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An Approach Based on Simulation and Optimization to Integrate Ride-Pooling with Public Transport for a Cooperative Approach

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Abstract

Mobility as a Service (MaaS), appeared as a tool to provide more efficient solutions in large urban areas, but, it hasn't always been the case. The International Union of Public Transport (UITP) and the International Transport Forum (ITF) proposed policies to use such services as feeders for public transport, raising the challenge of how to integrate them. Ride-pooling, a type of Demand Responsive Transport, coordinated with public transport could be a solution. This paper explores how to model such intermodal system by an agent-based intermodal simulator that manages service requests while accounting for vehicle capabilities, transit schedules, and time constraints, integrated with an intermodal dispatcher defined by an optimization model, which proposes the best-combined solution.

Key-words: intermodal assignment, ride-pooling, public transport

Introduction

Mobility uses change, the way we travel to overcome the spatial separation of activities, the consequence of the urban spatial structure determined by the land use, and the physical connectivity provided by the transport infrastructure, changes over time due to technological and societal changes. Mobility as a Service (MaaS) emerged as a new form of combining both factors expected to improve mobility, especially in large urban areas. After a few years, the experience shows that has not always been the case, not only the expectancies have not been met, but the new mode has hindered public transport. The International Union of Public Transport (UITP) and the International Transport Forum (ITF) have made proposals and conducted exploratory studies aimed at defining policies to use these services as feeders of public transport to achieve a win-to-win strategy. This raises the problem of how to combine both modes in an intermodal system to achieve such objectives, especially in those areas of large metropolitan conurbations that, as a consequence of urban sprawl, cannot be efficiently served by conventional public transport. Ride-pooling, a form of Demand Responsive Transport, coordinated with multimodal public transport could be a solution. This paper explores how to model such systems, based on a simulation-based intermodal assignment approach, where an agent-based simulator manages service requests, accounting for the locations and capabilities of the vehicles in the fleet, and the schedules of the public transport, and the time constraints in a dialogue with an intermodal dispatcher defined by an optimization model, that proposes the best-combined solution.

Since the present system accounts for an intermodal scenario in which the ride-pooling serves as a feeder of the public transport, it makes sense to account for five different intermodal types of journeys: a 1-leg trip of either ride-pooling (RP) or public transport (PT), a 2-leg combined one of either RP+PT or PT+RP and a 3-leg combined one of RP+PT+RP. While the first four possibilities would be more common in areas with short routes, the latter one would be more suitable in lengthy interurban journeys since the additional transfer times may be absorbed into the overall journey duration.

This topic has lately been gaining some interest in the research community. Yet, based on our findings, the intermodality appears to be oversimplified. The majority simply assess the combination resulting from the nearest vehicle and stop, with only Hickman and Blume (2001) considering more than one stop. Moreover, studies such as Liang et al. (2016) and Stiglic et al. (2018) evaluate their approaches on artificial or small PT networks, as well as with a limited set of trip requests. Pinto et al. (2020), on the other hand, employ a larger test area but do not evaluate all intermodal types of journeys. In contrast, our research relies on a simulated approach that accounts for all the intermodal types, not only the nearest vehicle and stop, and is tested in a large realistic transportation network.

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Figure 1. Intermodal system architecture.

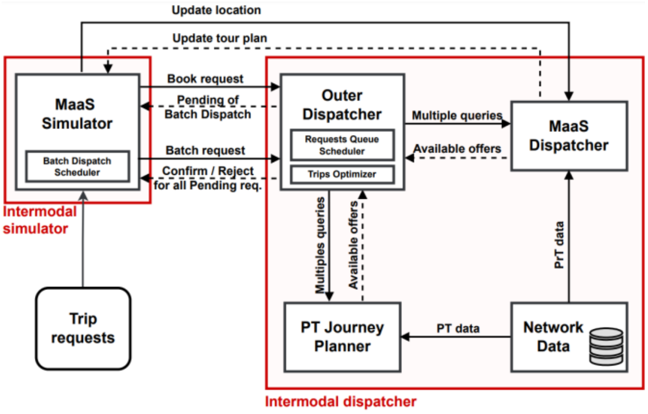


Figure 2. Relationships in the optimization model.

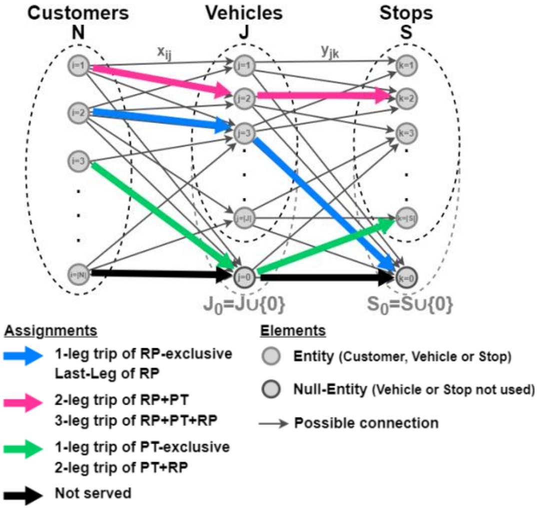


Figure 1 below depicts the proposed intermodal system. It consists of a simulator that evaluates the new use case based on simulation, and a dispatcher that, among other functions, calculates the new intermodal routes. The methodology of the present system is as the follow. When a request's booking time is reached, the simulator sends the request to the dispatcher, who responds with the proposed intermodal route. The simulator then updates the new tour plan and begins its simulation. Vehicle location updates are given to the dispatcher on a regular basis in accordance with these tour plans, ensuring that every component in the system is informed and up to date for future booking requests.

The intermodal simulator

The intermodal simulator, introduced in Lorente et al. (2021), is an event-scheduling and agent-based simulator that originally covered a ride-pooling exclusive scenario. However, for this research, it has been extended to account for the integration with the public transport. It has two type of agents: vehicles and customers. The vehicle represents a vehicle moving between pick-up and drop-off locations. A customer, on the other hand, represents a customer who books and performs a trip. Its behavior has been extended so that his journey consists of various legs of ride-pooling and public transportation modes, and may transfer between modes. It has also been enhanced with a batch dispatching strategy, which groups and solves requests that arrive in a short period of time (a batch) together to maximize the system's resources (fleet of vehicles and system performance).

The intermodal dispatcher

The intermodal dispatcher, introduced in Lorente et al. (2022), is made up of various components. The core, the Outer Dispatcher, determines the intermodal tour plans based on the information supplied by the other two components that handle each transport mode to combine: MaaS Dispatcher, a ride-pooling dispatcher, and PT Journey Planner, a route planner based on rRAPTOR (Delling et al. (2012).

Due to the batch dispatching strategy, the booking requests, when received by the dispatcher, are queued in the dispatcher's queue and kept unanswered until a batch request arrives and responds with a solution for every pending request in the queue. Furthermore, because it is difficult to accurately determine the best ride-pooling vehicle for long trips containing a last leg of ride-pooling that far in advance, a delay-dispatching strategy has been adopted, which separates the dispatching procedure of these kinds of trips into two batch iterations: in the first, the first part of the trip is determined (until the transit leg) with an estimation of the last leg of ride-pooling. Then, in a second iteration, when the time-window of this last leg approaches, the ride-pooling vehicle is finally determined. This makes it necessary to consider the so-called LL request types referring to Last Leg requests.

The intermodal dispatching algorithm consists of a three-step algorithm. First, the candidate vehicles and stops that could be potentially combined to form these combined trips are heuristically determined by restricting the search space from the origin and destination areas. Then, the tour plans options are determined using the MaaS Dispatcher and PT Journey Planner, finding suitable combinations from the set of candidate found before. And lastly, the best-combined solution is determined by means of an optimization model explained below.

The model assumes that there is a set of customer requests N, a set of ride-pooling vehicles J and a set of transit stops S. Each customer will be assigned to a vehicle and a stop. Figure 2 depicts the possible decisions. For convenience, a "null-vehicle" and a "null-stop" represent not using a vehicle or a stop. Hence, two additional sets are defined: $J_0 = J \cup \{0\}$ and $S_0 = S \cup \{0\}$.This suggests the use of model using binary variables x_{ij} and $y_{jk}, i \in N, j \in J_0,\ k \in S_0$, representing the customer-to-vehicle and vehicle-to-stop assignment, which admit a representation as binary network flow on the graph. Additionally, variable z_{ijk}represents the customer-to-vehicle-and-stop assignment. The optimization model (c1) to (c6') below yields the modal trip composition. Constraints (c1) to (c2''') verify the flow restrictions, while (c3) to (c5) (omitted due to abstract space limitations) express the time-constraints of the assignments. (c6) to (c6') impose the fulfillment of the customer's intermodal preference (N^a wants RP-exclusive and N^b the PT included. Requests not in these sets do not impose a preference). The model seeks to minimize the overall cost of the assignments denoted by c_{ijk} considering their travel time and fare (based on reported fares from equivalent enterprises already operating in the experiment's test area), while also penalize requests not served with T_1 to T_4, which applies a 4-level request prioritization that prioritizes LL requests with the highest priority, followed by requests that could not be solved in a previous dispatch, and a priority distinction to encourage requests to be booked in advance rather than at the last minute.

$$\mathrm{Min}_{x,y,z,T} \sum_{i \in N} \sum_{j \in J_0} \sum_{k \in S_0} c_{ijk} z_{ijk} + T_1 + T_2 + T_3 + T_4$$

$$\sum_{j \in J_0} x_{ij} = 1, \qquad \mathrm{i} \in N \qquad (c1)$$

$$\sum_{i \in N} x_{ij} \leq 1, \qquad j \in J \qquad (c1')$$

$$\sum_{i \in N} x_{ij} = \sum_{k \in S_0} y_{jk}\,, \qquad j \in J \qquad (c1'')$$

$$z_{ijk} \geq x_{ij} + y_{jk} - 1, \qquad i \in N, j \in J,\ k \in S_0 \qquad (c2)$$

$$z_{ijk} \leq x_{ij},\ \ z_{ijk} \leq y_{jk}, \qquad i \in N, j \in J_0,\ k \in S_0 \qquad (c2')$$

$$x_{i0} \leq \sum_{k \in S_0} z_{i0k}\,, \qquad i \in N \qquad (c2'')$$

$$y_{0k} \leq \sum_{i \in N} z_{i0k}\,, \qquad k \in S_0 \qquad (c2''')$$

$$\sum_{j \in J} z_{ij0} = 1 - x_{i0}, \qquad \mathrm{i} \in N^a \cup N_{LL}, \qquad (c6)$$

$$\sum_{j \in J} \sum_{k \in S} z_{ijk} = 1 - x_{i0}, \qquad i \in N^b \qquad (c6')$$

$$x_{ij} \in \{0,1\},\ y_{jk} \in \{0,1\},\ z_{ijk} \in \{0,1\}, \qquad i \in N,\ j \in J_0,\ k \in S_0$$

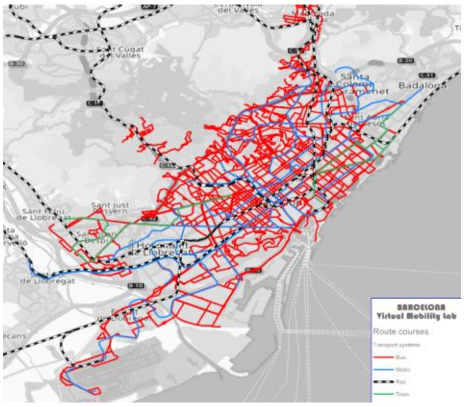
$$T_i \geq 0, \qquad i \in N$$

It is assumed that for each stop, the most convenient stop near the destination location has been established in a prior step of the dispatching algorithm. Depending on how close it is to the destination, the customer may be able to walk there, but if not, a ride-pooling last leg would be estimated.

Results

The proposed approach has been computationally tested in the close to reality large real transport system of the main part of the First Crown of the Metropolitan Area of Barcelona, with an extension of 20x15 kilometers and a high urban density. The required data has been obtained from the Barcelona Virtual Mobility Lab model (Montero et al. (2018)), which is depicted in Figure 3. The public transport network includes bus, metro, railways and trams, with about 3,000 stops, nearly 300 distinct bus lines, 10 metro lines, 16 railways lines and 2 tramways and providing more than 6,000 services during the operational horizon assumed in the tests (from 9 am to 13 pm). Moreover, the private traffic network is constituted of 114,000 links and 87,300 nodes.

Figure 3. Test area showing the transit network.



The experiments were carried out using a collection of 10,031 trip requests, with departures spread over a 4-hour period (from 9 am to 12 pm). Table 1 shows an example of three experiments that assess if the LL is not delayed, if it is dispatched 40 minutes before the customer leaves the PT system, or if a vehicle reservation strategy is employed 60 minutes in advance. These findings show how not delaying the LL dispatch is the most reliable option and delaying it may result in some being left at the stop (the LL could not be dispatched). However, if a vehicle reservation strategy is used, the system serves slightly more requests, completes all trips while also producing more profitable results.

Table 1. Results summary, including number of trips, average travel time and fare per intermodal type, number of customers left at stop (LL could not be dispatched), and system's profit (deducting salaries and fuel costs).

LL configuration	Served demand					Left at stop	Profit
	RP	PT	RP+PT	PT+RP	3-leg		
Dispatch not delayed	1,216 58.5min 10,4€	5,540 26.5min 1,1€	574 40.8min 4,4€	501 56.6min 5,1€	113 68.1min 8,8€	0	5,543.6€
Dispatch 40 min adv. No reservation	1,144 62.9min 10,9€	5,418 26.0min 1,1€	443 40.5min 4,3€	774 52.5min 5,0€	123 59.5min 8,6€	27	5,882.3€
Dispatch 40 min adv. Reservation 60 min adv.	1,206 58.7min 10,3€	5,497 26.4min 1,1€	545 40.7min 4,3€	570 54.9min 5,4€	136 62.7min 8,8€	0	5,747.9€

Conclusions

The simulations show that travel times and user fares are competitive, especially for 2- and 3-leg trips and that the system is appealing as it may not only act as a feeder for the central PT system, but also for the RP system, since commuters in the surrounding areas may become its clients.

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