A dynamic simulation model of a flexible transport services for people in congested area

Pasquale Carotenuto\textsuperscript{a*}, Daniele Monacelli\textsuperscript{b}, Giuseppe Raponi\textsuperscript{b}, Marco Turco\textsuperscript{b}

\textsuperscript{a}Istituto per le Applicazioni del Calcolo “M. Picone”, Consiglio Nazionale delle Ricerche, via dei Taurini 19, Roma 00185, Italy
\textsuperscript{b}Università degli studi di Roma “Tor Vergata”, via del Politecnico 1, Roma 00133, Italy

Abstract

The realization of innovative transport services, require increasingly greater flexibility and inexpensiveness of the service. In many cases the solution is to realize a demand responsive transportation system, in which there are two main goals: minimize costs and maximize flexibility. In this work, we address a Demand Responsive Transport System capable of managing incoming transport demand using a solution based on an insertion heuristics to solve an On-Line dynamic DaRP instance. The solutions provided by the heuristics are simulated dynamically in a discrete events environment in which it is possible to reproduce the movement of the vehicles, the passengers’ arrival to the stops, the delays due to the traffic congestion and possible anomalies in the behavior of the passengers. Finally, at the end of the simulation, a set of performance indicators summarize the solution planned by the heuristics.

1. Introduction

The realization of an innovative transport services, requires increasingly great flexibility and inexpensiveness of the service. In many cases the solution is to realize a demand responsive transportation system, in which there are two main goals: minimize costs and maximize flexibility.

A Demand Responsive Transport System (DRTS) requires planning of travel paths (routing) and customer pick-up and drop-off times (scheduling) on the basis of received requests. In particular, problems encountered could be: multiplicity of vehicles, limited fleet capacity and temporal constraints (time windows).
A DRTS may operate according to a static or to a dynamic mode. In the static setting, customers requests could be inserted in all possible positions of the planned routes without taking into consideration the actual time the request has been received. This is possible because vehicles have not yet left. The DRTS then realize, using a Dial-a-Ride solution (DaRP) for the presented situation, the tour that each bus has to take, respecting the established pick up and delivery time windows while optimizing the solution using either single vehicle (Psaraftis, 1980; Sexton, 1979; Sexton and Bodin, 1985a and 1985b; Desrosiers et al.1986) or multiple vehicle (Jaw et al., 1986; Toth and Vigo, 1997; Borndörfer et al., 1997; Uchimura et al., 1999; Cordeau and Laporte, 2003a; Aldaihani and Dessouky, 2003, Diana and Dessouky, 2004; Bergvinsdottir et al., 2004; Rekiek et al., 2006; Xiang et al., 2006; Wong and Bell, 2006; Wolfer Calvo and Colorni, 2006; Melachrinoudis et al. 2007; Jørgensen et al., 2007).

In the dynamic mode, the routes are evaluated taking into account the actual time the request has been received and the actual vehicle position because in this case vehicles have already partially carried out their route. Usually in both static and dynamic modes customers requests are evaluated ON-LINE by the DRTS centre, this means that such requests would be accepted or refused without taking into consideration future requests. Therefore the routes will be rearranged over time based on the new requests and the actual time they are received. Also in this case single vehicle (Psaraftis, 1980; Gendreau et al., 2001) or multiple vehicle can be used (Madsen et al., 1995; Jih and Hsu, 1999; Teodorovic and radivojevic, 2000; Colorni and Righini, 2001; Mitrovic-Minic et al., 2004; Coslovich et al., 2006; Carotenuto et al. 2006; Beaudry et al., 2010; Berbeglia et al., 2010; Schilde et al., 2011).

In this work, we address the simulation of a Demand Responsive Transport System in a discrete events environment. This is able to manage incoming transport demand using for the moment a simple insertion heuristics that solves ON-LINE and dynamically Dial-a-Ride-Problems. The solution provided by the heuristics is then simulated in a discrete events environment in which it is possible to reproduce the movement of the vehicles, the passengers’ arrival to the stops and eventually the delays due to traffic congestion and possible anomalies in passengers’ behaviors. Finally, at the end of the simulation, a set of performance indicators summarize the solution planned by the heuristics.

2. Objectives

The aim of the work was to create a discrete event simulation model that would allow to correctly reproduce the schedule evaluated by a heuristics that solves a Dial-a-Ride problem but also that would allow the testing of other heuristic able to solve the same problem by using the same platform. The realization of the environment simulation, allows to understand the logic, the strengths and weaknesses of the DRTS and allows to analyze empirically the uncertainty, dynamism, and the interconnection of the examined variables.

In order to perform the dynamic simulation of a DRTS, it was necessary to design a model similar to the methodological and conceptual structure of the flexible transport system. In other words, in the second step, it was necessary to model the architecture of the DRTS in all its aspects: the reservations made by users, the process of optimization of routes, the arrival of customers at the stops, the movement of vehicles on the transport network to pickup and delivery users and so on.

The design of the dynamic simulator has the only purpose of examining meticulously the processes inherent in the system modeled, whilst it is the decision support tool, which allows to assess and predict the unfolding of a series of events and results by varying certain conditions set by the analyst. In other words, you can create a feasibility study of operations in the territory, in order to conceive a model of the impacts and discern what resolution can actually achieve the three goals of the DRTS: reduce operating costs of the service, maximizing customer satisfaction (especially in terms of flexibility of the service) and maximizing the number of requests accepted.

As already mentioned the advantages of simulation are manifold: for example the simulation allows to make
“What If” analysis, to assess the consequences of particular actions and to understand the actual functioning of the system, the strengths and weaknesses of the DRTS. As part of Transport System, the simulation allows to study the sturdiness of the system to some disturbing factors such as traffic congestion, vehicle breakdown or users absence at bus stops, in order to test the efficiency of DRTS in weak demand areas and in not-weak demand areas.

3. Simulation software

To create the simulation model that will be illustrated hereafter, Arena was chosen amongst potential software products available on the market, due to its General-Purpose nature and its flexibility. It is successfully applicable to the construction of a large variety of models included transport services, thanks to the many modules dedicated to the movement simulation and the programming language like Visual Basic for Applications in order to develop capabilities not included in the standard module. Another key aspect in the choice of Arena was the ease with which such a product can be connected with a relational DB.

A model developed in the Arena environment is composed of a set of modules each of which reproduces the behavior of the physical objects or information (entities) in the specific observed case or changes their characteristics. Prior to the execution of the model, these modules are transformed by Arena into instructions handled by a simulation engine named Siman. Whilst the model is running, Siman interprets the instructions and operates on the basis of their content. In addition, the Arena environment is made more flexible and adaptable to the needs of the model to realize by the VBA engine which allows to easily build new specific required functionalities and create user forms to collect parameters required to run tests. Moreover it is also able to communicate in an efficient manner with relational databases in order to record the simulation results or to acquire information for further tests to be carried out. Finally VBA and Siman through the use of dedicated statements can easily exchange values whenever it is required and therefore fully interface with each other.

4. Model Description

The architecture of the proposed simulation model is made up of a series of modules dedicated respectively to: the acquisition of requests to be evaluated and carried out, the simulation of movement of buses and passengers, the monitoring of possible delays and display of events that actually occur while the simulation runs. During these activities, the model generates randomly disturbing factors such as traffic congestion or unusual passengers’ behavior that the basic heuristics is unable to take into consideration when producing fleet schedules. Finally, during the course of the simulation a set of performance indicators are calculated to evaluate the robustness of the schedule produced by the Heuristics in response to the disturbing elements introduced in the simulation.

Below is shown a graphic description of the three operational phases the model is divided in:

- Phase I shows the movement of buses between stops and the pick up and drop off of passengers.
- Phase II regards passengers arrival at bus stops.
- Phase III the system randomly generates unusual passengers behavior at bus stops such as “no-show” or refused rides due to the bus being late.

In phase I (see figure 1) buses movements are described through various steps starting from their exit from the depot. This phase consists of standard and special modules written in VBA:

The first three modules up to the VBA8, performs the function of directing buses to the first stop according to its schedule. This action is performed through the acquisition of data registered in the database and setting each bus characteristic through the use of Siman language.

- The further modules up to the VBA9 element describe the effective system behavior once the bus has left the depot. The modules actually acquire the information about which stop to go to and the time they need to be there according to the schedule.
• The two pink blocks simulate the movement from two stops and the time it takes the bus to go from one to the other. This module also takes into account a possible delay due to traffic congestion.
• The module “Delay 6” reproduces the arrival of the bus at a stop in the event it has arrived in advance.
• The next part assumes that the bus has come to a stop and simulates through the modules “search” and “remove” the pick up and drop off of passengers.
• After this the “entity bus” goes back to module VBA9 to once again acquire information about the next mission. However in case the bus should have carried out its last scheduled mission, it can return to the depot.

Phase II (see figure 2) of the model simulates passengers behavior. They reach the bus stop at the agreed time and await the bus arrival. The module “Decide 8” ensures that the number of the generated “user entity” is the same as the actual number of scheduled transportation requests. The next modules up to VBA13 assign to each user entity a set of information regarding their pick up and drop off stops and times. Finally, with the last module passengers are placed in a queue at the bus stops from which they are removed once the bus arrives as described in Phase I.

Phase III (see figure 3) simulates passengers behavior when exceeded a certain waiting time decide, according to a given probability function, to leave the bus stop. Finally in the model have been added two service level indicators called “service level 1” (LS1) and “service level 2” (LS2). The first one takes into consideration passengers waiting time at bus stops and the second the number of passengers that leave the bus stops without using the service.

Figure 1. Buses movement
Figure 2. Passengers arrival at bus stops.

Figure 3. Customers behavior at bus stops

5. Model validation and tests

After having developed the model, it was carried out the verification of the reliability of the results produced by the model in various operating conditions.

To do so, has been calculated the value of two indicators: LS1 and LS2. The first one takes into consideration passengers waiting time at bus stops and the second the number of passengers that leave the bus stops without using the service.

The four diagrams in figure 4 and 5 show the trend of LS1 in function of the speed by which it is apparent that the increases in speed results in any case an improvement of the service, which of course in case of no congestion is greater than in the case of congestion. In addition, this graph shows that at a given speed decreases the level of service, as expected, with increasing demand.

In LS2 in case of congestion the trend is not uniform because since there is no congestion results coincide with those expected from the schedule and finally with the increase of demand of the trend LS2 coincides with the trend of LS1.

The model is characterized by great flexibility because it was easily adapted to the basin of Ostia – Acilia comprising in particular a fleet of 5 buses and 23 stops. As already mentioned before, it was possible to calibrate the module which takes account of the congestion. In this regard it was decided that the transit time between 2 stations affected by congestion follows a uniform probabilistic law as the distances between the bus stops are relatively small.

This behavior is performed by the module Route 2, described above, which uses the function called in the Arena UNIF and which is inserted in the window associated with it. This formula uses the values in the histogram by side, indicating the change in speed according to the time slots compared to a standard default value.

This form I have developed within the model in VBA environment is presented during the initialization phase and is the setting that allows the operating modes. In particular 1) the button Randomness sect to true or false value of the variable logic that as mentioned above means that the model takes into account or not the influence
of traffic congestion. 2) Adding Bus. The model has the possibility, if this variable is set to true, change the assignment of a passenger on a bus to eliminate the possible waiver. 3) Bus speed is set as the value of the standard cruise speed of bus. One of the results from the analysis of the influence that size has on levels of service consisting of a possible indication that there should be bus lanes or route changes. 4) in respect of waiting time Max has already said that a passenger can probabilistically refraining from using the bus after waiting some time whose value is defined by this variable. 5) Start Run button informs Arena to start the simulation, and finally 6) the data presented in the list are the results of the run and that is how the schedule of departure was eventually changed.
Having developed and tested the model has passed the planning phase to achieve the objective of the work was to validate a set of schedules generated by the module dedicated to managing reservations and check the effects of these products by the presence of traffic congestion. This work has been performed using two levels of service, as defined above, both without and with congestion and calculated on a progressive basis from every event that has occurred in the course of the simulation. Have been made all over 504 tests that involved schedule with 1, 3, 5 respectively with bus 20, 80,160 and 240 travel requests.

From the results obtained it is deduced that both without and with the value of congestion LS1 decreases with the increase in demand and this is due to the fact that increasing the number of requests to be served may increase the waiting time for customers impinging on this level of service. The values for LS2 obviously remain constant in the absence of congestion while vary in much the same way if one takes account of traffic congestion.

These graphs show the trend of LS1 with constant demand and variable number of means, from which it can be deduced from the considerations made above, that with a low demand can be distributed in a regular manner the service among the various buses and therefore equal to number of low demand bus allows for a greater level of service. The considerations on the results obtained for LS2 are similar to those made for LS1 congestion without bearing in mind that the value of LS2 is constant and equal to 100%.

6. Conclusions

To conclude it can be said that the purpose of this work was to create a discrete event simulation model that would allow to correctly reproducing the Transportation Plan evaluated by a heuristics that solves a Dial-a-Ride problem but also that would allow the testing of other heuristic able to solve the same problem by using the same platform. The realization of the environment simulation allows to understand the logic, the strengths and weaknesses of the DRTS and allows to analyze empirically the uncertainty, dynamism, and the interconnection of the examined variables.

The simulation model is made up of a series of modules dedicated respectively to the acquisition of requests to be evaluated and carried out, the simulation of movement of buses and passengers, the monitoring of possible delays and display of events that actually occur while the simulation runs. During these activities, the model generates randomly disturbing factors such as traffic congestion or unusual passengers behavior that the basic heuristics is unable to take into consideration when producing fleet schedules. Moreover, during the course of the simulation a set of performance indicators are calculated to evaluate the robustness of the schedule produced by the Heuristics in response to the disturbing elements introduced in the simulation.

Finally there have also been identified operating variables, LS1 And LS2, that evaluate the performance of the system and refer if the service can provide performance as close as possible to the expectations of customers.

References


