1 INTRODUCTION

The latest developments in transport telematics, also identified as Intelligent Transport Systems (ITS), have generated an increasing interest in improving the efficiency and reliability of transit systems. This interest has induced the need for suitable methodologies and tools to help in investigating the effectiveness of ITS. A useful evaluation tool for achieving these objectives, in particular when lacking real applications, is simulation. In this context, simulation is used as the process of designing and creating a model of a likely or expected public transport system for conducting numerical experiments. The purpose is to obtain a better understanding of the behaviour of such a system in a given set of conditions, even with uncertain treatment of events.

The paper deals in particular with Dial-A-Ride services, also called Demand Responsive Transport Services (DRTS), which could be an interesting solution in the modern concept of personal (info)mobility, although they present many difficulties as far as the implementation aspects, hereafter explored. The traditional regular transport services are generally characterized by a defined itinerary, offering customers specific stops at which to board: for each service journey of the vehicle a specific timetable is valid; the route, bus-stops and timetable are planned in advance and vehicles remain often empty during some periods. DRTS aims to supply a service for individual requests by using vehicles that do not operate on a fixed route or on a fixed schedule. In the same vehicle, different passengers can be conveyed at the same time; this provides a public transport alternative that can compete with the private car for its flexibility. The challenge is to make these operations so effective that the unit cost per passenger comes closer to that of fixed-route services than to taxi services and gives operators more flexibility while containing expenses.

Usually the planning of journeys for DRTS vehicles cannot take into account all of the real-life aspects, such as travel time variability and user delays at stop, for example. Nevertheless, performance of the system can be ascertained by observing what happens on the network, during simulation, when different conditions occur.

2 THE SIMULATION SYSTEM PROPOSED

In order to evaluate the efficiency of a DRTS service, a simulation system was implemented (Figure 1). The main modules are:
− **Travel Requests Generator**, which generates travel requests on the network (during the day), based on socio-economic characteristics obtained through statistical data concerning population and taking into account companies settled in the area;

− **Trip Planner**, which defines travel plans and timetables for vehicles and users, by using the ADARTW (*Advanced Dial-A-Ride with Time Windows*) heuristic algorithm (Jaw *et al.*, 1986);

− **DRT Service Simulator** for evaluating DRTS behaviour under uncertain events, such as user and vehicle arrivals at stops, by using ARENA simulation tool.

The first module has been coded in Visual Basic and tries to emulate travel demand, positioning user requests at nodes of the network and at specific times, starting from macro-descriptive variables. The area can be split into several zones; travel requests on the network are generated by using socio-economic variables related to the activity system, such as the number of employed people within each zone.

The *ADARTW Trip Planner* is the module that codes in C++ the *Advanced Dial-A-Ride with Time Windows* algorithm and elaborates the requests obtained through the first module; it gives results as route plans and time schedules for each vehicle needed and each request accepted by the system. This paper does not deal with the capabilities of the algorithm in solving a travel request with appropriate plans, rather, it focuses on the “Service Simulator” and its aptitude in evaluating real-world aspects, which can influence the system performance.

![Diagram of the simulation system](image-url)

**Figure 1. Scheme of the simulation system**
The simulation module was built with ARENA (Systems Modeling Corporation, 1998), a simulation software package based on a discrete, flow-oriented, modelling language named Siman. The logic of the simulation model is divided into different sub-models; each of them simulates a specific component of the system: the network, the vehicle departure from depot, passenger arrivals at stops, vehicle journeys, passenger pick-up and drop-off at stops. A more detailed description of the simulation system built by means of ARENA is reported in a previous research work (Dalla Chiara et al., 2001), even though, in the last version, some modifications were made for adapting the model to simulate “a many to many” DRTS.

The service simulator allows the observation of most of the real-world aspects related to the DRTS, such as the propagation effect of users and vehicles delays upon the actual timetable, during the journey. Both users and vehicles can actually arrive later than planned, and this can generate a decrease in the quality of the service supplied.

Further modules are needed to convert data and analyse results:

- Route plans must be converted from ASCII format to Siman format in order to obtain the input for the Service Simulator module; this function is accomplished with the Siman Format Converter module;
- A specific module, coded in Visual Basic, elaborates the aforementioned data output for obtaining, for each user, efficiency and quality parameters of the service such as the Relative Ride Time and the Level of Service, supplied by the DRTS system (Dalla Chiara et al., 2001).

3 APPLICATION OF THE MODEL

Having defined the general methodology of research, the dial-a-ride service has to be tested by simulating a realistic situation, based on data deriving from an existing demand and territory features. The network chosen for the simulation study represents an area positioned in the middle of a district called Canavese, in the north of Italy, close to Turin; this area includes the town of Ivrea and its surroundings, therefore both an urban context and its countryside. The graph consists of 319 nodes and 808 unidirectional links, for a total extension of travelling distances of 1915 kilometres. For each link of the network, distances and travel times are provided. Speed variability on the network was assumed to consider changes in traffic conditions over time. Travel requests were generated considering about 200 journeys with a Desired Delivery Time within the peak morning period of 7:30 to 9:00.

In order to satisfy the entire travel demand, the ADARTW Trip Planner activated 51 vehicles with 8 seats on-board, leaving from one depot, which is located in a node within the urban network of Ivrea, approximately in the middle of the area. For the service supply, the following features are assumed:
the Wait State (WS), i.e. the maximum admitted deviation for a passenger from the requested pick up or delivery time - therefore the maximum time the user waits at destination before his Desired Delivery Time (DDT) - is equal to 10 minutes;

the Maximum Ride Time (MRT) for the user is 10 minutes plus 30% of his individual Direct Ride Time (DRT).

Four aspects of service operations, which can be related to random events, were investigated in order to ascertain their relevance and assess both the level of service supplied to users and the efficiency of the system:

1. Accuracy of departure time of vehicles from depot;
2. “Patience” of drivers picking up late users at stops;
3. Punctuality of users at stops;
4. “Patience” of users waiting for late vehicles.

The following illustrations (Figure 2, Figure 3) describe the distributions used in the model.

![Figure 2. Distribution used for describing the delay of the vehicles leaving from the depot and the driver waiting time at stops.](image)

The first two are related to the policy of the service operator, whereas the others involve user behaviour. On the other hand, the service operator can influence the punctuality of users, if a modified pick-up time is communicated during the booking operations.

![Figure 3. Distribution used for describing the delay of users at stops.](image)

In the base scenario (1) type “A” distribution has been used for all aspects, while distribution “B” has been used:

- for the delay of the vehicles leaving from the depot (scenario 2), to simulate more accurate driver departure time;
to investigate the decrease in the variance of the time drivers wait at stops to pick up late users (scenario 3);
− to emulate a “less prudent” user behaviour (the average arrival time is the Estimated Pick-up Time [scenario 4]).

The time users wait for late vehicles is maintained constant (10 minutes) for the first four scenarios, while a different value was used only for scenario 5 (20 minutes). After this time, users leave stops to look for other transport systems.

4 MAIN RESULTS

Different replications simulate the same scenario with different random drawings from the same distribution. At the end of the series of replications, the expected values of a performance indicator can be calculated. In this study, 10 replications per scenario were processed. Vehicle speed on the network was assumed variable and lower than that assumed during the trip planning, to consider traffic conditions changes over time.

The overall results reported in Table 1 show the differences between the estimated (or planned) and the simulated Relative Ride Time (RRT) 1 for the various scenarios, as a consequence of random events. The accuracy of vehicle departure time from the depot (scenario 2) does not increase the number of picked up passengers, rather, increases the value of the RRT of the service (scenario 2). More evident is the effect of the waiting time distribution of drivers at stops: the percentage of picked-up users is 90%, the highest value (Scenario3), if drivers are more accurate to wait for late users.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Requests</td>
<td>198</td>
<td>198</td>
<td>198</td>
<td>198</td>
<td>198</td>
</tr>
<tr>
<td>Travelled Passengers</td>
<td>171</td>
<td>169</td>
<td>178</td>
<td>82</td>
<td>170</td>
</tr>
<tr>
<td>Left Passengers</td>
<td>27</td>
<td>29</td>
<td>20</td>
<td>116</td>
<td>28</td>
</tr>
<tr>
<td>Satisfied requests</td>
<td>86%</td>
<td>85%</td>
<td>90%</td>
<td>41%</td>
<td>86%</td>
</tr>
</tbody>
</table>

An important result derives from scenario 4: only 41% of the total passengers are picked up, if we assume a “less prudent” user behaviour (during simulation, the average waiting time at stops is only 0.33 minutes), when network conditions can affect the vehicle speed. Nevertheless, in this scenario we have the lowest simulated Relative Ride Time (RRT).

5 CONCLUSIONS

The simulation system proposed is able to evaluate several quality and efficiency parameters of a DRTS service. The DRT Service Simulator, in particular, considers most of the possible uncertainties, such as the arrival time of passengers at their pickup points, the
travel time on the network links, or the driver punctuality in leaving the depot. The service simulator was previously tested on a small portion of the urban network of Turin. From that study many interesting results were achieved, and many aspects were investigated to confirm the effectiveness of the system implemented as tool for evaluating the efficiency of a Dial a Ride service and to help in adopting transportation policies.

In this paper, the real-word events taken into account concern user and driver behaviour, considering their punctuality in arriving at stops or their patience in waiting for late vehicles and users. The simulation results show that these aspects affect service operations and the quality of a DRTS, if network conditions change over time.

At the present, the simulation system does not take into account that vehicles are moving within the traffic flow on the network, although speed variability is considered by multiplying all link travel times used for trip planning by a coefficient, variable during simulation.

In real life, on the other hand, the vehicle speed is conditioned by congestion on the network or by particular events, such as bottlenecks at congested intersections. In order to emulate realistically the flow of vehicles on road networks and to capture the dynamics of time-dependent traffic phenomena, a microscopic traffic simulator could be used. The next step of the research is then addressed to deal with this problem, by implementing a service simulator within a micro-simulator, in order to make the model more realistic in evaluating performance parameters of the service.

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1 RRT expresses the increase of the Actual Ride Time (ART) observed during simulation, with respect to the Direct Ride Time (DRT) [\( \text{RRT} = \frac{\text{ART}}{\text{DRT}} \)].

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