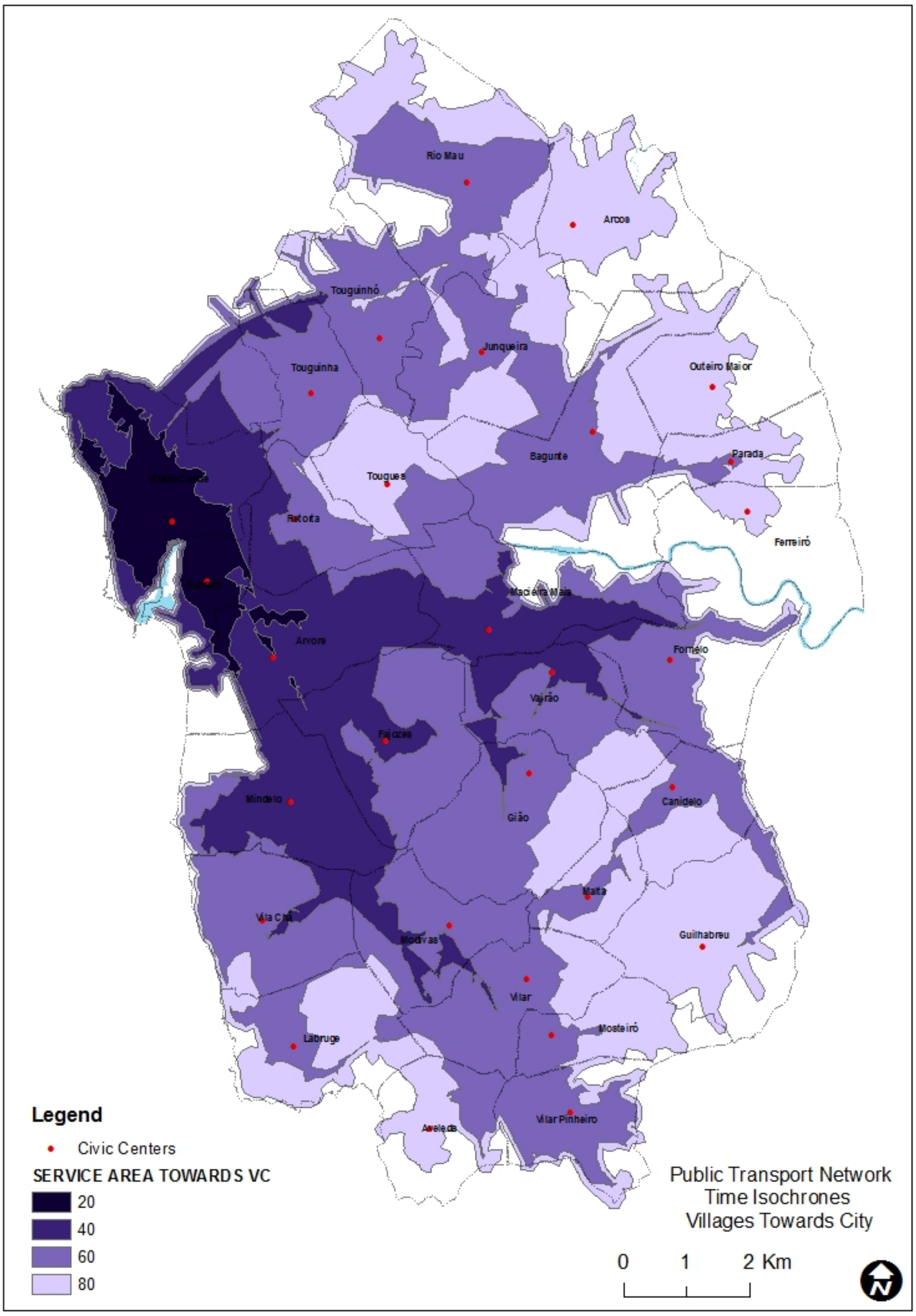


Figure 6.18: Map of Time Isochrones when travelling from Villages towards City

6.3.2.2. Accessibility from Villages to Health Centers

The resulting isochrone maps for health center areas illustrate that most of the villages associated to health centers are within the 40 minute isochrone. This is the case of the villages served by the health centers of Vairão, Malta, Modivas and Vila do Conde, with the exception of Fajozes. In contrast, some villages of the service areas of Junqueira and Labruge have low accessibility to health centers, taking generally at least 60 minutes to travel towards them. This is the case of Outeiro Maior, Parada, Ferreiró and Aveleda (Figure 6.19, Figure 6.20, Figure 6.21, Figure 6.22, Figure 6.23 and Figure 6.24).

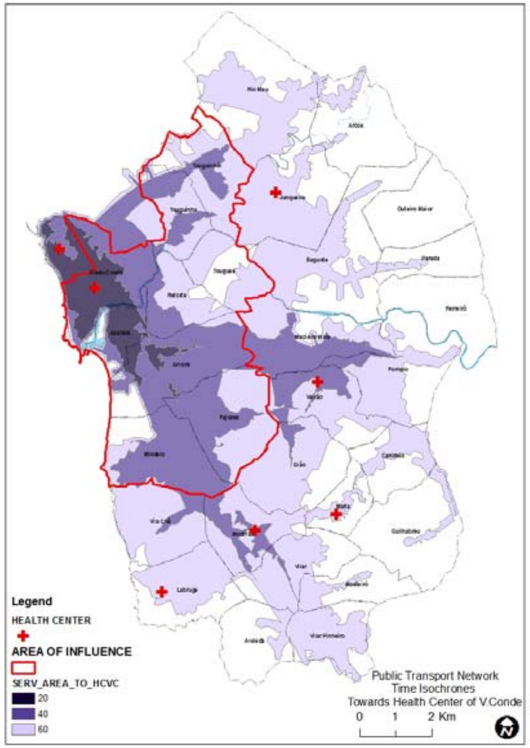


Figure 6.19– Isochrone Map to Health C. V.Conde

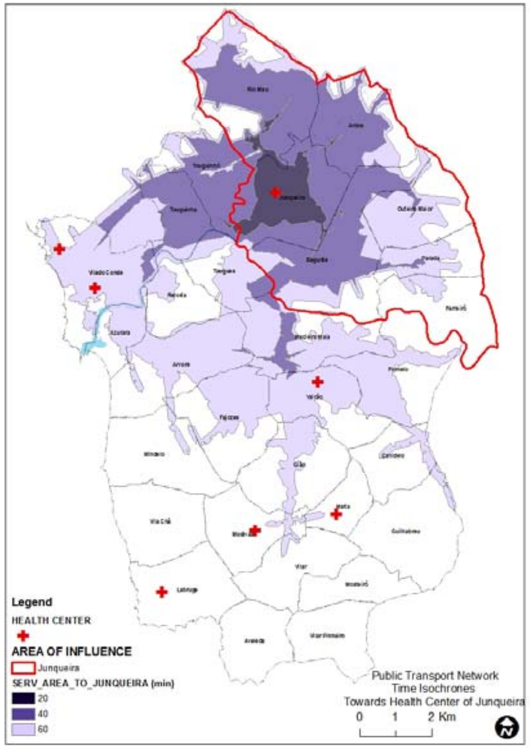


Figure 6.20 – Isochrone Map to Health C. Junqueira

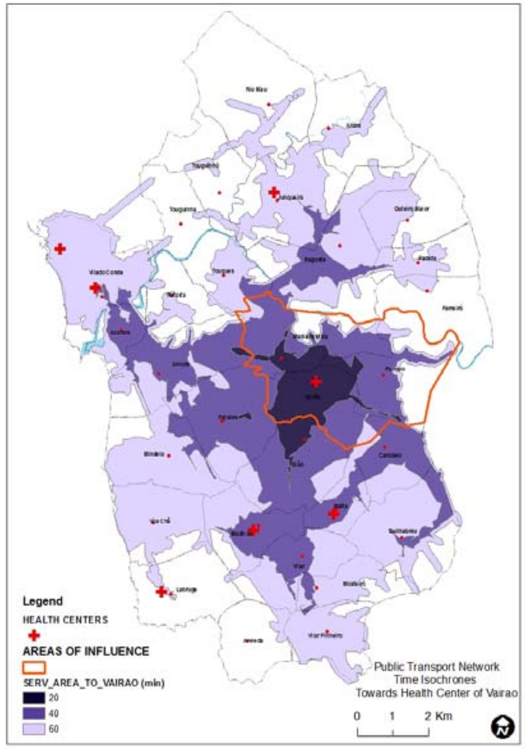


Figure 6.21– Isochrone Map to Health C Vairão

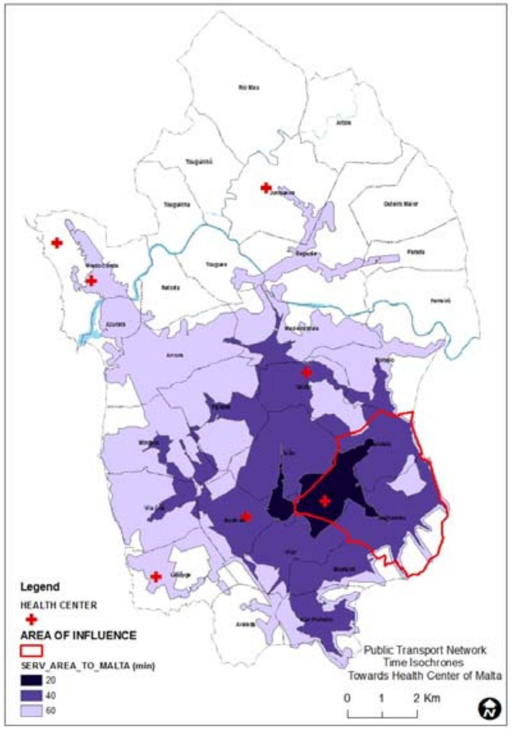


Figure 6.22– Isochrone Map to Health C. Malta

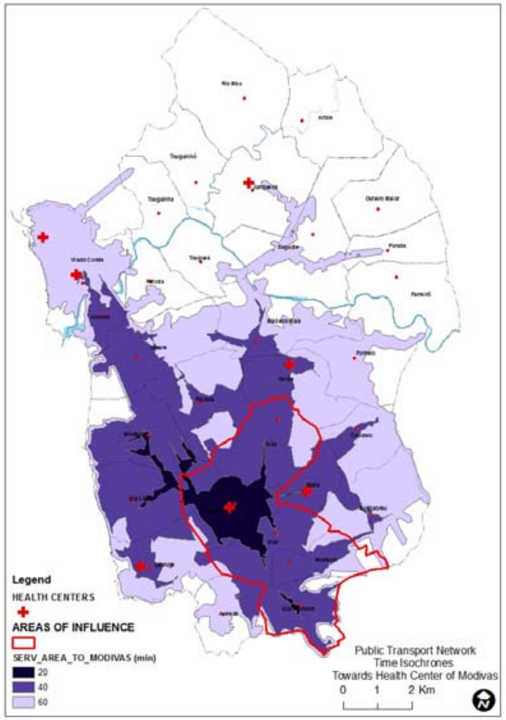


Figure 6.23– Isochrone Map to Health C. Modivas

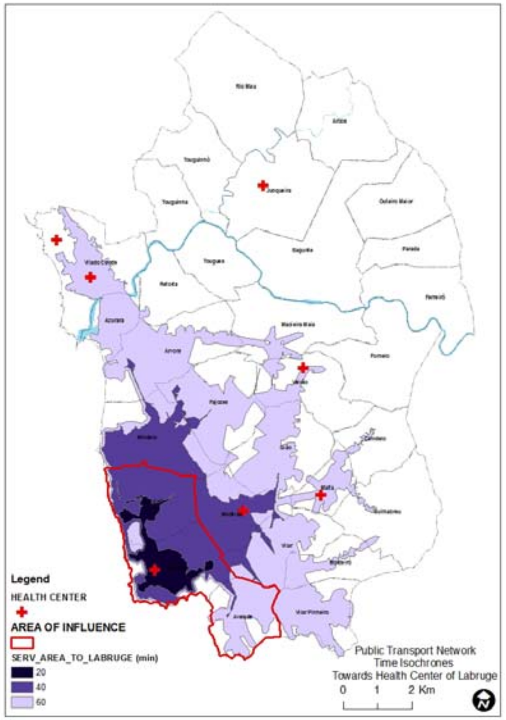


Figure 6.24– Isochrone Map to Health C. Labruge

6.3.3. SPATIAL DRT NEED INDEX

The previous indicators of the access and accessibility analysis have allowed to identify village areas that do not have access to public transport and villages with low frequency of services, poorly connected to important centers or other modes of transport, or unreasonably distant in time cost from important centers. All these are indicators of supply deficiencies and weaknesses in existing public transport services.

These weaknesses can be minimized or resolved with the implementation of DRT services. To summarize the analysis results, the Spatial DRT Need Index (see Section 5.5) was calculated (Table 6.8, Fig 6.25).

Table 6.8: SPATIAL DRT NEED INDEX

RURAL VILLAGE	Nº Buses to city Weekdays	Nº Buses to Metro Weekdays	Nº Buses to H Centers Weekdays	300m Buffer Coverage Area (%)	Time Isochrone to City	Time Isochrone to HC	DRT NEED INDEX
Arcos	3	3	3	3	3	2	3
Arvore	1	1	1	1	2	2	1
Aveleda	3	2	3	2	3	3	3
Azurara	1	1	1	1	1	1	1
Bagunte	2	2	3	2	2	2	2
Canidelo	2	1	3	3	2	2	2
Fajozes	1	2	1	1	2	2	2
Ferreiró	3	3	3	3	3	3	3
Fornelo	1	1	2	2	2	2	2
Gião	2	2	3	3	2	2	2
Guilhabreu	1	1	2	2	3	2	2
Junqueira	1	1	1	1	2	1	1
Labruge	2	2	1	1	3	1	2
Macieira da Maia	1	1	3	3	2	2	2
Malta	1	1	1	1	2	1	1
Mindelo	1	2	1	1	2	2	2
Modivas	1	3	1	1	2	1	2
Mosteiró	3	3	3	3	3	2	3
Outeiro	3	3	3	3	3	3	3
Parada	2	2	2	2	3	3	2
Retorta							
Rio Mau	3	3	3	3	3	2	3
Tougues							
Touguinha	1	1	1	1	2	2	1
Touguinhó	1	1	1	1	2	2	1
Vairão	1	1	1	1	2	1	1
Vila Chã	2	2	2	2	2	2	2
Vilar	1	2	1	1	2	2	2
Vilar do Pinheiro	1	2	1	1	2	2	2

The Spatial DRT Need Index map identifies 6 rural villages with Level 3 (High) needs of complementary transport services: Rio Mau, Arcos, Outeiro Maior and Ferreiró in the northern region and Mosteiró and Aveleda in the south. Their transport system has various identified deficiencies.

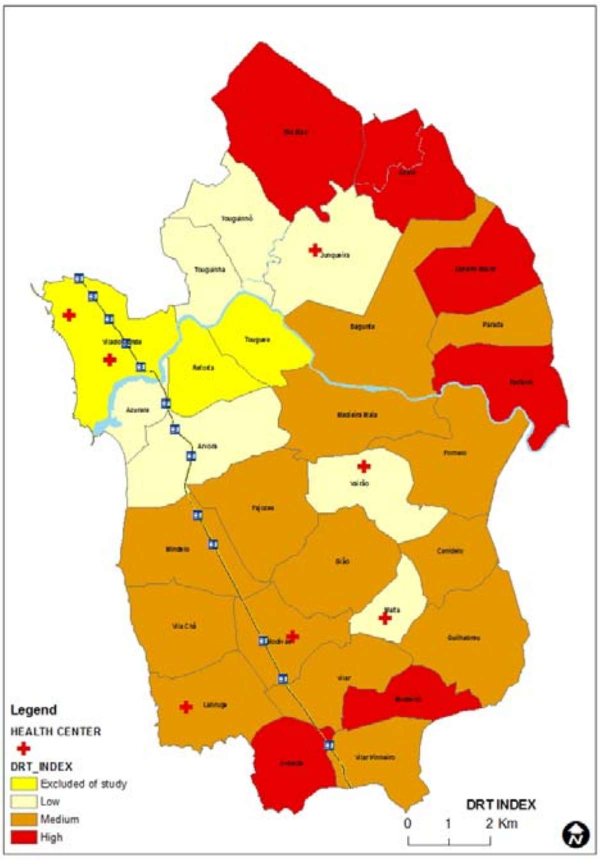


Figure 6.25– SPATIAL DRT NEED INDEX Map

With the exception of Aveleda, all have low transport coverage and their existing transport connections with the city, metro and health centers also have very low frequencies. Aveleda, however, has a slightly better bus connection to the metro system and coverage area.

All identified villages have low accessibility to the city. Most of their territory is more than 60 minutes distance from the city center. As for the travelling cost towards the respective health centers, it is the villages of Outeiro Maior, Ferreiró and Aveleda that have more significant time constraints.

The 7 villages with Level 1 (Low) needs of DRT services are those with higher levels of access and accessibility indicators. These are Azurara, Árvore, Touguinha and Touguinhó, which are near the city and are linked to the health center of Vila do Conde. The other 3 are more distant villages of the interior region of the municipality, Vairão, Malta and Junqueira, with high levels of transport coverage, frequency and bus connections to the city and metro. They are all health service centralities, which makes of them important local centers. Their only low indicator is the time distance when travelling to the city.

For the villages with Level 2 (Medium) needs of DRT service, which are the majority of them, either they generically have medium results for all transport aspects studied, which is the case of Vila Chã and Bagunte, or they have variable levels for the different indicators which balance each other.

6.4. CONCLUSIONS

The case study aimed to develop a UNA to study the viability of introducing a DRT system in Vila do Conde, particularly in the rural areas, addressing general mobility problems and in particular, those associated to health issues. The UNA methodology developed in Chapter 5 was applied with the objective of identifying areas of the territory where the operation of DRT services is necessary as well as recognizing possible service typologies to implement.

Various indicators of the viability of implementing a DRT service in Vila do Conde were found:

- The municipality of Vila Conde, besides having a growing population has also an aging population, which anticipates greater mobility demands and constraints. Its territory covers an extensive rural area, with low population densities, where the fixed route buses do not invest much because of low potential patronage.

- The transport system of Vila do Conde is composed of bus and metro service. It is the bus network which provides a more extensive transport service in the rural areas, but these services are practically inexistant on weekends and nonexistent at all during the night period. With some exceptions, the rural bus lines frequencies are low and ajusted to school schedules. The lowest frequencies are verified in the villages of Arcos, Outeiro Maior, Ferreiró and Aveleda with less than 6 daily buses.

- Only 10% of the population of the rural area have a bus stop within a walking distance of 150 m and 50% at 300 m, leaving around 24 449 individuals uncovered of public transport system.

- There are 155 bus stops with 5 or less daily buses passing by. These are distributed mainly in the villages of Rio Mau, Arcos, Bagunte, Outeiro Maior, Ferreiró, Aveleda, Mosteiró and Vilar Pinheiro.

- The transport connections of rural villages such as Rio Mau, Arcos, Outeiro Maior Ferreiró, Mosteiró and Aveleda to the city are undersupplied and at least an hour distance away also for Rio Mau, Arcos, Outeiro Maior Ferreiró, Guilhabreu and Aveleda.

- The transport connections to health centers are very reduced once again in the villages of Rio Mau, Arcos, Outeiro Maior Ferreiró, Mosteiró e Aveleda and as for the villages of Canidelo, Gião and Macieira da Maia are inappropriate or because destiny bus stops are located at least 1Km distance from health center or because almost whole territory of Macieira does not have bus service. The villages of Outeiro Maior, Parada, Ferreiró and Aveleda require generally 60 minutes trips to health center.

- The bus connections to metro system are only provided to 5 metro stations, Portas Fronhas and Santa Clara, in the city, Árvore, Modivas Centro and Vilar Pinheiro. For the Mindelo station, which provides high trip frequencies, it does not have adequate bus connections and villages, while Malta, Guilhabreu and Canidelo, which are geographically closer to this station, are connected exclusively to the station of Árvore.

The resulting Spatial DRT Need Index map identifies 6 rural villages with High needs of additional transport services: Rio Mau, Arcos, Outeiro Maior and Ferreiró in the northern region and Mosteiró and Aveleda in the south. Effectively this map summarizes most of the identified constraints.

The Spatial DRT Need Index map when overlaid with map of areas of influence of health centers, suggests the development of two DRT service areas (Figure 6.26), one in the northern region of Vila do Conde (A) and another in the south (B). For an efficient design of DRT system each of these service areas require closer studies and local inquiries. However, the developed

UNA methodology, applied to this case study, made become evident some general indications for DRT service implementation.

DRT service area A:

This DRT service area would serve delimited area, focusing on connecting villages to city center and metro stations of Vila do Conde and Portas Fronhas which have higher trip frequency, as well to the health center of Junqueira. Night (at least until midnight) and weekend services must be provided.

This DRT service area has clearly two centers, the village of Junqueira and city of Vila do Conde, molding a possible DRT concept based on a corridor service with 2 or 3 predefined stops between Vila do Conde and Junqueira which connects to an area-wide service because, with the exception of Junqueira, all the served villages have very dispersed population centers and low population densities, requiring disperse stops (see Figure 2.8)

DRT service area B:

This DRT service area will would serve a delimited area and, because it has an extensive area, it should focus exclusively on connecting villages to metro stations of Mindelo (higher trip frequency), Modivas and Vilar do Pinheiro, as well as to the health center of Malta, Vairão, Modivas and Labruge.

Some routes and schedules can be adjusted to fixed route bus lines and metro, to connect villages to city, developing a DRT with multiple service roles (Figure 2.12), giving passengers access to other public transport systems as well as taking them to health centers and other required active destinations. Because this service area is extensive and focuses in 4 geographic centers, a DRT typology based on predefined stops in a corridor (see Figure 2.5) is a possible scenario, however requiring more additional studies.

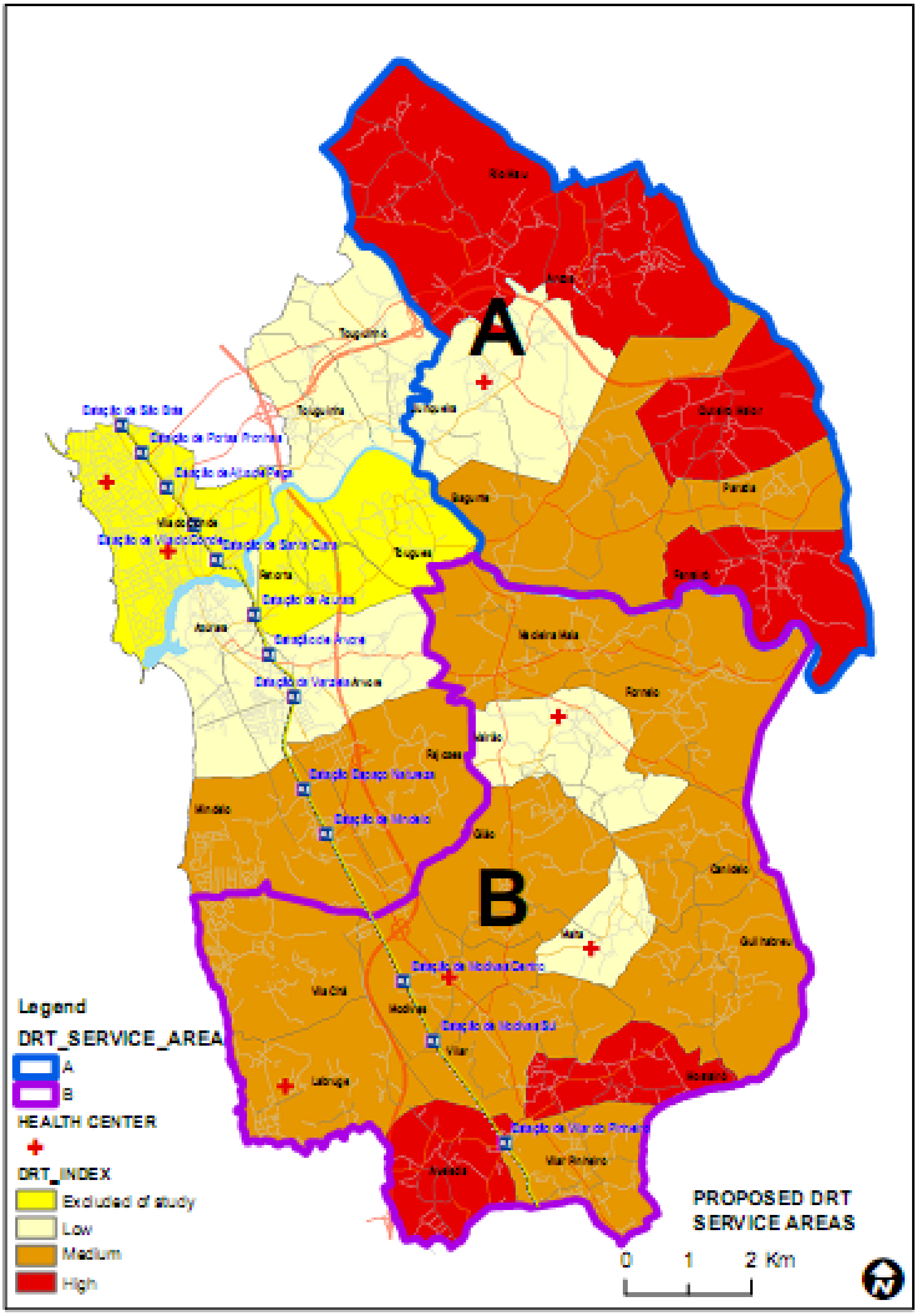


Figure 6.26: Proposed DRT Service Areas

7. FURTHER WORK

The development of further research focusing on each proposed DRT service area is required to obtain additional information about demand needs and constraints of their end user's. Setting up a public survey that questions them about their mobility needs and preferences and asks to identify the difficulties they have to face when using existing public transport system, would be the ideal strategy. This additional information is important to validate proposed DRT service typologies or help define other more adequate schemes.

To identify additional mobility needs and constraints, this research should also be extended to the study of other active destinations such as the shopping center "Outlet Factory" located in Modivas, and the extensive Industrial Zone of Fajozes, which are two very important centers that generate numerous daily movements.

A further development of SPATIAL DRT NEED INDEX could be of interest, focusing on the development of a forth level to widen the classification range. The conception of another intermediate class of DRT NEED would have as a result, a more detailed map, improving the geographical delimitation of focus areas. Moreover, the SPATIAL DRT NEED INDEX could incorporate the assignment of different weights to the indicators which would reflect different priorities.

8. CONCLUSIONS

A new emerging model of mobility, which is more extended in time and space and closer to life rhythms, has generated a new demand of transport, with new needs to which conventional transports systems do not adjust.

The DRT has evolved from the need to attend these changing mobility demands, to rationalize the organization of traditional scheduled public transport, to fight social exclusion and to develop an alternative transport to car use aiming to reduce congestion and pollution.

It is a flexible transport with many possible levels of demand responsiveness that can occur in its various elements, such as route, vehicle, operator, passenger and payment mode. The articulation of the various levels of flexibility of these different elements produces a composite transport system, creating many different possibilities of service typologies and scenarios.

Due to its flexibility, the design of DRT services and the development of its system architecture is a complex process. To identify the system requirements a Users Need Analysis must be developed to help identify who are all of the users that will be involved, and secondly what are the needs of each of the different types of user. The results of this study are the identification of key markets, design of transport network, and required system architecture.

Because transportation problems have necessarily a geographic approach, the application of GIS technologies in this study area is increasing. The need to model the transport network and the spatial data that influences transportation problems has led to the integration of transport models and GIS technologies, emerging a new branch of GIS, called GIS-T.

GIS-T refers to the principles and applications of applying geographic information technologies to transportation problems, adapting the four components of GIS – encoding, management, analysis and reporting – to specific needs of transportation studies.

In this context, GIS functions can be used in three levels. At the lowest level, GIS is used to represent and store land use and network data. At the next level, GIS is used for information manipulation to model transportation data, and at the highest level, used as an analysis tool, where the transportation analyst scrutinizes existing geographic data that leads to the creation of new additional geographic information.

With GIS technologies it is possible to model the transport network and the spatial data that influences it, which is a major requirement in any process of transport planning. Various methods and models have been developed in its context, being most of them based on network analysis procedures.

Because GIS is a powerful tool, also many specific GIS-T applications have been developed and applied in various components of transportation studies such as infrastructure planning, design and management, travel demand analysis, ITS, among others.

GIS has also an important role in the development of DRT systems. Most literature about the application of GIS to DRT systems focus mainly on the operational phase of this transport system, where GIS technologies are widely applied as a tool for managing the network, scheduling and mapping the location of the vehicle in real-time, as well as communicating with costumers.

The scheduling and dispatching are complex operations that critically affect the daily service performance, therefore most DRT agencies, with some exceptions, implement these operations using customized software developed with applications based on digital maps and GIS technology, that improve routing and scheduling and vehicle tracking, contributing to service performance and productivity. Some applications also supply tools to better collect and understand provided statistical data, helping measure performance and develop reports, which are very useful for service monitoring and evaluation.

When vehicles are equipped with a location system they provide additional map information to the TDC, such as vehicle position and status, contributing to greater efficiency of service performance.

Besides being applied to map the real-time location of vehicles and improving dispatching, scheduling and monitoring functions, GIS technologies are also applied in the operation phase to communicate with the customers. The development of internet based DRT information system based on GIS technologies, provides mapped information, in some cases real-time information, to costumers

GIS technologies can also be useful in the initial stages of the planning process, but this issue is rarely referred to in the DRT literature. The Users Needs Analysis, which is at the basis of service design involves the organization and analysis of diverse geographic information that can be better accommodated and processed with GIS technologies to help identify key markets, as well as the services and features that they need, and design of transport network.

An analysis methodology in the context of the User's Needs Analysis of DRT services, applying GIS tools and analysis techniques is proposed in this research study. Its main objective is to identify mobility requirements and constraints of travelers to evaluate feasibility of implementation of DRT within a municipality.

After defining the data requirements and methodology to collect data, an analysis procedure is developed aiming to identify the supply deficiencies and weaknesses in existing public transport services as well as the geographic areas that are most affected, focusing on inadequate access and accessibility, low frequencies, deficient connections between places, or between transport modes. On the other hand, the analysis procedure also aims to study demand, analyzing the geographic distribution of end-users, identifying their active destinations, their schedule needs, and relating them to existing supply.

Finally, the development of a Spatial DRT Need Index helps summarize the analysis results for each indicator. Classifying the final values of each indicator to a level of need to provide DRT services as, 3- High, 2-Medium or 1-Low, and calculating the medium value of all indicators for each geographic area studied, leads to the development of a Spatial DRT Need Index. Mapping these values help identify broader focus areas and give possible indications of required route and network DRT typologies to implement, when layers of existing transport system are added to map.

The developed methodology was applied to the case study of the municipality of Vila do Conde, which aimed to study the viability of introducing a DRT system in Vila do Conde, particularly in the rural areas, addressing general mobility problems and those associated to health issues.

After applying the analysis methodology, it was possible to identify areas of Vila do Conde's territory where the operation of DRT services are necessary leading to the proposal of 2 DRT service areas, as well as possible service typologies to implement in each area.

This study required a vast amount of spatial and non-spatial information that was stored in a GIS system. Its capacity to easily organize, manage and analyze vast quantities of information is a great advantage in the development of transport studies. Its capability to model a multimodal transport network, allowing to simulate flows in the system is also a very powerful tool in the transport context. However, the modeling of the network is a complicated, time consuming process with many exigencies.

Another limitation experienced in the development of the case study was the need to incorporate the transport schedules into the modeled network system, which was not possible. At present the integration of the temporal component in GIS-T technologies is still a developing challenge.

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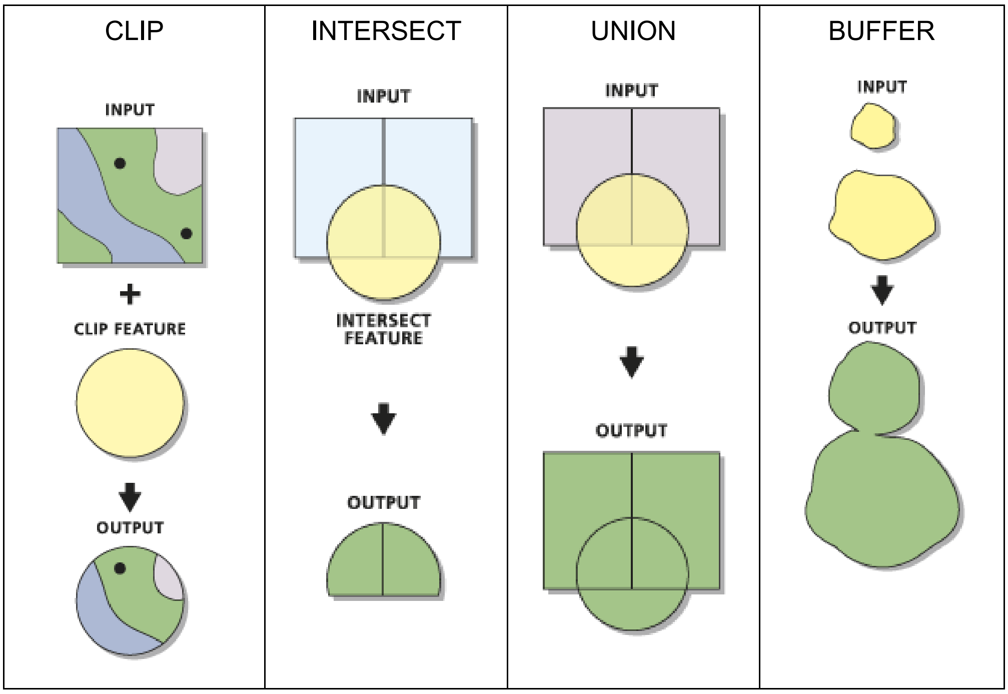
APPENDIX A

Fig A1: GIS Spatial Analysis Operations



Source: adapted from ArcGis Desktop Help

Buffer - A zone around a map feature measured in units of distance or time. A buffer is useful for proximity analysis.

Clip - A command that extracts features from one feature class that reside entirely within a boundary defined by features in another feature class.

Geocoding - A GIS operation for converting street addresses into spatial data that can be displayed as features on a map, usually by referencing address information from a street segment data layer.

Intersect - A geometric integration of spatial datasets that preserves features or portions of features that fall within areas common to all input datasets.

Overlay - the geometric intersection of multiple datasets to combine, erase, modify, or update features in a new output dataset.

Union - A topological overlay of two or more polygon spatial datasets that preserves the features that fall within the spatial extent of either input dataset; that is, all features from both datasets are retained and extracted into a new polygon dataset.

Query - A request to select features or records from a database. A query is often written as a statement or logical expression.

(source: ESRI GIS Dictionary

http://support.esri.com/index.cfm?fa=search.results)

Table A1: Resident Population and Population Density

Parish	Resident Population	0-14 age	15-24 age	25 - 64 age	65 or more of age
ARCOS	869	171	129	454	115
ÁRVORE	4261	736	594	2438	493
AVELEDA	1479	228	231	818	202
AZURARA	2102	387	296	1197	222
BAGUNTE	1662	290	283	867	222
CANIDELO	941	174	154	516	97
FAJÕZES	1467	240	195	830	202
FERREIRÓ	660	150	101	329	80
FORNELO	1504	287	227	807	183
GIÃO	1535	278	202	866	189
GUILHABREU	2386	426	384	1311	265
JUNQUEIRA	2234	432	359	1177	266
LABRUGE	2472	404	335	1394	339
MACIEIRA DA MAIA	1898	339	273	1064	222
MALTA	1206	209	197	674	126
MINDELO	3402	561	442	1965	434
MÓDIVAS	1899	270	316	1053	260
MOSTEIRÓ	891	139	108	471	173
OUTEIRO MAIOR	378	69	48	207	54
PARADA	365	77	53	195	40
RETORTA	1022	197	127	576	122
RIO MAU	1907	387	320	998	202
TOUGUES	788	128	127	435	98
TOUGUINHA	1410	252	203	768	187
TOUGUINHÓ	1458	257	230	795	176
VAIRÃO	1191	182	165	667	177
VILA CHÃ	2957	560	435	1640	322
VILA DO CONDE	25731	4851	4150	14091	2639
VILAR	1737	275	233	997	232
VILAR DE PINHEIRO	2579	413	359	1466	341
CONCELHO	**74391**	**13369**	**11276**	**41066**	**8680**
		18,0%	**15,2%**	**55,2%**	**11,7%**

Source: INE-Census 2001

Table A2 : Population Age Structure

Parish	Resident Population			Density (heads/km2)
	Total	Men	Women	
ARCOS	869	429	440	161
ARVORE	4261	2106	2155	687
AVELEDA	1479	722	757	423
AZURARA	2102	990	1112	1001
BAGUNTE	1662	806	856	168
CANIDELO	941	451	490	254
FAJOZES	1467	740	727	207
FERREIRO	660	326	334	138
FORNELO	1504	753	751	269
GIAO	1535	743	792	313
GUILHABREU	2386	1155	1231	336
JUNQUEIRA	2234	1109	1125	310
LABRUGE	2472	1198	1274	434
MACIEIRA DA MAIA	1898	936	962	358
MALTA	1206	596	610	635
MINDELO	3402	1658	1744	630
MODIVAS	1899	904	995	475
MOSTEIRO	891	421	470	287
OUTEIRO MAIOR	378	187	191	122
PARADA	365	180	185	111
RETORTA	1022	525	497	269
RIO MAU	1907	897	1010	183
TOUGUES	788	387	401	219
TOUGUINHA	1410	683	727	455
TOUGUINHO	1458	722	736	304
VAIRAO	1191	554	637	277
VILA CHA	2957	1461	1496	538
VILA DO CONDE	25731	12600	13131	3729
VILAR	1737	839	898	483
VILAR DE PINHEIRO	2579	1260	1319	697
CONCELHO	**74391**	**36338**	**38053**	**499**

Source: INE-Census 2001

Table A3: Bus Lines of Vila do Conde – Number of Bus Lines on Week Days

	ORIGIN	DESTINY	BUS LINE	Nº of B LINES	COMPANY
RURAL	Touguinha	Rio Mau	115	16	Arriva Portugal
	Mindelo	Mosteiró	201	3	Arriva Portugal
	Mindelo	Vilar do Pinheiro	202	2	Arriva Portugal
	Vila Chã	Fajozes	203	1	Arriva Portugal
	Vila do Conde	Labruge	204	8	Arriva Portugal
	Vila do Conde	Aveleda	205	6	Arriva Portugal
	Vila do Conde	Vilar do Pinheiro	206	5	Arriva Portugal
	Vila do Conde	Guilhabreu	207	1	Arriva Portugal
	Vila do Conde	Guilhabreu	208	7	Arriva Portugal
	Vila do Conde	Guilhabreu	210	10	Arriva Portugal
	Vila do Conde	Fornelo	211	11	Arriva Portugal
	Vila do Conde	Parada	213	14	Arriva Portugal
	Vila do Conde	Parada	214	5	Arriva Portugal
	Arcos	Vila do Conde	215	2	Arriva Portugal
	Arcos	Junqueira	219	2	Arriva Portugal
	Parada	Vilar Pinheiro	224	1	Arriva Portugal
	Arcos	Parada	233	1	Arriva Portugal
	Junqueira	Ferreiró	739	1	Arriva Portugal
	Mosteiró	Vila do Conde	740	2	Arriva Portugal
	Fajozes	Macieira da Maia	741	3	Arriva Portugal
	Junqueira	Arcos	744	3	Arriva Portugal
	Barcelos	Porto	BAR_PORTO	7	Castro Linhares
	Viana de Castelo	Porto	VC_PORTO	3	Castro Linhares
	Póvoa Varzim	Porto	PV_PORTO	12	Castro Linhares
	Póvoa Varzim	Sanfins	PV_SAN	4	Castro Linhares
	Póvoa Varzim	Santo Tirso	PV_ST	9	Castro Linhares
URBAN	Vila do Conde	Vila do Conde	209	1	Arriva Portugal
	Feira Nova	Vila do Conde	216	6	Arriva Portugal
	Povoa Varzim	ES José Régio	LN_A	26	Litoral Norte
	Povoa Varzim	Azurara	LN_B	25	Litoral Norte
	Póvoa Varzim	V.Conde - Piscinas	PV_VCcax	22	Castro Linhares
	Póvoa Varzim	V.Conde - Correios	PV_VCcor	27	Castro Linhares

Chart A1: Daily Number of Bus Lines on Week Days

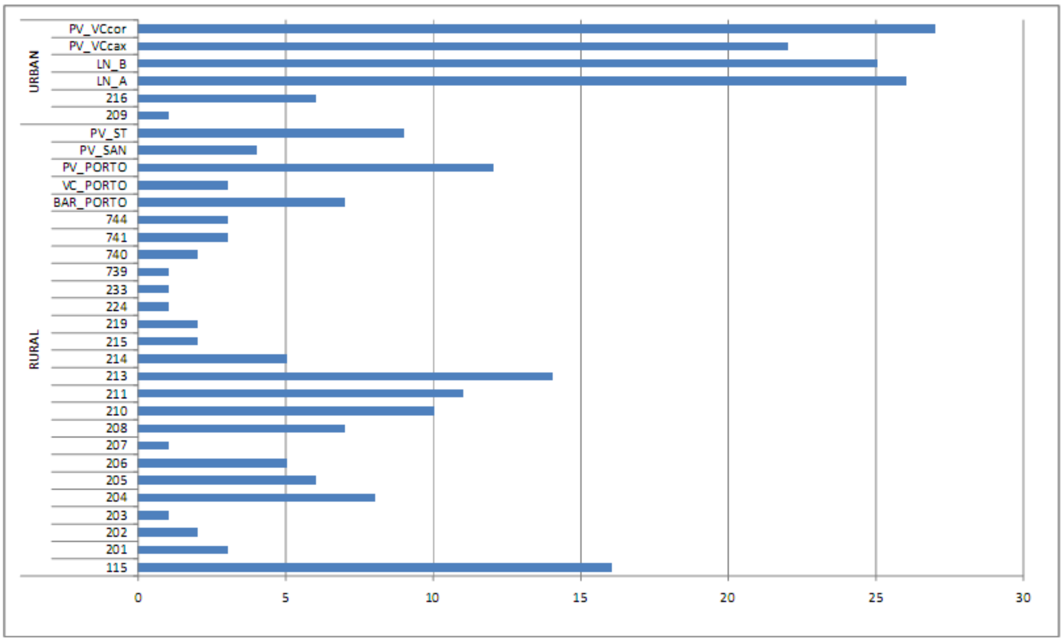


Table A4-Coverage Areas of 300 m buffer for each Village

RURAL VILLAGE	Density (hab/km2)	Area (km2)	Nº B.STOPS	Nº METRO ST	300m Buffer Coverage Area (m2)	300m Buffer Coverage Area (Km2)	%
Arcos	161	5,8	9		1094890,12	1,1	18,8%
Arvore	687	6,6	17	2	1774472,54	1,8	27,0%
Aveleda	423	3,7	13		1285520,43	1,3	34,7%
Azurara	1001	2,2	4	1	648479,59	0,6	30,0%
Bagunte	168	9,2	15		1674261,55	1,7	18,2%
Canidelo	254	3,3	9		805612,69	0,8	24,1%
Fajozes	207	6,0	14		1372401,48	1,4	23,0%
Ferreiró	138	4,9	1		182620,55	0,2	3,7%
Fornelo	269	6,3	13		1279873,47	1,3	20,4%
Glao	313	5,7	7		998232,02	1,0	17,6%
Guilhabreu	336	6,5	13		1346242,60	1,3	20,8%
Junqueira	310	6,8	17		1492285,46	1,5	21,9%
Labruge	434	5,1	10		1145000,13	1,1	22,6%
Madeira da Maia	358	5,9	14		1496897,65	1,5	25,3%
Malta	635	2,1	8		801887,58	0,8	37,7%
Mindelo	630	5,7	15	2	1669026,45	1,7	29,1%
Modivas	475	4,1	15	2	862949,49	0,9	21,1%
Mosteiró	287	3,0	9		969685,80	1,0	31,8%
Outeiro	122	4,8	6		625857,43	0,6	13,1%
Parada	111	3,0	6		491275,52	0,5	16,6%
Retorta	269	3,2				0,0	0,0%
Rio Mau	183	9,9	18		2028490,66	2,0	20,5%
Tougues	219	3,3				0,0	0,0%
Touguinha	455	3,2	11		1226827,97	1,2	38,1%
Touguinhó	304	4,5	11		1021403,12	1,0	22,7%
Vairao	277	4,6	13		1233673,29	1,2	27,0%
Vila Cha	538	4,8	13		1326153,78	1,3	27,6%
Vilar	483	4,3	7		862949,49	0,9	20,2%
Vilar do Pinheiro	697	3,8	19	1	1687011,47	1,7	44,6%

Table A5-Connections between City and Villages

VILLAGE	Nº B.STOPS	Nº METRO ST	Nº B LINES	Nº BUS WDAY	Nº BUS SAT	Nº BUS SUN	BUS LINES	Nº METRO WDAY	Nº METRO SAT	Nº METRO SUN
Arcos - Vila do Conde	9		1	2	0	0	215			
Arvore - Vila do Conde	17	2	10	70	12	2	BAR_PORTO, PV_PORTO, VC_PORTO, 204, 205, 206, 207, 208, 210, 211	60	56	38
Aveêda - Vila do Conde	13		1	6	0	0	205			
Azurara - Vila do Conde	4	1	14	110	31	10	208, 210, 211,740	38	38	38
Bagunte - Vila do Conde	15		1	14	5	0	213			
Candelo - Vila do Conde	9		2	12	2	0	210, 740			
Fajozes - Vila do Conde	14		5	30	5	2	206,207, BAR_PORTO; PV_PORTO; VC_PORTO			
Ferreiró - Vila do Conde	1		1	4	0	0	214			
Fornelo - Vila do Conde	13		4	36	11	8	210, 211, PV_SAN, PV_ST,			
Giao - Vila do Conde	7		3	11	2	0	206,207,208			
Guilhabreu - Vila do Conde	13		4	20	4	0	207,208,210,740			
Junqueira - Vila do Conde	17		4	16	4	0	213,214,215,219			
Labruge - Vila do Conde	10		2	11	0	0	204, 205			
Macieira da Maia - Vila do Conde	14		6	43	12	8	208, 210, 211, 740, PV_SAN, PV_ST			
Malta - Vilã do Conde	8		3	17	4	0	207, 208, 210			
Mindelo - Vila do Conde	15	2	5	28	4	2	204, 205, BAR_PORTO; PV_PORTO; VC_PORTO	60	56	38
Modivas - Vila do Conde	15	2	6	35	6	2	206,207,208,BAR_PORTO; PV_PORTO; VC_PORTO	38	38	38
Mosteiró - Vila do Conde	9		2	6	0	0	206, 740			
Outeiro - Vila do Conde	6		1	4	0	0	214			
Parada - Vila do Conde	6		2	14	4	0	213,214			
Retorta - Vila do Conde										
Rio Mau - Vila do Conde	18		1	2	0	0	215			
Tougues - Vilã do Conde										
Touguinha - Vilã do Conde	11		3	23	4	0	213, 214, 215,219			
Touguinhó - Vilã do Conde	11		3	23	4	0	213, 214, 215,219			
Vairao - Vila do Conde	13		5	23	4	0	206,207,208,210,740			
Vila Cha - Vila do Conde	13		2	11	0	0	204, 205			
Vilar - Vila do Conde	7		4	28	4	2	206,BAR_PORTO; PV_PORTO; VC_PORTO			
Vilar do Pinheiro - Vila do Conde	19	1	4	28	4	2	206,BAR_PORTO; PV_PORTO; VC_PORTO	38	38	38

Table A6-Connections between Villages and Health Centers

RURAL VILLAGE	HEALTH CENTER	Total TIME (min)	Total DISTANCE (m)	Nº B.LINES	Nº BUS WDAY	BUS LINES
Arcos	Junqueira	28,8402169	3597,014652	3	5	215,219,233
Arvore	Vila Conde	24,83841243	3502,816182	10	70	BAR_PORTO, PV_PORTO, VC_PORTO, 204, 205, 206, 207, 208, 210, 211
Aveleda	Labruge	47,62955381	4842,816459	1	6	205
Azurara	Vila Conde	13,58465725	1941,104369	14	110	BAR_PORTO, PV_PORTO, VC_PORTO, LN_B, PV_ST, PV_SAN, 204, 205, 206, 207, 208, 210, 211,740
Bagunte	Junqueira	27,62031779	4440,447529	3	6	214, 739
Canidelo	Malta	16,42799739	2585,055833	0	0	210 * destiny bus stop in Malta is a 1km away from HC
Fajozes	Vila Conde	31,11292639	6229,550349	5	30	206,207, BAR_PORTO; PV_PORTO; VC_PORTO
Ferreiró	Junqueira	55,17842679	7728,910054	1	5	214
Fornelo	Vairão	35,17235155	5114,261555	2	12	210, 740
Giao	Modivas	33,08939772	4603,886868	0	0	206, 207, 208, 224 * destiny bus stop in Modivas is more than 1km away from HC
Guilhabreu	Malta	24,09142982	3411,021476	2	8	207,208
Junqueira	Junqueira	7,246603767	390,3464614			
Labruge	Labruge	5,098843792	332,3129806			
Macieira da Maia	Vairão	13,26655725	2362,123807	0	0	210, 740 * only one origin bus stop in Macieira. Almost whole territory has no access to bus line
Malta	Malta	4,716309455	205,1858622			
Mindelo	Vila Conde	29,52753879	7235,638849	5	28	204, 205, BAR_PORTO; PV_PORTO; VC_PORTO
Modivas	Modivas	6,869082061	619,5633826			
Mosteiró	Modivas	25,53998351	3815,772321	1	2	201
Outeiro	Junqueira	42,80947524	7140,557205	1	5	214
Parada	Junqueira	36,72227159	6838,541388	2	15	213, 233
Retorta	Vila Conde					
Rio Mau	Junqueira	28,23283316	4251,339366	1	3	744
Tougues	Vila Conde					
Touguinha	Vila Conde	33,69345472	8133,863435	4	23	213,214,215, 219
Touguinhó	Vila Conde	36,71276772	10951,94936	4	23	213,214,215, 219
Vairao	Vairão	0,392071603	23,52429618			
Vila Cha	Labruge	17,58181646	3033,551593	2	14	204,205
Vilar	Modivas	22,10037668	2528,145228	5	26	201,202, BAR_PORTO; PV_PORTO; VC_PORTO
Vilar do Pinheiro	Modivas	18,46010694	3895,995618	4	24	202, BAR_PORTO; PV_PORTO; VC_PORTO

Table A7-Connections between Villages and Metro Stations

VILLAGE	Nº B. LINES	METRO STATION	NAME B LINES
Arcos	2	Portas Fronhas	215
Arvore	44	Árvore	207, 208, 210, 211, 740, PV_SAN,PV_ST
Aveleda	13	V. Pinheiro	202, 205
Azurara	49	Árvore	206,207,208, 210, 211, 740, PV_SAN,PV_ST
Bagunte	19	Santa Clara	213, 214
Canidelo	23	Árvore	210, 211, 740
Fajozes	8	Mindelo, Árvore	203, 206, 207
Ferreiró	5	Santa Clara	214
Fornelo	36	Árvore	210, 211, 740, PV_SAN,PV_ST
Glao	13	Árvore	206, 207, 208
Guilhabreu	31	Árvore	207, 208, 210, 211, 740,
Junqueira	21	Portas Fronhas ,Santa Clara	213, 215, 214
Labruge	6	V. Pinheiro	205
Macieira da Maia	43	Árvore	208, 210, 211, 740, PV_SAN, PV_ST
Malta	29	Árvore	207, 208, 210, 211,
Mindelo	20	Modivas Centro, V. Pinheiro, Mindelo	201, 202, 203, 205
Modivas	5	Modivas Centro, V. Pinheiro	201,202
Mosteiró	5	Modivas Centro, V. Pinheiro	201,202
Outeiro	5	Santa Clara	214
Parada	19	Santa Clara	213, 214
Retorta			
Rio Mau	2	Portas Fronhas	215
Tougues			
Touguinha	21	Portas Fronhas,Santa Clara	213, 214, 215
Touguinhó	21	Portas Fronhas, Santa Clara	213, 214, 215
Vairao	36	Árvore	206, 207, 208, 210, 211, 740
Vila Cha	13	Modivas Centro, Mindelo, V.Pinheiro	201, 203, 205
Vilar	12	Modivas Centro, V. Pinheiro	201,202,
Vilar do Pinheiro	7	V. Pinheiro	201,202,

Table A8: Shortest Path distance between City and Villages

VILLAGES	Total TIME (min)	Total DISTANCE (m)
Azurara - Vila do Conde	14,25479664	1567,520873
Arvore - Vila do Conde	25,50855181	3129,232686
Macieira da Maia - Vila do Conde	27,37263523	6518,287456
Mindelo - Vila do Conde	30,19767818	6862,055353
Fajozes - Vila do Conde	31,78306578	5855,966853
Touguinha - Vila do Conde	37,65982669	8344,630575
Vairao - Vila do Conde	39,46298177	8426,889809
Modivas - Vila do Conde	40,12591773	9332,155164
Touguinhó - Vila do Conde	40,67913969	11162,7165
Vila Cha - Vila do Conde	40,91334189	9243,581896
Retorta - Vila do Conde	44,40541174	2664,324704
Vilar do Pinheiro - Vila do Conde	46,23098012	12292,59783
Giao - Vila do Conde	47,16695324	9908,445258
Vilar - Vila do Conde	50,04993728	11529,3724
Labruge - Vila do Conde	50,98384392	11356,29108
Junqueira - Vila do Conde	53,14246906	13975,51081
Malta - Vila do Conde	53,42467092	13206,63566
Mosteiró - Vila do Conde	53,48954411	12816,99949
Canidelo - Vila do Conde	53,54115801	12838,50528
Fornelo - Vila do Conde	54,26259073	10631,70538
Parada - Vila do Conde	55,38631291	14023,98649
Rio Mau - Vila do Conde	55,9173276	14006,16162
Bagunte - Vila do Conde	59,63243705	14687,59177
Guilhabreu - Vila do Conde	65,15110482	15725,51858
Tougues - Vila do Conde	65,31618283	10544,31685
Aveleda - Vila do Conde	71,75805908	13363,0578
Arcos - Vila do Conde	71,89288762	16830,84793
Ferreiró - Vila do Conde	73,8424681	14914,35516
Outeiro - Vila do Conde	74,8215945	17387,70145