

A DECISION SUPPORT SYSTEM FOR A FLEXIBLE TRANSPORT SYSTEM

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ABSTRACT

The provision of traditional public transport services in rural areas have shown to be very inefficient and ineffective. In fact, rural areas are typically characterized by low levels of population density leading to complex demand patterns (low levels and high spatial and temporal dispersion), which in turn leads to low levels of service of conventional transport services (low frequencies, usage of old vehicles, etc). Demand Responsive Transport (DRT) systems have been seen as an effective alternative solution already adopted in several countries. In most cases, however, the services provided by the implementation of the system have revealed to be somewhat inadequate or even unsustainable, and therefore they needed to be either substantially redefined or abandoned. The principal reason for this is the lack of a proper design of the system before undergoing its implementation. The problem is that the viability and sustainability of a DRT system is, in general, highly dependent on the correct tuning of some organizational and functional parameters, namely all those related to the level of flexibility of the services provided. This design work must be carried out before the implementation phase of the system, by using adequate demand and supply models and related methodological approaches to accurately estimate the effects of alternative DRT solutions. Despite the existence of a vast literature concerning DRT systems, there is currently a lack in terms of comprehensive approaches to tackle this problem. In this way, this research proposes an integrated multi-disciplinary framework to support decision-makers in the design and planning of flexible transportation systems.

INTRODUCTION

Traditionally, public transport systems in rural areas have been based on static services: fixed routes, fixed stops and fixed schedules. However, the low levels of density observed in some of these areas leads to high levels of inefficiency and efficacy. In fact, low rates of occupation of vehicles and high rates of population dissatisfaction are frequently observed. Moreover,

vehicles used are the oldest of operator fleet, does not attracting many potential users.

Therefore, many potential users have difficulty to reach their desired destination, because either they are too far away from fixed route or they want to travel out of predefined schedule. As a result rural area inhabitants are seeing their mobility limited, increasing social exclusion of some population sectors, such as children, elderly and/or mobility impaired people.

One way to overcome some of these problems is a flexible transportation system based on flexible services and called Demand Responsive Transport (DRT). DRT has been adopted over the last decades all over the world and some cases have been reported in the literature. Authors are unanimous in stressing that the success of these transportation systems depends on the use of intelligence solutions to process trip requests, optimizes routes and schedules in order to respond in real time to users mobility needs. Such intelligent solutions require the use of modern information and communication technologies and operational research optimizations approaches either at planning and operational level. According to 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 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 as a complex system as it the case of a DRT system. Furthermore, the tool will ultimately assure the adoption of a sustainable DRT system, by properly adequate supply (e.g. fleet of vehicles and typology of services provided) to estimated demand levels and patterns, taking into account financial, economic and social decision criteria.

The decision support system is part of a general framework that combines data with analytical tools in order to provide information that will support top management strategic decisions.

This paper is structured as follows. Section 2 presents a brief literature review on flexible transportation systems

in order to highlight the main design issues concerning the design of DRT systems. In Section 3, a new framework to support strategic decisions concerning the design and planning of DRT systems is proposed. Finally, section 4 presents the main conclusions and final considerations regarding future developments.

LITERATURE REVIEW

Flexible transportation systems have been adopted over the last decades, as reported in some studies (Brake *et al.*, 2004; Mulley and Nelson, 2009). In fact, there are many successful cases of DRT systems all over the world. Most of the cases reported are serving rural areas, small towns or special populations (elderly and people with disabilities) in large cities.

These systems provide transport on demand from users, using flexible schedules and routes to pick up and drop off users as required. A DRT system receives trip requests either for an immediate service or as an advanced reservation and organizes routes and schedules to accommodate trip requests aiming to respond in real time to user's mobility needs. Its implementation typically involves the use of information and communication technologies as shown in Figure 1.

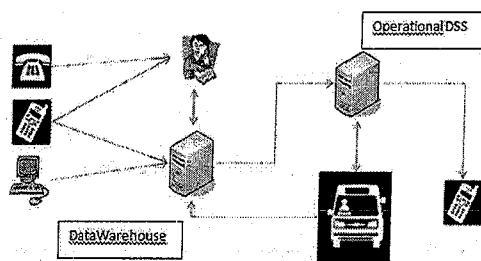


Figure 1: Elements of a demand responsive transport system.

Trip requests are, in general, made using telephone or internet and stored in a data warehouse which holds all the relevant data concerning the transportation network. A fleet of vehicles are available: buses, mini buses, taxis provided by a variety of providers (taxi owners, bus operators, community transport, etc). Services can be operated on their own or integrated with traditional transportation systems, acting as feeder services for buses or rail services. The heterogeneous fleet of vehicles is coordinated by a Travel Dispatch Centres (TDC) with advanced information and communication technologies such as on-board integrated GPS, continuous GPRS connection to TDC. An operational decision support system (DSS) incorporating mathematical models (optimization, simulation and statistical methods), will provide the most adequate transport solution according to the area characteristics and demand pattern.

If possible, a flexible transportation system will combine the advantages of a private car solution, characterized by high levels of commodity and

responsiveness, with economies of scale of public transportation systems. 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 shows the range of options for these aspects of demand responsiveness.

It is essential to realize the role of each flexible typology of transport service as part of the overall public transport system. DRT system is flexible in terms of route, vehicle allocation, vehicle operator, type of payment and passenger category. The flexibility of each element can vary along a continuum of demand responsiveness from services where all variables are established a considerable time before the operation (*e.g.* a conventional fixed public transport bus route) to services where variables are determined close to the time of operation (Brake *et al.*, 2007).

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).

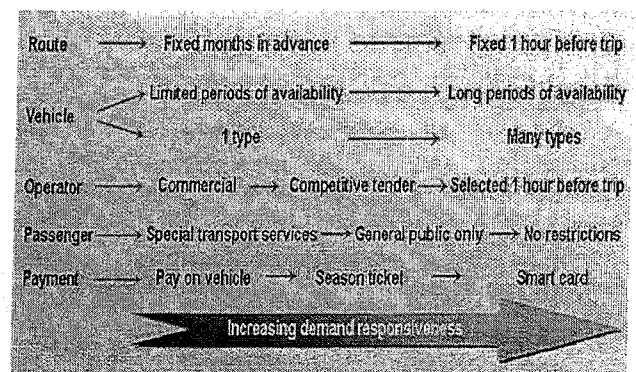


Figure 2: Different levels of flexibility (adapted from Brake *et al.*, 2007).

Different types of contributions can be found in the literature concerning flexible transportation systems. In general, they can be grouped in three categories: general articles, case studies, and analytical models. Although, there are some review papers reporting good practices and difficulties, the bulk of the literature is related to general issues and case studies (*e.g.* Enoch *et al.*, 2006).

General issues papers address advantages and disadvantages of DTR systems or conceptual questions related with flexible transportation systems, as well as critical factors for their success or failure in practice (*e.g.* Giannopoulos, 2004; Mulley and Nelson, 2009).

Case studies papers report experiences of DRT implementation and discuss main results achieved benefits, problems and limitations of adopted solutions (*e.g.* SAMPLUS, 2000; Gray *et al.*, 2001; McDonagh J., 2006).

Finally, modeling papers are, by far, the most numerous, and propose mathematical models to address some of the most complex problems faced in the operational management of these transportation systems such as network routing and scheduling, demand forecasting models, simulation models, etc (e.g. Parragh *et al.*, 2008; Quadrifoglio and Li, 2009).

Interesting review articles have been proposed by Savelsbergh (1995), Desaulniers *et al.* (2000), and Cordeau *et al.* (2007).

From some DRT systems reported in literature, its implementation obeys to several conditions, encompassing 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).

Although DRT is a very interesting solution since it offers a very user-friendly solution to their potential passengers (small and comfortable vehicles on demand) and overcomes some of the shortcomings of the traditional transport services, its use has been limited due to the relatively high costs of operation as a result of high levels of resources (vehicles and drivers) and to the relatively high complexity associated to planning and operational issues. Additionally other issues have been pointed out by several authors (Brake *et al.*, 2004) which can have a significant impact on its implementation: the lack of legal and regulatory framework in most countries to accommodate flexible transport services; technological issues including the selection of algorithms to provide operational solutions; sustainability of DRT services and the lack of support to select the most appropriate service and system design.

In this research project a framework is proposed to address some of the main difficulties associated to the design and management of a DRT system. A methodology is suggested involving some of the key issues that must be taken into account when defining the most adequate transportation solution according to the area characteristics, population demographics and legal and regulatory framework.

CONCEPTUAL FRAMEWORK

As it was already stated, the aim of the underlying project of this paper is the development of a methodology to help the design and management of efficient and sustainable flexible transportation systems, whose services combine the flexibility of a private car with the economies of scale of a public transportation system. Such a DSS will be essential to minimize the increased operational costs connected to the requirements associated to a flexible transport system.

In the proposed framework, the conception of a DRT system involves a concurrent engineering approach since

it allows to integrate and analyze all the main design, planning and operational issues (economical, social, environmental) at its conceptual stage. This includes establishing user requirements and expectations, by considering perspectives altogether from the beginning of the project, running computational models (software has a huge role in the design process) and creating prototypes.

By adopting a concurrent engineering approach, the DRT system solution (for a particular operating area) will integrate technical and non-technical cross-functional cooperation in order to produce better services for users and more efficient and sustainable operations for operators.

Based on demand and supply models of the area where a DRT system is to be implemented, for a given level of resources and a set of operating rules, the system simulates the real system and will produce a set of performance indicators associated to the tested scenario.

Additional analysis is then performed to assess solution viability and encompassing several dimensions such as: technical, financial and economical. A sustainable transportation system must be achieved to guarantee that population needs are met now and for generations to come. The result of the assessment process will provide guidelines and the required feedback to adjust system resources and operating parameters as illustrated in Figure 3.

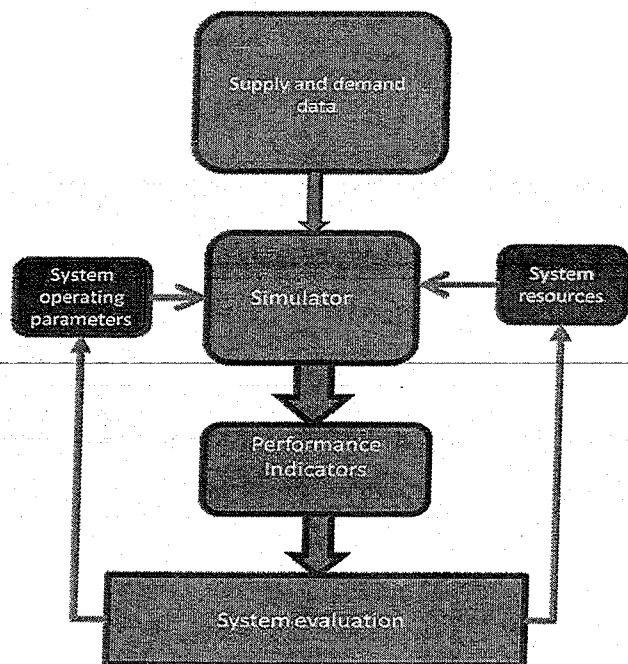


Figure 3: Conceptual framework.

The simulator constitutes one of the key elements of this framework since it will be responsible for reproducing the real system behavior and provide essential information for system evaluation process. The simulation model (Figure 4) incorporates a data base with data concerning travel demand – origin/destination information and geo-referenced data on the network.

Based on these data, a trip request generator reproduces users mobility needs for a given period.

Then, operational configuration must be defined by setting objectives, operating rules and level of resources. Objectives can include total cost minimization (a generalized distance/time cost function or multi-objective function can be used), minimizations of delays, minimization of vehicles, among others.

Different operation rules can be adopted associated with different levels of flexibility: fixed routes, fully flexible routes or a mixed solution, minimum advance booking time, level of articulation between DRT and fixed transportation systems, pick up and drop off points, dynamic or static planning, etc. In terms of resources, it can be assumed that available vehicles can have different characteristics, such as taxis, mini buses or buses.

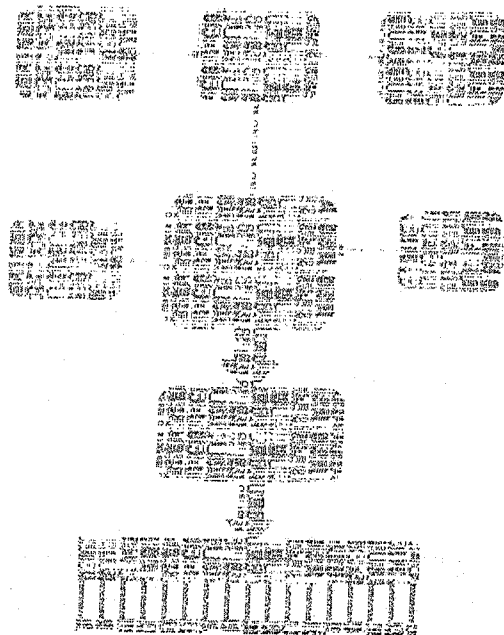


Figure 4: Simulation model of the DSS

The simulation model uses optimization routines to produce solutions (routes/schedules/drivers plans/users notifications) as well as, printed reports on systems performance. In fact, several performance indicators can be produced in order to provide insight on systems operations: total generalized costs of trip plan, medium delay of each vehicle; mean users delay time; mean waiting time; vehicles utilization; requests not satisfied; level of service

Two different types of information can be generated: strategic information crucial in a design stage of DRT system to set up the correct level of resources and there is operational information required to define the most adequate operational rules to be adopted in a daily operations context.

The last step, and undoubtedly one of the most challenging ones, is to carry out systematic system evaluation of the transportation system, setting up the most important evaluation criteria and their quantification. Specificities of these transportation

systems must be taken into account: spatial aspects of public transport such as the characteristics of the local population, transport network, the patterns of commuters, and the framework within which the system works, determine the demand and operational scale of system and, as such, can affect performance and efficiency. Eventually, the primary purpose of a public transportation system is to serve people who chose not to use their own vehicle due to their low income, to some resource constraints or to other personal reasons. Globally, these projects aim to improve customer satisfaction, with regard to their mobility.

Performance measurement is a procedure to monitor progress toward a result or goal. Based on the literature on transport performance measurement 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.

Traditional methods to economic evaluation of transport projects have been based on two approaches: public and private. The financial assessment, which evaluates the point of view of the expected transport operators' profitability, naturally refers to private operators. It is therefore assumed that the DRT must be efficient, and the use of telematics combined with optimization models is fundamental. This results on the consideration of Intelligent Transportation Systems (ITS). On the other hand, public or economic evaluation focuses on Regional, Local or National interest of a project. The environmental and social impacts must then be considered. 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. This evaluation is often based on cost-benefit analysis.

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 obviously implicates a set of performance indicators that can be ideally translated into a monetary scale. However 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.

CONCLUSIONS

Prior to the implementation of a DRT system there are a lot of issues that must be properly addressed at the design and planning phases of its project. Many DRT projects has been implement world-wide without taken 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 this research, an attempt is made to develop a framework that will provide an integrated decision support system to enable decision makers to perform systematic analysis leading to intelligent strategic solutions. The proposed approach includes a realistic micro-simulator of alternative transportation scenarios and functional parameterization (e.g. flexibility and operating rules) allowing planners to estimate accurately the correspondent performance indicators. Additionally, there is an evaluation module to incorporate sustainability of alternative transportation systems, including financial and economic viability and sustainability. Following a concurrent engineering approach, the adoption of this methodological framework will certainly contribute to a better understanding of the key issues in the design of DRT systems.

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

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