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Stopping Pattern and Frequency Determination for a Multi-Modal Network

Oded Cats · Merlijn van Beurden

Abstract This paper proposes a model for simultaneously determining the stopping patterns and frequencies of public transport services. Model formulation considers the impacts of alternative network design with limited stop solutions on passenger choice of origin and destination stations, route choice and possibly unsatisfied demand. The model is tested for a large range of numerical scenarios to test its sensitivity and then applied to the Amsterdam metro and rail network to assess the potential of integrated operations.

Keywords: Public transport · Line planning · Service frequency · Stopping pattern · Network design

1 Introduction

To tackle the increasing demand for mobility in general and public transport in particular, it is essential to provision the most effective service using the available infrastructure. This entails the design of a line service network along with their corresponding frequencies. These line planning decisions involve the consideration of network-wide consequences for passenger route choice and thus travel (dis)utility, investment and variable operational costs, while satisfying the underlying vehicle, section and station capacity.

Route sets and frequencies per route are the decision variables in the transit network design problem which was studied among others by Ceder and Wilson (1986), van

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Nes and Bovy (2000) and Lopez-Ramos et al. (2017). The stopping pattern can be optimized per line in isolation assuming that all passengers board the first arriving train (Lin and Ku 2014) or combined with frequency determination (Goossens et al. 2006). In this study, a model is developed to optimize stopping patterns and frequencies of a given set of lines, which can be a subset of the total public transport network. The topology of the (rail) infrastructure layer is considered given. Unlike previous studies, passengers' access stop is explicitly modelled as part of the iterative network loading model, without fixing passengers' origins and destinations to pre-determined stations. This is essential in order to model the impact of limited stop service on passengers walking, waiting and in-vehicle times.

2 Method

The framework of the proposed stopping pattern and frequency optimization model is shown in Figure 1. The input includes network topology, track and station infrastructure and respective capacities, track alignments, a pool of lines to be optimized, candidate stations per line, an origin-destination demand matrix, and a fixed underlying network. It is possible to indicate which stations are fixed and which are subject to optimization per line.

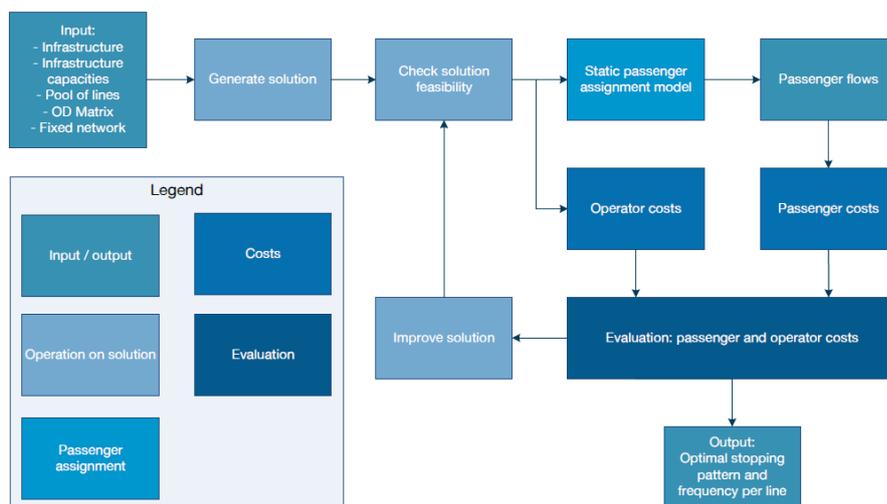


Fig. 1 Stopping pattern and frequency optimization model framework.

The model consists of the following modules:

- (i) a static and deterministic frequency-based capacity-constrained passenger assignment model, OmniTRANS, is used for loading the demand on each alternative network solution;
- (ii) passenger and operator costs are calculated for each candidate solution. The objective function includes the following terms: total passenger access walking

time, total passenger waiting time, total passenger in-vehicle time, total passenger transferring time, total passenger egress walking time, total penalty for unsatisfied passenger demand, total fixed operational costs, total variable operational cost as function of vehicle hours and total variable operational cost as function of vehicle kilometres;

- (iii) the total cost is used as the solution fitness score which is then used in the process of generating a new set of solution using genetic algorithm operations while deploying a set of constraints which enforces: symmetrical stopping patterns and frequencies for opposite line directions, single frequency value per line, node capacity in terms of throughput and service time, and link infrastructure capacity.

The evolution continues until a stopping criterion is met. The output of this model consists of the set of stops to be served by each line and the corresponding service frequency.

3 Applications

The model is applied to both a synthetic network and the existing metro and train network of Amsterdam.

3.1 Numerical Experiments

A series of numerical experiments are performed with a synthetic network consisting of two diagonal lines and eight angular lines, connecting a total of twenty zones (Figure 2, left). The network is simple enough to explain the performance of the model by running a large number of scenarios while still allowing for station access choice, detours and stop skipping. Various demand distribution, capacity constraints and cost parameter scenarios are tested and results of which will be detailed in the full paper. Based on the results it can be concluded that waiting time is the most important factor in reducing the total costs. Stopping patterns were adapted in such a way, that the frequencies of as many angular lines as possible could be increased at the expense of the shortened lines. One or both of the diagonal lines were in almost all scenarios eliminated from the network (Figure 2, right).

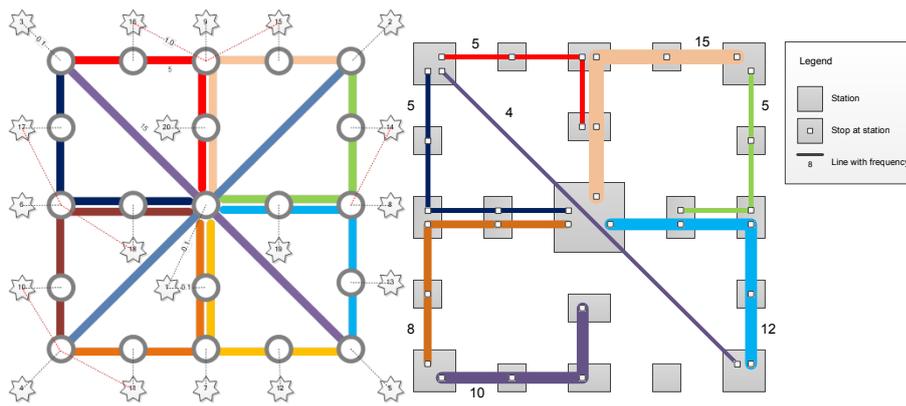


Fig. 2 Synthetic test network (left) and the stopping pattern and frequencies obtained in the final solution for the base case scenario (right)

3.2 Amsterdam case study

The model is then applied to the metro and rail network of Amsterdam for the year 2040 and compared to the currently planned 2040 service. This application allows exploring the prospects of operating an integrated train-metro network as at the moment the two services run separately with many overlapping sections. The remaining public transport network was part of the passenger assignment model as an underlying network. Some changes to the pool of lines were adopted to include prevailing ideas that circulate in planning circles to observe the consequences of these plans. For the Amsterdam case study, the focus is on how the network should develop towards 2040, hence no capacity constraints were specified.

The resulting network after 669 generations (each consisting of 32 solutions) is shown in Figure 3, which shows only the lines included in the final solution. The same trend can be observed as in the numerical experiments, namely that the frequencies of lines with many stops have increased the most to reduce passenger waiting time. In the absence of infrastructure capacity constraints, the lines run twice as frequently as currently possible. The final solution includes regional train lines running through the metro tunnel between Amsterdam Centraal and Amstel. Two of the three metro lines are cut short as a result. This indicates that there are certainly parts of Amsterdam where a different type of service can improve service performance for passengers.

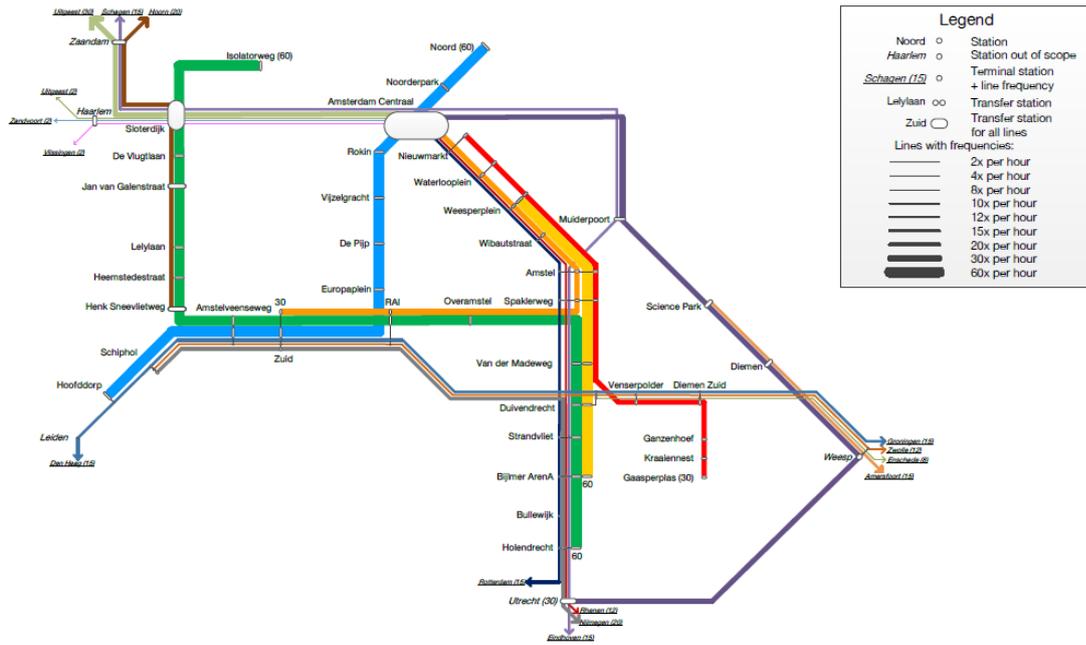


Fig. 3 Final solution Amsterdam case study

4 Conclusion

The proposed model has shown to be capable of systematically improving stopping patterns and frequencies for a predetermined set of lines within a public transport network, taking into account both passenger and operator costs and capacity constraints. The results suggest that it is preferable to have a few lines with many stops and high frequencies, than many lines with different stopping patterns and low frequencies. Notwithstanding, if multiple lines run through an infrastructure bottleneck, some of them should be shortened so other lines' frequencies can be increased.

While the unconstrained application allows identifying the main lines and the related capacity needs, the model allows also for a capacity constrained implementation that will result with more realistic outcomes given network limitations. The model can be used for a variety of separate or integrated multi-modal service networks. Future work should consider the generation of the line pool which will then be selected using the frequency determination results as well as the railway traffic modelling of heterogenous stopping patterns and their consequences for capacity.

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