1 INTRODUCTION

Demand Responsive Transport Systems (DRTS) were introduced for the first time in North America in the 1970’s as Paratransit services for elderly and handicapped passengers. They have recently been reconsidered, thanks to innovative technologies. They are usually adopted for low-demand areas or as night services in large cities or an addition to traditional transit service during peak hours. Unlike traditional transit services, DRTS are characterized by variable paths and timetables and they can operate door-to-door as well as stop-to-stop. Moreover, they can be classified according to how many origin and destination points there are and whether they deal only with advanced requests or also immediate requests. This work refers to a many-to-many service (customers have different points of origin and destination) and to advanced requests (all requests are received before the time of vehicle dispatch).

2 METHODOLOGY

A DRT system requires the planning of travel paths (routing) and customer pick-up and drop-off times (scheduling) on the basis of received requests. It has to tackle, in particular, multiple vehicles, limited capacity of fleet vehicles and temporal constraints (time windows). The problem of working out optimal service paths and times is called Dial a Ride Problem (DaRP), which derives from the well-known Vehicle Routing Problem (VRP), with the addition of precedence constraints between pick-up and drop-off locations. Their computational complexity makes both DaRP and VRP NP-hard problems, so attempts to develop optimal solutions have been limited to simple and small-size problems. On the other hand, heuristic procedures are more suitable for realistic network and demand, because they allow the good solutions to be attained in limited time. Heuristics are usually distinguished by:

- Polynomial constructive procedures: they build solutions by incrementally instantiating decision variables until a complete feasible solution is obtained;
– Iterative procedures or local search: they evolve in a space of complete solutions, where all decision variables have been instantiated. They use transformation operators to move from one complete solution to another until a feasible and satisfactory solution has been found or until some predetermined condition, such as maximum number of iterations, is satisfied.

Constructive approaches can provide sub-optimal solutions quickly, while iterative techniques spend additional time to improve solution quality and can start from solutions calculated by constructive procedures.

This work deals with the algorithm Advanced Dial A Ride with Time Windows (ADARTW), proposed by Jaw and Psaraftis (Jaw et al, 1986); this is a heuristic constructive procedure based on insertion technique, that makes it suitable for handling dynamic requests as well.

The ADARTW algorithm has been coded using the ANSI standard C++ programming language because it permits a strict organization of the necessary data structures into classes (according to the Object-Oriented paradigm). The choice of this programming language guarantees the portability of the implementation on various platforms (recompilation needed) and good performances in elaboration time.

2.1 The trip planning algorithm

This algorithm sequentially processes received requests up to a given time, inserting one customer at a time into the work schedule of any vehicle, until all requests have been processed. The main stages of the algorithm are:
– The research of feasible insertions of requests in different trip plans;
– The optimisation phase to select the best insertion.

An insertion of a customer into the work schedule of a vehicle is feasible, if it observes the service quality constraints both for the newly assigned passenger and for all other customers already assigned to that vehicle. Additional vehicles are added only if there are no feasible insertions for a customer within the existing vehicles.

Inserting a new customer in a work schedule means finding an Actual Pick-up and Delivery Time. This location can be placed in a time interval in which all constraints are observed, so it should be optimised; but, for the moment, the implemented algorithm places APT and ADT as late as possible in that feasible interval. A future improvement could deal with this.

The optimisation step tries to find the insertion that minimizes the additional cost due to inserting the customer into a vehicle’s work schedule. It has to consider the objectives of service operators as well as the objectives of users, therefore the optimisation model uses an objective function calculated as sum of different parts:
– The first part refers to the customer being assigned to a vehicle, therefore it considers his disutility due to deviation of pick-up or drop-off time from desired time and to the excess ride time in comparison with the direct ride time;
– The second part expresses the additional disutility of all the other customers already assigned to that vehicle due to the insertion of a new customer; it takes into account the deviation of pick-up or drop-off time from desired time and the excess ride time in comparison with the direct ride time for the other customers;
– The third part is a linear function of additional ride time of the vehicle, which the new customer is assigned to due to his insertion; therefore it takes into account the objectives of system operators.

2.2 The Dial a Ride service proposed

The trip planning algorithm has been applied to manage a hypothetical Dial a Ride service in a rural area in the Northwest of Italy, which is comprised of the town of Ivrea and surroundings. The input data are characteristic elements of supply, demand and level of service assured by service operators. As for supply, a network composed of 319 nodes and 808 links was considered. It represents only principal urban and rural roads and, for each link of the network, a commercial speed has been introduced, to simplify the travel time computation.
The fleet characteristics are bus number and bus capacity. All buses leave from the same depot located in a node belonging to the Ivrea urban network.

As for the demand characteristics, this work refers to:
– journeys for home-work purpose;
– peak hour in the morning as for time period of reference;
– a many-to-many demand generated in each node of the network, according to socio-economic characteristics.

The level of service assured by service operators is represented basically by the following parameters:
– Maximum Ride Time expresses the maximum travel time on board the vehicle for each customer as a linear combination of the direct ride time for his origin and destination: 
  \[ \text{MRT} = A + B \times \text{DRT} \];
– Wait State expresses the maximum deviation of actual pick-up or drop-off time from the desired corresponding time.

2.3 Analysis and evaluations

In this work the effects of changing service quality on customer satisfaction and on service operator cost have been analysed. Changes of Wait State and coefficients in the expression of the Maximum Ride Time obviously affect the disutility related to customers, but in some way also influence the operator cost. In order to evaluate these effects, some scenarios have been established, according to different values of the Wait State in the range between 8 and 16 min.; as for MRT, A varies between 8 and 16 min. and the coefficient B varies between 1 and 3.
In the following two diagrams (Figure 1), the effects on all the customers, both the inserted one and the others already on board, are considered. The first one refers to the increase in travel time compared with the Direct Ride Time, whereas the second one concerns the advance of the Actual Delivery Time in comparison with the requested delivery time, that is assumed in the algorithm as the Latest Delivery Time.

In both diagrams average values are calculated for all customers.

![Increase of travel time compared with direct ride time](chart1)

![Advance of actual delivery time compared with the latest delivery time](chart2)

Figure 1. Effects of changing service quality on customer satisfaction.

In the analysed scenarios, increasing values of Wait State, A and B mean a worse level of service for the customer: the worse the level of service becomes, the more Actual Ride Time increases and customers are delivered too earlier than the requested time.

In the following four diagrams (Figure 2), for the same scenarios above introduced, the effects on operator cost are analysed, referring to different indicators. The first of them is the number of buses required for the service: it decreases for worse levels of customer service, and in parallel the average passenger loads increase. This happens because the algorithm plans journeys which are more and more advantageous for operators, serving the same number of customers by means of fewer buses; this leads also to a growing average Tbus, evident in the third diagram of the same figure.
The last indicator of operator cost analysed in the diagrams is a bus utilisation index, which is calculated as \((\Sigma \text{ART})/\text{Tbus}\) and is always greater than zero, but lower than the on-board customer number; it allows the evaluation of the extent to which the operator exploits each trip plan. In the diagram, an average value calculated referring to all buses requested for each scenario is shown.

In order to evaluate how the above-mentioned indicators are distributed among the various customers and buses, some histograms have been yielded, referring indicator values to suitable intervals. In the following, for sake of brevity, two of them will be introduced. The first (Figure 3) shows how the distribution of ART-DRT changes from the scenario with \(A=8, B=1, WS=8\), advantageous for customers, to that with \(A=11, B=1.6, WS=11\). This analysis allows one to remark that in the second scenario (worse for customers), although the average travel time increase is about 10 min., almost 40% of customers see their trips increase less than 2 min, with respect to their DRT.
The second one (Figure 4) refers to operator costs and depicts the distribution of Utilisation Index among various buses requested in the two scenarios; it is possible to deduce that the trip plans of the second scenario exploit bus capacity better than the first one, by overlapping customer trips.

The trip planning algorithm has also been used to evaluate each part of the objective function, every time a customer is inserted in a work schedule. For each additional customer assigned, the number of alternatives might increase, because a new vehicles can be utilized. Nevertheless, there is an opposite aspect: as the number of customers assigned increases, the time window constraints become stronger, making the research of feasible insertions more difficult. For this reason, all alternatives analysed from the algorithm for each customer have been monitored: they are all feasible insertions handled by ADARTW. In the histogram in Figure 5, the attempts related to sets of twenty users, grouped according to insertion order, are depicted. We deduce that the greater the number of customers already assigned, the more the number of feasible insertions increases.

Moreover, by monitoring the three components of the objective function while requests are processed, it is also possible to recognize the worst insertions, which generate the greatest increase of any part of the objective function. To this purpose, in the following tables the number of definitive insertions, classified on the basis of their disutility intervals, is shown.
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</table>

Table 1. The components of objective function

For example, the 5 insertions which have an operator disutility between 140 and 160 could be re-examined and allocated in different work-schedules, by means of post-optimisation procedures.

3 CONCLUSIONS

This work refers to a Demand Responsive Transport System, in particular a *many-to-many* service (customers have different origin and destination points), addressed to *advanced requests* (all requests are received before the time of vehicle dispatch). The research uses the algorithm Advanced Dial A Ride with Time Windows, a heuristic procedure based on insertion technique. The objective of this study is to understand and predict the consequences of different management policies in these innovative transit systems, by analysing passenger requirements and operator costs, mainly expressed as bus travel time. The next steps of this research will tackle post-optimisation procedures, in order to improve the quality of heuristic solutions and multi-depot allocation.

REFERENCES


