A SIMULATION APPROACH TO SUPPORT THE DESIGN OF FLEXIBLE TRANSPORT SYSTEMS

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ABSTRACT  
Rural areas are characterized by low levels of population density and complex mobility patterns. Conventional transport services have shown to be very inefficient and ineffective in these environments and the provision of additional public transport services in these areas presents, very often, low levels of service. In this context, an alternative solution - a Demand Responsive Transport (DRT) system - has already been adopted in several countries. Although the literature reports some successful cases of DRT systems, these flexible transportation systems have still some issues to be addressed. A main question that still requires additional interest of researchers is the assessment of their overall sustainability, since its implementation, in general, requires a strong technological component and the integration of several technologies. Additionally, they are highly dependent on the correct calibration of some organization and functional parameters. In this paper, a comprehensive framework to support decision-makers in the design and planning of flexible transportation systems is proposed. The developed approach allows the simulation of different scenarios corresponding to different design alternative solutions. Accurate estimation of their global impact can be obtained providing effective support in the design and operational stages of a DRT system implementation.

INTRODUCTION  
Additionally, public transport systems in rural areas have traditionally been based on static services: fixed routes, stops and schedules. However, the low levels of density observed in these areas leads to very low levels of vehicles occupancy and high levels of inefficiency. Also, vehicles are frequently the oldest of operator fleet, frequencies are low, some schedules are omitted and, more importantly, such a transportation system does not attract potential users. In these circumstances, rural areas tend to have their mobility limited, increased social exclusion of some population sectors, such as children, elderly and/or mobility impaired people, forcing people to use private cars.

The adoption of a flexible transportation system such as a Demand Responsive Transport (DRT) which can meet users’ mobility needs by adopting flexible routes and stops constitute a very interesting and attractive alternative.

Authors are unanimous in stressing that the success of DRT systems depends on the use of intelligence solutions to process trip requests, to optimize routes and schedules in order to respond in real time to users mobility needs. According to the literature, one of the gaps associated to DRT systems (already implemented) is a framework that could provide an integrated decision support system to help decision makers on devising intelligent strategic solutions at the design phase.

In this research project, a simulation approach to allow the decision support system to design and plan a DRT system in rural areas has been developed. The objective is to reproduce and test different decision-making alternatives in order to assess, in advance, the quality of alternative design scenarios or management strategies.

In fact, such a tool can provide what-if analyses required to achieve better planning decisions and will allow evaluating operating strategies prior to the implementation of such a complex system as it is the case of a DRT system. Furthermore, the tool will ultimately assure the adoption of a sustainable DRT system, by properly adequate supply to estimated demand levels and patterns, taking into account financial, economic and social decision criteria.

The remainder of the paper is organized as follows: next section presents a brief literature review on flexible transportation systems in order to highlight the main design issues concerning DRT systems. The following section a Decision Support System based on a simulation approach to support strategic decisions concerning the design and planning of DRT systems is proposed. Then, the work implemented so far is described and performance measures are discussed. Finally, the last section presents the main conclusions and final
considerations regarding future developments.

STATE OF THE ART

Flexible transportation systems, in particular, Demand Responsive Transport (DRT) systems have been adopted over the last decades, as reported in some studies (Brake et al. 2004; Mulley and Nelson 2009). Increasing interest have been devoted to DRT as a mean to combat social exclusion. They are an attractive solution, because they offer a user-friendly answer to passengers needs and overcome some shortcomings of traditional transport services in areas with widely dispersed trip patterns. These systems provide transport on demand, using flexible schedules and routes to pick up and drop off users as required.

In general, trip requests are made by telephone dialing directly to a travel dispatch center (TDC), during a pre-defined time window; alternatively, there are cases where users can also use a messaging system (SMS) to request a service or use a web portal (Oliveira et al. 2011). Trip requests are then stored in a database system, which holds all the relevant data concerning the transportation network. The TDC coordinates a fleet of vehicles with communication technologies such as on-board integrated GPS, continuous GPRS connection to TDC. A heterogeneous fleet of vehicles is frequently available: buses, mini buses, taxis supplied by a variety of providers (taxi owners, bus operators, community transport, etc).

A DRT system can receive trip requests either for an immediate service or as an advanced reservation. It should have the capacity to organize routes and schedules to accommodate trip requests, aiming to respond in real time to users' mobility needs. Its implementation typically involves the use of information and communication technologies (Frosini et al. 2004) as shown in Figure 1.

The development of Intelligent Transport Systems (ITS) tools, as well as the availability of mobile communications, has allowed new public transport service options to be developed whereby the service is more responsive to customer demand in terms of time and space (Mageean and Nelson 2003; Ambrosino et al. 2004; Brake et al. 2004).

Figure 1 Elements of a demand responsive transport system (Oliveira 2009).

In practice, different levels of flexibility can be adopted and customer demand determines the route and vehicle used at varying timescales prior to travel as illustrated in

Figure 2. This figure summarizes the range of options for a flexible transportation system configuration.

It is essential to realize the role of each flexible type of transport service as part of the overall public transport system. A DRT system can be flexible in terms of vehicle allocation and operator, type of passenger category, level of automation and level of integration with the transportation network. Flexibility of each element can vary along a continuous demand responsiveness from services where all variables are established and fixed at a considerable time before operation, to services where variables are determined close to the time of operation (Brake et al. 2007). A transport service can be operated on their own, integrated with traditional transportation systems, and feeder services for buses or rail services.

Different types of contributions can be found in literature concerning flexible transportation systems; they can be grouped in three categories: general articles, case studies, and analytical models. Savelberg, Desaulniers & Villeneuve (2000) and Cordeau & Laporte (2007) have proposed interesting review articles on flexible transportation systems.

General papers address essential aspects and design DTR systems (e.g. Giannopoulos 2004; Enright 2006; Mulley and Nelson 2009).

Case studies papers report experiences, implementation and discuss main results, benefits, problems and limitations of adoption (e.g. SAMPLUS 2000; Gray et al. 2001; Muro 2006).

Finally, modeling papers, by far, the most numerous propose mathematical models to address the most complex problems faced in the management of DRT systems such as network and scheduling, demand forecasting models, mixed models, etc (e.g. Farragh et al. 2008; Quadrifoglio 2009).

The DRT operation planning problem can be an optimization problem where there is a need for vehicles and drivers which pick up passengers.
point and delivery them to another within a time interval
with the objective of minimizing total system costs or
maximizing customers level of service, subject to several
constraints. This issue is considered a vehicle routing
problem with pickup and delivery (VRPPD) (Xiang et al
2006). A specific case of VRPPD is the dial-a-ride
problem (DARP). The DARP have been focused on
human resources and in time windows. Bolin et al. (1983)
developed one of the first studies on the characterization
of route planning problems of goods and people.

From some DRT systems reported in literature its
implementation obeys to several conditions,
encapsulating high dynamic levels of both planning and
coordination processes. The use of modern information
and communication technologies, transport telematics/
Intelligent Transport Systems or even, Flexible
Transportation Services (FTS) allied to adequate strategy
planning services has been pointed out as the solution to
improve the costs-effective performance of DRT services
(Mulley and Nelson 2009).

A conclusion that can be draw from the literature devoted
to DRT systems is that these transportation systems are
supposed to be used for a considerable time during which
many parameters can change, in particular, demand
profiles or mobility needs. It involves several decisions,
one of them strategic but also tactical and operational.

In this sense, strategic decision should last for a substantial
amount of time due to the large investments normally
associated with this type of decisions. Strategic decisions
are concerned with the definition of the most adequate
supply chain which involves many choices associated with the
level of responsiveness to adopt (route, vehicles,
quality, level of integration with PT, level of
synchronization, etc.). These decisions have a critical impact
in the level of resources to be allocated and, therefore, in
overall operational costs.

Though DRT is a very interesting solution, its use has
limited due to the relatively high costs of operation
result of high levels of resources (vehicles and
costs) and to the relatively high complexity associated
planning and operational issues. Additionally other
concerns have been pointed out by several authors (Brake et
al. 2014), which can have a significant impact on its
implementation. Such as, the lack of legal and regulatory
frameworks in most countries to accommodate flexible
demand services; the technological issues including the
availability of algorithms to provide operational solutions;
the reliability of DRT services and the lack of support for
the most appropriate service and system

use of simulation approaches have been reported in
literature to support some design decisions whenever
solutions are associated with some parameters. It
to take into account different configuration
helping the decision making process.

Feuerstein and Stougie (2001); Bailey and Clark (1987)
developed one of the first studies on the characterization
of route planning problems of goods and people.

Some studies—
implemented of a transport system. Fu (2002) develops a simulation model to evaluate
the potential impact of the latest progress in information
on dial-a-ride systems. Diana
(2006) appraised the effectiveness of a DRT scheduling
algorithm by Diana and Dessouky (2004) of dynamic
parameters such as proportion of real time requests and
interval between call-in time and requested pick-up time.

Quadrifiglio and Dessouky (2007) tested the efficiency
of the insertion heuristic scheduling algorithm for MAST
systems; they also used simulation to perform a
demand sensitivity analysis of the accomplishment of a MAST
system varying the shape of its service area. Quadrifiglio
et al. (2008) used the simulation methods to investigate
the effect of using a zoning versus a no zoning strategy
and time window settings.

Dias et al. (2011) proposed a framework that will allow
achieving the most adequate configuration by evaluating
different design strategies prior to the implementation of
such a complex system as it the case of a DRT system.

Following the approach proposed by Dias et al. (2011), an
integrated approach devised to address some of the main
difficulties associated with the design and management of a
DRT system was developed and will be described in
more detail. A decision support system (DSS)
incorporating mathematical models (optimization,
simulation and statistical methods) and integrating some
important characteristics of the real context such as the
area characteristics, population demographics and legal
and regulatory frameworks will provide an effective
support in the decision making process. Additionally this
DSS will incorporate a comprehensive evaluation module
able to assess system performance providing valuable
information on systems sustainability. Next section will
discuss transportation performance indicators
frameworks.

PERFORMANCE INDICATORS

In order to evaluate the sustainability of the system it is
necessary to define and use performance measures or
indicators.

The performance evaluation module was intended to be
as much comprehensive as possible, including a wide set
of indicators from three main dimensions: social,
economic and environmental. A research was carried out
to identify which performance indicators are more
appropriate to assess the quality of transportation
systems. Based on the literature on transport performance
systems (NCHRP 2006), there are a large number of
measures that can be grouped in four categories:
preservation of assets; mobility and accessibility;
operations and maintenance and safety.
Several performance indicators can be produced in order to provide insight on systems operations, such as, total generalized costs of trip plan; medium delay of each vehicle; mean users delay time; mean waiting and travel time; vehicles utilization rate; capacity and availability rate; requests not satisfied; level of service; incident response.

According to the literature, efforts have been made in order to identify the potential benefits with the least impact on costs, but the convergence of methods for costs and benefits assessment turns difficult to measure or evaluate impacts in monetary terms. This is a complex task and additional research is needed to develop models and better evaluate the socio-economic development of ITS. Furthermore, some authors refer the absence of sufficient information to make a quantitative analysis of transport services. This information can be obtained through surveys of potential users of the service.

Particularly, in DRT projects, social assessment stands out as fundamental, addressing the efficiency for all stakeholders, including aspects like customer acceptance, impact on traffic, environmental and socio-economic impacts, and other externalities. There are also some environmental indicators, but their analysis is out of the scope of this project. But indeed, that smaller vehicles at least produce less CO2 emissions than the oldest and biggest conventional public transport. Additional research is still required to complete this evaluation module.

THE DECISION SUPPORT SYSTEM

The main objective of the decision support system developed is to configure a DRT system that incorporates a high level of flexibility and that responds in real-time to users demand taking into account the real context: socio-economic, demographic, legal, etc.

Approaches proposed so far focus on some particular aspects of design process, such as the fleet size or, the most numerous ones, the definition of schedules and routes allowed, as the result of explicit requests for travel (Oliveira et al., 2011). Therefore, they cannot provide additional information for the overall system evaluation.

The conceptual model proposed is illustrated in Figure 3: characteristics of the study area, including demand, and supply for transport services must be collected and stored in a data base which is the basis of the main information system that constitutes the DSS. A trip demand generator will produce trip requests by applying a probabilistic model for destination choice, based on the socio-economic and demographic characteristics of the residents (from Census), and the locations and characteristics of the main attraction poles. A simulator module will determine dynamically the most appropriate (rational) set of routes and schedules to satisfy requested trips, and will reproduce all movements of users and vehicles according to predefined system operating parameters. Routing and scheduling solutions are obtained by automatically selecting the most appropriate solution method, depending on the typology of a dimension of the problems/situations, the computation time performance of the algorithms and the time available to obtain the required solution. Various alternative a complementary solution methods (or algorithms) were incorporated in the routing and scheduling sub-modules ranging from an exact dynamic programming method basic construction heuristics (ex., Clark & Wright saving method) and more advanced heuristics.

The simulator is one of the key elements of the DSS framework since it will reproduce the real system behavior (supply and demand for transport and different operation choices). The DSS, by integrating all the main design, planning and operational issues will allow analyzing and evaluating different scenarios for the DRT system integrating technical and non-technical cross-functional cooperation in order to produce better service for users and more efficient and sustainable operation for operators.

A set of discrete alternative scenarios can be produced associated with different levels of resources or different operating rules. Sensitivity analysis for small changes in parameters can be carried out to evaluate impacts on general systems performance. Examples of tests that can be performed are: spots of population concentration within counties; different routes and stops in a particular area; DRT system integration with regular transport service; flexibility of services as a function of economic efficiency, costs effectiveness and resources availability.

A main feature of the system is the routing planning module. Both advanced booking and on-line trip requests are accepted and, therefore, a highly dynamic routing and scheduling approach is highly desirable. A set of exact methods and heuristics approaches have been provided and an intelligent routine will select the most appropriate algorithm according with planning context (for instance, an exact solution can provide optimal solutions but may not achieve the required solution in the time window available) or with the type of problem to solve. Information concerning routes and schedules is produced and it is available both to the drivers and to users (Oliveira 2009). Whenever a trip request cannot be satisfied due to lack of operational capacity (no vehicles available or no slack time), users are notified.

Additional analysis is then performed to assess solution viability and encompassing several dimensions such as: technical, financial and economical. Performance measurement is essential to monitor progress toward a result or goal. It is also a process of gathering information to make well-informed decisions. The result of the assessment process will provide guidelines and the required feedback to adjust system resources and operating parameters as illustrated by the feedback arrows in Figure 3.

Furthermore, beside the route optimization module, the decision support system proposed include other characteristics, such as, request management, drivers and
customers' communication systems and integration with a Geographic Information Systems (GIS) tool.

![Figure 3 Conceptual framework.](image)

**WORK DEVELOPED**

As it was already stated, our aim is to develop an intelligence solution for flexible transportation decision makers.

Figure 4 sows in greater detail the main module of the DRT simulator. Based on information of the real area to be analyzed such as demand patterns (in particular, form this data element a survey must be carried out to devise origin destination trip matrices, for each time period) and the road network, trip requests are generated and routes and schedules are produced, that will allow to simulate different alternatives in order to assess, in advance, the performance of a wide range of scenarios or management strategies. The production of routes and schedules follow some pre-defined objectives established by the user such as: distance minimization, minimization of the number of vehicles; minimum user delay; minimum time, minimum costs (a generalized distance/time cost function or multi-objective function can also be used), etc. Constrains associated with physical resources availability and system operating parameters must be also set to configure the operational context. Additionally, associated to the production of each solution, several performance indicators are produced to allow decision maker to assess solution's quality.

The simulation model by incorporating analytical models and using data on the transportation system will be able to produce scheduling and routing plans. The analytical tool to be used in each situation depends on the typology of the problem to address and the time available to calculate the solution.

![Figure 4 Simulation model of the DSS.](image)

Implemented situations were:

- "many-to-one" or "one-to-many" where there are many origins and a single destination or one origin and several destinations (e.g. school service or enterprises) – the solution method adopted is the Clark & Wright heuristic. Figure 5 illustrates the interface of a solution obtained for an instance of twenty-two requests with three vehicles available inside of a region. The green point is the pickup point and the red delivery points. The heuristic objective is to determine a good solution, that is a route or a set routes associated to a total distance as shorter as possible (but not the necessarily the shortest of them) by using a minimum of vehicles from a fleet of vehicles with different capacities. The route(s) initiate and finish at the same spot, never overcharge the vehicles maximum capacities.

![Figure 5 Many to one.](image)

- The vehicle only travel inside an area. It can be solved with an exact dynamic programming method because is a very restricted situation and computational time is more efficient comparing to other exact methods. Figure 6 illustrates the solution obtained for an instance of seven trip requests and with one vehicle available.
Besides the optimization routing module, the system is being enriched by the incorporating of several modules developed or under development, requests management, drivers’ communication, communication (including a web portal) and database and GIS tools. The storage and flow of data are fundamental to maintain the global efficiency system.

Figure 8 represents the proposal architecture for information system, showing the integration among models and other elements of the system.

This information system will be able to combine with analytical tools in order to put available information to support top management strategic decisions. However, this tool is automatic and will be able to be used as an operational tool to plan schedules on demand, whenever system configuration is already set.

A data warehouse is used to assemble, organize, and to store all the relevant data: transportation network, trips (demand), user’s data, available resources, scheduling plans, etc.

Trip requests are added to the system using a trip generator which reproduces user’s mobility needs for a given period (when using this approach in the experimental stage) or using a web application designed for specific purposes. An additional facility was incorporated by integrating Google Maps allowing a visual interface both for input (data points), the shorter route, the mean travel time, distance and the schedule of the trip.

There is an advantage in the use of GIS technology, integrating the Google Maps service. Google maps the representation of geo-referenced information can be a very user-friendly way and is a free service.

Google maps needs JavaScript technology that has been supported by browsers to represent the information as a route design (Figure 9).
CONCLUSIONS

Prior to the implementation of a DRT system there are many issues to be properly addressed at the design and planning phases. Many DRT projects have been implemented worldwide without taking adequate care of such issues, and therefore some related failures (that have led to system re-engineering or even project withdrawal) have been reported. In addition, there is currently a lack of comprehensive methodologies to address the problem of designing and planning such systems. In order to achieve a successful DRT service it is important to develop a framework that provides an integrated DSS to enable decision makers to perform systematic analysis leading to intelligent strategic solutions.

This project includes the simulation model incorporating more efficient routing and scheduling algorithms, using different solution methods (exact algorithms, heuristics, meta-heuristics), and provide the system with cleverness to adopt the most appropriate models according with the context. Furthermore, this simulation tool integrates GIS in order to enhance the graphical displaying of the solutions produced, and allow further statistical analyses of spatio-temporal indicators. A case study in a small rural area of the north of Portugal is used to validate the framework.

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