Real Time Software Solution for the Integration of Dynamic On-Demand Services in Rural Public Transport

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***Abstract*— On-demand public transport satisfies many of the needs that traditional public transport, with fixed predetermined routes and schedules, cannot fulfill. Both schemas are able to work together, as it is discussed in this paper, being on-demand services a good alternative in the areas and time intervals where low demand makes fixed routes unsustainable. This work presents a new integrated real-time management system for road public transport services, focusing on the integration of three kinds of services: fixed services, on-demand fixed services and on-demand dynamic services. The architecture of the system and the features of the tailored algorithm for dynamic services are detailed in the paper. The main objective of the algorithm is to solve the multi-vehicle Dial-a-Ride Problem (DARP) minimizing the number of vehicles and the total distance of the routes. A heterogeneous capacitated fleet is used to serve the customers and the cost matrix is asymmetric, as real-life conditions are assumed. The desired quality of service is set by configurable parameters (e.g., waiting time window and maximum ride time). The algorithm is designed to work with two operating modes (insertion and optimization), concluding that a fast response can be achieved with the insertion mode, improving the results with the optimization mode.**

I. INTRODUCTION

New generations of collective road public transport need to offer efficient demand-responsive systems where traditional predefined services become loss-making activities. Geographical areas with low or sparse population usually have lack of competitive public transportation options due to the small amount of potential users. Fixed services operate according to a fixed schedule, and vehicles run their designated route at designated times even though there are no passengers on board. This means that there is quite a lot of waste in operating the transport system. Avoiding this waste implies reducing the frequency of the buses and, thus, the general quality of the service.

On-demand public transport works following user requests, and therefore satisfies many of the needs that traditional public transport cannot fulfill. Both schemas are able to work together, as it is discussed in this paper, being on-demand services a great alternative in the areas and time intervals where low demand makes fixed routes and schedules unsustainable.

This work presents an integrated real-time management system for three kinds of public transport services. These are: fixed services, on-demand fixed services and on-demand dynamic services. A new algorithm has been developed and integrated in the system for the generation of routes and schedules needed by these latter services. The on-demand dynamic transportation approach presented here is found in the literature inside the Dial-A-Ride Problem (DARP) variants.

DARP is a particular case of the Pickup and Delivery Problems (PDP). In [1], authors provide a general framework for dynamic one-to-one PDPs, presenting the most relevant literature about a class of vehicle routing problems in which objects or people have to be transported between an origin and a destination (see also [2]). Unlike in static routing problems, in a dynamic routing problem, some of the input data (in most cases user requests) are revealed or updated during the period of time in which operations take place. Therefore, a solution cannot be a static output. Several constraints exist and are used to classify different problems: e.g. limits in the fleet and in the capacity of the vehicles, time windows, journey durations, distance limits.

DARP describes the specifical problem of passenger transportation. Users require transportation from an origin to a destination with stricter constraints concerning quality of service than, for the sake of example, some courier services. Vehicles are always capacitated, as the number of seats is finite. Moreover, passengers are not willing to wait for long at the pickup stop and they cannot spend more than certain time inside a vehicle, neither traveling nor waiting for other passengers. That is why most applied constraints in DARP models are waiting time windows and maximum ride times [3] [4]. An in-depth classification can be found in [5]. Door-to-door services for elderly or disabled people are the clearest examples widely put in practice in many countries [6].

The rest of the paper is organized as follows: First of all, a general overview of the problem to solve is described giving a real location example. After that, the proposal of the solution and the architecture of the platform are shown, explaining each of the modules that constitute the system. The developed algorithm and its features are discussed later. Finally, conclusions and some remarkable results are given.

II. GENERAL OVERVIEW OF PUBLIC ROAD TRANSPORT IN RURAL GIPUZKOA

Gipuzkoa (Spain) is a very dispersive province with vast highly populated areas and high mobility rates among different municipalities. It is divided in 7 smaller regions and they all display important levels of generation and attraction of journeys as the weight of the capital Donostia-San Sebastian with respect of the rest of the territory is relatively low in comparison to the other provinces [7].

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A real alternative to the private car is still needed in many intraregional trips because the current situation of public transport in rural areas cannot handle the following facts with success:

- Lots of services carry very few passengers
- Inefficient fleet management
- Many time-outs
- Areas of difficult access
- Fixed routes regardless of the number of users

A. Objectives

The promotion of the use of public transport lies in improving the service offered, towards a flexible and fast public transport, adapted to the needs of users in small municipalities.

- Improve mobility rates in the regions of Gipuzkoa
- Increase the number of users
- Optimize the offered services
- Extend the service to currently non-served areas
- Provide the user with updated information about traffic flow and ways of mobility

B. LANDABUS Project in Aia

The aim of the LANDABUS project in Aia (Gipuzkoa, Spain) was to cover the rural area of Aia-Zarautz-Orio with flexible bus services. Fixed and on-demand routes were designed to serve the local inhabitants. On-demand routes visit predetermined stops at previously set schedules, but each user willing to travel must make a request by telephone, SMS or Internet, at least 30 minutes in advance so as to activate the desired service.

The trial with an initial duration of a year started in June 2008 and by October, passengers tripled. After 3 years, the service still continues running with users showing high degrees of satisfaction. LANDABUS meant to be a basis to afterwards expand the concept to other regions. The new implementations of the model want to migrate to a totally on-demand service looking for a higher degree of resource optimization.

C. Specific Drawbacks of the Current Bus System in other areas

One of the seven regions of Gipuzkoa has been analyzed to show the specific situation of the transportation in other rural communities. For example, Tolosaldea, with an area of 332 km^2, it is the less populated region with 45000 inhabitants. However, it has the biggest amount of municipalities, 29. Bus services and mobility in this area were studied during the year 2008, in order to define the road map to strengthen and improve the offer. It was concluded that the current public transport was not equally distributed and it deserved a reorganization. The municipalities mainly located along the 4 central axis of the region, showed quite good overall access to transportation. Otherwise, the rest were very limited and some small population nucleus did not even have any scheduled service.

Many logistical problems were detected:

- Some journeys are run with empty buses (out of service or in service without any passengers)
- Dead intervals between services
- Different areas are not equally covered
- Errors and incoherences in the data collected
- Inaccurate definition of routes and lines

This collective road transport offer is provided by 8 bus lines (L1-L8) with origin/destination Tolosa, the main town of Tolosaldea. The uneven relevance of these lines in the average day use is considerable. Three lines carry the 71% of the mobility demand and the others handle very low numbers.

The general demand changes significantly during the day. E.g., Fig. 1 displays the distribution of the passengers served by L1 regarding the time of the day.

The fleet is now composed by 8 buses. As a general description of their use, four buses have high activity, two can be pointed out as of medium activity and the other two of low. Furthermore, between services, vehicles spend large amounts of time, up to several hours, in idle state during the day. The inadequate size of the buses is also understood as a problem to travel along some of the narrow winding roads.

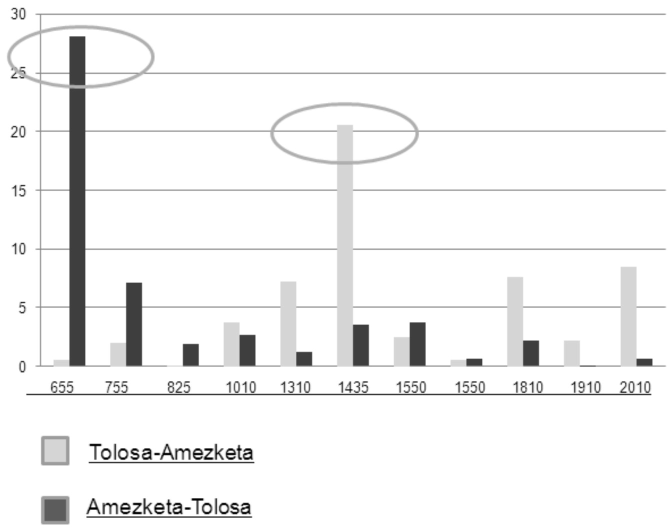

Fig. 1. Distribution of passengers of Line 1 during an average day

III. NEW PROPOSAL

For all of the above, a new redefinition of lines and routes emerges necessary. With the success of the experience in Aia in mind, a newer version with more flexible features is decided to include in the system in order to increase the number of passengers, optimize the journeys and extend the service to areas that are currently neglected.

The proposal of the new public transport system combines 3 kinds of services:

- Fixed services (FS): Fixed timetables and routes that do not vary and are always active.

- On Demand Fixed Services (ODFS): Fixed timetables and routes, activated on demand (e.g. LANDABUS in Aia).
- On Demand Dynamic Services (ODDS): Vehicles pick riders up at the times and places specified by them. Hence, services must be generated or updated each time a request is received.

The area is divided in two line types:

- Main lines: they visit nodes in easily accessible areas, often with high population rates.
- Secondary lines: they connect more remote nodes, accessible by secondary roads.

In addition, the day is divided in different time intervals according to the demand:

- Rush hours: more than 5 passengers by vehicle on average (the example in Fig. 1 shows the most important rush hours highlighted).
- Valley hours: less than 5 passengers by vehicle on average.

Services types are, therefore, assigned to each kind of daytime and areas, like shown in Table I.

TABLE I
SERVICE TYPE ASSIGNMENT

	Main Lines	Secondary Lines
Rush Hours	FS	FS
Valley Hours	ODFS	ODDS

Fixed services are scheduled for rush hours. They travel along fast lines through the four main routes and make few stops, lasting no more than 30 minutes. Shuttle services may connect the main routes with the more scattered municipalities that are not included in the fast lines.

Demand responsive services are chosen for the valley hours, at the intervals where traditional fixed routes are more likely to travel empty or with very few passengers. The vehicles that are in idle state, waiting for their fixed routes to start, can be used to transport on-demand users. On the one hand, the main lines will be supplied by on-demand services that follow preestablished routes and schedules. On the other hand, the secondary areas will be traveled following dynamically generated routes.

A. On-Demand Dynamic Services

ODDS need users to specify the origin and destination stops and the desired time of pickup (the algorithm can manage the dropoff time instead, if preferred). For each request the algorithm must be run and give an immediate response to the user about its acceptance or rejection.

In early stages of the design and development of the solution, one of the options considered was to send that response once the whole calculation of the best routes had finished. Nevertheless, that choice was soon discarded to avoid the need of later communicating with the users.

The generation of this services is discussed later on in section V.

IV. SYSTEM ARCHITECTURE

The general schema of the platform is shown in Fig. 2.

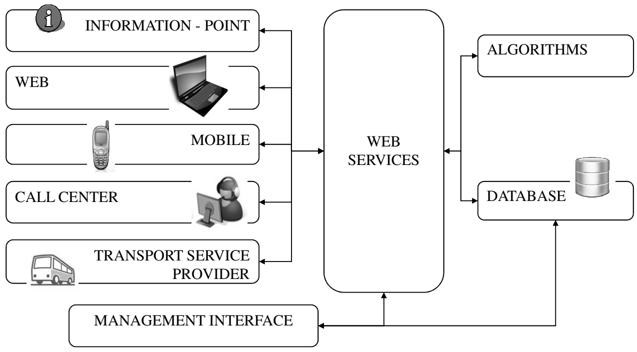

Fig. 2. General architecture of the system

Control Center hosts the server management application for complete transport system/route administration. It includes this main modules:

- Database designed for the management of the entities involved
- Routing and scheduling algorithm to calculate ODDS
- Complete web service platform
- Management interface

Multimodal interfaces can access the system through the web service platform in order to allow users make/update requests and consult services on line, via SMS, using the Call-Center service or information points. Transport service provider is informed about the routes that the vehicles must follow thanks to the interface created for that purpose. Onboard equipment in vehicles is able to connect to the system to update their location and the status of the services.

V. ODDS ALGORITHM

An insertion heuristic algorithm is used for on-demand dynamic services. According to the requests received, it dynamically generates the order of the stops to pickup and to deliver all the users at the specified time, assigning a suitable vehicle to ensure that capacity constraints are not violated. The problem set for the algorithm follows the approach of the Dial-a-Ride Problem. The solution presented in this paper relies on two operating modes (insertion and optimization) and it has been designed to minimize the number of vehicles and the total distance run by the whole set of services generated for the considered time slot. It successfully administers a heterogeneous fleet with seats for the general public and for those users with limited mobility. The quality of service is guaranteed by a maximum waiting time threshold at the pickup stops and a maximum ride time threshold for each user, defined as a linear function of the direct travel time between pickup and delivery.

A. General Parameters and Constraints

1) Stops and distances: For the implementation of the system it was decided that the list of possible pickup and dropoff stops would be previously predetermined. The management interface allows the administrator to add and update the location and information of stops in the database. The driving distances (in minutes and kilometers) between all the pairs of stops are automatically obtained using publicly available geocoding and directions web services, and a matrix is built. The algorithm uses the distance measured in time, that is, the duration of the journeys.

- $d(A, B)$: Direct (shortest) driving distance in minutes between stop A and stop B.

Being,

$$d(A, B) \leq d(A, C) + d(C, B) \tag{1}$$

Generally speaking, in real-life conditions distance matrix is asymmetric:

$$d(A, B) \neq d(B, A) \tag{2}$$

2) Requests: The parameters retrieved from each request r are:

- O_r: Origin stop.
- D_r: Destination stop.
- TO_r: Pick-up time at origin.
- p_r: Number of general passengers.
- p_{RMr}: Number of passengers with special mobility needs.

3) Passengers: For each stop i in a service passengers can be divided in:

- $pin(i)$: Number of general passengers willing to get on the vehicle.
- $pout(i)$: Number of general passengers that get off the vehicle.
- $pin_{RM}(i)$: Number of passengers with limited mobility willing to get on the vehicle.
- $pout_{RM}(i)$: Number of passengers with limited mobility that get off the vehicle.

4) Finite heterogeneous capacitated fleet: The information of the vehicles must be stored in the database previously using the management interface. It is possible to specify the time slot according to each type of day, when a vehicle is available for ODDS services. Their capacity is defined by the number of general seats, the number of seats for handicapped passengers, and the relation of how many general users can travel in the place of a handicapped passenger when possible.

For a vehicle v, its capacity can be defined with the three following parameters:

- C_v: Number of seats for general passengers.
- C_{RMv}: Number of seats for mobility reduced passengers.
- eq_v: Equivalence between general and mobility reduced seats, thus, number of general passengers that can travel in the place of a mobility reduced passenger. This value has to be $eq_v \geq 0$.

Being n the number of stops to visit by vehicle v, capacity must ensure that $\forall s = 0, 1, ..., n$, if $C_v \geq \sum_{i=0}^{s} (pin(i) - pout(i))$ then,

$$C_{RMv} \geq \sum_{i=0}^{s} (pin_{RM}(i) - pout_{RM}(i)) \tag{3}$$

Else, eq_v must be non-zero and,

$$C_{RMv} - \sum_{i=0}^{s} (pin_{RM}(i) - pout_{RM}(i))$$
$$- \frac{1}{eq_v} (\sum_{i=0}^{s} (pin(i) - pout(i)) - C_v) \geq 0 \tag{4}$$

If none of the conditions is satisfied passengers cannot be served by vehicle v.

5) Waiting time window W: Waiting time window defines the maximum time a user should be awaiting at the pickup stop. The maximum time window W is used as an adjustable parameter of the system, and its value is applied for all the requests at first. Every time new requested stops are introduced into the stop sequence of a service l, time windows W_l are readjusted (tightened) by the Insertion Mode of the ODDS algorithm. The width of these time windows is the same for all the stops in a service at the end of the procedure, and the widest the window, the more flexibility the service has to accept new requests. The vehicle assigned should preferably visit stops at the beginning of the window.

6) Maximum ride time M_r: The maximum ride time is defined for each request r as a linear function of the direct travel time between pickup and delivery. It guarantees that each user does not spend more than a certain time on the vehicle.

The value of M_r is defined as:

$$M_r = d(O_r, D_r)[1 + R] \tag{5}$$

where R is the maximum percentage of time that the system is allowed to exceed the direct traveling time between two points.

In addition, absolute maximum and minimum values are established (i.e. T_{max} and T_{min}), so that if $M_r \geq T_{max}$ or $M_r \leq T_{min}$, they are respectively considered as threshold.

Finally, notice that the time $T(O_r, D_r)$ spent by a service to travel between O_r and D_r must fulfill:

$$d(O_r, D_r) \leq T(O_r, D_r) \leq M_r \tag{6}$$

B. Insertion Mode

The basis of the algorithm is to insert new requests into existing services thanks to the flexibility given by the non-negative time window parameter. The origin and destination stops of each request are chronologically ordered in a list and the feasibility of the sequence is analyzed. The procedure is shown in Fig. 3.

Time windows are adjusted taking into account the distances between each pair of sequential stops in the new order.

- $TO1_r$: time window beginning at origin
- $TO2_r$: time window end at origin
- $TD1_r$: time window beginning at destination
- $TD2_r$: time window end at destination

A service l dedicated uniquely to serve a request r is graphically represented in Fig. 4 (a). If a new request q is received, Fig. 4 (b), the system tries to insert it in the same service and update the time windows, Fig. 4 (c). Chronologically ordered the beginning of the windows, the new temporal sequence of the stops is (O_r, O_q, D_q, D_r).

Once inserted, stops lose their pickup/dropoff meaning, and a service becomes a sequence of n generic stops $(A, B, C, ...n)$. A stop sequence is feasible if a vehicle can travel from the first to the last stop visiting each stop at a time inside its window. Taking into account that the traveling time between two consecutive stops A and B is $d(A, B)$, the beginning and end of the time windows must be adjusted ensuring $W_l > 0$.

If that not feasible, while the maximum ride time constraint is not violated, the drop-off time of the new request can be shifted forward changing the sequence and checking the feasibility again.

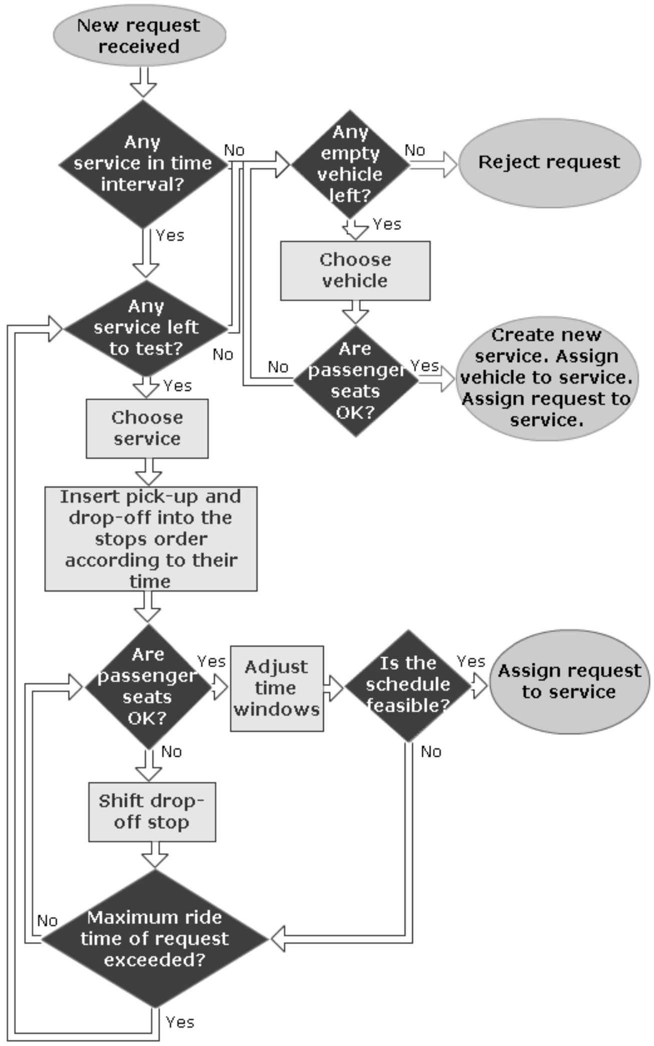

Fig. 3. Insertion Mode Procedure

The Insertion Mode is of great interest in the case of users asking for immediate transportation to accept them

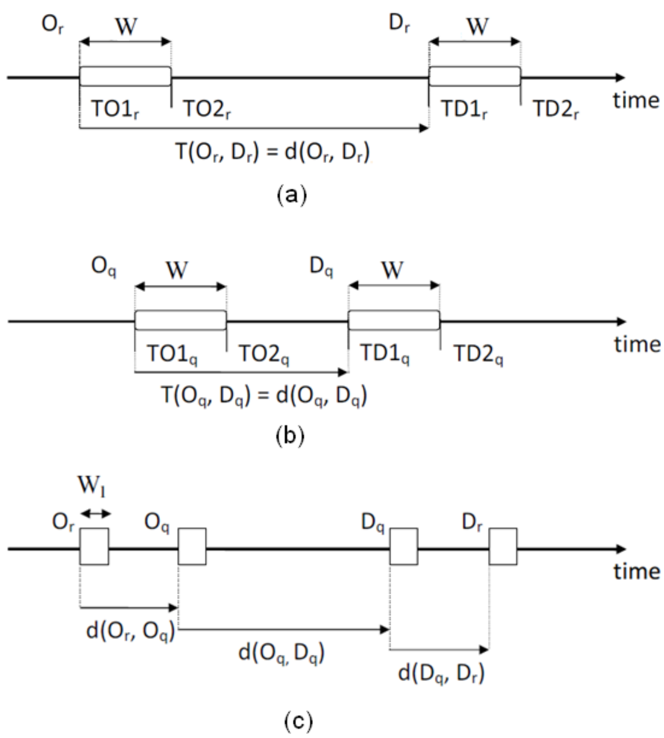

Fig. 4. Request r (a) and Request q (b) are inserted into the same service (c). Notice new time window W_l is narrower than original W, but its width is positive. Therefore, this stop sequence is feasible.

in services that are already running. It ensures that the scheduled stops will be traveled as expected without delay even if a new stop is included in the journey.

C. Optimization Mode

Periodically, for services that are still not running, the set of results that has been accepted by the Insertion Mode is reconsidered by the Optimization Mode. This amount of requests is taken and the order they are introduced into the stops sequence is changed in each run, choosing the best result at the end of the computing time. Note that requests previously accepted and confirmed to the users cannot be rejected now. This optimization is multi-objective, the best result can be chosen among different priorities or a combination of them:

- Reduce total route duration
- Reduce total vehicles
- Reduce rejected requests (only those not confirmed)

The objective selected for the implementation of the final management system is the one with the minimum number of vehicles, with the shortest total traveled route.

D. Promoting Users Awareness about Efficiency in Transport: Availability Calculation

With the objective of making users be aware of the need to efficiently use road transportation and stress the difference between the ODDS and a traditional taxi service, a calculation of Availability can be performed as a step before the final request of a web user is introduced in the system.

This first checks if any previously accepted request coincides with the new one. If so, both are joined. Otherwise, Availability performs the Insertion Mode several times, changing the pickup time of the new request in each run, inside a time slot. Thus, the system gets a sorted list of service options for alternative pickup hours. The ones that can be accepted making better use of the resources (e.g. avoiding to create new services) are shown and the user is invited to choose one of them, if possible.

VI. RESULTS

In order to analyze the operation of the ODDS algorithm, several tests have been made simulating the expected demand according to the mobility study described above. Due to the lack of known specific benchmark data sets for this DARP, requests were generated on purpose using real stop locations in the studied geographical area. The general configuration parameters used are W: 10 minutes and R: 0.4.

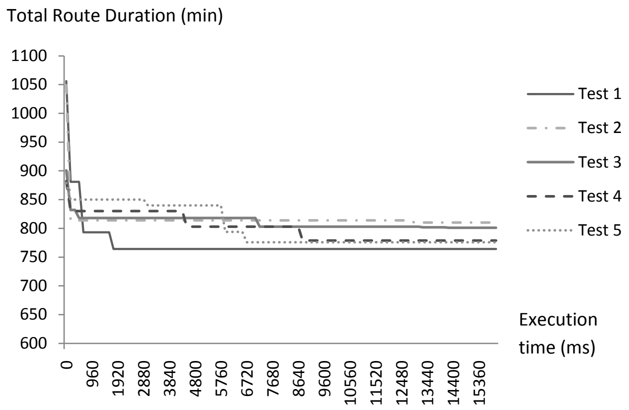

Fig. 5. Total duration of the journeys, for 5 tests performing Optimization Mode

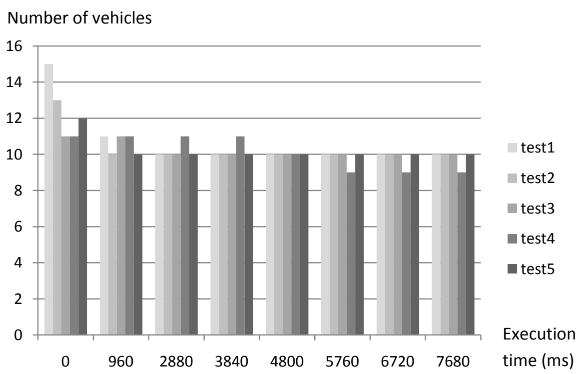

Fig. 6. Total number of vehicles needed, for 5 tests performing Optimization Mode

The charts in Fig. 5 and Fig. 6 show the performance for a test case of 40 user requests distributed in 20 different stop locations, in a three hours time slot. The optimization algorithm has been tested 5 times to measure the response. The insertion algorithm applied in each iteration has taken an average of 16 miliseconds (Intel Core2 Quad CPU, Q8400 at 2.66 GHz).

It is shown that an immediate response can be achieved even with the optimization mode for the data used. In all 5 tests it takes less than a second to improve the route duration obtained by the first insertion execution reducing values to the 75% and they soon get to an almost stable solution. For instance, after one minute of execution total journey duration values for Test1 and Test4 remained the same as the ones obtained at 1.7 and 8.8 seconds respectively.

VII. CONCLUSIONS

In this work a new integrated real-time management system for road public transport services has been presented, describing a possible solution for the transportation problems found in rural areas. ODDS are proposed for specific areas and time slots and a new algorithm has been developed to manage requests and generate routes. Insertion Mode can easily study the acceptance of users even in vehicles that are running without making major changes in the routes. Optimization Mode can be configured to be performed during the desired computation time and, for the demand load in the studied geographical areas, Optimization Mode can even be valid to answer user requests on line. The Availability calculation has been presented in order to describe a way to promote user awareness towards sustainability in transport. In conclusion, the system is of great help for an innovative understanding of efficient collective transportation.

VIII. ACKNOWLEDGMENTS

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