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Assessment of schedule-based and frequency-based assignment models for strategic and operational planning of high-speed rail services

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ABSTRACT

Despite some substantial limitations in the simulation of low-frequency scheduled services, frequency-based (FB) assignment models are by far the most widely used in practice. They are less expensive to build and less demanding from the computational viewpoint with respect to schedule-based (SB) models, as they require neither explicit simulation of the timetable (on the supply side), nor segmentation of OD matrices by desired departure/arrival time (on the demand side).

The objective of this paper is to assess to what extent the lack of modeling capabilities of FB models is acceptable, and, on the other hand, the cases in which such approximations are substantial and more detailed SB models are needed. This is a first attempt to shed light on the trade-off between (frequency-based) model inaccuracy and (scheduled-based) model development costs in the field of long-distance (e.g. High-speed Rail, HSR) service modeling.

To this aim, we considered two modeling specifications estimated using mixed Revealed Preferences (RP) and Stated Preferences (SP) surveys and validated with respect to the same case study. Starting from an observed (baseline) scenario, we artificially altered the demand distributions (uniform vs. time-varying demand) and the supply configuration (i.e. train departure times), and analyzed the differences in modal split estimates and flows on individual trains, using the two different model specifications.

It resulted that when the demand distribution is uniform within the period of analysis, such differences are significant only when departure times of trains are strongly unevenly spaced in time. In such cases, the difference in modal shares, using FB w.r.t. SB, is in the range of [0%, +5%] meaning that FB models tend to overestimate HSR modal shares. When the demand distribution is not uniform, the difference in modal shares, using FB w.r.t. SB, is in the range of [−10%, +10%] meaning that FB models can overestimate or underestimate HSR modal shares, depending on timetable settings with respect to travelers' desired departure times. The differences in on-board train flow estimates are more substantial in both cases of uniform and not uniform demand distribution.

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1. Introduction

High-speed Rail (HSR) lines are being built in several countries as the new intercity transport mode, competing with air, bus, conventional train and private cars, in distance ranges of 200–1000 km s (Campos and de Rus, 2009). Design and business cases are traditionally based on demand and supply models capturing the competition among modes based on different travel times and costs. The models developed to support such analysis (see for instance, Mandel et al., 1997; Froidh, 2005; Roman et al., 2007; Martin and Nombela, 2007; Yao and Morikawa, 2005; Park and Ha, 2006) typically follow a frequency-based (FB) approach. Such models do not allow for demand flows varying within the simulation period. Indeed, uniform demand distributions are typically assumed. Moreover, they cannot assess the effects of different timetables and fare structures characterized by ticket prices varying with time-of-day, on-board flows, and ticket flexibility, but consider uniform headways (depending on the service frequency on each line) and one Origin–Destination (OD) fare, eventually differentiated by service (e.g. first and second class), given by the average of different price points available. Failure to consider such effects, especially in the case of low-frequency systems (such as inter-city rail services), can lead to two types of errors:

a. errors in the flow estimates on single services (e.g. trains) and hence in the revenues;
b. errors in the expected modal diversion due to modification (e.g. improvements) of service supply (in term of price, schedules and also frequency).

In the first case, the problem of service capacity underestimation and/or overestimation may arise, since the frequency-based approach is unable to assess the effect of the concentration and dispersion of departure times respectively during high demand (e.g. morning peak) and low demand periods. Moreover, it is not possible to assess, with a proper level of accuracy, the impacts of congestion and differentiated prices (yield management) on travelers' choices.

In the second case, the estimation error in modal diversion can lead to incorrect assessment of the direct benefits (surplus) of travelers, in alternative supply scenarios. In the strategic (medium–long term) planning of the low-frequency scheduled services network (e.g. rail or air networks), travelers select their modal alternatives depending on actual departure or arrival time and not, simplistically, on service frequency. Moreover, in some cases modal choices arise from discounted prices on "low cost" rides (nowadays very frequent not only in passenger aviation, but also in the rail sector), whereas frequency-based models assume an average OD cost for each mode-service which does not allow certain choices to be properly justified. This leads to errors in estimated cost elasticities and, ultimately, in forecasting modal diversion and travelers' benefits.

In order to avoid such errors, occurring especially in the simulation of low-frequency services, schedule-based modeling approaches have been proposed. These models (see for instance Nuzzolo et al., 2001), on the supply side, require explicit simulation of departure/arrival time of each scheduled service (timetable) resulting in an expanded network representation, first introduced as a diachronic network adding temporal coordinates of all nodes of the graph (Nuzzolo and Russo, 1993). On the demand side, schedule-based models assume travelers choose among alternatives (i.e. the runs belonging to a given path) based not only on their perceived travel times and costs, as in the frequency-based approach, but also on the time-distance between the departure/arrival time of each run and their desired ones (i.e. early/late schedule penalty). To this aim, they require the segmentation of OD matrices by travelers' desired departure/arrival times.

These additional modeling requirements probably constitute the main reason why, despite some successful experiences and many applications both in urban and ex-urban cases (for a review see Wilson and Nuzzolo, 2004), frequency-based models are by far the most widely used in planning practice to simulate also low-frequency scheduled service systems. Indeed, they are less expensive and cumbersome from a computational viewpoint.

The objective of this paper is to assess to what extent the lack of modeling capabilities of FB models is acceptable, and, on the other hand, the cases in which such approximations are substantial and more detailed SB models are needed. This is a first attempt to shed light on the trade-off between (frequency-based) model accuracy and (scheduled-based) model development requirements in the field of public transport service modeling.

To this aim, we considered two modeling specifications calibrated and validated with respect to the empirical case study of the Italian HSR service: one following a frequency-based approach (Ben-Akiva et al., 2010), the other schedule-based (Cascetta and Coppola, 2012). Although the models reproduce the observed modal shares, some substantial differences can be appreciated in the on-board train flow estimates, compared to the observed (i.e. counted) ones. Moreover, starting from an observed (baseline) scenario, we artificially altered the demand distributions (uniform vs. time-varying demand distributions) and the supply configuration (i.e. train departure times), and analyzed the differences in modal split estimates and flows on individual trains, using the two different model specifications. The results of this application may be of interest to modelers and practitioners in the field of scheduled service network simulation and design, in order to obtain a range of approximation of passenger flow estimates on single runs when using an FB approach to simulate low-frequency service systems under different cases of demand variability and headway configurations (timetable).

The paper is organized as follows. Section 2 proposes a taxonomy of the different components of generated demand on HSR services and reviews the modeling approaches proposed in the literature to forecast such demand components. Section 3 describes the modeling architecture consisting of: (a) the supply models used for the computation of the level-of-service (LOS) attributes; (b) the mode-service choice model, including the above two specifications; (c) the procedure to load the

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