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DECISION SUPPORT SYSTEM FOR THE DESIGN OF SUSTAINABLE DEMAND RESPONSIVE TRANSPORT

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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 naturally categorized by low levels of population density leading to complex demand patterns (low levels and high spatial and temporal dispersion), which leads to low levels of service of conventional transport services (low frequencies, usage of old vehicles, etc). Demand Responsive Transport systems have been seen as an effective alternative solution already adopted in several countries.

There are however some issues concerning DRT costs and benefits that still have to be addressed. In this research work an integrated analysis incorporating both internal and external costs is proposed aiming to support decision makers investigating the impacts and performance measures related to the adoption of a flexible transportation system solution.

Additionally, DRT systems are highly dependent on the correct calibration of some organizational 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 performance, in terms of both viability and sustainability, can be obtained providing effective support in the design and operational stages of a DRT system implementation in low density areas.

Keywords: Demand Responsive Transport, Dynamic Vehicle Scheduling and Routing, Simulation Modeling, Decision Support System, Transport System Evaluation, Sustainable Transport.

1. INTRODUCTION

Rural areas are typically characterized by low levels of population density and complex mobility patterns. Conventional public transport services (based on static services: fixed routes, fixed stops and fixed schedules) have shown to be very inefficient and ineffective in these environments, presenting, very often, low levels of service (low frequency, old vehicles, etc.) and high rates of population dissatisfaction. Rural areas inhabitants with their mobility limited, use frequently, the good-wiling of neighbors or a family member to make their trips. Therefore, functional social exclusion increases for residents in those areas.

In this context, an effective solution to overcome some of these problems may consist on a flexible transport system, based on dynamic routes and schedules, whose services are triggered by demand calls, commonly knows as Demand Responsive Transport (DRT) system. DRT systems have been already adopted over the last decades all over the world, and several success cases that have been reported in the literature (e.g. Brake *et al.*, 2004; Nelson *et al.*, 2010). However there are still some issues to be addressed, since these systems have revealed, in some situations, to be inadequate or even unsustainable, requiring substantial redefinition or even to be abandoned.

A main question that 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, there are also some issues concerning the costs and benefits of DRT system that require further analysis and still need to be addressed, in order to evaluate the transport system viability and sustainability.

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 integrated in a decision support system to support the design and planning of DRT systems for 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. Furthermore, the tool will ultimately assure, as much as it can be predicted, 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.

This paper is structured as follows. Section 2 presents the main characteristics, functionalities and support resources that a DRT system needs in order to be viable and sustainable. In Section 3 it is proposed the conceptual/methodological framework that is the base of our Decision Support System for properly design a DRT system. Finally Section 4 some general conclusions are presented.

2. MAIN ASPECTS AND COMPONENTS OF A DRT SYSTEM

In DRT systems, trip requests are, in general, made by telephone dialing directly to a travel dispatch center (TDC), alternatively, there are cases where users can also use a messaging system (SMS) or a web portal (Oliveira *et al.* 2011). Trip requests are stored in a database system, which holds all the relevant data concerning the transportation network. The routes and schedules are organized 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. The TDC coordinates a fleet of vehicles with communication technologies such as on-board integrated GPS. 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).

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 (Brake *et al.* 2004).

It is essential to realize the role of flexible typology of transport service (in terms of route, vehicle and operator allocation, type of payment, passenger category, automation and integration level) as part of the overall public transport system. Also, transport services can be operated on their own or integrated with traditional transportation systems, acting as feeder services for buses or rail services. The flexibility of each element can vary along a continuum of demand responsiveness from services (Brake *et al.* 2007).

A DRT system involves several decisions, some of them strategic but also tactical and operational. Strategic decisions are concerned with the definition of the most adequate design which involves many choices associated with the level of responsiveness to adopt. These decisions have a critical impact on the level of resources to be allocated and, therefore, on its overall operational costs.

Several specificities of DRT systems must be taken into account: the characteristics of the local population, the transport network, the patterns of commuters, and the framework within which the system works, will determine the demand and operational scale of system (Wright *et al.*, 2009).

TDC costs are highly dependent on the level of complexity and cleverness of the system, namely its degree of flexibility (time window restrictions of pre-booking; dynamic routing and scheduling) and other functionalities, such as Interactive Voice Response System or Internet booking.

Additionally other issues can have a significant impact on DRT implementation: the lack of legal and regulatory framework 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 order to evaluate the sustainability of the system it is necessary to define and use performance measures or indicators.

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.

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.

In DRT projects it is possible to assessment in three main groups: Social, Environmental and Financial (Litman, 2009). Social assessment stands out as fundamental, addressing the efficiency for all stakeholders, including aspects like customer acceptance, congestion, delays, travel time, accessibility to facilities and services, passenger usage, transport diversity and community quality of life like health problems due to pollution and waste. Environmental assessment includes vehicle emissions, air pollution and climate changes, energy and noise impacts, road damage, barrier effects, water pollution, waste, aesthetic degradation and depletion of nonrenewable resources. And economic assessment include financial impacts like vehicle acquisition and registration, service license, annual insurance, parking, drivers', TDC operators and software operators earnings, fuel, and cost efficiency, maintenance and cleaning vehicles, software maintenance, updates costs, telematics costs, vehicle operations, crash, vehicle usage, route flexibility, operating subsidies, road facilities and responsiveness.

On the other hand, the service generates benefits in each group considered. As so, one of the most important impacts of flexible transportation systems is Social benefits (e.g., social inclusion, improve mobility and accessibility, easier access to medical treatment, bigger groups movement), Environmental benefits, (e.g., less pollutant then conventional bus, increasing adherence, reduce congestion and accidents risk), and Economic benefits (e.g., economic productivity, area development, ability to support services on low demand routes and bigger vehicle occupation rate).

Many of these benefits and costs aren't easy to measure, but they are substantially important to the sustainability of the system. Many authors, considered crucial to evaluate a transport project by internalizing externalities of transport, however this is quite difficult to accomplish (Jakob *et al.*, 2006).

There are several techniques in the literature to quantify and monetize external effects of vehicles such as, damage cost method or control and prevention cost method (Litman, 2009). Alternatively, some authors advocate the implementation of eco-taxes, subsidies for using cleaner technologies, thus avoiding socio-environmental costs, or using evaluation methods such as cost benefit analysis or life-cycle analysis (ExternE, 2005). Several authors refer that cost-benefit analysis (CBA) is one of the most widely applied methods for project appraisal for large-scale investments in the terrestrial transport sector (e.g. Jakob *et al.*, 2006). On the other hand, an investment project can be evaluated taking into account both social and economic impacts on the local community through social return on investment (SROI) analysis (Wright *et al.*, 2009).

In the next section it is proposed a framework (decision support system – DSS) that incorporates operational research and statistical methods with mathematical models (route and schedule optimization and simulation), that will provide an adequate tool to aid decision makers in planning transport solutions according to the area characteristics and demand patterns as well economic tolls to evaluate performance indicators.

3. PROPOSED CONCEPTUAL FRAMEWORK

At the design level, in our approach, the main objective of a DSS is to configure a DRT system with high level of flexibility that responds in real time to users demand. Such a DSS will be essential to guarantee that minimize the increased operational costs connected to the requirements associated to a flexible transport system.

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 2. Additional analysis is performed to assess solution viability and sustainability, encompassing several dimensions such as: social, financial/economic and environmental. 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.

Due to the system complexity, with a complex process (still in planning phase) based in forecasted models of demand and resources, the simulator will incorporates (as a resource) an operational DSS, namely the vehicle routing and scheduling to obtain a better insight on general costs of the system performance functioning in a rational regime. Furthermore, it is considered that the main feature of the system is the routing planning module. Both advanced booking and on-line trip request 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 appropriated one according to the operational planning context. For example, an exact solution method provide optimal solutions but allowing planning efficiency may not achieve the required solution in the time window available.

Beside the route optimization module, the DSS proposed include other characteristics, such as, request management, drivers and customers' communication systems and integration with a Geographic Information Systems (GIS) tool to allow statistical analyses, to analyze new trends or new patterns, all together creating a new service.

Figure 3 shows in greater detail the main module of the DSS: the DRT simulator. Based on information of the real area to be analyzed such as demand patterns and the road network, trip requests are generated and routes and schedules are produced. 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, among others. Constrains associated with physical resources availability and system operating parameters must be also set to configure the operational context.

For instance, one implemented situation was ''many-to-one'', where there are many origins and a single destination (or it could have been a "one-to-many" one origin and several destinations) for a school service or enterprises services. Figure 4 illustrates the solution obtained for an instance of 22 requests with 3 vehicles available (in this case the method adopted is Clark &Wright heuristic).

Trip requests are added to the system using a trip request generator which reproduces user's mobility needs for a given period (when using this approach in the design stage) or using a web application designed for this purpose. An additional facility was incorporated by using Google Maps allowing a visual interface both for input as for output (results) purposes. Google maps tool allow users to see the origin and destination points of their requested trips, the shorter route, the mean travel time and distance and the schedule of the trip, in a very user-friendly way. From the operator viewpoint, Google maps toll is high desirable because it is provided as a free web service (Figure 5).

Additionally, associated to the production of each solution, several performance indicators are produced to allow decision maker to assess the overall performance of the system. The simulation model uses optimization routines to produce solutions (routes/schedules/drivers plans/users notifications) as referred before, but it also print reports on systems performance. In fact, several performance indicators can be produced in order to provide insight on the efficiency of 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.

A set of discrete alternative scenarios can be produced associated with sensitivity analysis for small changes in parameters to evaluate impacts on general systems performance. Examples of testes 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.

4. 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. Transport systems costs structure was discussed and a classification of costs attributes was proposed. A case study in a small rural area of the north of Portugal is currently under study in order to validate the framework.

Specific characteristics of DRT systems were analyzed and the three most relevant impacts that must be considered: economic, social and environmental were considered. A framework of performance indicators was identified as essential to the evaluation process.

Since the outcome of the evaluation is highly dependent on the DRT specification (in terms of operational parameters, such as the level of spatial and temporal flexibility of their services), this framework must comprise an iterative approach that consists on defining an initial DRT specification, estimating their impacts in terms of performance indicators, redefining the specification and re-estimating the new impacts, and so on until a suitable solution is found, in terms of technical and economic viability and sustainability. The estimating of the impacts of the alternative DRT specifications can be performed by using a computerized simulator that makes the interaction between the demand (customers) and the supply (vehicles and system coordinator) at the individual level thus capturing the proper dynamics of the system.

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.

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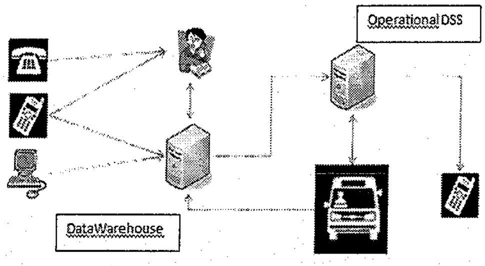

Figure 1. Elements of a demand responsive transport system.

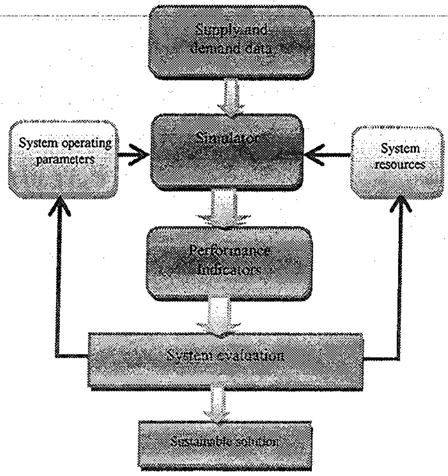

Figure 2. Conceptual framework.

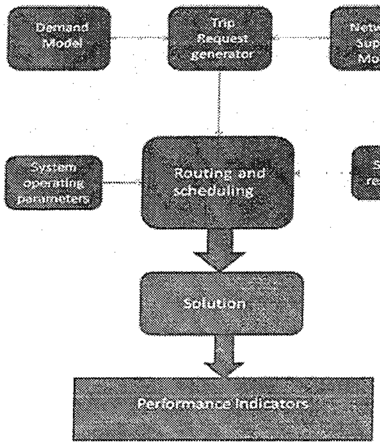

Figure 3. Simulation module of DSS.

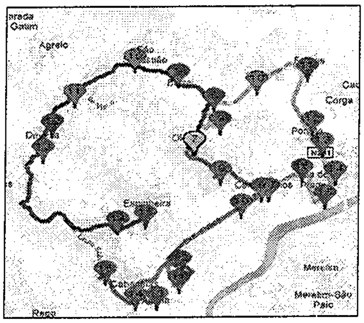

Figure 4. Many to one

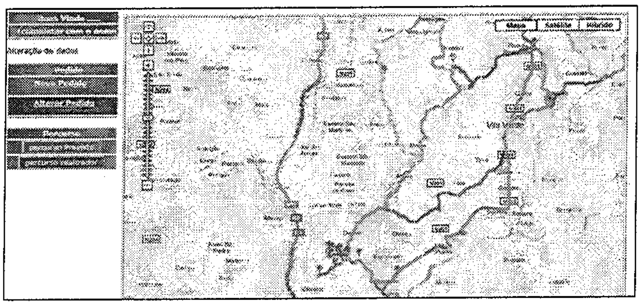

Figure 5. User interface of the system.