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# Exogenous priority rules for the capacitated passenger assignment problem

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ABSTRACT

We propose a novel algorithm for the capacitated passenger assignment problem in public transportation where exogenous priority lists define the order in which passengers are assigned. Separating explicitly theses rules from the assignment procedure allows for a great deal of flexibility to model various priority rules. When the actual rules are endogenous, the framework can easily be embedded in a fixed-point specification. Computational experiments are performed on a realistic case study based on the morning rush hours of the timetable of Canton Vaud, Switzerland. The algorithm is able to assign the demand in very low computational times. The results provide evidences that the ordering of the passengers does not have a significant impact on aggregate performance indicators (such as average delay and level of unsatisfied demand), but that the variability at the individual passenger level is substantial. Thanks to its flexibility, our framework can easily be implemented by a railway operator who wishes to evaluate the effects of different policies in terms of passenger priorities.



## 1. Introduction

In the context of public transportation, passenger assignment models are used to predict the distribution of passengers over the network. These models thus play a critical role in identifying saturated parts of the network, by detecting crowded vehicles or train lines, for instance. The insights gained by these models can then be used in order to direct investments towards portions of the transportation network where alleviating congestion is most crucial.

One of the main issues of passenger assignment models is to account properly for passenger behavior in case of vehicle saturation. When passengers compete for the limited available capacity of trains, it is of critical importance to decide which passengers can board the train and which cannot. Indeed, consider a situation where a passenger has the choice to board a train or to wait for the next one on the same line. If she boards the train, she will use some of its available capacity and, at a later stop, her presence in the train might prevent another passenger to board. On the contrary, if she decides not to board the train, the available capacity might be sufficient to let the subsequent passenger board.

This simple example highlights why priorities between passengers lie at the core of a behaviorally meaningful passenger assignment model. Most frameworks in the field use a first-in-first-out queue at the stations, coupled with the rule that

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on-board passengers have priority over those wishing to board. This priority rule is endogenous because it depends on the passenger assignment. The endogeneity forces the existing frameworks to embed the passenger priorities implicitly in the network loading process, making them difficult to modify, in the case where one desires to study the impacts of alternative orderings.

In this paper, we propose a novel framework that considers an exogenous ordering of the passengers. By defining beforehand the rules that govern passenger priorities, complexity is extracted from the assignment problem itself. The main contribution of this paper is to completely separate the problem of defining priorities among passengers from the actual assignment problem. By doing so, it becomes much simpler for the analyst to alter one problem without affecting the other. For instance, we use the shortest-path assignment in the illustrative case study presented in this paper, but a more complex route choice model may be implemented easily. The fact that the priority lists are completely independent from the assignment process also guarantees their flexibility. Any behavioral or control rule can be used to construct the priority list, including rules that account for the results of a previous assignment, in an iterative context. In this case, an additional fixed-point problem needs to be solved.

The actual assignment algorithm takes three elements as input: (i) a time-dependent origin-destination matrix representing passenger demand, (ii) a space-time graph constructed from the railway timetable, and (iii) the passenger priority list. Passenger flows in the network are obtained by assigning the demand in the order given by the priority list (i.e., a passenger with higher priority will be assigned before a passenger with lower priority), thus settling the issues that arise in case of insufficient train capacity. We compare five different priority specifications on a realistic case study based on the S-train network of Canton Vaud, Switzerland. The algorithm assigns the demand in a few seconds, thus making it practical for real-time evaluation of timetables from the passenger perspective and for a detailed investigation of the distribution of the performance indicators.

The remainder of this paper is structured as follows. Section 2 reviews recent contributions to the field of passenger assignment models. The problem is then formally introduced in Section 3. The generation process for the exogenous passenger priority lists is explained in Section 4, whereas the assignment algorithm itself is described in Section 5. This section also details how our formulation can be embedded in a fixed-point specification in order to address endogenous passenger demand and priority specifications. Section 6 reports the results of the computational experiments on the case study. Finally, Section 7 concludes the paper and provides directions for future research.

## 2. Literature review

The recent literature on passenger assignment models for transit systems is either *frequency-based* or *schedule-based*. In the former approach, transit services are represented by lines with travel frequencies and single vehicles are not explicitly considered. Frequency-based static assignment models are generally suited for urban transportation systems (metro, bus) where the service is so frequent that it can be assumed that a passenger boards the first “attractive” vehicle when waiting at a stop. Seminal works in this field include Spiess and Florian (1989), who introduced the concept of optimal strategies and Nguyen and Pallottino (1988), who formalized the concept in terms of shortest hyperpaths. Many extensions have been proposed in the following years (e.g., de Cea and Fernández, 1993; Cominetti and Correa, 2001). The interested reader can refer to Fu et al. (2012) for an in-depth review of frequency-based passenger assignment models.

Single vehicle loads can only be approximated in frequency-based models. This approximation is especially unsuitable in case of irregular service (which is common in inter-urban systems such as trains or long-distance coaches), as it cannot account for peaks of passengers waiting at the station. In order to model the choice of passengers for a specific run of a specific transportation line, a schedule-based approach is needed. The loads and the performance of each single run can be obtained in such a framework. In schedule-based models, each vehicle is considered individually with its capacity, either implicitly or explicitly. The implicit approach is similar to road network modeling, where link costs are related to link flows through non-decreasing functions. Papers such as Tong and Wong (1999); Nuzzolo et al. (2012b), and Nielsen (2004) use this approach. By contrast, the explicit schedule-based approach introduces vehicle capacity constraints, thus letting waiting passengers board the arriving train according to its residual capacity. The following papers use the explicit schedule-based approach to assign passengers on transit networks.

Nguyen et al. (2001) consider the case where timetables are reasonably reliable, and the number and frequencies of transit vehicles are low. For this kind of networks, departure time and route choice are both equivalently important decisions that passengers face. Further, the concept of path available capacity is introduced in order to capture the flow priority aspect (i.e., giving priority to passengers already on-board the transit vehicles with respect to passengers waiting at the station). A traffic equilibrium model of the assignment problem is presented, and a computational procedure based on asymmetric boarding penalty functions is suggested to avoid the explicit enumeration of all paths connecting origins and destinations.

Poon et al. (2004) propose a model that explicitly describes the available capacity of every vehicle at each station, as well as the queuing time for every passenger. The paper focuses on the route choice problem, ignoring other choice dimensions, such as departure time or departure station. In their formulation, route choice for every passenger is modelled by selecting a path that minimizes a generalized cost function consisting of in-vehicle time, waiting time, walking time and line change penalties. The network is loaded (i.e., user equilibrium is achieved) by using a Method of Successive Averages (MSA) algorithm. The authors assume a First-In-First-Out (FIFO) queue discipline at the stations. Depending on the spare capacity of a