

The 5th International Workshop on Agent-based Mobility, Traffic and Transportation Models,
Methodologies and Applications
(ABMTRANS 2016)

Towards an Agent-based Model for Demand-Responsive Transport Serving Thin Flows

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Abstract

Low volume traveler flows cause problems for public transportation (PT) providers. The Smart-PT project aims to find out how such flows can be combined to increase the service provider viability. The capability to conceive multi-modal trips is fundamental in that context and is modeled by the Trip Sequence Composer (TSC) concept. A TSC is an essential component of the traveler's brain, of the customer support operated by collective transport providers, of trip advisers in websites etc. We present a simulation model design to evaluate the effect of cooperating TSCs on the viability of demand responsive collective transport providers. While obeying specific regulations, specialized services targeting mobility impaired people can also serve regular requests in order to save fleet and personnel costs. **All stakeholders are assumed to optimize their private objectives and none of them has global perfect knowledge.**

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Peer-review under responsibility of the Conference Program Chairs.

Keywords: Demand-Responsive Transport, Thin Flows, Micro-Simulation, Agent-Based Modeling, Organizational Modeling

1. Problem Context and Objectives

Informally, a *flow* is a set of movements (partial trips, legs) that uses a path in a given *connection* during a period that overlaps with a given *period sequence*, for instance the movements from a given bus stop to the central station on Sunday morning between 09:00h and 12:00h in 2015. In a *thin flow* the number of movements is below a given threshold. *Thin flows* originate from low demand which in turn is caused by lack of zonal attraction or low customer density. The latter can follow from low population density and from special customer requirements (e.g. wheelchair bound customers). *Thin flows* are defined using *period sequences* and *connections*. A *period sequence* is defined by a tuple $\langle I, S, E \rangle$ where I is a time-of-day interval, S is a period specifier and E is an era specified by $\langle D_0, D_1 \rangle$ where D_0

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is the initial date and D_1 is the final date. For example, every first Wednesday of the month from 13:30h till 16:30 in September–December 2016. A *connection* between a source S and a target T is a set of paths connecting S to T .

Due to budgetary constraints time table based public transportation (PT) on thin flows is reduced and services on demand are discontinued. The Flemish government decided to investigate the viability of providers that serve demand from customers both with and without special requirements. This requires accurate modeling (i) of companies collecting (customer class specific) fares and spending money to run the operations, (ii) of customers who are sensitive to cost, trip duration and timely service and (iii) of interactions between providers and customers.

An agent-based model (ABM) is a class of computational models to simulate the actions and interactions of autonomous agents with a view to assess their effects on the system as a whole. ABM is now widely used for modeling increasingly complex systems. Application of ABM is not only limited to the computer science domain. Currently, many research areas such as transportation behavior modeling need to analyze and understand the complex phenomenon of interactions between different entities. While traditional modeling tools cannot catch the complexity, ABM can do it through modeling the interaction of autonomous agents and deducing the rules for such a system. Nevertheless, for a successful application and deployment of an agent-based system, a large number of the agent methodologies recognizes (to varying extents) the idea that a multi-agent system can be conceived in terms of an organized society of individuals in which each agent plays specific roles and interacts with other agents¹. As pointed out by Ferber et al.², an approach based on organizations and roles offers a number of advantages and can contribute to agent-oriented software development in the following points: heterogeneity of languages, modularity, multiple possible architectures and security of applications. In other words, an organizational approach may break down the design complexity of an agent-based system. Therefore, in this paper, **an organizational and agent-based model is proposed to evaluate travel demand and supply in thin flows. The model is aimed to simulate thin flow travel over a two year period in order to determine the conditions of viability for the competing and optimizing transport providing companies, none of which has full knowledge about the universe. This paper constitutes the first step towards this goal by providing a simulation model.** Thin flows are expected to be highly variable in time because the demand for each individual can show trips separated by stochastic periods of time and consist of trips covering several locations. Furthermore, the capacity of the vehicles is typically small. Hence, providers need to solve vehicle routing problems frequently in order to deliver high quality service while keeping the vehicle occupancy at a decent level. The resulting solutions of the combinatorial optimization are expected to differ greatly from day to day. Under such conditions, economic viability can be assessed only by integration over a long period.

The remainder of the paper is organized as follows: in Section 2, an overview of important related work is given. Section 3 introduces the main concepts used in the simulation. Section 4 describes the agent-based framework which will be used to develop the simulation software. Finally, in Section 5, a conclusion is presented and future work is discussed. This paper reports on the ongoing design of *Demand-Responsive Transport (DRT)* simulation.

2. Related Work

Zografos et al.³ attempt to find a methodological framework for developing and assessing Flexible Transport System (FTS) business models. They discuss three dimensions, namely the *FTS context*, *business strategy and functions* and *service offerings*. The FTS context describes elements such as the site location, potential market and market opportunities. The business strategy handles elements such as business vision and the economic structure. Finally the service provided is characterized by elements such as *service topology*, *target market* and *types of vehicles* used. The authors state that it is sufficient to specify these three dimensions in order to define a new business. The developed framework to help decision makers consists of a development phase in which alternative FTS businesses that are compatible in the local market are identified, a screening phase in which the economic feasibility is analyzed and a prioritization phase in which the remaining models of the screen phase are ranked and assessed. They tested their framework in a case study located in Helsinki, Finland.

Neven et al.⁴ assess the impact of different policy decisions on resource requirements of Demand Responsive Transport (DRT) services in Flanders, Belgium. Mainly, there are two types of DRT: (i) services offered in low demand rural areas and (ii) door-to-door services for mobility impaired people. The authors focus on (ii). A synthetic population of mobility impaired people was created, and their corresponding transportation requests with specific travel-characteristics (the specific travel demand) were generated, based on survey data and official data about disabil-

ity. This is assigned to the transportation network and time dependent inter-zonal travel times are computed. VRPs are solved under several budgetary constraints resulting in a what-if analysis to support policy decisions by the Flemish government. Spatial and temporal effects are taken into account. The results show that the change of the modal split, better accessible public transport and improved flexibility regarding customers are the key elements to minimize resource requirements in a DRT system for mobility impaired people. **Similar to many other papers, the solution is OR-based and assumes full knowledge by a central optimizer.**

The model described in this paper provides several refinements. A multi-month period is simulated to average the effects of stochastic demand. Thereto, a multi-day agenda (having a one or two week period) needs to be generated for each participant in a *thin flow*. Trips requested by customers with and without special requirements will be served by the same provider and can be combined. Multi-modal trips are supported because a thin flow can feed a thick flow. Customer behavior is modeled explicitly because service quality perception feeds back to trip request behavior. Customer satisfaction determines recurrent use of services and depends on the travel cost (monetary, time loss) and on the ability to match the preferred time windows. Finally, modeling thin flows requires the use of street addresses. The spatial granularity of a zone based system is insufficient to achieve accurate results.

3. Concepts

3.1. Demand-Responsive Transport

According to Ellis⁵, *Demand-Responsive Transport (DRT)* is handled by a company, which provides transport by passenger cars, vans or small buses. Customers, e.g. (mobility impaired) people or other companies can call a DRT company who then dispatches a vehicle to bring a customer from his origin to his destination. The characteristics of a DRT service is twofold: (i) vehicles do not serve a fixed route or a fixed time schedule, however this is possible on peak times and (ii) vehicles tend to pick up multiple customers at different locations (new requests can be handled in real time) before dropping them off at their destination.

The following measurement **quantities proposed by Ellis⁵ are used to evaluate DRT provider viability in a multi-year simulation:** (i) *passenger trips* which measures the amount of served customer requests, (ii) *on-time trips* which measures the amount of trips in which customers are picked-up in the predefined time window, (iii) *no-shows* which is the failure or not willingness of a customer to show up for a reserved trip at the scheduled time and location, (iv) *late cancellation* which is a cancellation done by the customer of a reserved trip shortly before the vehicle is scheduled to arrive, (v) *missed trips* which are trips in which a DRT company fails to pick up a scheduled customer and (vi) *trip denials* which are trips that could not be fulfilled by a DRT company (e.g. no vehicles available). Those variables will be used to estimate the revenues and costs associated with the services, in order to assess the viability of the DRT companies.

3.2. Booking TripSequences

Planning and booking trips are essential mechanisms. A *trip* corresponds to a movement between two locations. It consists of *tripComponents* (legs using different modes or providers). A *tripSequence* consists of trips that are to be handled atomically; the requester is interested in receiving a proposal for either *all* or *none* of them (e.g. round trips). A request for booking can apply to multiple *tripSequences* at once.

Both customers and providers are characterized by means of *labels* defining specific requirements and provisions. Four categories of *labels* are distinguished: (i) *physical* labels which describe the mobility impairment, (ii) *personal* labels which affect the fares (e.g. family status, age and employment status, income category), (iii) *preference* labels which describe person specific preferences such as transportation mode or maximum travel time and (iv) *financial* labels which constrain the mode choice (e.g. income category and car ownership).

Operational, legal and infrastructure labels define the capabilities and properties for the transport providers (e.g. target customer population segment, wheelchair support, etc).

Label matching is used to decide which customer categories can be served based on physical requirements (wheelchair, visual support) and tariff rules (based on impairment, age, income, etc) and which fares apply in each particular case.

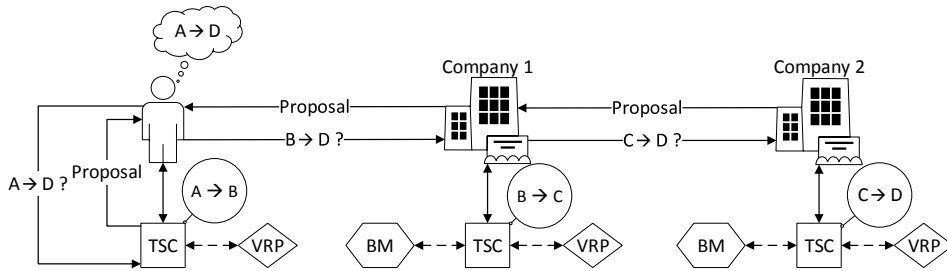


Fig. 1: The main communication flows between agents and TSCs to request a trip. TSC stands for trip sequence composer, VRP stands for vehicle routing problem solver and BM stands for business manager. Solid arrows indicate direct communication between autonomous agents, while dashed arrows indicate function calls to entities.

To conclude, several kinds of constraints need to be taken into account: customer and provider properties encoded by labels as well as time windows applying to both the booking procedure (time between request issuing and required trip start) and the requested trips (pick-up, drop-off).

When a trip request is sent to a company, eventually the customer will get a reply, either positive or negative. If the reply is positive, a *trip proposal* is sent to the customer. Analogous to the trip request, this consists of *trip proposal components*. First of all, every trip proposal component refers to a trip request component in order to identify which components belong together. Note that a trip request proposal can be subdivided in different legs (=multi-modal trip). A trip proposal component has (i) an origin-destination pair $\langle (X_{from}, Y_{from}), (X_{to}, Y_{to}) \rangle$, (ii) a departure time window $[DTW_s (hh_s:mm_s:ss_s), DTW_e (hh_e:mm_e:ss_e)]$, (iii) an arrival time window $[ATW_s (hh_s:mm_s:ss_s), ATW_e (hh_e:mm_e:ss_e)]$, (iv) a time until the proposal expires, (v) a commitment of the travel, (vi) a price in the desired monetary unit per customer and (vii) a transport mode. Important elements of this trip proposal component are the commitment of the travel which means whether or not a company ensures that the customer can travel, e.g. if a customer travels with public transport there is a (small) chance that there is no place left in the vehicle. Another important aspect is the time until the proposal expires. When a proposal is sent out to a customer, the company keeps **track of the reservation until the proposal expiration** time. Hence, a customer can lose the trip proposal if **he fails to approve it before it expires**.

3.3. Trip Sequence Composer

The *trip sequence composer* (TSC) is an important entity in this design and every autonomous agent contains a TSC instance. The TSC can be seen as the knowledge of an agent **of whatever kind** to compose (multi-modal) trips. Examples of such TSCs in reality **are** (i) the brain of a traveler, (ii) help desk support of a provider, (iii) a website of a public transport provider (route planner), (iv) a navigation app of a smartphone **and** (v) the personal coach of a mentally disabled person. An important fact is that every agent's TSC has a limited knowledge about the "world". A TSC might have some knowledge about his own capabilities (e.g. schedules of public transport or driving a car) and he might know some other TSCs such as a taxi company or his own navigation app. An agent is for instance able to compose a trip to his work by using public transport (because he knows the schedules). In contrast, if he wants to travel to the airport he might want to rely on the knowledge of a taxi company. Hence, a TSC is able to arrange trips (by using his own knowledge) from point A to point B (i) by only using his own capabilities or (ii) by subdividing the trip request component and delegate some of the simplified requests to other TSCs.

In Figure 1 the conceptual design of booking a trip in combination with the different agents is shown. A specific customer wants to travel from A to D, hence a trip request from A to D is sent to his own TSC. His own TSC is not able to fulfill the complete request, hence the TSC will split it in $A \rightarrow B$ (which can be done by himself) and $B \rightarrow D$ (which another TSC needs to solve). The TSC of the customer is aware of some companies **providing transport services**, hence company 1 is contacted. The TSC of company 1 is able to fulfill the request partially. **It** is able to bring the customer from $B \rightarrow C$. The remaining part of the trip ($C \rightarrow D$) is propagated to company 2 (which is known by company 1). The TSC of company 2 is able to fulfill this request. A proposal is sent to company 1, which combines

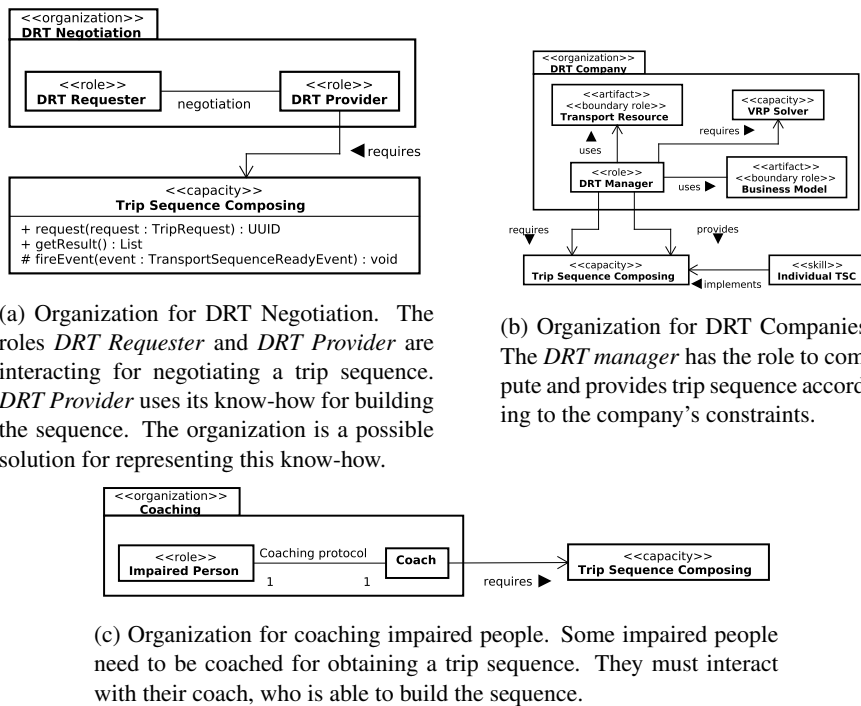


Fig. 2: Organizations in the DRT system.

this proposal with his own proposal and sends it back to the customer. Eventually, his proposal is combined with the proposal of company 1 and hence, a full proposal from $A \rightarrow D$ is made. Note that the TSC invoke other entities such as the *business manager* and the *vehicle routing problem solver* as well. The business manager keeps track of the number of customers served, the revenues, the time spent, the distance driven etc., while the vehicle routing problem solver attempts to schedule the trip.

4. Organizational and Agent-based Models

In this section, we propose an organizational model for the *thin flows* application and its mapping to the corresponding ABM, based on the meta-model defined by Cossentino et al.⁶ The concepts presented in the previous sections are mapped to three organizations and their respective roles. These organizations are then mapped to agents that are playing the roles in the different organizations for fulfilling the system's requirements.

The DRT system that is considered in this paper is decomposed into three different organizations (Figure 2). Each organization is a subsystem that fulfills one more of the requirements of the system. The central organization is related to the *DRT Negotiation* (Figure 2a). It enables an agent to request and negotiate a trip sequence. The requester and the trip sequence provider are defined as the two roles in this subsystem. The latter role requires a specific know-how from the playing agent for building and composing the trip sequence. This know-how is represented by the concept of *capacity* in the organizational meta-model.

The second organization defines the transport companies as a specific subsystem (Figure 2b). The DRT managers in the companies are in charge of building and composing trip sequences. If the agent playing this role owns a dedicated skill, i.e. an concrete realization of the *Trip Sequence Composing* capacity, then it uses it for building the sequence. Otherwise, the role's behavior will contact other transport companies by joining a new instance of the *DRT Negotiation* organization, in which it will play the role *DRT Requester*. According to the organizational meta-model, a contribution link between the two organizations exists since the *DRT Manager* and *DRT Requester* roles require and

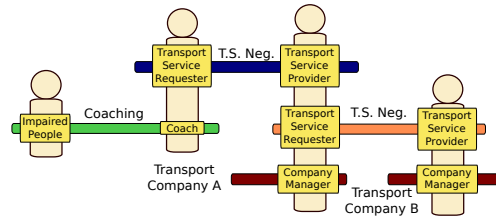


Fig. 3: Example of the agents that are playing roles in the defined organizations.

provide respectively the same *Trip Sequence Composing* capacity. In other words, the *DRT Negotiation* organization contributes to the *DRT Manager* behavior by providing the part that is corresponding to the capacity.

Finally, several impaired persons will need a coach for negotiating their trip sequences. The *Coaching* organization (Figure 2c) defines the specific interaction in this context. If the coach has not the personal capacity to build the trip sequence, she/he could participate to an instance of the *DRT Negotiation* organization for obtaining a valid sequence from the transport companies.

At the end of this organizational design phase, the organization structure is mapped into a society of agents in charge of realizing the expected behaviors. Each of the previously identified organizations is instantiated in form of groups. Corresponding roles are then associated to agents. The agents are assumed to run the behavior of each role they are playing. Consequently, a part of their personal behaviors is related to the decisions of joining or exiting the groups, and selecting the scheduling policy of their different played roles. All of these elements are finally merged to obtain the complete set of agents involved in the solution. Figure 3 presents an example of four agents (one impaired person, one coach and two transport companies) that are participating to five different groups.

5. Conclusion and Future Work

The model proposed in this paper is currently being implemented with the SARL agent-oriented language. It provides concepts and statements that could be directly mapped to the organizational concepts used for building our model. In order to provide a proof-of-concept and to validate the added value of our proposal, the model will be applied during the next couple of months to the region of Leuven, Belgium for which historic DRT bus occupation data as well as historic data about trips generated by a day-care center are available to generate the demand.

Acknowledgements

The research reported was partially funded by the IWT 135026 Smart-PT: Smart Adaptive Public Transport (ERA-NET Transport III Flagship Call 2013 “Future Traveling”).

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