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A simulation model for flexible public transport in rural/ peri-urban areas

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Dissertação de Mestrado

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Abstract

Due to the world's urbanization growth and as a result the decrease of the population density in rural areas, these areas and the peri-urban zones are being often out of the public transportation studies spectrum and the subsequent investments.

Therefore, this dissertation aims to support the design of a Decision Support System (DSS) for addressing the design of transportation systems in low-density areas, together with a framework of analysis and indicators of performance. The DSS focus on designing DRT systems, which are frequently mentioned in literature as a promising rural transport alternative to the inefficient traditional fixed-route and fixed-scheduling system. The system envisage specifically the implementation of a "route deviation" DRT system. In this system, there is a predefined vehicle route, from which the vehicle can deviate a specified distance to attend to a demand requirement, making a previous functioning route more efficient and effective in providing its welfare service for the community. The DSS includes a graphic interface of the points of interest through a location platform. It operates by submitting input parameters and getting a set of KPIs' as outputs of the system. Those KPI's facilitate the understanding and the system analysis made by the decision-maker. The system was developed keeping in mind some assumptions as basis of the project development.

Furthermore, the results of this project were obtained by testing the platform, evaluating how it could be useful for a decision-maker. The method involved verifying the effect of different input parameters and check if they were in accordance with the expected results. In addition, the results phase incorporates how the information can be beneficial in the analysis.

Finally, some suggestions are made for future works in this area. The current system has characteristics that allow extensions to be included in future works, such as multiple routes of the DRT service (not only the route deviation) and other transport services as well. Thus, this work may be extended in order to suit better the reality of a particular territory and to be a useful modeling support application to the decision-maker by adjusting the constraints of the software to the reality of the passengers behavior and operation of the service.

Resumo

Devido ao crescimento mundial da urbanização e consequente diminuição da densidade populacional nas áreas rurais, estas áreas e as áreas suburbanas estão frequentemente fora do espetro de estudos para o transporte público e para possíveis investimentos.

Portanto, esta dissertação visa apoiar a concepção de novos sistemas, proporcionando uma ferramenta de apoio à decisão (DSS) para abordar o desenvolvimento de sistemas de transporte em áreas com baixa densidade populacional, juntamente com um quadro de análise e indicadores de desempenho. A ferramenta destina-se a projetar sistemas de transporte denominados "Demand Responsive Transport" (DRT) que respondem à procura. Estes sistemas são frequentemente mencionados na literatura como uma alternativa promissora de transporte em zonas rurais em relação às rotas tradicionais e ineficientes com rota e horário fixos. O sistema prevê especificamente a implementação de "sistemas de desvio de rota". Nestes sistemas,existe uma rota predefinida, da qual o veículo se pode desviar até uma distância especificada para atender a um pedido de procura, tornando uma rota de funcionamento anterior mais eficiente e eficaz na prestação do seu serviço para a comunidade.

O desenvolvimento da ferramenta inclui uma interface gráfica dos pontos de interesse através de uma plataforma de localização. O DSS inclui uma interface gráfica dos pontos de interesse através de uma plataforma de localização. A plataforma opera através da submissão de parâmetros de entrada e obtém um conjunto de métricas para análise. As métricas obtidas (KPIs) facilitam a compreensão e a análise do sistema feita pelo decisor.

Além disso, os resultados desta dissertação foram obtidos testando a plataforma, avaliando se ela seria útil para o um operador. O método envolveu verificar o efeito de diferentes parâmetros de entrada e se eles estavam de acordo com os resultados esperados. No final da avaliação, a ferramenta cumpriu o esperado e permanece assim disponível para uso do operador.

Por fim, foram feitas algumas sugestões para trabalhos futuros nesta área. O projeto atual tem características que permitem uma fácil inclusão de diferentes ramificações do serviço DRT (não apenas o desvio de rota) mas outros serviços de transporte também. Assim, este trabalho pode ser estendido para se adaptar à realidade de uma determinada região e ser uma útil ferramenta de apoio ao decisor, ajustando as condicionantes do software à realidade do comportamento dos passageiros e ao funcionamento do serviço.

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My family, for their affection and patience when dealing with me.

“You never fail until you stop trying.”

Contents

Acronyms and Symbols

KPI	Key Performance Indicator
DRT	Demand Responsive Transport
DSS	Decision Support System
MaaS	Mobility as a Service
DES	Discrete Event Simulation
PT	Public Transport

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Chapter 1

Introduction

This dissertation was developed in INESC TEC, as part of a broader project on Demand Responsive Transport (DRT) services.

1.1 Contextualization

Due to the increasing worldwide urbanization, rural areas have faced a reduction in population, and Public Transport (PT) providers of those regions struggle with increasing costs per passenger, mainly as a result of the demand decrease. The need for a sustainable, efficient, and cost-effective solution, especially in PT, aroused. One system often mentioned in the literature as a promising solution is flexible (or demand responsive) transport. These systems can adequate their routes and frequencies according to the observed demand.

The public authorities of rural and peri-urban areas may have in flexible transport an intermediate solution between a taxi (on-demand, door-to-door, expensive option) and a bus (usually cheaper but with a fixed route and schedule option). In general, this system can easily adjust to the needs of the operational area. It can both serve the overall population (as a stand-alone PT service), or complement an existing system as a para-transit, targeting a specific group, like the most vulnerable segments of the population (elderly, handicapped people, unemployed, etc), thus assisting these segments in achieving their welfare goals.

1.2 Motivation and objectives

The main goal for this work is to design a Decision Support System (DSS) to assist decision-makers, such as transport operators and public authorities, to analyse the current operation of the traditional PT and to evaluate a possible implementation of a DRT system. The DSS is focused on a set of Key Performance Indicators (KPIs) that show, based on the simulation, the parameters that evaluate the quality of the solution tested. These are both orientated towards the interests of the transport operators, public authorities and the passengers. Hence, the proposed metrics will consider the performance of the system and its cost for all stakeholders.

Although considered an option in rural areas with several pilot projects, the lack of knowledge disclosure to plan a DRT in rural areas and the emphasis of its use in urban areas as complement of existent PT has let its implementation on rural areas in a stagnant state. So, by giving a supporting tool to the decision-makers to better assess that possibility, the motivation of this dissertation is to support the development of more cost-efficient PT designs, provide better services and increase welfare in those regions, reaching in a easier way the more vulnerable people.

The main goal of this project is to provide a tool to the operator or interested decision-maker to make an easy assess of the impact of some decisions in the operational and tactical aspects of PT service in rural and peri-urban areas, assisting them to improve the service and reduce costs. Taking that into account, the project can be divided into a few complementary objectives:

- Design and conceptualize simulation assumptions according to the reality of the transportation paradigm, especially DRT;
- Develop a friendly-user interface for the DSS where the authorities can easily understand and apply their input data, visualise their results and evaluate options in a straightforward way;
- Determine and calculate the most adequate KPIs considering the stakeholders involved (operator and users);
- Run and analyse different simulations (study cases) in order to evaluate the benefits of using the designed DSS;

1.3 Dissertation structure

After this introduction on the context and objectives of the dissertation, a literature review of previous works is presented in Chapter 2. The problem description (Chapter 3) specifies the context of the work developed, including the assumptions that were made. Chapter 4 describes the methodology of the project, how the DSS was constructed, what type of input data was considered for the user to handle, how the KPIs were calculated and displayed and how the simulation runs were interpreted. Chapter 5 shows the results of the implementation of the DRT in a real-world scenario, comparing the result of the KPIs for different inputs. Chapter 6 discusses how this system can be applied, the main achievements and conclusions, and how the system can be improved in future works.

Chapter 2

Literature Review

This chapter presents a review of the relevant literature that supports the dissertation development. This includes the topics of Demand Responsive Transport, Simulation, Decision Support Systems, and the context of transport in rural areas and peri-rural areas.

2.1 Demand Responsive Transport

Public Transport (PT) services have been known for delivering a system to serve the population's need for commuting or travelling to a point of common interest. PT usually consists on fixed routes and fixed schedules and is dependent on the volume of passengers to be operationally feasible. This type of service works well in situations where it is more cost-efficient or time-efficient than riding a private car. Adding to that, it may be in some cases a way to diminish transportation accessibility inequality for vulnerable people. However, PT has faced challenges and encountered opportunities for changing its operation mode. One of those opportunities is flexible transport, also called Demand Responsive Transport (DRT) or Dial-a-ride transport (DART), depending on the geographical location. In this dissertation, the DRT designation will be used. This category has been studied and put into practice for over 50 years [27]. These particular services consider varying routes, schedules and/or vehicles as an alternative or complement to fixed-transport. The service collects passengers at their specified origins (i.e. their house, a bus stop, an assembly point) at a specified time and takes them to their requested destinations (not necessarily route stops). Thus, DRT is described as an intermediate form of transport, somewhere between a variably routed bus service and a taxi service [8]. As described in Figure 2.1, a DRT has some characteristics of taxis and traditional PT services. The cost efficiency and flexible demand are two of the most usual features of the service.

Replacing the traditional PT systems for this new type of service encompasses difficulties

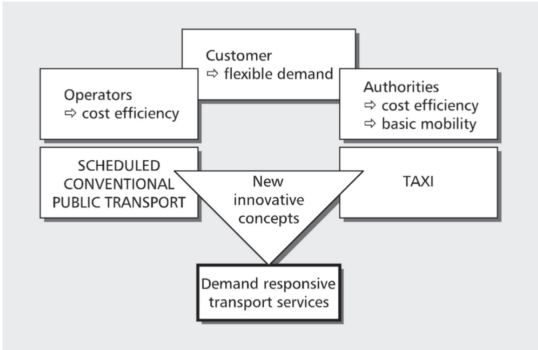

Figure 2.1: From conventional PT and taxis to DRT. (Source: [4])

in planning, as fixed-route transport is conventionally used in PT, having wide disclosure, know-how and more specialists knowing how to do it. Besides that, transport systems need to be well aligned with the population's reality and implementation constraints to be efficient. Due to budget constraints and operational sustainability, a flexible transport service may not be a full demand-responsive service. Regarding the qualities and social welfare benefits of DRT implementation, those include: increased ridership, more cost-effective and integrated service for people with disabilities; flexibility in accommodating demand in combination with traditional services; ability to operate effectively in medium-density areas to complement other transport services [39].

Flexible transport services may be designed for a certain type of users, usually disabled or elderly people, to fulfill welfare objectives and complement traditional transport systems, that in general were not designed to suit the physical constraints of those segments of the population. In these cases, a set of constraints can be established related to the passenger's class or constraints regarding the time and the location in which the service operates [16].

From the perspective of the passenger, route detours and flexible schedules can amplify uncertainty in waiting and in-vehicle times relative to traditional transport operations. Variations in the perceived reliability of the service can heavily influence the mode and route choices of passengers when presented with multiple alternatives for travelling. Thus, the DRT assignment of the fleet to passenger trip requests may be difficult due to the uncertainty of real-time demand forecasts [29].

The challenges of DRT are similar to those of the Dial-a-Ride problem (DARP). DARP involves designing vehicle routes and schedules for users who specify pickup and delivery requests between two locations. It usually requires a balance between the service quality (i.e. customer convenience) and an economic perspective [48].

There are actually a vast set of different services within the DRT framework [43],[27] (See Figure 2.2 below).

- *Route deviation* - a clearly defined route and timetabled checkpoints, but vehicles can deviate slightly between stops;
- *Request stops* - traditional fixed-route service with predetermined stops, but with the ability to stop anywhere along the route;
- *Zone route* - direct service transport of passengers from their origin to their destination inside a zone, whilst also servicing fixed stops at determined times on zonal boundaries;
- *Point deviation* - transports people inside a fixed zone directly from their origin to their destination, while serving probably a small number of fixed stops;
- *Flexible-route segments* - alternates between a fixed-route and a demand responsive service in different portions of the route;
- *Demand responsive connector* - collects passengers from specified origins and takes them to a transit hub for a fixed-route service-or the reverse.

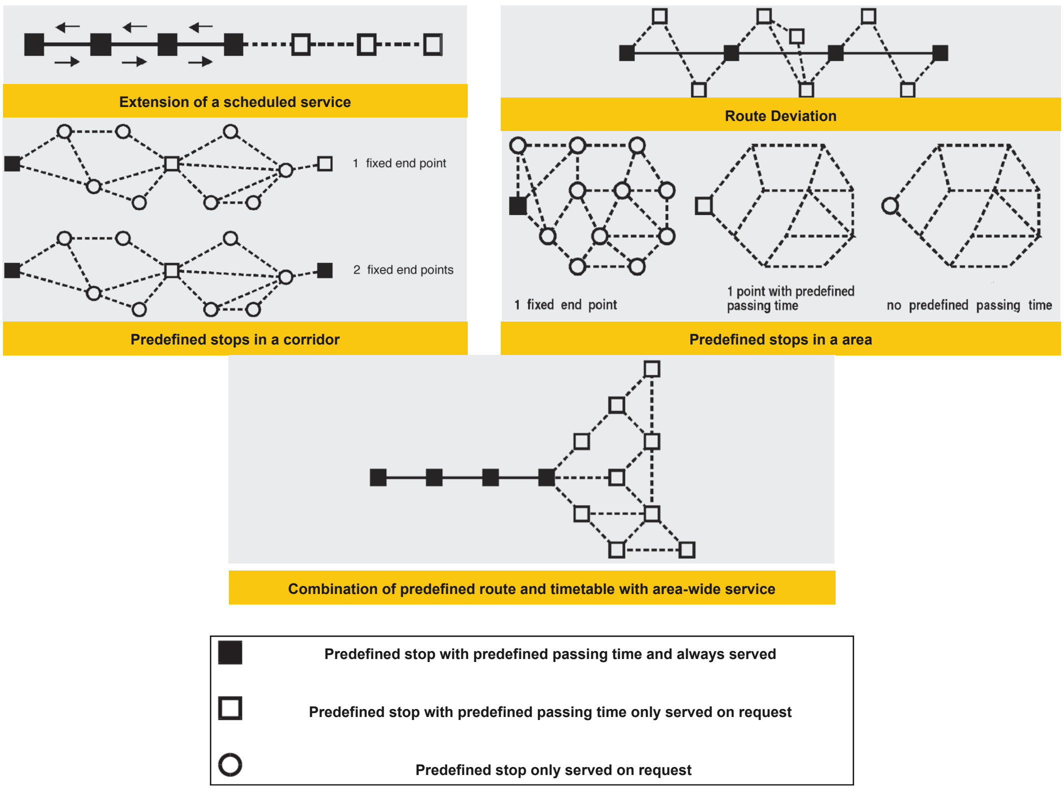

Figure 2.2: Examples of types of DRT operations (Source: [4]).

2.1.1 DRT studies and implementation as transportation alternative

Typically, the areas in which the DRT operates must be widely known by the inhabitants as well as the operating stops to assure the reliability of the service. The process of customer's trip request starts with his/her demand call to the operator, which is usually by phone or with an application with internet access. For some systems, there is the need to book the trip in advance of some minutes, hours or days. In others systems, the booking is processed in real-time, replied with a pick-up and delivery time, determined by historical bookings data and the route design system and flexibility. As the service journey is determined by actual trip requests, an algorithm is needed to provide the most effective path, offering a high quality customer-oriented service and a efficient resource-spending to the transport provider. The large scale implementation of DRT is only feasible when supported by an online system with an extended interface and automated journey management. Moreover, the preparation and management of data transfers and communications to and from the DRT vehicle are crucial for the operation of the system. Figure 2.3 shows the dynamics of the operation and information flow in a DRT system.

There are historical examples of implementation of DRT services. Taking into account the framework of two European DGXIII projects, DeLijn developed DRT supportive systems around a software module, called "The Ring". This software included all applications necessary to efficiently manage a DRT service as a base level in PT networking systems. The module includes sub-modules to handle reservations, cancelling and modifying, as well as providing PT information, online journey processing, registration of management information, preparation of data-communication and monitoring data [4].

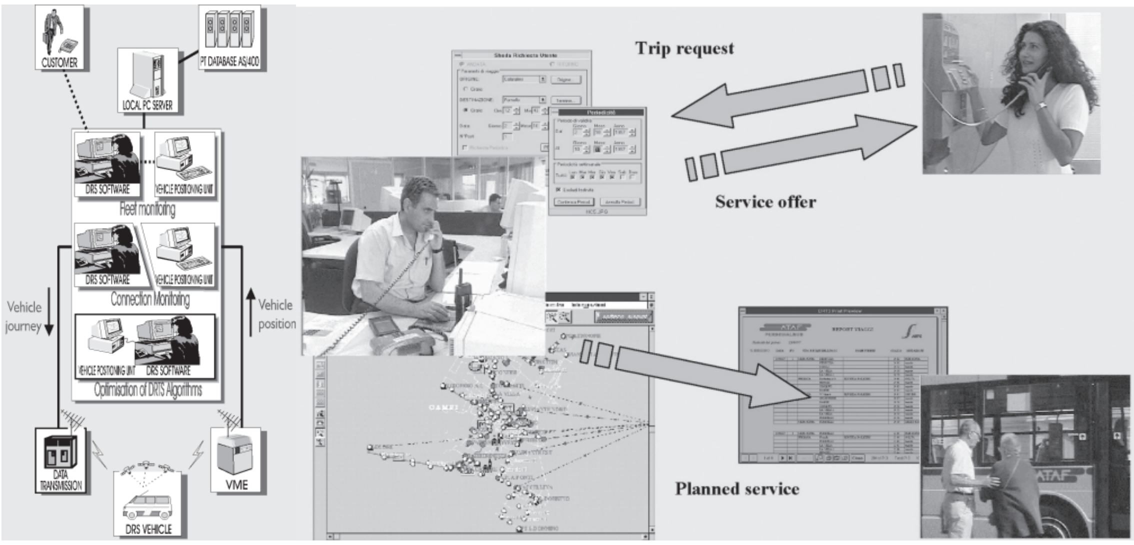

Figure 2.3: DRT information and operation procedures (Source: [4]).

DRT services may be a feeder system or even an alternative to traditional fixed PT. The combination of an on-demand and line-based service can lead to improved mobility and increased service coverage. To date, there are some implementations that satisfy those expectations. However, due to financing problems those systems are often excluded or shut down after some time of operation. The results of this dissertation may help in planning more efficient DRT networks by providing a tool that simulates and measures all the important metrics involved in the operation.

Despite the private car being in many situations the most flexible and convenient transport for travellers, its reduction is placed high on the agenda of transportation planners which are facing difficulties in finding alternatives. Thus, to compete with private cars, line-based fixed transportation could benefit from embracing a DRT type of service.

In spite of not being a innovation (DRT was recommended for future transportation in the 1960's [11]), only recent advancements in technology have turned out to achieve the level of a possible large-scale operation. Example of this are the new urban DRT services that appeared both in the United States (e.g., Bridj, Lyftline, UberPOOL, Via) and in Europe (Abel in Amsterdam, Kutsuplus in Helsinki, Padam in Paris, and Radiobus di Quartiere in Milan) [2]. Digital transformation helped to drive that effect by promoting customized services that are more user focused. The information and communication technology (such as smartphone apps and computer aided dispatching systems) made it possible for operators to provide DRT services more efficiently and cost-effectively than those in the past [38], helping to develop the recent concept of Mobility as a Service (MaaS).

Also, there are some key operational and tactical lessons that can be learnt from past few DRT trials [40]:

Technological issues: Translink in Shellharbour NSW, Australia, implemented DRT services in early 1990s. The trial did not go as expected mostly because of absence of structured planning and an over reliance on untested technology, which led to operator dissatisfaction and as a result, a reversion to a normal service.

Level of service flexibility: Dial-a-bus scheme in Adelaide, South Australia, was an 'many-to-many' service which did not prosper as it lacked proper passenger demand and was too flexible to be practical. While the removal of spatial and temporal aggregation of passengers increased flexibility, it also reduced the capacity to group trips. For situations with too low demand, a less flexible service (a pre-booked service, or one with fixed running times) is considered more suitable, as high levels of flexibility can not be economically sustainable if there is not enough passenger demand.

Fare structure: The Milton Keynes Dial-a-Bus trial in UK did not succeed because of too low fare price. In particular, after being cut back to off-peak DRT services only, the operational costs of this scheme were higher than expected.

There are several studies aimed to the design of DRT systems. They consist in studies that estimate the required capacity for a given level of service and the resulting operating costs [33], or that assess whether DRT should replace fixed transportation in a given scenario [26],[30]. A survey that assessed the replacement option found that the Demand Responsive Connector (DRC), which consists in a DRT that moves passengers to a transfer point of connection to a fixed-route network, is one of the most used DRT services, especially within low density residential areas, resulting of urban sprawl - a phenomena occurring in the last few decades [27]. Taking into account the performance, it is known that fixed-route systems are more capable to succeed under high demand levels while full flexible door-to-door are best under low demand levels. The route deviation (bus deviation from a fixed path) is often considered and used within the DRT framework as well. An analysis to feeder-based DRT shows that this service performs increasingly better when there are more drop-off than pick-up customers, such as in afternoon peak hours of a regular weekday [30].

In one research to test the feasibility of the DRT operation, a performance metric was tested, known as generalized journey time (GJT), which took different measured parameters with assigned weighs. Those parameters included walking time, waiting time, in-vehicle time and number of transfers. It was concluded in that research that there was a reduction of over half of the GJTs for half the rides that were performed using DRT, in comparison to fixed alternatives [30]. So, it is clear that DRT can have substantial benefits of service level in comparison to traditional fixed transportation.

Despite the advantage in many aspects of using a DRT, substantial research is still needed in the area to figure out to what extent can a DRT complement or add to the actual PT framework. The lack of in-depth analysis of potential and current passengers' behavior under different conditions and their socioeconomic characteristics makes it difficult to estimate demand elasticity and to get differences in their perceived value of trip time and in consequence the feasibility of DRT implementation in PT.

2.1.2 The rural and peri-urban areas analysis

The urbanization increasing rate over the last decades caused cities around the world to surpass their territory into the peripheral areas. Thus, this phenomenon creates zones known as peri-urban areas, in which the landscape is fragmented with urban and rural characteristics [12]. A typical rural area is defined as a geographic area located outside towns and cities, with low population density and small settlements.

The scattered location of residential buildings and the decentralization of points of interest for the community, especially in small towns or villages, hamper the establishment of effective traditional route-based transport systems. As a consequence, the population is car-dependent for all their daily activities whenever they need to travel. The accessibility is then worsened for those who, due to aging, economic difficulties, or disabilities, do not have access to private vehicles [51].

Long distances and scheduled frequencies of transport provision with low occupancy rates are key problems for the economic sustainability of classical transport services in lower-density areas and these motives often lead operators from these zones to disregard investments in transport systems. DRT may provide economically realistic solutions, as it has a wider space of action and higher occupancy rates than traditional transports. In this case, one needs to assess the population demographics of the region and the trip purposes. In low-density areas, the demand for this type of service usually comes from transit-dependent populations (elderly, disabled, and low-income people) when trip purposes are less time-sensitive [43]. Table 2.1 shows the potential interested candidates in using a DRT service.

So, the highest potential candidates for using a flexible transport service in these conditions are those seen in this table:

Youth (<18 years)	**Elderly, Disabled and Low-Income People**
Non-Emergency Medical Appointments	Non-Emergency Medical Appointments
Shopping (Non-Groceries)	Shopping (Non-Groceries)
Social	Social
	Shopping (Groceries)

Table 2.1: Population segments and related trip purposes with high potential of benefit from DRT in rural and peri-urban areas (Source: [43]).

DRT includes several different services. The key characteristics of these services are the route (by flexibility and density of linkages between origins and destinations), the schedule (fixed or flexible), the process of collecting passengers, and quality factors [32].

2.1.3 Route deviation

The route deviation service is a particular type of DRT defined as a regularly scheduled service along a well-defined path, with or without bus stops, that deviates to serve requests within a zone around the path. The width of the zone may be established or not [43]. The predefined stops are positioned within a corridor around the route, so that the deviations on request are relatively short. This DRT scenario is theoretically interesting to organize PT systems on main axes where origin and destination points are located near the main transport axis. In these cases, the vehicle has only to leave the route if there are requests and unnecessary roundabout routes are avoided reducing time and kilometers, thus improving efficiency.

The action of deviation usually takes more time than the direct route. Because of that, there is a need to balance the deviations and the feasible time spans on the fixed timetable for the fixed stops as a consequence of deviations [4]. Figure 2.4 represents a route in a DRT system with examples of dashed deviations that the vehicle may do.

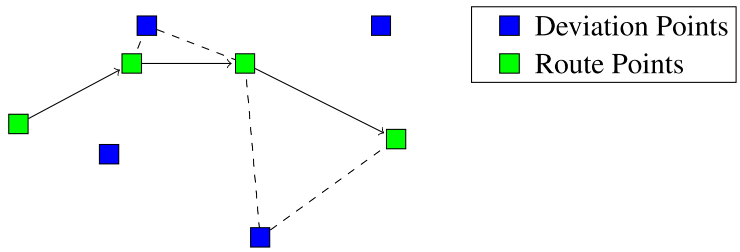

Figure 2.4: Route deviation

According to Potts *et al.* [43], the route deviation services work well if:

1. the deviations are a relatively small part of the overall demand and the overall running time of the route;

2. the majority of the riders are not highly time-sensitive. It is also expected that a basic route structure is needed for the community of study.

2.1.4 DRT in Portugal

The Portuguese Parliament decree nº 60 of September 8th 2016 establishes the jurisdiction in Portugal of the public service of flexible transport [42]. The decree defines the public flexible transport as a mode of transportation that complements but does not replace the current operative transport system. This type of service is to be applied in the cases that nor a regular PT neither a taxi can support the travelling needs of the citizens, specifically in low density areas.

Some pilot-tests have been carried out in Portugal, most of them known as "Blue Lines". The type of the service assumes there fixed routes and fixed schedules with flexible stops. In most cases, the flexible stops are along the route and the passengers only need to raise their hands. Those services are implemented by the municipality authorities and are particularly focused on historical centres [24]. Examples of those applications are: the SIT Flexi in Coimbra region; ECO line in Funchal, Madeira; FlexiBus in Almada; Blue lines in Portalegre and Viana do Castelo; Pantufinhas in Coimbra; Loures Rodinhas in Loures; Colective Taxis in Beja.

2.2 Simulation

Simulation is a method and an instrument for evaluating real behaviours, used in the fields of social sciences, economics, and business. According to Altiok and Melamed [3], transportation-related simulation models can be helpful instruments to identify correct designs for large-scale transportation projects.

The need for careful studies is high because transportation operations are very expensive. This need is even higher since many of the system's capabilities, constraints, and events are difficult to predict (failures, weather, strikes, trip demand, etc.). Thus, simulation is a remarkable tool that approaches the problem with flexibility in evaluating realistic solutions for transportation design problems.

Although sometimes simulation is costly, complex, and time-consuming [28], it allows a sensitivity analysis and helps to understand the real system in study. Moreover, a simulation analysis assesses the real system conditions with better control than the real system itself, being in some cases the only type of model possible for complex systems [20].

With the increase of computational power and the diffusion of digital-based mobility services, the integration among mobility services (MaaS), the testing and the implementation of feasible DRT solutions are becoming easier. Currently, modelling tools can represent the complexity of the PT landscape and identify those areas that are currently served by inaccessible and inappropriate transports [18].

Agent-based simulations, with real-time adaptive behavioral representation of passengers and dynamic transit operations, are often need in studies of DRT [46]. Several agent-based frameworks combining methods of dynamic vehicle routing problems underlying DRT with simulation of traffic and passenger interactions for the evaluation of DRT have been proposed over the last years. The focus and detail of those suggestions depends on application, ranging from case studies of simplified networks to large-scale simulations of several milions of vehicles [29].

2.2.1 Discrete-event simulation

A Discrete Event Simulation (DES) is a type of simulation that models the operation of a system as a (discrete) sequence of events in time. This system is represented as entities flowing from one process to another, tracing down state conditions over time. DES provides the flexibility to model intricate scenarios at the individual level, as the variables that govern the movement of entities through the system can be random and thus readily capture the variation that is inherent in the system [14].

The process-based approach is one branch of DES that conceives the model as a set of processes instead of events acting as the building block of the simulation model. The process-based approach has the advantage to intuitively specify an entity (e.g. a customer or a bus) that follows a given process. The downside of this approach may be the difficulty to manage the simulation when there are many entities interacting with one another [45]. On the other hand, the main benefit of this approach is the possibility of expressing the model in terms of the structures observable in the real world, which makes it more intuitive and more easily interpretable [41].

2.2.2 Simulation applied to public transport

Simulation models have been used to test PT systems with good achievements in reducing time and enabling cost-effectiveness and safe testing of the results of the proposed solutions. Moreover, the use of simulation is also recurrent when researching traffic planning, modeling and traffic networks [6]. One research proposed establishing PT priority at the network level under variable demand conditions. This work showed that it is important to take into account hourly variations in demand when planning PT priority [19]. Haitao *et al.* [21] proposed procedures for PT priority in bi-modal urban networks. The results from this study suggest an increase in total passenger capacity if different strategies were applied depending on the situation. Another simulation-based study found that conditional bus priority reduces the travel time of PT on certain corridors by between 7.64% and 18.76% in the morning peak period, and 5.60% to 22.50% in the afternoon peak period [37].

Another work, namely Mohring [34], involved the construction of a micro-economic model to determine the optimal frequency of buses serving a corridor with fixed demand, considering all resources ("operators" and "users") when calculating the minimum operation cost. The conclusion of that study was that the frequency should be proportional to the square root of demand. Along with that, the experience over the years has shown that this type of simulation studies evolved in improving our understanding of PT operations and found that the role of "users" costs is crucial whenever it is needed to address the problem of PT services design [25].

2.3 Decision Support Systems

A Decision Support System (DSS) is a tool, more specifically an information system, that helps organizational decision-makers in choosing the best options regarding their policy alternatives, facilitating organizational processes. This type of systems has been used worldwide nowadays, often incorporated with a software system. In this way, a DSS uses data, models, and computerized knowledge bases [36]. In essence, the purpose of DSS is to help decision-makers improve decision quality by integrating information resources and analysis tools [31].

A DSS is interactive and helps solving complex, unstructured or semi-structured decision problems where a human assistant or several ones would be otherwise needed. DSS systems are meant to support decision-makers rather than replace them. With data and models, they solve problems focusing on improving the effectiveness of the decision processes [15], leading to test cautious, data-based solution proposals that are then at the disposal of the decision-maker to manage and decide.

These proposals, depending on the theme at study or/and context, may include different KPIs that are crucial for the interpretation of the best solution to follow according to the decision-maker's wishes. Defining priorities or qualitative ranges may help defining clear thresholds and limits of some parameters at study in the DSS system.

A DSS must have a body of knowledge, a record-keeping capability that can present knowledge on an *ad hoc* basis in various customized ways as well as in standardized reports, a capability for selecting a desired subset of stored knowledge for either presentation or for deriving new knowledge, and must be designed to interact directly with a decision maker in such a way that the user has a flexible choice and sequence of knowledge-management activities [23].

In sum, three major characteristics of a DSS system can be identified [44]:

1. A DSS is designed to facilitate decision processes;
2. DSS should support rather than automate decision making;
3. DSS should be able to respond quickly to the changing needs of decision makers.

Being based on a software, the DSS displays a user interface, enabling the users to manage the information, usually the input data, to see the results of the simulation as several KPIs, and assess the reliability of the solution, thus helping the user's decision-making process. The user's interface consists on a set of menus, icons, commands, graphical display formats, and/or other elements of the software program that allow a user to communicate with and use the program.

An effective user interface is important because the data and graphics displayed on a computer screen can provide a context for human interaction and cues for desired actions by a user. Furthermore, it can increase human processing speed, reduce errors, increase productivity, and create a sense of user control. It also depends upon what the user sees or senses, what the user must know to understand what is seen or sensed, and what actions the user can and, in some cases, must take to obtain desired results [44]. Figure 2.5 illustrates a typical interface of a DSS, allowing the user to see some KPIs and providing him/her with an easy visualization to differentiate their values. In this example, the quantitative indicators were transformed into qualitative categories divided by colors.

2.3.1 Key Performance Indicators for public transport

KPIs provide reliable barometers assisting decision makers in identifying successful actions, problems arising and monitoring improvements and results. Choosing the appropriate KPIs is dependent on the understanding of what is important to an organization. Thus, it is possible to

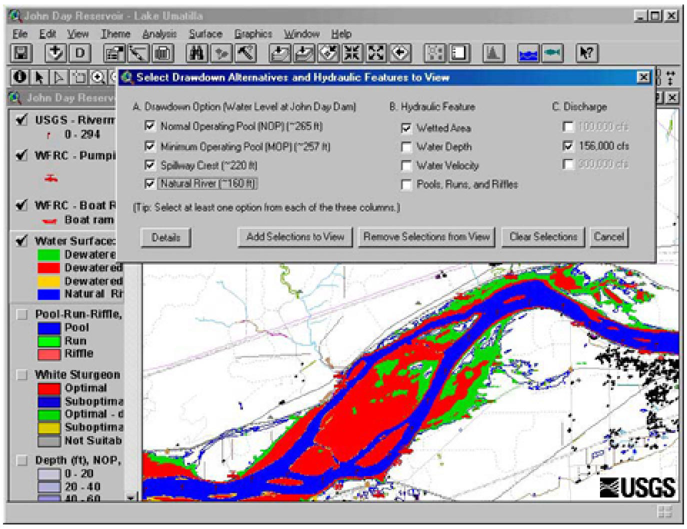

Figure 2.5: Example of a DSS (Source:[50])

employ diversified frameworks to select a required set of KPIs. PT organizations involve a vast range of functions, including planning, procurement, maintenance, operations, investment, customer services, driver affairs, etc. As expected, decision-makers need tools to monitor and assess performance of the organization's activities, in order to reach their goals, which include welfare objectives. So, the outcome performance and achievements of PT organizations can be reported and assessed by the following types of indicators [1]:

- Key Basic Absolute Indicators
  - Absolute indicators that are crucial to be reported and assessed. Examples include: fleet size, operable fleet, number of staff, kilometers travelled, passengers carried, calculated operating cost, operating revenue generated, etc.
- Efficiency of Productivity
  - Related to the amount of output that a unit input produces. An input may be in this case: available/operated vehicles, operated kilometers or hours, seats, seats.kilometers.
- Efficiency of Utilisation
  - Amount of output utilized as compared to the amount of output produced. Produced service outputs once used become consumed service outputs. Examples of consumed outputs include carried passengers, passenger.kilometres and passenger hours.
- Other Key Relative Indicators
  - Financial, internal, customer, learn and growth aspects.
- Effectiveness Indicators

– Concerning the degree of achievement of targeted results i.e. the ratio measured between results and targets.

Several authors tried to establish adequate indicators of service performance regarding PT. Trompet *et al.* [49] used excess waiting time, defined as the difference between actual waiting time and scheduled waiting time. Cats *et al.* [9] considered the time intervals observed between trips of the same line when evaluating a system of regular frequency of vehicle in a given period, calculated as a standard deviation between the observed frequency and programmed frequency.

On the other hand, Bhouri *et al.* [7] Henderson. *et al.* [22] present the Gini index as other indicator of regularity in these services. By transposing the index to the transportation field (usually this index is used to analyse income inequality), the authors apply it as a degree of inequality of performance within a group of trips of the same line to perceive situations that disturb the traffic.

Other projects define punctuality as a relevant indicator. Noorfakhriah Madzlan [52] define the punctuality as a comparison of the departure times and scheduled departure times at the station. Other authors (Chen *et al.* [10]) consider three types of punctuality measurements: the Punctuality Index, which is ground on Routes (PIR) and consists on the probability that a bus will arrive at the terminals during a established time span; the Deviation Index on Stops (DIS), which measures the ability to maintain distances and minimize the passenger waiting time at a stop; the Evenness Index on Stops (EIS), that determines the consistency and distance balance between vehicles.

In Saberi, Meead *et al.* [47], different indexes were used to capture the characteristics of the unreliability of bus service, namely, distribution of time span deviations of trips for frequent services and distribution of delays for non-frequent services.

Ceder [5] indicates transfer time as another indicator. This one consists on the passenger waiting time for a vehicle when changing the line at a connecting station. Other authors use running time (walking in the transfer station) in the calculation of the transfer time, instead.

In sum, it is clear that a standard reference for performance indicators in PT is hardly achievable. Thus, the challenge is to select the right ones that can encompass an accepting overall performance in PT [35]. Abbas [1] assessed representative inputs and outputs to calculate KPIs in a PT organization (Figure 2.6). His approach, which involved outlining different types of information and their importance in this area, was taken into account when choosing the indicators of the system performance in this work.

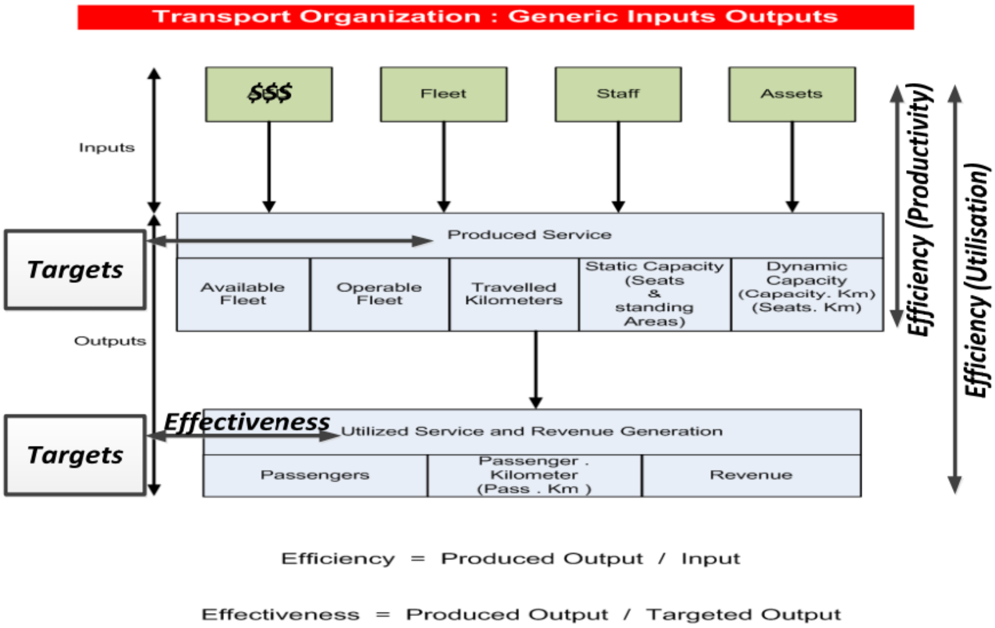

Figure 2.6: Typical Inputs, Outputs and metrics to assess the performance of a PT organization (Source: [1]).

Chapter 3

Problem Description

3.1 Problem definition

In most rural and peri-urban communities, the efficiency of traditional PT is quite small, which increases its costs. This leads in general to a reduction in the service, missing local points of interest, and lacking the capability to reach potential passengers. The population, also, might lose the availability of transport if the cost of transport provision increases too much. For this reason, these populations usually present a high dependence on private transportation. The lack of transportation alternatives usually affects the most vulnerable individuals (young and elderly population, impaired people, and low-income households).

With these groups in mind, this project proposes a tool for assisting the design of a route deviation system (a type of DRT), taking into account the specific characteristics of rural and peri-urban areas. This system allows the vehicle to deviate from a pre-established route, reaching potential passengers in the surroundings. The project will be done using a process-based DES. Thus, the simulation method uses processes to design the vehicle's path, identify its current action, and with discrete event triggers, it establishes the next move.

3.1.1 Assumptions

Some assumptions were considered to guide the development of this research, including:

- Possibility of incorporating a joint digital channel that enables passengers to book their trips and paying for distinct mobility modes with customized and real-time information - concept known as MaaS;

- Passengers must buy the trip ticket some predefined time before entering the vehicle (by smartphone apps, phone calls or SMSs) - in order to plan the trip deviations;
- Demand input is assumed to be on a daily basis with the simulation being done in one day;
- A table with the information regarding all the demand for one day will be available (sorted by ascending order of the time that the passenger required the trip);
- Only a single vehicle is operating in order to simplify the computational processing. Testing the behaviour of more vehicles in the system is expected in future works.

Moreover, the demand information used in the simulation may be obtained by predictions with estimations based on surveys, deadhead checks and other methods. With that information available, the decision-maker will only need to analyse the indicators related to the operational and tactical frameworks of the service. Some terms were designated to represent elements of the problem. For setting up the problem, those are clarified thereafter.

First, the Zone Stop. The Zone Stop is a stop point for the vehicle, either a mandatory stop (route) or an optional stop (needed request - deviation). The Zone Stops do not only represent specifically the stop point of the bus, but also the whole region surrounding it - a neighbourhood, a commercial centre, a hospital, a park, etc. Additionally, if a passenger requests a trip from or to a particular location within the Zone, it is assumed the Zone Stop point as the requested location, for simplification purposes.

In order to address the amount of time passengers walk in a trip, which is relevant when assessing the service reliability of any PT, a parameter denominated Walking Distance Limit was created. This parameter takes into consideration the pedestrian velocity and the maximum time a pedestrian is willing to walk to a Zone Stop. Those are inputs that can be changed by the decision-maker and are needed to calculate the Walking Distance Limit [Distance=Velocity/Time]. If the distance between a route stop point and a requested Zone Stop outside the route is greater than the Walking Distance Limit, that is the distance the passenger is willing to walk, then the vehicle operating proceeds to a deviation.

Finally, the Deviation Distance Limit is a parameter representing the maximum distance from the route that a vehicle is allowed to deviate. This parameter is also defined by the decision-maker and can be changed.

Some assumptions were made, including those described above as follows:

- The DSS assesses specifically the possibility of adopting a route deviation system.
- The simulation is made for a time-span of a single day.
- There is only one vehicle in service.

- The stops represent neighbourhoods or districts - they were called Zones - and are displayed as points in the simulation interface.
- Traffic is considered constant, so the time that a vehicle spends when travelling between two known points is always the same (calculated by the software).
- The vehicle may only deviate one time for each segment of the route.
- The actual aggregated demand or demand prediction is defined by a set of individual trip requests for the day at study (sorted by ascending order of required scheduled pick-up time). The demand data (Table 3.1) includes the pick-up time the passenger wishes, his/her age or condition, the purpose of the trip, and the origin and destination zones. The age or condition of the passenger is a categorical variable, which is important in cases the decision-maker wants only to make a deviation if the request is from an elder or disabled person. The purpose of the trip may be important for future works.

TripID	**PickUpTimeRequest**	**Age/Condition**	**Purpose**	**Origin**	**Destination**
1	6:21	Elder	Residential	Zone1074	Zone804
2	7:56	Adult	Shopping	Zone29	Zone975
...	...	...	...	...	...

Table 3.1: Example of a table for the input demand data used in the simulation.

- For each trip there is a maximum distance limit between the requested pick-up/drop-off zone stop and the actual route stop. If that distance is less than the Walking Distance Limit, then we assume that the passenger will walk and the vehicle will not deviate. In this case, it is considered that the passenger appears at the route stop at the time that he/she requested the trip. If the distance is greater than the Walking Distance Limit and less than the Deviation Distance Limit, then the vehicle will deviate to the requested Zone. Otherwise the vehicle will not deviate and the passenger walks to the required Zone.

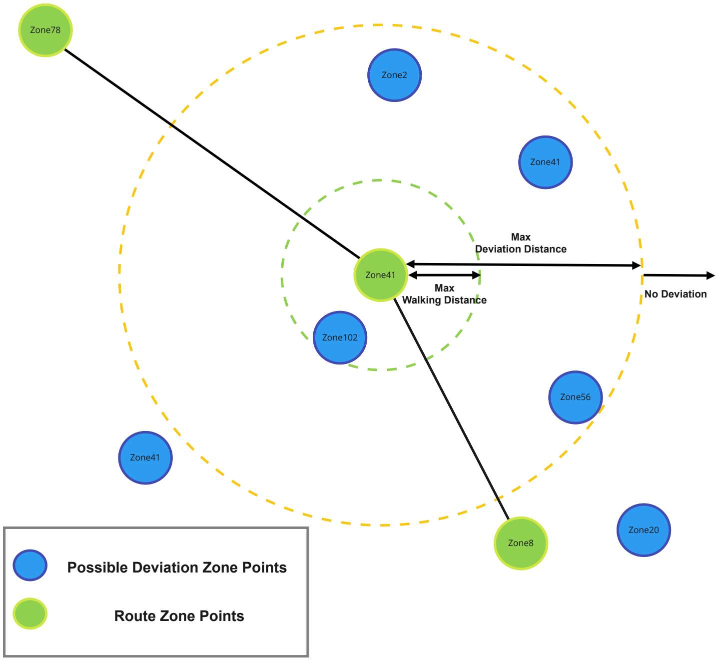

Figure 3.1: Distance limits for action decision towards a deviation request (both pick-up and drop-off cases)

It is worth mentioning that the operator may simulate the system for a particular time interval (for example, peak hours) if he/she wants to analyse the adoption of the route deviation DRT exclusively on that time interval, as it is recommended in some cases in the literature. After knowing the characteristics of the PT service he/she is willing to test, the decision-maker may run the simulation, analyse the KPIs of the DSS and come to a decision of how better to address a fixed route PT service and how to invest in new ways of operating it. The KPIs presented to the operator were considered taking into account the stakeholders of the service and the metrics that evaluate the benefits and drawbacks of adopting a route deviation DRT strategy, instead of maintaining the fixed route service. The proposed KPIs are the following:

1. Average passenger walking time from origin zone to pick-up zone;
2. Average passenger walking time from drop-off zone to destination zone;
3. Average passenger departing delay time;
4. Average passenger arriving delay time;
5. Average passenger time inside vehicle;
6. Average passenger time spent on trip;
7. Total passengers served;

8. Percentage of demand served;
9. Average number of passengers per trip;
10. Standard deviation of boarding passengers per route trip;
11. Total running cost;
12. Total running revenue;
13. Increase in the number of passengers served by adopting route deviation DRT;
14. Average route passenger departing delay time due to DRT implementation;
15. Average route passenger arriving delay time due to DRT implementation;
16. Average increase in the route passenger's time inside vehicle due to DRT implementation;
17. Cost increase by adopting route deviation DRT;
18. Revenue increase by adopting route deviation DRT;
19. Average number of passengers per kilometre (km);
20. Average number of kilometres per trip;
21. Average number of minutes per trip.

According to the literature review, the KPIs were chosen to best suit the categories explained before and to balance the interests of the operators and the passengers, evaluating the service level and showing economic parameters. Concerning Key Basic Absolute Indicators, those include (1) to (13). The service level and the provision dimension represented mainly with the KPI (1) to (10). (11) and (12) are considered the financial operational indicators for the implementation of a DRT. The Productivity indicator is represented by the number (19), the Utilization indicators are (20) and (21) and from (13) to (18) of the relative performance of the route deviation DRT system in comparison to the fixed-route system. The Effectiveness indicators are: the number of passengers the service assisted (7); the percentage of passengers assisted in relation to overall demand (8); the number of passengers assisted due to deviations (13), thanks to the DRT mode of service. The effectiveness of the service is then related to the number of people that use the service. Furthermore, parameters (1), (2), (3) and (5) are linearly dependent of parameter (6). That is because the sum of the walking times to the departing delay and to the time inside the transport vehicle equals the total trip time. Almost all the indicators are estimated using the average of the values. However, the standard deviation is also used in (8) to assess the variability of the service productivity along the time experiment.

3.2 Considerations about the demand

Data produced by the demand generation process is considered an input of the simulation. Thus, when performing the simulation it was necessary to consider a set of demand requests to test and assess the DSS. In order to perform a reasonable prediction of the demand, a maximum and a minimum number of requests per unit of time were established. The prediction was done using a minute-based generation of demand and considering a Poisson distribution of the rate of arrival requests. The generation of the trips was addressed by a stochastic approach which takes into account a probability of a trip "arrival" for each hour and probabilities regarding the Age/Condition of the customer and their trip purpose. Knowing the trip purpose and the requested time, the algorithm assigns origin and destination zones according to given probabilities. This process was based on a previous work about a framework of DRT to implement also in rural and peri-urban areas [13].

To study the effect of a established route in the nearby zones demand, it was considered that a determined percentage of the demand generated requests is route-based. These data can be changed by decision-makers according to their analysis and the context of the socio-economic system at study. So, to fulfill this assumption, the non-route requests resulted in the demand prediction were artificially converted to have origin and destination requests on the route, specifically in the route stop points nearest to the original requested zone point. This work emphasizes the existence of aggregated demand prediction (both route-based and deviation-based) considering an *a priori* route installed, which is something that previous works on demand prediction lack to analyse. Future works will have the means to assess these issues as information technology advancements make surveys and analysis cheaper and faster. If the demand for route and deviation requests was obtained separately the decision-maker may also join them when using the DSS. Figure 3.2 is a scheme of the Demand Generation Process considered for the project's simulation.

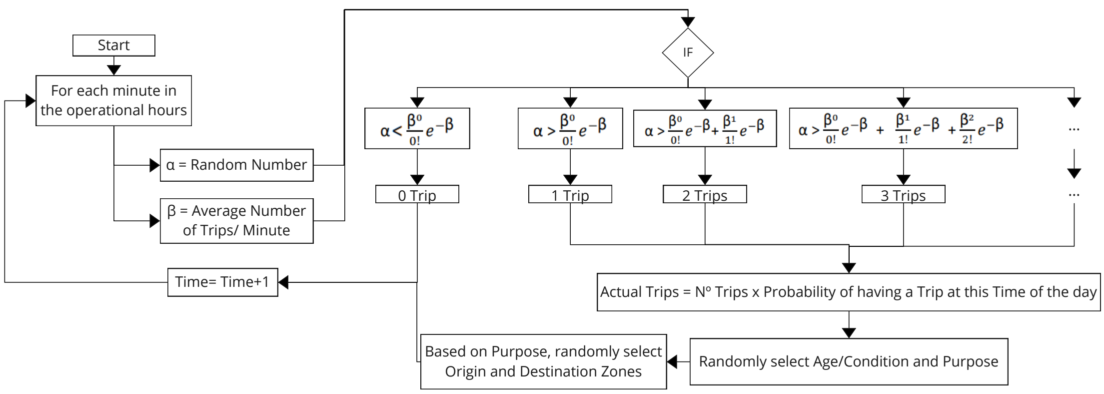

Figure 3.2: Demand Generation Process.

Chapter 4

Methodology

4.1 Introduction

The proposed DSS assumes the existence of a traditional route system already implemented in the location at study. This type of route, with fixed schedules and frequencies, is broadly the most common even in rural communities. Thus, in this work relative performance analysis is assessed between a traditional route and a possible flexible solution with the indicators of relative costs and gains displayed for the decision-maker. So, this approach tests the route-deviation DRT strategy, which consists of an established route that deviates in some cases to pick-up or drop-off a passenger.

The methodological approach to design a DRT, according to Papanikolaou *et al.* [39], can be structured around economic and econometric methods, associated with the strategic phase, and operational research methods, which are concerned with the tactical and operational stages. As this dissertation is a research with the purpose of designing an operational and tactical framework, its main objective is to provide a tool for decision-makers that can assess the best investment possibilities for a community with a bus route already installed.

As mentioned in the literature review, the problems of operating a DRT have the same nature of the Dial-a-Ride models, in the sense that one is interested not only in minimizing operating costs or the distance travelled by the vehicles, but also in maximizing the quality of the service, expressed by indicators such as the average passenger waiting time or the on-board (ride) passenger time. Thus, this type of service model operation needs to be understood, specially in how the different ways of operating affect customers and operators [20].

The DSS should have the possibility of changing route stop points, deviation points, frequencies, maximum distance allowed to deviate, etc. For rural areas, a careful analysis of trip purposes is needed. That is because, in the case that the trips are time sensitive, such as work or school commutes, DRT may result in a loss of ridership [43]. On the other hand, in small urban areas the route deviation may be the best candidate for the implementation of DRT. Nonetheless, in this case existing routes productivity's, population density, incomes, etc. should be assessed as well [43]. So, as the operator has this information and knows the demand patterns for each zone of a determined rural or peri-urban location, he/she will be capable to make the best decision with the adequate indicators. This may mean to implement a new route with deviation, try a deviation strategy on a traditional route or/and make changes in route stops locations.

This work assumes that demand data is already known, being it an estimation or a collection of transit data (point checks, deadhead checks, surveys, etc.) to get an approximation of the actual route trips demand and deviations demand. Thus, the project focus on KPIs and the delivery of an useful DSS to the operator. The inter-connectivity of transport services in digital platforms will provide the user with an easier way to book a trip, and give to operators a cheaper way to get demand estimations and requests data. This work emphasizes the development of a platform that can support the analysis of data. Hence, demand modelling and prediction are outside the scope of this work. Those features can, however, be studied in future works.

The operator may define the values of certain decision inputs, including:

- Simulation start scheduled hour;
- Simulation end scheduled hour;
- Maximum deviation distance permitted in relation to the route in metres (m);
- Cost per hour;
- Cost per kilometre (km);
- Ticket revenue per passenger;
- Route zone stop points including the 2 terminals zone locations;
- Trip maximum duration from terminal 1 to terminal 2 and vice-versa (scheduled time of next trip for return);
- Average pedestrian walk velocity (km/hour);
- Average vehicle velocity (km/hour);
- Maximum minutes that a person is willing to walk to get to a stop;
- Time-span in which a passenger is willing to anticipate or postpone their trip (min).

It is also assumed in this work that the demand is an input data, namely a set of individual trips with requested time, origin, destination and population segment specification. The time frame of the simulation is considered to be a single day in order to simplify the problem. The operator may run several times the simulation with different inputs and check the KPIs' values to evaluate the pros and cons of a determined set of decision inputs and make a decision afterwards.

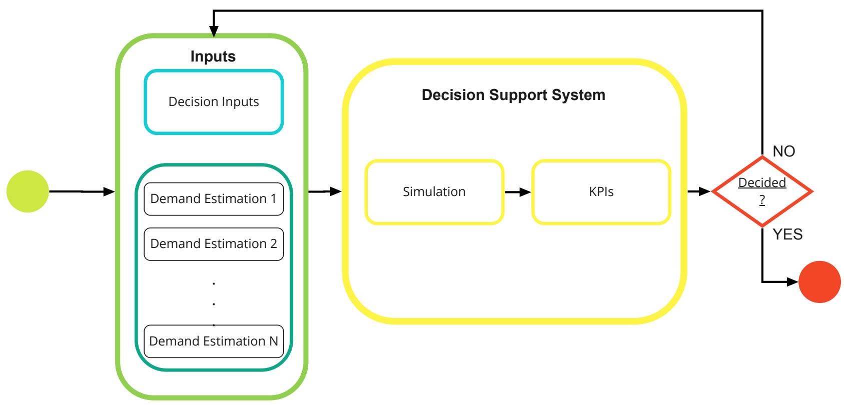

Figure 4.1: Process involving the use of the DSS by an operator

the following sections, taking into account the assumptions presented in Chapter 3, aim to explore those assumptions and how to implement them in the DSS.

4.2 The software and the simulation

The *FlexSim* simulation modeling software was used in this project. *FlexSim*[1] is used for processes' analysis in areas such as manufacturing, robotics, healthcare, logistics, etc. The module employed in the project was GIS, that is a new tool for modeling transportation where travel time and distance are a factor.

Within the GIS model the driving roads route type was used. This is a pre-configured mode that downloads the roads information from a routing server. Based on that information, the vehicles may take the shortest route, the fastest route or even consider weights combining the two options (minimize time or distance) to get the best option of the path between two connected points [17]. The times and distances between two points are constant, so the effect of traffic is not considered in this work. The values that the software uses for those metrics are based on a routing server.

4.2.1 Process-flow

The implementation of the process-based discrete event simulation (DES) using *FlexSim* makes the modeling of the system easier for complex models, saving large amounts of customiza-

[1]https://www.flexsim.com/

tion efforts and many lines of computer code. *FlexSim* process-flow work component offers a picklist of choices for the user, tackling the usual setbacks of simulation in two ways [17]:

- Replacing modules and instructions of computer code with pre-built activity block diagrams, building the logic as a flowchart of the system;
- Allowing the user to organize the rationale behind the system and tracking the steps in a process or procedure (which is difficult in only code-based simulation).

Thus, the process-flow offers a practical option for modeling complex systems, such as the implementation of DRT. As the simulation progresses, tokens will move through the system and show in which step the simulation is on. In the present work, the custom code blocks were mostly used within the process-plow diagrams.

4.2.2 System development

The simulation design of the Route Deviation DRT is divided in two phases: the Network Setup and the Route Mission. The Network Setup is a static procedure performed by the user that encompasses the creation of the route Zone points, their paths, and the deviation paths. The Route Mission covers the dynamic process of the DRT service for the vehicle and it will run during the day considered for the simulation.

4.2.2.1 Network Setup

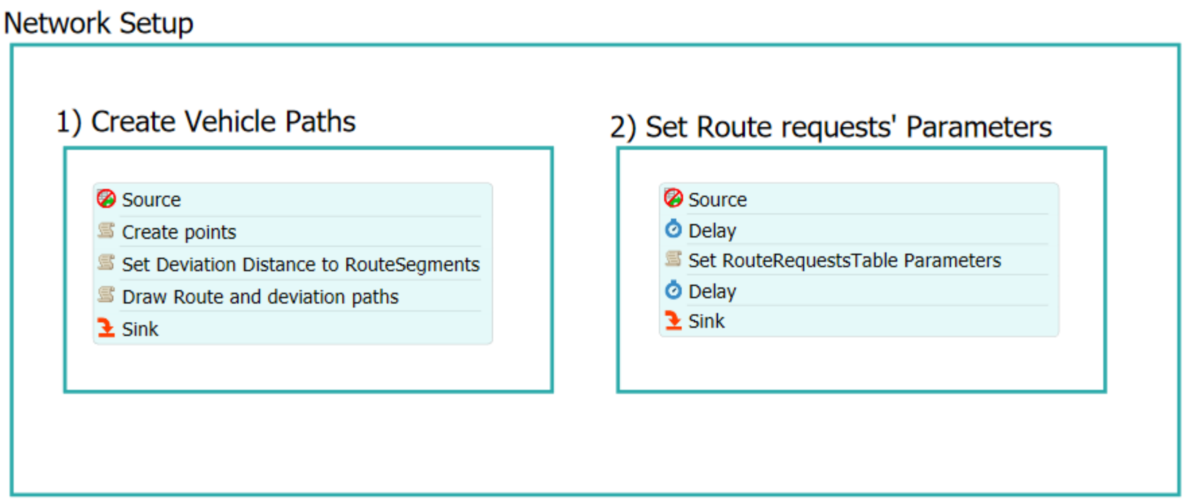

Figure 4.2: Process-flow of the Network Setup simulation phase

The simulation starts assuming the existence of three *a priori* tables that the decision-maker needs to fill: the Route table, the Zone points table and the Requests table. The first table deals with the route information, namely geographical mandatory stop points' locations and their function or interest purpose.The Zone points table includes all points that the decision-maker is willing to study as possible origin or destination Zones for a trip, either route-based or deviation-based. The Requests table holds information regarding the aggregated demand, both for route trips and deviation trips (described in detail in Sections 3.1.1 and 3.2).

As shown in Figure 4.2, the Network Setup is divided into two subroutines. The first one creates all zone points in the GIS map and the possible vehicle paths for the day taking into account the requests table and the route path. The second one (Set Route requests' parameters) consists in creating a table denominated *RouteRequests* in which the demand requests for the already existing route, i.e. the requests where origin and destination zones are route points, are obtained from the aggregated demand (Requests table). After getting all the information from that table, the algorithm takes into account the GIS road distances and times, to calculate the expected arrival time for each route request, considering that the potential passenger is picked-up by the vehicle in the route stop at the required time. These times consider the nonexistence of deviations and are necessary for the calculation of KPIs ahead in the simulation, namely the delay times. One factor at study is then for example the influence of deviations on trip expected times.

4.2.2.2 Route Mission

The Route Mission phase follows the Network Setup phase and consists on a dynamic assessment of the schedule time, the vehicle (bus) position and its procedures along the journey process.

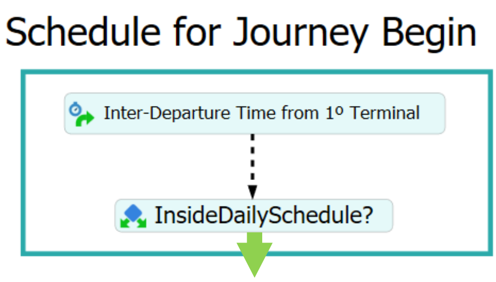

Figure 4.3: Process-flow of the Route Mission simulation phase - Journey Begin Assessment.

Figure 4.3 shows a flowchart representing the initial step of the Route Mission phase. That step consists in examining if the simulation time and the time for a journey beginning are compatible. First, it creates a token each time in-between trips departing from the 1st Terminal, starting the first time at the Simulation Start Time. Then, if the simulation time is within the daily schedule established by the decision-maker, the vehicle is ready to start the journey.

After setting up the bus on the 1st Terminal, a token is created and a loop code is in place to represent the bus actions throughout its path during the first direct journey and then the inverse

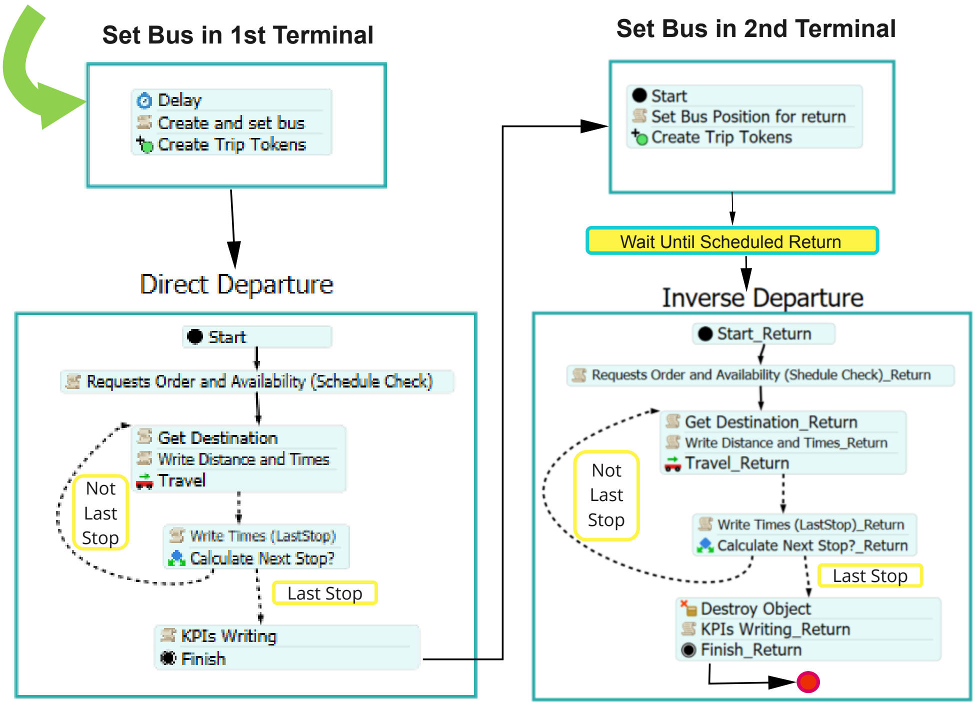

Figure 4.4: Process-flow of the Route Mission simulation phase (Bus Journey)

journey on return afterwards. The token stops in-between the two complementary journeys when reached the 2nd Terminal to wait for the scheduled departure from it. This process is presented in Figure 4.4.

The actions of the token are redefined each time the bus arrives at a stop point and when the bus reaches again the start zone point, the token is destroyed and it is necessary to wait an inter-arrival time until a new vehicle is on the road again (process always active shown in Figure 4.3). At the end of each journey, the KPIs are collected and the results can be assessed by the decision-maker.

4.3 Pick-up, drop-off and delays

4.3.1 Route requests

Once the route request pick-up time is known, the schedule for the route requests drop-off times is considered to be known, as the software calculates automatically the time a vehicle needs to travel from and to each route stop. For these trips, the departure delays and the arrival delays are calculated automatically. Figure 4.5 shows how the delays are calculated.

Taking into account the value of time for the passenger, it is reasonable to establish that if

PickUpTimeRequest	ActualPickUpTime	Departure Delay Time (in minutes)	DropOffExpectedTime	ActualDropOffTime	Arrival Delay Time (in minutes)
10:05	10:20	15	10:15	10:30	0
11:15	11:08	0	11:20	11:21	8
Request Table	Obtained during simulation	ActualPickUpTime - PickUpTimeRequest	Calculated by the software (GIS Module)	Obtained during simulation	ActualTripDuration - ExpectTripDuration

ActualTripDuration = ActualDropOffTime - ActualPickUpTime

ExpectTripDuration = DropOffExpectedTime - PickUpTimeRequest

Figure 4.5: times and delays for route requests

the passenger is picked-up before the required times, then the delay time for departure is considered to be null. This happens when the bus arrives in advance to the pick-up stop and the passenger enters the vehicle before the scheduled time. This is considered to have no costs for the passenger and the decision-maker defines the appropriate time-span in which the passenger is willing to anticipate the ride request (see section 3.1.1). The arrival delay time takes into account the amount of extended time losses during the trip related to the expected time of trip duration. This is relevant to evaluate the consequence of the DRT route deviation in the usual route passengers trip times.

4.3.2 Deviation Requests

PickUpTimeRequest	ActualPickUpTime	Departure Delay Time (in minutes)	DropOffExpectedTime	ActualDropOffTime	Arrival Delay Time (in minutes)
15:09	15:05	0	15:17	15:25	12
18:10	18:17	7	18:30	18:25	0
Request Table	Obtained during the simulation	ActualPickUpTime - PickUpTimeRequest	PickUpTimeRequest + ExpectTripDuration	Obtained during the simulation	ActualTripDuration - ExpectTripDuration

ActualTripDuration = ActualDropOffTime - ActualPickUpTime

ExpectTripDuration = Distance/Velocity

Figure 4.6: times and delays for deviation requests

The deviation requests, i.e. the requests that have an origin or a destination on zone points outside those on the routes, do not have a predetermined *a priori* path and consequently a time defined trip. So, in order to calculate the time expected for the trip, the direct distance between the two points was considered as an approximation, and the vehicle speed as a parameter controlled by the decision-maker. Then, as presented in Figure 4.6, the *ExpectedTripDuration* is estimated dividing the distance value by the value considered. Concerning the other times, they were obtained in the same way as the route requests.

4.4 Path and deviation

The vehicle path is redefined each time it passes through a zone stop point. When passing that point, the algorithm checks the requests table and the current time of the system and if there is a deviation request for pick-up or drop-Off (considering the time-span limits mentioned in section 3.1.1), the vehicle may proceed to a deviation. However, that only occurs in the cases the total time the vehicle needs until the end of the trip in the next terminal (with the deviation) is less than the time left for the vehicle to start the return journey at the same terminal. Furthermore, the deviation points are assigned to specific route segments, taking into account the minimum distance to the route in order to minimize the distance travelled by the vehicle.

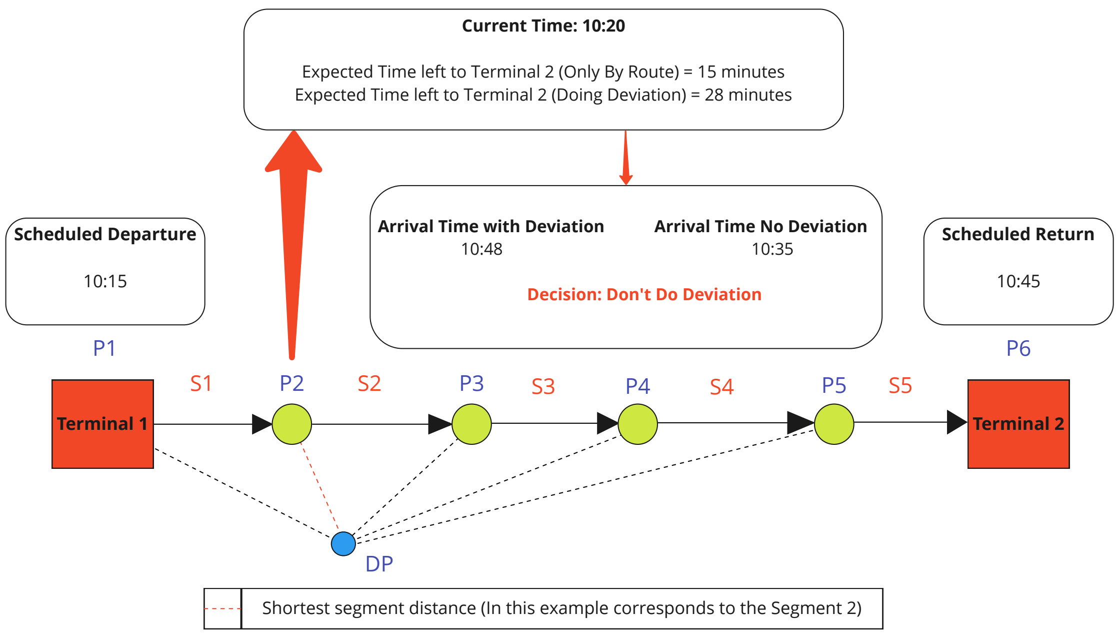

Figure 4.7: Scheduled path predictions and decisions applied to the DRT route deviation

Figure 4.7 represents how the simulation checks if a particular request for deviation is accepted or not as described earlier. In the *TripRequests* table, the data of individual passengers is collected (by ascending order of request) and when for a certain request time (within the time-span range) the vehicle stops at a route Zone point with the shortest segment distance to the Deviation point (DP), the system calculates the expected time the vehicle needs to reach the next Terminal considering the deviation. For instance, in the example (Figure 4.7) the deviation would take 28 minutes and if the scheduled return trip would need 28 minutes or less at that point, then the vehicle would not make the deviation in order to keep with the scheduled time.

These situations may require that the decision-maker or the operator choose one of the two options: either to outsource the service provision with partnerships of other transport providers (for example UBER or taxis) to safeguard the service level and to provide the service to the largest possible number of requesters. The second alternative, without cancelling the requests, would be to increase the time-span between the departures of the two terminals in question, which is a parameter of the decision-maker. However, in that case it may be necessary to invest in the fleet of vehicles to seize the demand, otherwise the passengers may lose interest in the service in the cases in which the vehicle stops at times far off of their requests.

As described in the literature review, in many cases flexible transportation services focus on a specific segment of the population, namely disabled or elderly people. Taking that into account, the system user has the possibility of deciding to make deviations only if the person who requested is disabled or elderly (based on the request information of the table *TripRequests*).

4.5 The *TripsRequest* table

The *TripRequests* table is a data table in which the operator has the information about the requests service demand. The table is organized by ascending order of customer request times. This way, the simulation selects the deviations based on who demanded the service first, and it takes into account also the time-span and the route direction. Finally, for each request the system checks whether or not the total time needed to reach the terminal is less than the time remaining for the next trip, to decide if it is better to do the deviation or not.

4.6 Performance Indicators

A brief explanation of the delay KPIs was already presented in Section 4.3. Thus, in this section it is only needed to present the other indicators. These indicators are shown in an interface which divides the KPIs into different categories, as explained in detail in Chapter 3. The dashboard model interface is displayed in Figure 4.8.

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	7.00
CostIncreaseDRT	58.56
RevenueIncreaseDRT	10.50
DepartureDelayRR_average	7.30
ArriveDelayRR_average	7.70
IncreaseTimeInsideVehicleRR_average	0.80

Financial Operation Indicators

Name	Value
TotalCostRunning	516.85
RevenueRunning	40.50

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	2.84
DepartDelay_average	5.89
ArriveDelay_average	7.20
TimeInsideBus_average	7.63
TimeSpentOnTrip_average	10.47
BoardingPassengersPerTrip_average	1.93
BoardingPassengersPerTrip_stdev	1.28
TotalPassengersServed	27.00
PercentageDemandServed	0.30

Utilization Indicators

Name	Value
NumberKmPerTrip_average	4.80
NumberMinutesPerTrip_average	7.63

Productivity Indicators

Name	Value
PassengersPerKm_average	0.19

Figure 4.8: Dashboard model for the considered KPIs

4.6.1 *The walking times*

The walking time measures, in minutes, the time that a passenger spends walking from the requested zone point to the nearest route stop point, or from the route stop point nearest the destination zone point to the destination zone point. This happens when the user origin or destination zones are near enough to a route stop point so that the vehicle makes no deviation and the user simply walks. Adding to those cases, it is also considered that a passenger whose destination is far beyond the limit distance for a possible deviation will be dropped off at the nearest route stop point, walking from there to his/her final destination.

This metric is important in estimating the total time spent by a passenger in a trip and to noticing how much the transport service does not cover the passengers' trips and their needs. Thus, walking times calculation is important and takes into account the person walking speed (user input) and the distance between the two points [Time=Distance/Velocity]. The value displayed is the mean of the walking times of all passengers, which is an important statistical estimator for the parameter assuming a commonality and a generalization of the service level provided. Some times it may be biased due to disparities in the location of points of interest and residential areas.

4.6.2 *The passenger trip times*

The *passenger trip times* measure the total time that a passenger spends in the desired trip and can be used as a cost indicator for that trip. Apart from the financial cost and despite the value of time varies from passenger to passenger, the mean of the total trip time is a relevant estimator for generalizing the real cost of a passenger in taking a trip using the DRT service.

4.6.3 *Percentage of demand served*

The percentage of demand provided by the service shows to what extent the DRT service is effective in satisfying the demand or the service requests for the day, available in the *RequestsTable*. This metric includes deviation requests and route requests as well.

4.6.4 *Number of passengers per trip*

The *number of passengers per trip* is a metric that shows the number of passengers that are served in each journey, considered as the movement of the vehicle from one terminal to the other. The best estimator for this parameter is the mean, but the standard deviation is also shown to the decision-maker, with the aim to examine if the number of passengers per trip is constant or if it varies throughout the simulation time-span. For example, good values for these parameters would be a high mean value of the number of passengers per trip and a low value of the standard deviation, which would ensure that there is constant high demand being dealt with the DRT service. High values of the standard deviation suggest that there are trips during some time of the simulation day that account for much less passengers than other times, which can support the decision-maker in addressing the inefficiency of the service.

4.6.5 Financial operational indicators

The financial indicators for this service aim to provide the decision-maker with information on the total costs and total revenue of running the DRT service, from an operational perspective. Total revenue is obtained by multiplying the total number of passengers served by the ticket fare applied to each passenger.

Concerning the total costs, there are two types of costs, namely distance costs, corresponding to a monetary value related to the distance covered while providing the service, and time costs, which consider the time-span at which the service is operating. Time costs are simply calculated by multiplying a predefined cost per unit time by the total time elapsed in the simulation for analysis. The distance cost is calculated in the same manner, with the cost per unit of distance being a parameter inserted by the decision-maker. This may represent the maintenance financial costs due to the utilization of the vehicle, as long as the overheads of the service related to the distance. The time costs focus primarily in the personnel costs, but can also take into account other overheads. Finally, the result parameter of total costs is regarded as the sum of the two terms above-mentioned.

4.6.6 Utilization indicators

Utilization indicators aim to show how much the service uses time and distance covered to fulfill passengers' demands. So, they support the decision-maker with the average time and distance used for travelling per trip. This metric is important because it provides the decision-maker with information that may be crucial for understanding if the time and distance provided by the vehicle are reasonable, or if it is needed to extend or decrease the number of stops and the route length.

4.6.7 Productivity indicators

Productivity indicators aim to indicate the depth of the value that the service provides, that is the extensiveness of the service in the location in analysis. So, they support the decision-maker with the average number of passengers served per distance unit travelled by the vehicle. Thus, these KPIs show an effectiveness metric of the DRT service.

4.6.8 Relative performance indicators

Relative performance indicators aim to deliver the decision-maker metrics that may support the assessment of the DRT service to address the performance of the route deviation service vis-à-vis the traditional route transport service provided.

These indicators include the increase of the number of passengers with the DRT service, the cost increase, the revenue increase, the departure and arrival delays of the route requests' service and the time increase inside the vehicle of the route requests' passengers. All these indices are average values that appropriately address in which way the DRT service can be different of the traditional service. The revenue, cost and number of passengers are straightforward to evaluate. Concerning the other indicators, related to the route requests, they aim to specify to what extent the route deviation service is jeopardizing the route passengers' service level.

4.7 The user interface

The user interface of the DSS is integrated with the simulation and shows the journey of the vehicle in real time and updates the KPIs shown each time it finishes a journey from one terminal to the other. Moreover, the visualization of the system provides the decision-maker with the capacity to access the position of the bus, the location of the zone points, the KPIs values and the inputs that were chosen.

This way, the analysis of the global system makes it easier and more practical for the decision-maker to check the parameters, visualize the distance and behaviour of the vehicle and ultimately decide what is the best course of action when dealing with a PT service in the requested region.

The region chosen as the scenario to test the DSS was the city of Crateús in Brasil, having similar characteristics to a regular peri-urban community. Thus, the information of the points of interest, that is the Zone Points, were retrieved from an assessment in the software QGis, taking into consideration the most likely origins and destinations for population commute.

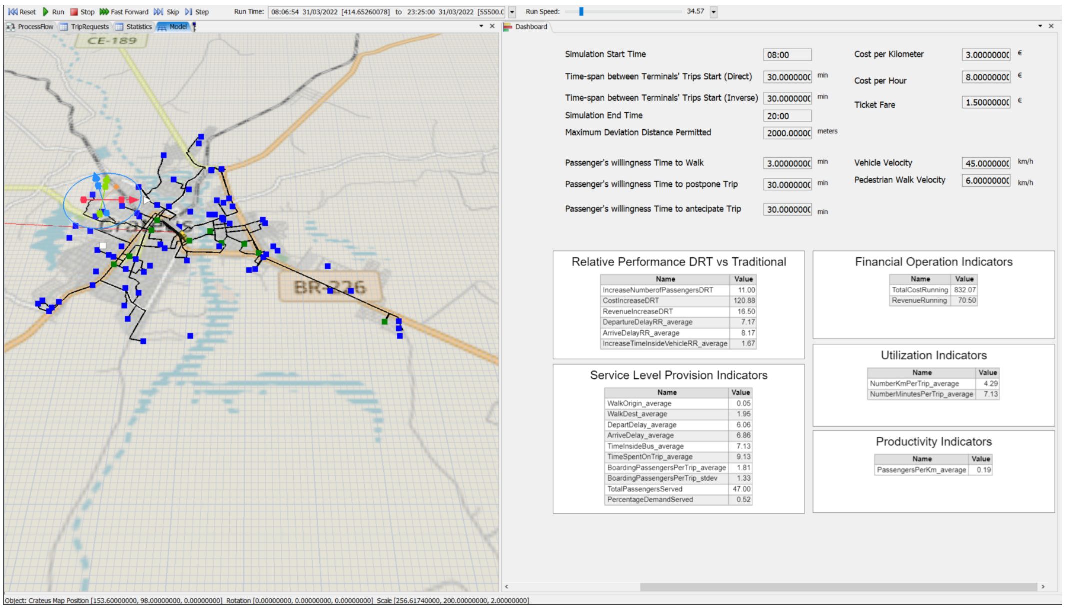

Figure 4.9: Interface of the DSS

Chapter 5

Evaluation of the DSS

This section presents some tests that aim to show the quality of the DSS developed in this dissertation. In addition to that, the results will be explained and it will be clarified in what extent this DSS simplifies and improves the decision-maker analysis for an operational implementation of a route deviation DRT service.

The region considered for the study was the city of Crateús, located in the State of Ceará, Brazil. This city has around 75000 inhabitants according to the last census [1], having a clear peri-urban region. The selection of zone points took into consideration the socio-economic context of that region. Figure 5.1 shows the Crateús city along with the contemplated zone points.

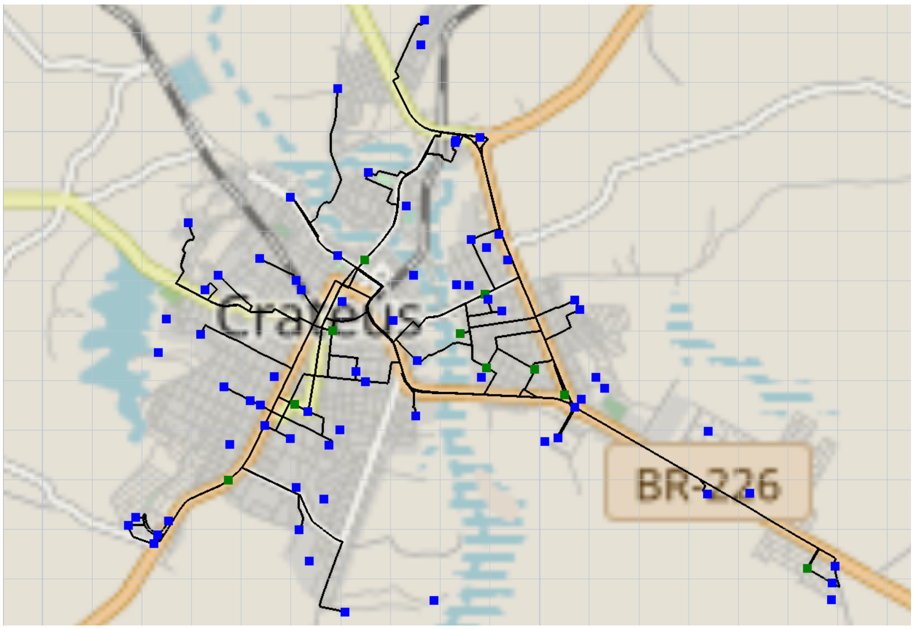

Figure 5.1: Map of Crateús (Brazil) and its zone points used for simulation

[1]https://www.ibge.gov.br/cidades-e-estados/ce/crateus.html

5.1 Case studies

In regard of the objectives mentioned above, the following tests will be presented:

Test Base) Base test for input data;

Test 1) Extension of the simulation time, and consequently extension of the service operation time-span;

Test 2) Reduction of the time-span between terminals trip start (both direct and inverse), increasing the frequency of DRT service (only one vehicle);

Test 3) Increase of the Deviation Distance allowed, reaching deviation requests farther from the route;

Test 4) Change of the route stop Points location to check if the new route set seizes more demand requests and improves the service level;

Test 5) Aggregate tests (1) to (4).

The same number of demand requests in the *RequestTable* is assumed throughout the testing of the DSS. For the simulations, a random generation of requests was followed as specified in Chapter 3. Then, the route requests were created artificially by selecting the closest requests' distances to the route (average distance of pick-up and drop-off points to the route shortest stop points). The selection was made until a stipulated ratio of demand requests in relation to total demand. The decision-maker may use other values in the analysis and it is advisable for he/her to run the simulation with different samples of demand, specially if it has components that are predictions in order to ensure the viability of the proposed system.

For this study, all the routes' paths were considered as being the shortest between the start and ending points. Nevertheless, the decision-maker is able to adjust these values, balancing between the fastest trip or the shortest trip, using durations or distances for the route costs.

Moreover, the Route Stop Points are represented in green in the simulation and the points representing the different Zones are in blue. The first and the last route stop points considered correspond to the first and second terminals respectively. Furthermore, for all the tests it was considered that the user is interested in establishing deviations not only for the disabled or elderly people but for all the passengers. The main characteristics of the simulation are presented in Table 5.1.

Ratio of Route Requests	Nº Route Stops	Passengers Segment	Nº Generated Requests
4/9	10	All people allowed	90

Table 5.1: Characteristics of DSS tests

Taking into account this procedure, the input parameters' values considered for the tests are shown in Figure 5.2.

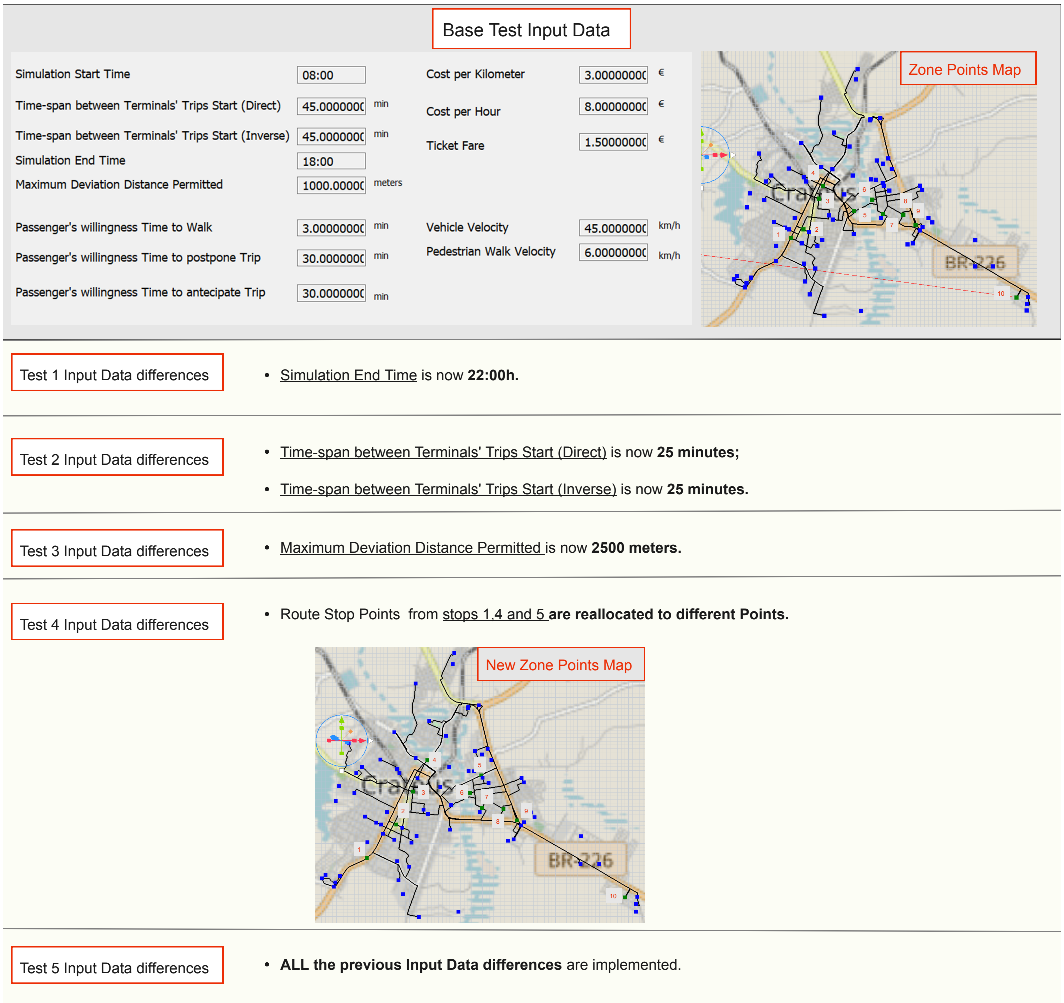

Figure 5.2: Input parameters of the Base Test and the changes made for the Tests 1 to 5.

5.2 KPIs and discussion

This section analyses the obtained KPIs. This analysis encompasses the comparison of the tests for the five cases with the Base Test. After the tests comparison, a final remark will be made to conclude the assessment of the DSS and to show its benefits.

5.2.1 Test 1

Base Test

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Test 1

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	8.00
CostIncreaseDRT	100.26
RevenueIncreaseDRT	12.00
DepartureDelayRR_average	7.37
ArriveDelayRR_average	8.07
IncreaseTimeInsideVehicleRR_average	1.22

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.07
WalkDest_average	3.94
DepartDelay_average	7.20
ArriveDelay_average	6.67
TimeInsideBus_average	6.06
TimeSpentOnTrip_average	10.06
BoardingPassengersPerTrip_average	1.75
BoardingPassengersPerTrip_stdev	1.44
TotalPassengersServed	35.00
PercentageDemandServed	0.39

Requests Served Traditional (No DRT)	**Requests Served DRT (Base Test)**	**Requests Served DRT (Test 1)**
19	24	35
Net Financial income Traditional (No DRT)	**Net Financial income DRT (Base Test)**	**Net Financial income DRT (Test 1)**
-354,45 €	-417,53 €	-594,82 €
Cost per Passenger Traditional (No DRT)	**Cost per Passenger DRT (Base Test)**	**Cost per Passenger DRT (Test 1)**
18,66€	17,40€	16,99€

Figure 5.3: Test 1 - only service level and relative performance

The difference between the Base Test and the Test 1 is the extension of the service time. Thus, by analysing Figure 5.3, an increase of the passengers served was expected, as well as the costs - because of the increased time and distance travelled by the vehicle. At first glance, it is notable the increase of almost half of the total number of passengers from the Base Test to Test 1. Besides that, the route passengers do not have their service level changed much. The analysis of the figure suggests slightly decreases of delays and of the time spent inside the vehicle, which indicates a slight increase of the service quality. If we analyse the service level indicators for all the passengers together, we reach also to the same conclusions. When coming to financial return, the decrease of the cost per passenger suggests higher efficiency regarding the allocation of financial investment.

5.2.2 Test 2

Base Test

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Test 2

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	3.00
CostIncreaseDRT	48.90
RevenueIncreaseDRT	4.50
DepartureDelayRR_average	5.57
ArriveDelayRR_average	6.13
IncreaseTimeInsideVehicleRR_average	0.80

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	0.69
DepartDelay_average	5.45
ArriveDelay_average	5.89
TimeInsideBus_average	6.91
TimeSpentOnTrip_average	7.60
BoardingPassengersPerTrip_average	1.27
BoardingPassengersPerTrip_stdev	1.19
TotalPassengersServed	33.00
PercentageDemandServed	0.37

Requests Served Traditional (No DRT)	**Requests Served DRT (Base Test)**	**Requests Served DRT (Test 1)**
19	24	33
Net Financial income Traditional (No DRT)	**Net Financial income DRT (Base Test)**	**Net Financial income DRT (Test 1)**
-354,45 €	-417,53 €	-710,59 €
Cost per Passenger Traditional (No DRT)	**Cost per Passenger DRT (Base Test)**	**Cost per Passenger DRT (Test 1)**
18,66€	17,40€	21,53€

Figure 5.4: Test 2 - only service level and relative performance

The second test envisages to demonstrate the influence of the frequency of the vehicle rides in the indicators by diminishing the departure time-spans between terminals. Hence, the service is expected to have less time for deviations and consequently an increase of service level (less delays) is expected. The frequency increase can also improve the number of route requests served, as those passengers wait less time in this case. By analysing Figure 5.4, that was exactly what happened. It is worth mention the increase of route requests addressed by the service because the augment of DRT/Deviation passengers is lower in Test 2 and still the service has a very much high number of requests served. Besides, the time spent on trip decreased considerably and the delay values were much better. Despite that, the cost per passenger increased and is worse than the traditional (no-DRT) option, leading to a less efficient allocation of money to the service.

5.2.3 Test 3

Base Test

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Test 3

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	12.00
CostIncreaseDRT	188.36
RevenueIncreaseDRT	18.00
DepartureDelayRR_average	6.56
ArriveDelayRR_average	10.56
IncreaseTimeInsideVehicleRR_average	5.50

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	2.66
DepartDelay_average	6.87
ArriveDelay_average	7.25
TimeInsideBus_average	9.97
TimeSpentOnTrip_average	12.63
BoardingPassengersPerTrip_average	2.14
BoardingPassengersPerTrip_stdev	1.51
TotalPassengersServed	30.00
PercentageDemandServed	0.33

Requests Served Traditional (No DRT)	**Requests Served DRT (Base Test)**	**Requests Served DRT (Test 1)**
19	24	30
Net Financial income Traditional (No DRT)	**Net Financial income DRT (Base Test)**	**Net Financial income DRT (Test 1)**
-354,45 €	-417,53 €	-526,31 €
Cost per Passenger Traditional (No DRT)	**Cost per Passenger DRT (Base Test)**	**Cost per Passenger DRT (Test 1)**
18,66€	17,40€	17,54€

Figure 5.5: Test 3 - only service level and relative performance

The third test envisages to show the influence of the extension of the distance in the service provided. According to Figure 5.5, the extension of the distance increased substantially the number of Deviation requests and therefore the number of total passengers. Despite that increase, the time spent on trip also increased for the passengers and the effect is worse for the route passengers, who stay an average of 5.5 minutes inside the vehicle than in a case of traditional PT service. The net financial income is the lowest so far in test 3, although in test 1 the cost per passenger is lower and the service level and relative performance DRT indicators are better.

5.2.4 Test 4

Base Test

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Test 4

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	7.00
CostIncreaseDRT	58.56
RevenueIncreaseDRT	10.50
DepartureDelayRR_average	7.30
ArriveDelayRR_average	7.70
IncreaseTimeInsideVehicleRR_average	0.80

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	2.84
DepartDelay_average	5.89
ArriveDelay_average	7.20
TimeInsideBus_average	7.63
TimeSpentOnTrip_average	10.47
BoardingPassengersPerTrip_average	1.93
BoardingPassengersPerTrip_stdev	1.28
TotalPassengersServed	27.00
PercentageDemandServed	0.30

Requests Served Traditional (No DRT)	Requests Served DRT (Base Test)	Requests Served DRT (Test 1)
19	24	27
Net Financial income Traditional (No DRT)	**Net Financial income DRT (Base Test)**	**Net Financial income DRT (Test 1)**
-354,45 €	-417,53 €	-476,35 €
Cost per Passenger Traditional (No DRT)	**Cost per Passenger DRT (Base Test)**	**Cost per Passenger DRT (Test 1)**
18,66€	17,40€	17,64€

Figure 5.6: Test 4 - only service level and relative performance

This test compares the influence of the changing position of two route stop points. If we analyse Figure 5.6, the difference between Base test and Test 1 is only the position of 2 route stops. The results show a slight decrease on delay times and trip times and a slight decrease of the deviation of the number of passengers, which means less concentration and more even distribution of passengers along the simulation service time. There was also a small increase of the number of passengers served (24->27). On the other hand, a marginal increase of costs is visible.

5.2.5 Test 5

Base Test

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Test 5

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	15.00
CostIncreaseDRT	139.13
RevenueIncreaseDRT	22.50
DepartureDelayRR_average	5.79
ArriveDelayRR_average	6.59
IncreaseTimeInsideVehicleRR_average	1.31

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	0.26
DepartDelay_average	5.69
ArriveDelay_average	6.07
TimeInsideBus_average	8.69
TimeSpentOnTrip_average	8.95
BoardingPassengersPerTrip_average	1.59
BoardingPassengersPerTrip_stdev	1.22
TotalPassengersServed	54.00
PercentageDemandServed	0.60

Requests Served Traditional (No DRT)	**Requests Served DRT (Base Test)**	**Requests Served DRT (Test 1)**
19	24	54
Net Financial income Traditional (No DRT)	**Net Financial income DRT (Base Test)**	**Net Financial income DRT (Test 1)**
-354,45 €	-417,53 €	-1171,13€
Cost per Passenger Traditional (No DRT)	**Cost per Passenger DRT (Base Test)**	**Cost per Passenger DRT (Test 1)**
18,66€	17,40€	21,69€

Figure 5.7: Test 5 - only service level and relative performance

The last test encompasses the comparison between the Base Test and all the previous tested changes together in the same test. Figure 5.7 shows the results of Test 5. They show a significant decrease in the service level times (delays and trip times) comparing to the Base Test, being only worse than those obtained in Test 2. The most relevant parameter in this test is the number of passengers served. Both deviation and route passengers increased significantly, adding up to more than double the passengers on the Base Test and actually the double of those served in Test 4. Despite the good service indicators performance, the monetary costs are the largest in all the tests, both the cost per passenger and the total net costs.

5.2.6 Preliminary Conclusions

These assessment tests show that the current DSS is useful for decision-makers when analysing DRT systems in rural or peri-urban areas, supporting an analysis of the service level, of the monetary costs and also the performance comparing to traditional PT. The decision-maker has the opportunity to make several tests with different input parameter values and to decide the best procedure with the support of metrics displayed in the DSS, taking into consideration their own constraints and limits in recognizing the feasibility of the service. Thus, the input parameters' values that remained constant, that is the costs per time and distance, the ticket fare, pedestrian and vehicle velocities and passenger willingness times may be replaced by others that suit better the reality or the decision-maker's will.

The conducted experiments have shown the capability of the DSS in addressing the decision-maker's doubts and concerns about the transport system and its service mode of operation. The simulation running time is low (less than 5 minutes - depending on whether the user wants to rigorously see the simulation on-time or not) so the user can easily check results with different demand data to reach more accurate conclusions for the implementation of the service.

Furthermore, the decision-maker can analyse the number of passengers served in each journey from one terminal to the other. An example of that information is available in Table 5.3 for Test 3. By observing it, the decision-maker can realise the journeys in which the service did provide transport to a certain number of passengers and then make adjustments in the system based on that information. Moreover, the decision-maker may also access information about each one of the requests attended by the service in the simulation, including distance travelled, walking times, delays, trip times, etc. That information is very specific to the analysis of the system as it provides the metrics for each individual passenger. It is presented in Table 5.2. Those tables provide complementary data to the results interface and may support possible improvements of the system and the search for sources of inefficiency or other problems in the service.

Request	**Walk Origin-Time**	**Walk DestTime**	**Depart Delay**	**Arrive Delay**	**TimePickUp**	**Time-DropOff**	**Time InVehicle**	**Total TripTime**	**Total Distance**
11	0	1,305	0	0	8:01	8:03	2	3,305	3190,1
50	0	0	23	24	8:49	8:54	5	5	4891,1,1
69	0	0	27	2,82987	9:36	9:46	10	10	7125,3
40	0	0	0	2,8268	11:00	11:10	10	10	5946,6
28	0	0	0	0	11:05	11:08	3	3	745,8
...	...	...	...	...	...	...	...	...	...

Table 5.2: Table *Statistics* output for the Test 3 - example

TripID	DepartureTime	NumPassengersDeviation	NumPassengersRoute	NumPassengersTotal
1	8:00	1	0	1
2	8:45	0	1	1
3	9:30	1	0	1
4	10:15	0	0	0
5	11:00	2	1	3
6	11:45	1	4	5
7	12:30	0	2	2
8	13:15	0	0	0
9	14:00	1	1	2
10	14:45	1	2	3
11	15:30	1	2	3
12	16:15	1	3	4
13	17:00	2	2	4
14	17:45	1	0	1

Table 5.3: Table *Trips* output for the Test 3 - example

The KPIs displayed in these simulations provide different ways to evaluate the performance of the transport system. The division between Productivity, Utilization, Service Level, Relative DRT performance and Financial indicators provides the decision-maker with a differentiated understanding of the system and supports an aggregated reasoning of how the system is functioning. It should be noted that, in the examaples, the input monetary costs and ticket fares do not necessarily represent the real values, as those used were not based on the related literature. Nevertheless, the financial assessment could be made and if the financial results are not reasonable to a decision-maker, he/she may change the ticket fare or try to adjust the costs to the reality or implemented policies.

Chapter 6

Conclusions and Future Work

The DSS developed in this project can be an useful tool for decision-makers in the design and evaluation of DRT services, specifically in rural or peri-urban areas. It can also serve as a support to other instruments of analysis to search for the reliability of the system or a basis to compare different DRT operations between two terminals.

The case studies addressed in Chapter 5 show how the DSS can be used in a decision-maker's analysis. For the input data considered and the tests made, a decision-maker may conclude that an increase of the working time (Test 1) can capture in this case more demand than increased frequency (Test 2) or even an extended maximum deviation distance (Test 3). Moreover, with the tests made a decision-maker may realise that if he/she needs to have less than 1000€ of net financial operational cost in the service, then the best option, taking into consideration only the service quality, is Test 2 (overall lower values of transportation times and costs below 1000€). Otherwise, if there are no financial restrictions, the best option is Test 5, which has the best service quality and the highest number of requests served. These possibilities and analysis depend only on the decision-maker's constraints, on the selected inputs, and ultimately on his/her will.

The analysis can be time-consuming and not straightforward for a decision-maker. The division of indicators' numerical units (times, number of passengers and money quantities) into colored categories would improve the visual understanding and the perception of the resulted values' quality in future works. The most relevant service KPIs are the trip times average, the number of passengers served and its percentage related to total demand. The relative performance of DRT is also important, as it compares the impact of adopting a DRT service to the service level of route-based passengers. Additionally, it shows the increase of the number of passengers by adopting the DRT and its financial turnover. The global financial indicators are also very important to address and the others (Productivity and Utilization) are more complementary but still relevant to evaluate.

This DSS is a base of what can be done within this framework. It is addressed to a specific case, but can also be developed further to add other types of DRT services, such as area-wide services. Although this DSS only addresses rural or peri-urban areas with just one vehicle operating, it is also relevant to support regions in which there is not much supply of PT services. The service level indicators are often very important in those areas, as there are not many alternatives in travelling (except private vehicles) and public authorities and other entities may want to improve (or at least not decrease) the easiness of transportation in those locations. Thus, the service level KPIs revealed themselves very relevant by dividing delay, walking and trip times to detail the characteristics of the transportation process to the decision-makers.

The DSS can be improved by adding more features to the simulation. The improvements can include: the possibility for the operator to add more vehicles in the service provision (the DSS only assumes one vehicle); the incorporation of transfers between transport modes as a component of the system; adding traffic variability to simulate the effect of rush hours.

Additionally, the assumptions already made may be improved further to better suit the reality of PT systems. In this DSS, the operator has to submit information that generalizes the capacities and needs of a given passenger, although they often don't have similar needs between each other. Thus, the pedestrian assumed velocity may be differentiated between Elders, Children and Adults. Also, the time that a passenger is willing to walk to get to a stop point and the maximum time-span to anticipate or postpone the trip can be specified in the table *Requests* at the time the passenger books a trip to assess their will. That specification will be easier if booking applications and platforms are user-friendly and accessible for the potential customer usage. Moreover, the walk destination distance obtained as a KPI is not representing only the distance travelled on foot to the destination but also the cases representing transfers. That is because if a given destination is too far from any route stop, the passenger is most likely to use other transportation to get to the destiny instead of walking.

Besides, it would be important in future works to increase the maximum number of deviations for each segment of the trip and incorporate other routes and means of transport to the simulation to compare and analyse the effect of the overall transport services of the location in the population's trip decisions and then easily assess the best way to fulfill their needs.

Furthermore, taking into account the difficulty of simulating and predicting people's activities in a location, it is important to get more information about users actions, which are easier today to track due to the rise of MaaS systems. The improving access to information and the development of simulation tools to face societal problems can be extremely important to improve efficiency and safeguard the effectiveness of welfare goals by supporting the decision-maker in reaching the best decisions.

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Appendix A

Interfaces of Tests results with all the system's KPIs

Base Test KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	5.00
CostIncreaseDRT	70.58
RevenueIncreaseDRT	7.50
DepartureDelayRR_average	7.58
ArriveDelayRR_average	8.47
IncreaseTimeInsideVehicleRR_average	1.58

Financial Operation Indicators

Name	Value
TotalCostRunning	453.53
RevenueRunning	36.00

Utilization Indicators

Name	Value
NumberKmPerTrip_average	4.18
NumberMinutesPerTrip_average	7.21

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	3.85
DepartDelay_average	8.21
ArriveDelay_average	7.09
TimeInsideBus_average	7.21
TimeSpentOnTrip_average	11.06
BoardingPassengersPerTrip_average	1.71
BoardingPassengersPerTrip_stdev	1.53
TotalPassengersServed	24.00
PercentageDemandServed	0.27

Productivity Indicators

Name	Value
PassengersPerKm_average	0.19

Test 1 KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	8.00
CostIncreaseDRT	100.26
RevenueIncreaseDRT	12.00
DepartureDelayRR_average	7.37
ArriveDelayRR_average	8.07
IncreaseTimeInsideVehicleRR_average	1.22

Financial Operation Indicators

Name	Value
TotalCostRunning	647.32
RevenueRunning	52.50

Utilization Indicators

Name	Value
NumberKmPerTrip_average	3.71
NumberMinutesPerTrip_average	6.06

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.07
WalkDest_average	3.94
DepartDelay_average	7.20
ArriveDelay_average	6.67
TimeInsideBus_average	6.06
TimeSpentOnTrip_average	10.06
BoardingPassengersPerTrip_average	1.75
BoardingPassengersPerTrip_stdev	1.44
TotalPassengersServed	35.00
PercentageDemandServed	0.39

Productivity Indicators

Name	Value
PassengersPerKm_average	0.20

Test 2 KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	3.00
CostIncreaseDRT	48.90
RevenueIncreaseDRT	4.50
DepartureDelayRR_average	5.57
ArriveDelayRR_average	6.13
IncreaseTimeInsideVehicleRR_average	0.80

Financial Operation Indicators

Name	Value
TotalCostRunning	760.09
RevenueRunning	49.50

Utilization Indicators

Name	Value
NumberKmPerTrip_average	4.23
NumberMinutesPerTrip_average	6.91

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	0.69
DepartDelay_average	5.45
ArriveDelay_average	5.89
TimeInsideBus_average	6.91
TimeSpentOnTrip_average	7.60
BoardingPassengersPerTrip_average	1.27
BoardingPassengersPerTrip_stdev	1.19
TotalPassengersServed	33.00
PercentageDemandServed	0.37

Productivity Indicators

Name	Value
PassengersPerKm_average	0.15

Test 3 KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	12.00
CostIncreaseDRT	188.36
RevenueIncreaseDRT	18.00
DepartureDelayRR_average	6.56
ArriveDelayRR_average	10.56
IncreaseTimeInsideVehicleRR_average	5.50

Financial Operation Indicators

Name	Value
TotalCostRunning	571.31
RevenueRunning	45.00

Utilization Indicators

Name	Value
NumberKmPerTrip_average	6.00
NumberMinutesPerTrip_average	9.97

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	2.66
DepartDelay_average	6.87
ArriveDelay_average	7.25
TimeInsideBus_average	9.97
TimeSpentOnTrip_average	12.63
BoardingPassengersPerTrip_average	2.14
BoardingPassengersPerTrip_stdev	1.51
TotalPassengersServed	30.00
PercentageDemandServed	0.33

Productivity Indicators

Name	Value
PassengersPerKm_average	0.18

Test 4 KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	7.00
CostIncreaseDRT	58.56
RevenueIncreaseDRT	10.50
DepartureDelayRR_average	7.30
ArriveDelayRR_average	7.70
IncreaseTimeInsideVehicleRR_average	0.80

Financial Operation Indicators

Name	Value
TotalCostRunning	516.85
RevenueRunning	40.50

Utilization Indicators

Name	Value
NumberKmPerTrip_average	4.80
NumberMinutesPerTrip_average	7.63

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	2.84
DepartDelay_average	5.89
ArriveDelay_average	7.20
TimeInsideBus_average	7.63
TimeSpentOnTrip_average	10.47
BoardingPassengersPerTrip_average	1.93
BoardingPassengersPerTrip_stdev	1.28
TotalPassengersServed	27.00
PercentageDemandServed	0.30

Productivity Indicators

Name	Value
PassengersPerKm_average	0.19

Test 5 KPIs

Relative Performance DRT vs Traditional

Name	Value
IncreaseNumberofPassengersDRT	15.00
CostIncreaseDRT	139.13
RevenueIncreaseDRT	22.50
DepartureDelayRR_average	5.79
ArriveDelayRR_average	6.59
IncreaseTimeInsideVehicleRR_average	1.31

Financial Operation Indicators

Name	Value
TotalCostRunning	1252.13
RevenueRunning	81.00

Utilization Indicators

Name	Value
NumberKmPerTrip_average	5.80
NumberMinutesPerTrip_average	8.69

Service Level Provision Indicators

Name	Value
WalkOrigin_average	0.00
WalkDest_average	0.26
DepartDelay_average	5.69
ArriveDelay_average	6.07
TimeInsideBus_average	8.69
TimeSpentOnTrip_average	8.95
BoardingPassengersPerTrip_average	1.59
BoardingPassengersPerTrip_stdev	1.22
TotalPassengersServed	54.00
PercentageDemandServed	0.60

Productivity Indicators

Name	Value
PassengersPerKm_average	0.14

Appendix B

Table Schedule - Test 3 example

Direct	**Inverse**
8:00	8:45
9:30	10:15
11:00	11:45
12:30	13:15
14:00	14:45
15:30	16:15
17:00	17:45

Table B.1: Table *Schedule* for the Test 3 - example

Appendix C

Code for the definition of the next vehicle destination (Direct)

```

Object current = param(1);
treenode activity = param(2);
Token token = param(3);
treenode processFlow = ownerobject(activity);
string CurrentTimeStr=Model.dateTime.toString("%H:%M");
double CurrentTimeDouble=convert(CurrentTimeStr,TIME_STR,FS_DATETIME);
DateTime CurrentTime=DateTime(CurrentTimeDouble);
double stopNum = token.Stop.as(string).toNum();
string stopfid=token.fid.as(string);
Table("StopNum")[1][1]=token.Stop.as(string);
Table("StopFid")[1][1]=token.fid.as(string);
if(stopNum<Table("Route").numRows)
{
 //if bus is still on the route

  int Deviation=0;
  double DistMin_Origin;
  double DistMin_Dest;
  double Segment_Origin;
  double Segment_Dest;
  //if bus is on a route stop then it may deviate
  if(Math.fmod(stopNum,1)==0)
  {
    for(int j=1;j<=Table("TripRequests").numRows;j++)
    {
      //look in the Table TripRequests for trips requested by passengers (both Deviation and Route)
      DistMin_Origin=100;
      DistMin_Dest=100;
      Segment_Origin=0;
      Segment_Dest=0;
      string StartDate=Table("TripRequests")[j]["StartingTime"];
      double RequestTime=convert(StartDate,TIME_STR,FS_DATETIME);
      DateTime MinTime=DateTime(RequestTime)-DateTime.minutes(Table("LimRequestTime")[1]["LimInf"].as(string).toNum());
      DateTime MaxTime=DateTime(RequestTime)+DateTime.minutes(Table("LimRequestTime")[1]["LimSup"].as(string).toNum());
```

```
  //find the minimum distance for request points and the segment of the route that is associated with
  DistMin_Origin=Table("RequestMinimumDistances")[j]["MinimumDist_Origin"].as(string).toNum();
  Segment_Origin=Table("RequestMinimumDistances")[j]["Segment_Origin"].as(string).toNum();
  DistMin_Dest=Table("RequestMinimumDistances")[j]["MinimumDist_Dest"].as(string).toNum();
  Segment_Dest=Table("RequestMinimumDistances")[j]["Segment_Dest"].as(string).toNum();
  //find if the Request is valid (that is if it is not a deviation that compromises the schedule)
  Table QueryTrips=Table.query("SELECT RequestsOrder.Trip FROM RequestsOrder WHERE RequestsOrder.Trip="+Table("TripRequests")[j]["Trip"]+";");
  //check if: (Segment Origin is next; Segment Dest beyond; current time is in between an acceptable time; request is valid)
  if(Segment_Origin==stopNum && Segment_Dest>=stopNum && Table("Request_OrigDest")[j]["Orig_Reached?"]=="0" && Table("Request_OrigDest")[j]["Dest_Reached?"]=="0" && CurrentTime>=MinTime && CurrentTime<=MaxTime && QueryTrips.numRows>0)
  {
    if(DistMin_Origin==0)//and DistMinOrigin=0 ->IT IS A ROUTE STOP FOR ORIGIN
    {
      Table QueryWalk=Table.query("SELECT Statistics.Index FROM Statistics WHERE Statistics.Request="+string.fromNum(j)+";");
      if(QueryWalk.numRows>0)
      {
        int ind=QueryWalk[1][1];
        if(Table("Statistics")[ind]["WalkOrigin"]>0)
        {
          Table("Statistics")[ind]["Completed"]="Not Yet";
        }
      }
      else
      {
        Table("Statistics").addRow();
        Table("Statistics")[Table("Statistics").numRows]["Index"]=Table("Statistics").numRows;
        Table("Statistics")[Table("Statistics").numRows]["Request"]=Table("TripRequests")[j]["Trip"];//save trip index in Statistic column
        Table("Statistics")[Table("Statistics").numRows]["WalkOrigin"]=0;
        Table("Statistics")[Table("Statistics").numRows]["Completed"]="Not Yet";
        Table("Statistics")[Table("Statistics").numRows]["Distance"]="0";
        Table("Request_OrigDest")[j]["Orig_Reached?"]="1";
      }
    }
    else
    {

      treenode point1 =Model.find("GISNavigator/"+"Point" + stopfid);
      treenode point2 =Model.find("GISNavigator/"+ "Point" +Table("TripRequests")[j]["Origin"]);
      int SecondBusStop=Segment_Origin+1;
      treenode point3=Model.find("GISNavigator/"+"Point" + Table("Route")[SecondBusStop]["fid"]);
      double distance1= function_s(point1,"getDistance",point2); //distance from 1   segment point to deviation point
      double distance2= function_s(point2,"getDistance",point3);
```

```
        if(distance1<Table("Deviation")[1][1].as(string).toNum())
        {//if (1   segment point<->deviation point) distance is less than the
treshold then the bus makes a deviation if passenger dont decide to walk

          //Consider that for any point at X minutes on foot to the bus stop,
the passenger will walk to there.
          double Walking_Distance=Table("WalkVelocity_kmh")[1][1].as(string).
toNum()*Math.pow(10,3)/60*Table("Max_MinutesWalkingToStop")[1][1].as(string).
toNum();
          //if there is already a deviation and the point of the request is the
 same as the deviation point then save statistics
          if(distance1>=Walking_Distance && distance2>=Walking_Distance &&
Deviation==1 && Table("TripRequests")[j]["Origin"].as(string)==token.fid.as(
string))
          {
            //add row in Table for statistics
            Table("Statistics").addRow();
            Table("Statistics")[Table("Statistics").numRows]["Index"]=Table("
Statistics").numRows;
            Table("Statistics")[Table("Statistics").numRows]["Request"]=Table("
TripRequests")[j]["Trip"];//save trip index in Statistic column
            Table("Statistics")[Table("Statistics").numRows]["WalkOrigin"]=0;
            Table("Statistics")[Table("Statistics").numRows]["Completed"]="Not
Yet";
            Table("Statistics")[Table("Statistics").numRows]["Distance"]="0";
            Table("Request_OrigDest")[j]["Orig_Reached?"]="1";
          }
          if(distance1>=Walking_Distance && distance2>=Walking_Distance &&
Deviation==0 && ((Table("DisabledAndElderly")[1][1].as(string).toNum()==1 &&
Table("TripRequests")[j]["Age"].as(string)=="Elder") || Table("
DisabledAndElderly")[1][1].as(string).toNum()==0))//if Deviation==0 and
distance is greater than walking limit then go to deviation
          {

            // the passenger does not go on foot to the stop -> bus deviates to
 there
            //add row in Table for statistics
            Table("Statistics").addRow();
            Table("Statistics")[Table("Statistics").numRows]["Index"]=Table("
Statistics").numRows;
            Table("Statistics")[Table("Statistics").numRows]["Request"]=Table("
TripRequests")[j]["Trip"];//save trip index in Statistic column
            Table("Statistics")[Table("Statistics").numRows]["Completed"]="Not
Yet";
            Table("Statistics")[Table("Statistics").numRows]["Distance"]="0";
            Deviation=1;
            token.Stop=token.Stop+".1";
            for(int i=1;i<=Table("Points").numRows;i++)
            {
              if(Table("Points")[i]["fid"]==Table("TripRequests")[j]["Origin"])
              {
              token.X=Table("Points")[i]["X"];
              token.Y=Table("Points")[i]["Y"];
              token.fid=Table("Points")[i]["fid"];
              token.function=Table("Points")[i]["Function"];
              break;
              }
            }
            Table("Statistics")[Table("Statistics").numRows]["WalkOrigin"]=0;
            Table("Request_OrigDest")[j]["Orig_Reached?"]="1";
```

```
          }
          else
          {
            //Walks to the stop
            if(distance1<Walking_Distance || distance2<Walking_Distance)
            {
              //add row in Table for statistics
              Table("Statistics").addRow();
              Table("Statistics")[Table("Statistics").numRows]["Index"]=Table("Statistics").numRows;
              Table("Statistics")[Table("Statistics").numRows]["Request"]=Table("TripRequests")[j]["Trip"];//save trip index in Statistic column
              Table("Statistics")[Table("Statistics").numRows]["Completed"]="Not Yet";
              Table("Statistics")[Table("Statistics").numRows]["Distance"]="0";
              //passenger goes on foot to Origin
              double WalkingTime;
              if(distance1>distance2)
              {
                WalkingTime=distance2/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                Table("RequestMinimumDistances")[j]["Segment_Origin"]=Segment_Origin+1;
                Table("TripRequests")[j]["Origin"]=Table("Route")[SecondBusStop]["fid"];
                Table("RequestMinimumDistances")[j]["MinimumDist_Origin"]=0;

              }
              else
              {
                WalkingTime=distance1/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                Table("Statistics")[Table("Statistics").numRows]["TimePickUp"]=Model.dateTime.toString("%H:%M");
              }
              Table("Statistics")[Table("Statistics").numRows]["WalkOrigin"]=WalkingTime;
              Table("Request_OrigDest")[j]["Orig_Reached?"]="1";
              Table("Statistics")[Table("Statistics").numRows]["Distance"]="0";
            }
          }
        }
      }
    }
    else
    {
      //check if: (Segment Origin is behind; Segment Dest next; current time is in between an acceptable time; request is valid)
      if(Segment_Dest==stopNum && Segment_Origin<=stopNum && Table("Request_OrigDest")[j]["Orig_Reached?"]=="1" && Table("Request_OrigDest")[j]["Dest_Reached?"]=="0" && QueryTrips.numRows>0)
      {
        Table result=Table.query("SELECT Statistics.Index FROM Statistics WHERE Statistics.Request="+string.fromNum(j)+";");
        int index=result[1][1].as(string).toNum();
        if(DistMin_Dest==0) //destination on route stop
        {
          if(Table("Statistics")[index]["WalkDest"]==0 || Table("Statistics")[index]["WalkDest"]==NULL || Table("Statistics")[index]["WalkDest"]=="0")
          {
```

```
          Table("Statistics")[index]["WalkDest"]=0;
        }
          Table("Statistics")[index]["Completed"]="Almost";
      }
      else
      {
        if(Table("Statistics")[index]["WalkDest"]!=0)
        {
          Table("Statistics")[index]["Completed"]="Almost";
        }
        else
        {
          treenode point4 =Model.find("GISNavigator/"+"Point" + stopfid);
          treenode point5 =Model.find("GISNavigator/"+ "Point" +Table("TripRequests")[j]["Destination"]);
          int SecondBusStop=Segment_Dest+1;
          treenode point6=Model.find("GISNavigator/"+"Point" + Table("Route")[SecondBusStop]["fid"]);
          double distance3= function_s(point4,"getDistance",point5); //distance from 1   segment point to deviation point
          double distance4= function_s(point5,"getDistance",point6); //distance from 2   segment point to deviation point
          Table result=Table.query("SELECT Statistics.Index FROM Statistics WHERE Statistics.Request="+string.fromNum(j)+";");
          int index=result[1][1].as(string).toNum();
          if(distance3<Table("Deviation")[1][1].as(string).toNum())
          {//if (1   segment point<->deviation point) distance is less than the treshold then the bus makes a deviation if passenger dont decide to walk

            //Consider that for any point at X minutes on foot to the bus stop, the passenger will walk to there.
            double Walking_Distance=Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60*Table("Max_MinutesWalkingToStop")[1][1].as(string).toNum();
            //if there is already a deviation and the point of the request is the same as the deviation point then save statistics
            if(distance3>=Walking_Distance && distance4>=Walking_Distance && Deviation==1)
            {
              if(Table("TripRequests")[j]["Destination"].as(string)==token.fid.as(string))
              {
                Table("Statistics")[index]["WalkDest"]=0;
                Table("Statistics")[index]["Completed"]="Almost";
              }
              else
              {
                //if bus is already taking a deviation then it doesnot make the deviation and the passenger goes on foot from quickest stop
                double WalkingTime;
                if(distance3>distance4)
                {
                  WalkingTime=distance4/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                  Table("TripRequests")[j]["Destination"]=Table("Route")[SecondBusStop]["fid"];
                  Table("RequestMinimumDistances")[j]["Segment_Dest"]=Segment_Dest+1;
                  Table("RequestMinimumDistances")[j]["MinimumDist_Dest"]=0;
                }
```

```
                    if(distance4>=distance3)
                    {
                      WalkingTime=distance3/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                      Table("Statistics")[index]["Completed"]="Almost";
                      Table("TripRequests")[j]["Destination"]=stopfid.toNum();
                    }
                    Table("Statistics")[index]["WalkDest"]=WalkingTime;

                  }
                }
                if(distance3>=Walking_Distance && distance4>=Walking_Distance && Deviation==0 && ((Table("DisabledAndElderly")[1][1].as(string).toNum()==1 && Table("TripRequests")[j]["Age"].as(string)=="Elder") || Table("DisabledAndElderly")[1][1].as(string).toNum()==0))//if Deviation==0 and distances greater than walking ones then go to deviation
                {
                  Table("Statistics")[index]["Completed"]="Almost";
                  // the passenger does not go on foot to the stop -> bus deviates to there
                  Deviation=1;
                  token.Stop=token.Stop+".1";
                  for(int i=1;i<=Table("Points").numRows;i++)
                  {
                    if(Table("Points")[i]["fid"]==Table("TripRequests")[j]["Destination"])
                    {
                    token.X=Table("Points")[i]["X"];
                    token.Y=Table("Points")[i]["Y"];
                    token.fid=Table("Points")[i]["fid"];
                    token.function=Table("Points")[i]["Function"];
                    break;
                    }
                  }
                  Table("Statistics")[index]["WalkDest"]=0;
                  Table("Statistics")[index]["Completed"]="Almost";
                }
                if(distance3<Walking_Distance || distance4<Walking_Distance)//if distance<WalkingDistance then the passenger goes on foot to the stop
                {

                  //if distance is less than threshold
                  double WalkingTime;
                  if(distance3>distance4)
                  {
                    WalkingTime=distance4/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                    Table("TripRequests")[j]["Destination"]=Table("Route")[SecondBusStop]["fid"];
                    Table("RequestMinimumDistances")[j]["Segment_Dest"]=Segment_Dest+1;
                    Table("RequestMinimumDistances")[j]["MinimumDist_Dest"]=0;
                  }
                  else
                  {
                    WalkingTime=distance3/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
                    Table("Statistics")[index]["Completed"]="Almost";
                    Table("TripRequests")[j]["Destination"]=stopfid.toNum();
                  }
```

```
         Table("Statistics")[index]["WalkDest"]=WalkingTime;
        }
       }
       else
       {

        //if distance is greater than threshold then it doesnot make the deviation and the passenger goes on foot from quickest stop
        double WalkingTime;
        if(distance3>distance4)
        {
         WalkingTime=distance4/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
         Table("TripRequests")[j]["Destination"]=Table("Route")[SecondBusStop]["fid"];
         Table("RequestMinimumDistances")[j]["Segment_Dest"]=Segment_Dest+1;
         Table("RequestMinimumDistances")[j]["MinimumDist_Dest"]=0;
        }
        if(distance4>=distance3)
        {
         WalkingTime=distance3/(Table("WalkVelocity_kmh")[1][1].as(string).toNum()*Math.pow(10,3)/60);
         Table("Statistics")[index]["Completed"]="Almost";
         Table("TripRequests")[j]["Destination"]=stopfid.toNum();
        }
        Table("Statistics")[index]["WalkDest"]=WalkingTime;
       }
      }
     }
    }
   }
  }
 }
 //if there are no deviation requests or the current stop is a deviation then procceed to the next route segment
 if(Deviation==0 || Math.fmod(stopNum,1)!=0)
 {
  //get next route stop
  token.Stop=Table("Route")[Math.trunc(stopNum)+1]["Stop"];
  token.X=Table("Route")[Math.trunc(stopNum)+1]["X"];
  token.Y=Table("Route")[Math.trunc(stopNum)+1]["Y"];
  token.fid=Table("Route")[Math.trunc(stopNum)+1]["fid"];
  token.function=Table("Route")[Math.trunc(stopNum)+1]["Function"];
 }
}
```

Appendix D

Code for the definition of Requests Order and Availability - Schedule Check (Direct)

```

Object current = param(1);
treenode activity = param(2);
Token token = param(3);
treenode processFlow = ownerobject(activity);
string CurrentTimeStr=Model.dateTime.toString("%H:%M");
double CurrentTimeDouble=convert(CurrentTimeStr,TIME_STR,FS_DATETIME);
DateTime CurrentTime=DateTime(CurrentTimeDouble);
double DistMin_Origin;
double DistMin_Dest;
double Segment_Origin;
double Segment_Dest;
Table("RequestsOrder").setSize(0,1);
double TotalRouteTime=0;
int counter=0;
for(int j=1;j<=Table("TripRequests").numRows;j++)
{
  int isRouteRequest=0;
  Segment_Origin=0;
  Segment_Dest=0;
  DistMin_Origin=0;
  DistMin_Dest=0;
  string StartDate=Table("TripRequests")[j]["StartingTime"];
  double RequestTime=convert(StartDate,TIME_STR,FS_DATETIME);
  DateTime MinTime=DateTime(RequestTime)-DateTime.minutes(Table("LimRequestTime")
    [1]["LimInf"].as(string).toNum());
  DateTime MaxTime=DateTime(RequestTime)+DateTime.minutes(Table("LimRequestTime")
    [1]["LimSup"].as(string).toNum());
  Segment_Origin=Table("RequestMinimumDistances")[j]["Segment_Origin"].as(string)
    .toNum();
  Segment_Dest=Table("RequestMinimumDistances")[j]["Segment_Dest"].as(string).
    toNum();
  DistMin_Origin=Table("RequestMinimumDistances")[j]["MinimumDist_Origin"].as(
    string).toNum();
  DistMin_Dest=Table("RequestMinimumDistances")[j]["MinimumDist_Dest"].as(string)
    .toNum();
```

```
for(int i=1;i<=Table("RouteRequests").numRows;i++)
{
  if(Table("RouteRequests")[i]["Trip"]==Table("TripRequests")[j]["Trip"])
  {
    isRouteRequest=1;
  }
}
if(Segment_Dest>Segment_Origin && CurrentTime>=MinTime && CurrentTime<=MaxTime)
{
  if(isRouteRequest==0)
  {
    counter+=1;
    if(DistMin_Origin>0 && DistMin_Dest>0)
    {
      for(int i=1;i<Segment_Origin;i++)
      {
        treenode Point7=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
        treenode Point8=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
        TotalRouteTime+=function_s(Point7,"getDuration",Point8)/60;
      }
      //go to origin
      treenode Point1=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Origin]["fid"]);
      treenode Point2=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Origin"]);
      TotalRouteTime+=function_s(Point1,"getDuration",Point2)/60;
      //return to route
      treenode Point3=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Origin"]);
      treenode Point4=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Origin+1]["fid"]);
      TotalRouteTime+=function_s(Point3,"getDuration",Point4)/60;
      for(int i=Segment_Origin+1;i<Segment_Dest;i++)
      {
        treenode Point5=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
        treenode Point6=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
        TotalRouteTime+=function_s(Point5,"getDuration",Point6)/60;
      }
      //go to destination
      treenode Point9=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Dest]["fid"]);
      treenode Point10=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Destination"]);
      TotalRouteTime+=function_s(Point9,"getDuration",Point10)/60;
      //return to route
      treenode Point11=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Destination"]);
      treenode Point12=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Dest+1]["fid"]);
      TotalRouteTime+=function_s(Point11,"getDuration",Point12)/60;
      for(int i=Segment_Dest+1;i<Table("Route").numRows;i++)
      {
        treenode Point5=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
        treenode Point6=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
```

```
        TotalRouteTime+=function_s(Point5,"getDuration",Point6)/60;
      }
    }
    else
    {
      if(DistMin_Origin==0 && DistMin_Dest>0)
      {
        for(int i=1;i<Segment_Dest;i++)
        {
          treenode Point5=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
          treenode Point6=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
          TotalRouteTime+=function_s(Point5,"getDuration",Point6)/60;
        }
        //go to destination
        treenode Point1=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Dest]["fid"]);
        treenode Point2=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Destination"]);
        TotalRouteTime+=function_s(Point1,"getDuration",Point2)/60;
        //return to route
        treenode Point3=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Destination"]);
        treenode Point4=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Dest+1]["fid"]);
        TotalRouteTime+=function_s(Point3,"getDuration",Point4)/60;
        for(int i=Segment_Dest+1;i<Table("Route").numRows;i++)
        {
          treenode Point5=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
          treenode Point6=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
          TotalRouteTime+=function_s(Point5,"getDuration",Point6)/60;
        }
      }
      else
      {
        if(DistMin_Origin>0 && DistMin_Dest==0)
        {
          for(int i=1;i<Segment_Origin;i++)
          {
            treenode Point7=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
            treenode Point8=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
            TotalRouteTime+=function_s(Point7,"getDuration",Point8)/60;
          }
          //go to origin
          treenode Point1=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Origin]["fid"]);
          treenode Point2=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Origin"]);
          TotalRouteTime+=function_s(Point1,"getDuration",Point2)/60;
          //return to route
          treenode Point3=Model.find("GISNavigator/"+"Point" + Table("TripRequests")[j]["Origin"]);
          treenode Point4=Model.find("GISNavigator/"+"Point" + Table("Route")[Segment_Origin+1]["fid"]);
          TotalRouteTime+=function_s(Point3,"getDuration",Point4)/60;
```

```
            for(int i=Segment_Origin+1;i<Table("Route").numRows;i++)
            {
              treenode Point5=Model.find("GISNavigator/"+"Point" + Table("Route")[i]["fid"]);
              treenode Point6=Model.find("GISNavigator/"+"Point" + Table("Route")[i+1]["fid"]);
              TotalRouteTime+=function_s(Point5,"getDuration",Point6)/60;
            }
          }
        }
      }
      if(counter>1)
      {
        TotalRouteTime=TotalRouteTime-(counter-1)*Table("DistanceandTimeRoute")[1][2].as(string).toNum();
        counter=1;
      }
    }
    double MaxRouteTime=Table("MaxTimeDirect")[1][1].as(string).toNum();
    if(isRouteRequest==1)
    {
      Table("RequestsOrder").addRow();
      Table("RequestsOrder")[Table("RequestsOrder").numRows][1]=Table("TripRequests")[j]["Trip"];
    }
    else
    {
      if(TotalRouteTime<MaxRouteTime)
      {
        Table("RequestsOrder").addRow();
        Table("RequestsOrder")[Table("RequestsOrder").numRows][1]=Table("TripRequests")[j]["Trip"];
      }
    }
  }
}
```