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Modelling Dynamic Demand Responsive Transport using an Agent Based Spatial Representation

Didier Josselin · Christophe Lang · Nicolas Marilleau

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Abstract Our purpose is to discuss how useful can be an agent based representation for modelling a high dynamic system of transport called 'Demand Responsive Transport' (DRT). We first give a few definitions of DRT and also enhance what are the relevant key components of such a transport service. The different flows and objects which are subject to dynamic change are identified. Then we present what could be an appropriate representation of a dynamic DRT based on Multi Agent Systems, using UML that handles the objects we identified and their properties. An example is given at the end of the paper and a more general model is provided and discussed.

Keywords First keyword · Second keyword · More

1 Demand Responsive Transport

DRT involves different services of transport and definitions according to country or continent mobilities and transportation practice. The one we are talking about now is a dynamic DRT whose key components own a large part of spatial temporal dynamics and thus concerns different kinds of flows (information, people, vehicles).

1.1 What is a flexible DRT?

A DRT is a transport service launched when a demand occurs. It differs from classical transport lines in the sense it is sometimes obviously not regular neither in location, nor in times. However, this is a point of view shared by most of the carriers. But there still exist differences if we look in details.

Let us start by two American definitions. A DRT is a "non-fixed-route service utilizing vans or buses with passengers boarding and alighting at pre-arranged times

D. Josselin, UMR ESPACE 6012, CNRS, Universit d'Avignon, 74 rue Louis Pasteur, 84000 Avignon, E-mail: didier.josselin@univ-avignon.fr ·
C. Lang LIFC, Universit de Franche-Comt, 16 route de Gray, 25030 Besanon CEDEX, E-mail: christophe.lang@lifc.univ-fcomte.fr ·
N. Marilleau, UMI 209 UMMISCO, Institut de Recherche pour le Dveloppement, 31 avenue Henri Varagnat, 93143 Bondy CEDEX, E-mail: nicolas.marilleau@ird.fr

at any location within the system's service area. Also called 'dial-a-ride"'. (American Public Transportation Association, APTA, 2003, http://www.apta.com/). "... (i) The vehicles do not operate over a fixed route or on a fixed schedule except, perhaps, on a temporary basis to satisfy a special need; and (ii) typically, the vehicle may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may even be interrupted en route to these destinations to pick up other passengers". (Transit Cooperative Research Program, TCRP, 2004). As we can see this point of view is rather oriented to flexibility.

On another hand, Europe seems to have a quite different definition, more quality of service oriented. "Demand Responsive Transport services provide transport 'on demand' from passengers using fleets of vehicles scheduled to pick up and drop off people in accordance with their needs. DRT is an intermediate form of transport, somewhere between bus and taxi which covers a wide range of transport services ranging from less formal community transport through to area-wide service networks", (Grosso et al, 2002). "Transportation options that fall between private car and conventional public bus services. It is usually considered to be an option only for less developed countries and for niches like elderly and disabled people"(Enoch et al., 2004). In France, DRTs clearly belong to public transportation: A DRT is a "collective service proposed as 'a seat', partly determined according to the client wish, whose general rules are fixed in advance according to the law, and whose routing is operated using vehicles with a low maximum capacity" (French law: LOTI , 1982-1985).

The last but maybe the most important service, called 'bush taxi', comes from Africa, where DRTs exist for a long time and are, in some parts of the continent, the only way to move on long distances, to isolated areas. "A 'bush taxi' is a taxi or any vehicle, that starts at more or less predefined times, that serves various destinations depending on the demand, whose price can change according to the travelling/er conditions. The main objective of a bush taxi is to group passengers sometimes over the vehicle capacity to provide an economic ratio as high as possible, while giving an acceptable service for the clients" (Castex et al, 2008). It is noticeable that this definition enhances the efficiency of the service.

In fact, DRTs needs to deal with those three somehow complementary and antagonist objectives: efficiency, flexibility and quality of service. In this context, Modulobus service [**?**,**?**,**?**,**?**,**?**] tries to take advantage of these three kinds of DRT.

1.2 The Modulobus service

Modulobus provides each component to tend to be managed in 'real time', thanks to a high level of flexibility and embarked technologies. The service is a kind of 'technological flexible bush taxi'. Clients can book it by several means (internet, mobile phone...) and ask for a pick up and delivery from door to door or on a set of located stops. Many vehicles are moving around with different capacities and design, optimizing their locations via an efficient communication, in order to serve the demand and to cover the whole territory. Optimal routes are created 'on fly' according to the various demands, and a necessary minimal quality of service (threshold of delays due to detours which cannot be overtaken). Let us imagine this service to be installed in a quite dense town, then there can be some potential clients walking down town and asking for the service. This implies some specific properties for the different elements fore moving, communicating, changing their behaviour (vehicles, clients, networks, stops...). The figure 1 shows the global design of the service, the mobile objects, the information flows and what, among all those components has already been tested and will be in the close future, thanks to French PREDIT funds.

La mise en place d'un tel sytme de transport rpond un besoin des agglomrations (aujourd'hui 650 aglo utilise un TAD qui repose sur l'une des trois fonctions d'objectifs). L'adoption d'un service Optimis de transport permettrait d'conomiser aurait un impact environnemental (conomie d'nergie, pollution, ..., meilleur service client...)

Mais pour mettre en place un tel service il faut convaincre les municipalits. cela passe par la ralisation de modles, de simulateur et d'exprimentation.

A REVOIR *In fact, DRTs needs to deal with those three somehow complementary and antagonist objectives: efficiency, flexibility and quality of service. As it would be too long to set a list of the DRTs existing in the world (only in France, we recorded more than 650 services!), we prefer to model an ideal DRT, that intends to mix a good quality of service, a real efficiency and a high flexibility. So do we have to set aside the systems where there still are some fixed constraints, such as predefined lines with fixed schedules or stops, or any delay constraints on booking.* Je pense qu'ici il faudrait dire qu'il serait intressant de concevoir un DRT qui rpond ces objectifs pourtant antagonists.

Pour cela il est important de concevoir un modle et un simulateur

1.3 Key components of the DRT "Modulobus"

As shown in the figure 1, the service process is theoretically a sequence of actions, from client booking to passenger arriving to his/her destination, with intermediate steps: communication between servers, vehicles and clients, optimization of paths and routes, vehicle optimal assignment and location, dynamic repricing in case of detours, for instance. Whatever complex and sophisticated is a stage in the process, the way to operate the Modulobus service remains quite classical. What is really different states in the presence of dynamic variables attached to fixed or mobile objects, that argues for providing multi-agent modelling. That means that local and global conditions of the service can change quickly and in a large rank: some peak of demands can occur, traffic congestion may reduce the speed, important detours can modify predefined routes due to isolated clients. All these functionalities are enabled by an accurate and efficient software managing this complexity.

Globally, there exist two main types of spatial data or objects having dynamic behaviour (fig.2). Firstly, those are spatial objects with quasi-fixed locations, which can support variable flows. Typically, road or communication networks are involved. Roadworks or traffic jams may have an influence on the DRT efficiency as well as SMS delays or server temporary lower capacity may be a problem for managing the service. Nevertheless, network structure evolves slowly (road and stop location, wireless communication structure) and allows to prevent or, at least, deal with eventual problems.

There indeed exists another type of spatial object: mobile objects. Beyond some information quantity or flows, locations of these objects may change. For example, a vehicle must be reactive and respond as soon as possible to any demand, while keeping a relative 'intelligent' location that enables an efficient next route and a vehicle homogeneous dispersion for supporting it. So does time become an information, useful and used for optimization for dynamic re-routing, dynamic re-pricing, dynamic information services. To enable such a process, the system must know at any time where are the vehicles and the clients (current and next passengers) to launch the optimization kernel in order to accept (or not) a detour, according to expected quality of service, efficiency and flexibility, we previously mentioned.

If we now consider the main information flows as depicted in figure 2, we notice that we handle different kinds of data and that their time dynamics can vary in a large rank. Socio-economic data remain quite stable, even if, from time to time, population may increase or decrease quite quickly in towns. Data that inform about location or used for geo-marketing assignment have a better accuracy in time, especially if one tracks or communicates information to clients via mobile phones. Dynamic dimension of data becomes of crucial interest for permanent monitoring of vehicle fleet using GPS. This is also right for dynamic (re)routing and, in a more limited way, for reservation process. For such operating conditions, the Modulobus DRT can be considered as a dynamic Dial A Ride Problem (see the complete state of the art about DARP from Cordeau Laporte, 2007).

We can also notice different levels of decision or objects to be depicted:

- global, environmental information or data (e.g. population density in the served areas, providing a probability of demands),
- high level decision centres for optimization (e.g. vehicle fleet management, requiring a global view)
- local spatial information (that can be implemented within each object):
  - spatial information described by variables with continuously changing values (e.g. road network with daily varying flows, that has effect on the routing efficiency),
  - mobile objects (e.g. vehicles, clients; those objects having complex, strong and relatively low predictable levels of information communication).

We believe that UML representation is useful for designing an adequate model for such a dynamic DRT service. Let us see now how can these models look like.

2 Modelling DRT system

Due to the objective of thematical goal of this work, the specificities of the studied complex systems (distributed entities, autonomous individuals and so one) the developped model is based on Agent paradigm. This model is presented in the following section.

A said before, common DRT systems take into account three kinds of individuals (customers, taxis and a reservation center) that interact together in order to transport customers from a point to another one. Naturly, we model the DRT system by three kinds of agents that model customers, taxis, and a reservation center. This model is developped within the RAFALE-SP Approach []. RAFALE-SP is to help out scientists in the definition of spatial mobility models and their simulation. It is composed of an oriented meta-model to describe spatial mobilities and an oriented toolkit to implement mobility simulators.

We shall first present some situated agents that describe pedestrians and taxis. After we will present an agent description of the reservation center. Among various supplies, the Modulobus service offers to pedestrians walking in town the opportunity to dial a ride at any time. The reservation center even can send to them a "push message" on their mobile phone giving the destination of any close current route.

Thus, pedestrian can assess to dynamic DRT making (or not) a previous reservation in advance, through an appropriate information exchange protocol.

2.1 Description of basic situated agents

The case study concerns a DRT that involves pedestrians (who can become clients) and taxis (a specific kind of vehicle). In this case, pedestrians want to dial a taxi in order to go to a unique merging point (for example a social event). So, we defined two simulated entities: pedestrians and taxis.

As it is advised by the RAFALE-SP methodology, these agents are modelled within a UML class diagram. It defines each kind of agent by its knowledge, goals, effectors, motion vectors, exchange protocols and behaviour. To model pedestrians and taxi agents, two UML class diagrams have been designed. They are presented in the following section.

Concerning taxis, here are their main features (figure 8):

– *Knowledge*: a taxi has a complete knowledge about the town map. It considers the map as a graph of streets (Bstreet) and locates all available stations (Bstation). Note that: (i) taxis do not know pedestrians, they interact with clients throughout the reservation center; (ii) on the opposite from pedestrians, they are able to remember any traffic information.
– *View*: Such as pedestrian agents, taxi agents see streets, buildings and stations. In addition, they see pedestrian agents located in the street where they are moving;
– *Goals*: The aims of taxi agent is to transport client agents from a station to another one, according to reservation center orders and to a given roadmap. When a taxi agent receives a call, it computes a sequence of goals in which the agent has to: (i) move to a station (MovingToStation), (ii) pick up clients (Pickup), (iii) transport clients to another station (MovingToStation), (iv) deliver clients to the destination stations (Delivering).
– *Effectors and Motion Vector*: Taxis move on the map such as pedestrians. They follow streets, change their direction at crossroads. The same motion vectors are also identified (MoveToNextStreet, MoveToNextCell). When they move, taxis modify the location on the map of the clients they carry. For that, they apply an effector (ChangeTransportedPedestrianLocation).
– *Exhange protocols*: To receive orders, taxis interact with the reservation center. These sata exchanges are done by using TaxiAssignement protocol.
– *Behaviour*: From the reservation center orders, taxi agents compute the best path that (i) achieves all goals and (ii) take into account traffic information (transportation duration). Taxi agents also use shortest path algorithms such as Diksjtra, to choose the best path to move from a point to another one.

Note that, the UML description of pedestrian is close to taxis description. But for futher information, readers can refer to [].

To facilitate the reading of the paper, let us notice that agent behaviour and exchange protocols are not accurately described. This description is done using PloomUnity and XML specifications. This will be provided in a further article.

2.2 Reservation center model

From the meta-model and the DRT system description, the figure 10 depicts a model established to represent reservation center. This service is modelled by a *ghost agent*. This kind of agent allows modelling entities that impact on population dynamics without having a concrete existence in studied complex systems. These agents have no location and no body in the space. Nevertheless, these agents should become available by other situated agents allowed to interact with them. Ghost agent are characterised by several desire, perception, and exchange protocols.

In the case of DRT system ABM, reservation agent perceives, at any time, GPS coordinates of taxis. From this perception, reservation center agent is able: (i) to update transport duration from a stop to another one stored in its knowledge (*TransportDuration* class); (ii) to compute optimized routes which take into account taxi location and town traffic according to a selected optimization strategy.

Different routing strategies can be supplied by the DRT model. These strategies represent different ways to optimize routes. They are integrated in the presented model in order to experiment and compare them according to simulated town topology, traffic and demand. For example, an American carrier strategy would be to provide a flexible service, although a local European authority would aim to propose a DRT with a high quality of service related to good economical efficiency (that is to say, the service would not serve the whole territory). An African region would propose a very cheap service with long time delay and uncertainty, but requiring an only vehicle to provide the route.

The reservation center receives calls coming from clients following Reservation exchange protocol. When a call is received, Reservation Center Agent defines new desires to compute a route (*ComputeRoute*) to edit taxi route (*EditTaxiPlanning*) and to assign it to a taxi (*CallTaxi*). Reservation center agent tries to achieve successively these three desires. At the begin, it computes a route by using one selected route optimization component. This component takes into account transport duration knowledge (*TransportDuration*), stop knowledge (*Stop*) and carrier location perception (*TaxiGPSState*). After that, Reservation Center Agent desire becomes *"EditTaxiPlanning"*. Agent also computes taxi route planning and finally sends road maps to carrier by using *TaxiAssignment* exchange protocol.

3 Conclusion and futher works

In fact, the DRT problem is almost naturally supported by the RAFALE-SP method, it is of interest to add a new kind of non spatial agent (the ghost agents) that will handle the global system: vehicle fleet management, routing optimization, interaction between agents. Other aspects are well supported by this method, particularly because of the agents. They are reactive and independent so they are good candidates to represent a such complex system. In a near future, we aim to implement this new kind of agents in the simulator which is associated to RAFALE-SP and simulate some cases of dynamic DRT in the urban context. This will require to precise the interaction protocols between ghost agents and mobile agents.

Although the Modulobus DRT is already put in operation in the town of Montbliard since 2006 with real clients and vehicles, we did not require the use of multi-agents representation for its monitoring. Because this service will remain used on specific

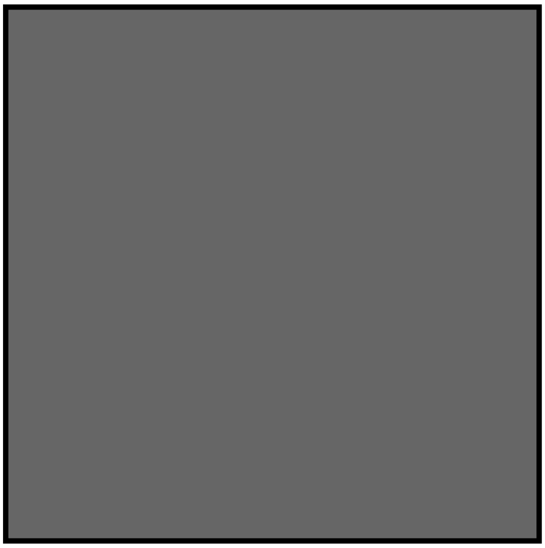

Fig. 1 Please write your figure caption here

niches (to serve events, shows at edge times), we shall use the Rafale-Sp framework for simulating an important increase of demand and supply. After having designed the system and how to implement it (as showed in this paper), it is indeed the next step of our research.

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