A passenger-centric approach to enhance railway services

Yousef Maknoon * Michel Bierlaire *

August 5, 2016

Report TRANSP-OR 160805
Transport and Mobility Laboratory
School of Architecture, Civil and Environmental Engineering
Ecole Polytechnique Fédérale de Lausanne
transp-or.epfl.ch

*École Polytechnique Fédérale de Lausanne (EPFL), School of Architecture, Civil and Environmental Engineering (ENAC), Transport and Mobility Laboratory, Switzerland, {yousef.maknoon,michel.bierlaire}@epfl.ch

Abstract

We present an approach for the design and operation of railways that is passenger-centric, as opposed to train-centric. The main idea is to account explicitly for the passengers' preferences in the entire process. In this paper, we provide a brief presentation of passenger-centric approaches developed as research projects in the Transport and Mobility Laboratory (TRANSP-OR) at École Polytechnique Fédérale de Lausanne (EPFL).

1 Introduction

The design and operation of railway services are traditionally tackled from an operator's perspective. Railway planners consider a microscopic model of infrastructure and look for a conflict-free and punctual train schedule, while less attention has been made toward the convenience of passengers as their main users.

The emerging technological advancements have recently provided high resolution data for transportation agencies. Transport planners can now use data analytics and modern behavioral models to predict the passengers' behaviors. Such advancements provide an opportunity to integrate aspects of the passengers' behaviors into design and operation of railways. This holistic approach (we call it passenger-centric) enables railway companies to explicitly quantify the satisfaction of passengers when planning railway services. Consequently, companies are able to enhance the satisfaction of their users at a lower operating cost.

The main research stream of the Transport and Mobility Laboratory (TRANSP-OR), located at the school of architecture, civil and environmental engineering at École Polytechnique Fédérale de Lausanne (EPFL), focuses on developing modern behavioral models and integrating them into operational plannings in the context of transport and mobility. The lab is engaged in many research projects, from simulating passenger flow dynamics in train stations using video camera data (Nikolić et al., 2016), route choice modeling using revealed preference data (Frejinger, 2008) to predicting pedestrian activities in transportation hubs using WiFi data (Danalet, 2015). TRANP-OR has also conducted concrete research projects on improving railway services using a passenger-centric approach. In this paper, we present some of the recent research projects from this laboratory.

2 Passenger-centric approach

A Passenger chooses a train itinerary by taking into account various factors such as travel time, price, number of transfers, wait time on the platform and the arrival time at the destination. Among all possible itineraries, he/she will then select the one with the highest level of satisfaction.

By using the utility function, we are able to quantify the notion of "satisfaction" or utility. The utility of an alternative is a relative value and is measured in comparison with other alternatives. Modern behavioral modeling uses the concept of utility to predict passengers' behaviors. In the context of mobility, these models are able to predict the most preferable choice for passengers for their trips.

The passenger-centric is a multi-objective approach with two main components. The first component models the operators' decisions. Generally, the objective is to minimize the cost of operation. The second component uses choice models to predict passengers' behavior. The desirable outcome of the second component is to maximize the satisfaction of passengers. In some cases, these objectives are contradictory. Therefore, this approach generates a set of non-dominated solutions that can be further analyzed by transport planners. In the following sections, we will describe the application of this approach in the design and operation of railway services.

3 Passenger-centric timetabling

Timetables are generated by solving two well-known sequential problems: line planning and train scheduling. Line planning uses the aggregated demand between every origin and destination to determine a set of lines as well as their frequencies to maximize the number of direct connections. The outcome of line planning is then used in the train scheduling phase. Traditionally, in this phase the infrastructure manager designs the timetable while avoiding potential conflicts. As a result, the timetable is generated based on the benefits of the operator and not necessarily by considering behavior of the passengers and their preferences, which can affect the quality of service. To overcome this issue, we suggest using the passenger-centric approach.

Generally, timetables could be either cyclic or non-cyclic. The cyclic timetable focuses on the connectivity of trains and psychologically preferred

by the passengers, as they are easy to remember. Conversely, a non-cyclic timetable has the flexibility of responding to passengers' demands at a lower operating cost.

The purpose of this project is to develop a passenger-centric approach to designing a timetable. The developed approach is able to generate the timetable that maximizes the passengers' satisfaction. This approach is used to generate cyclic and non-cyclic timetables. Interested readers are referred to (Robenek, Maknoon, Azadeh, Hang and Bierlaire, 2016) for a detailed description.

We then investigate two forms of hybrid timetables by systematically combining cyclic and non-cyclic timetables. These timetables are θ-shifted cycle and ξ partially cyclic. In θ-shifted cycle timetable, trains depart in a cycle; however, their departure time can be deviated up to θ minutes from it. In ξ partially cyclic timetables ξ% of trains are free to have a non-cyclic departure time. The detailed descriptions of hybrid timetables are presented in (Robenek, Azadeh, Maknoon and Bierlaire, 2016).

We have tested the aforementioned timetabling design on an Israel railway network. In order to have a fair comparison between timetables, we have assumed that all timetables should use fixed number of trains. We determine the timetable for cyclic, non-cyclic, θ shifted cyclic or ξ partially cyclic with the objective of maximizing passenger satisfaction. In order to have a better understanding about the satisfaction of passengers, we consider the cyclic timetable as a base and report the results as a percentage improvement of passenger satisfaction compared to a cyclic timetable.

As can be seen in Figure 1, the passengers' satisfaction improves around 20% when the operator shifts its timetable from cyclic to non-cyclic. Although in a non-cyclic timetable trains are dispatched irregularly, it has a higher level of satisfaction.

We have also tested the θ-shifted timetable (range from 0 to 30 minutes). In this form, if the deviation is 0, then it acts as a cyclic timetable. If we allow the trains' departure time to deviate up to 30 minutes from their scheduled cycle, the improvement in passengers' satisfaction increases by 10%. This improvement is rather exponential for ξ partially hybrid timetables. The passengers' satisfaction is slightly worse than the non-cyclic timetable, if we only allow 40% of trains to have a non-cyclic departure time. In this case, most of these trains depart during the peak hours.

In the next phase of this project, we have evaluated the impact of de-

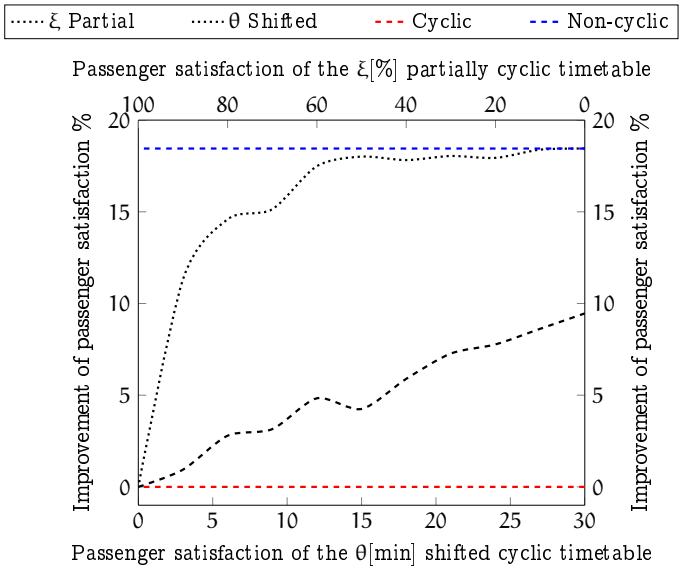

Figure 1: Passenger satisfaction of different timetables

mand evolution on the satisfaction of passengers as well as the profit of the railway company. In other words, our aim is to find a turning point in which the operator needs to revisit its line-planning decisions.

As a case study, we consider the S-train network of canton Vaud in Switzerland. First, for the current year, we schedule a non-cyclic timetable that maximizes the satisfaction of passengers and use it as a benchmark. Then, we increase the demand until 70% of the passengers could use trains with the current frequency and available rolling stock. For each case, we use our model to find the best timetable that maximizes the satisfaction of passengers.

As shown in Figure 2, the network becomes congested if the current demand evolves by almost 120%. Before this turning point, the profit of the operator improves exponentially. At the same time, the increment of future demand will not significantly affect the convenience of passengers. This trend is reversed when the network becomes congested. As can be seen, in the congested network there is a substantial increment in the passengers' satisfaction, while the resulting profit improves slightly.

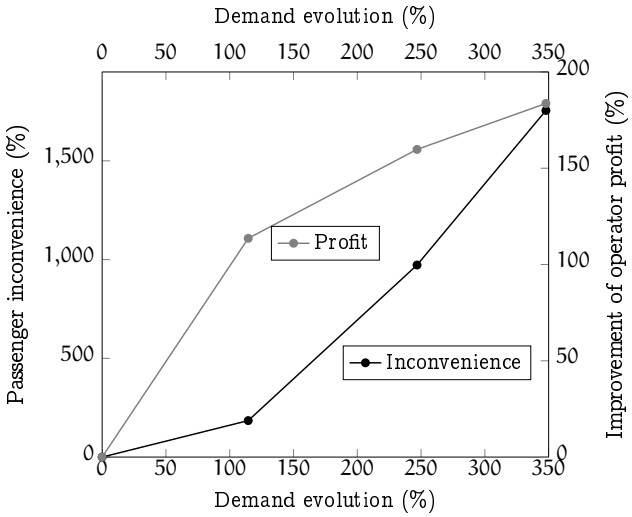

Figure 2: Impacts of Passenger Congestion

4 Disruption, recovery plan and its impact on passenger's satisfaction

Even with the most suitable timetable and high level of maintenance, it is probable that a railway service will face a large scale disruption. For example, Dutch railways experienced 22 infrastructure related disruptions per day, with an average duration of 1.7 hours, based on a statistic from the first half of 2006 (Jespersen-Groth et al., 2009). These events result in the delay and cancellation of trains and create an undesirable situation for the commuters.

Although it is impossible to avoid disruptions, it is possible to organize a recovery plan which is suitable for the passengers. The train operator has a limited number of possibilities to cope with the disruption: (1) totally/partially cancel the scheduled trains, (2) delay the departure time of the scheduled ones, (3) re-route the trains or (4) establish a new service during the period of disruption. Given these possibilities, the operator requires a decision making tool that provides a proper recovery plan. This tool needs to find an equilibrium between three goals: (1) minimizing the cost of handling the disruption (2) minimizing the passengers' inconvenience and (3) minimizing the deviation from the previously scheduled timetable. The third objective is critical as it helps the operator to easily

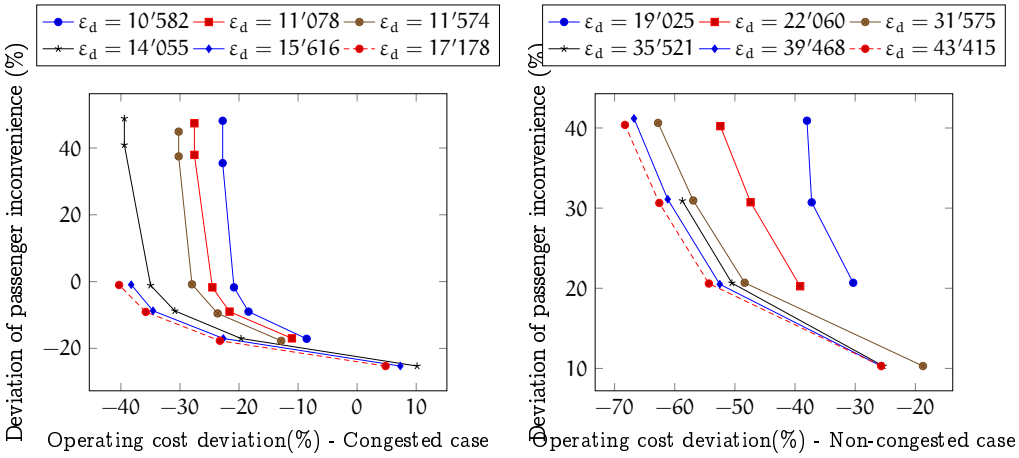

Figure 3: Comparison of recovery plans for a Dutch railway network

switch to the initial scheduled timetable at the end of the disruption.

We model the decisions of a recovery plan as a triple-objective mixed-integer optimization. The objectives are passengers' satisfaction, operating cost and deviation from the initial timetable. The model then generates a set of non-dominated solutions as recovery plans. Interested readers are referred to (Binder et al., 2016) for a detailed description of the model.

We have applied our model to a part of the Dutch railway network for two different scenarios. The first scenario considers a disruption in the congested part of the network. For the second scenario, we consider a case in which a non-congested part of the network is disrupted. We have applied our model to each scenario and have generated a set of solutions as a recovery plan.

Figure 3 represents a set of solutions for the two studied scenarios. We denote the deviation from the initial timetable by ε_d (in monetary value). Higher value denotes more deviation. Then for each value of ε_d, we report the percentage difference of operating cost and passengers' inconvenience from the initial timetable. As can be seen, the correlation between the passengers' inconvenience and the operating cost is less significant for the disruption in a non-congested part of the network. Moreover, with the higher deviation from the initial timetable, the operator has a better chance of controlling the passengers' inconvenience at the lower cost. The provided solutions help practitioners analyze various recovery plans and choose the one that minimizes the inconvenience of passengers.

5 Passenger flow dynamics at train stations

Understanding, reproducing and forecasting phenomena that characterize pedestrian traffic is necessary in order to provide services related to pedestrian safety and convenience. This becomes of utmost importance in areas of high congestion, which is a growing problem in many public spaces (transportation hubs, shopping malls, large sports and cultural events, etc.) Congestion in pedestrian-oriented facilities is a phenomenon with a negative impact on pedestrian dynamics. It prevents efficient pedestrian flow and may lead to an increase in travel time, delays and potential collisions among pedestrians. Because of the complex and heterogeneous patterns in pedestrian flows, a simple application of a particular policy may lead to costly trial-and-error solutions.

Data collection for pedestrian flow and behavior analysis used to be particularly cumbersome. Typically, manual counting methods (on-site or on video) and surveys distributed to randomly selected individuals were the main source of data. Nowadays, automatic pedestrian detection and tracking methods have evolved tremendously, allowing for more comprehensive analyses to be conducted as well.

In this project, we develop a novel speed-density relationship for pedestrian traffic. It is a probabilistic model designed to account for the heterogeneity of speed at a given density level, as observed in the data. Interested readers are referred to (Nikolić et al., 2016) for detailed description.

The suggested model could be utilized as such by practitioners for the evaluation and optimization of the level of service for pedestrian facilities. This approach yields a more realistic representation of the empirically observed phenomena.

5.1 Conclusion

The availability of high resolution data enables transport planners to use modern behavioral modeling to predict the behavior of passengers. With the integration of behavioral models into all aspects of decision making, the railway companies are able to enhance passengers' level of satisfaction and increase their profit. In this paper, we have introduced the passenger-centric approach to enhancing railway services. We have presented the rationale behind it and report three applications in which we can enhance

service by applying this approach. We have shown that by using this approach we are able to improve the satisfaction of passengers without facing any additional expense for the operators. However, this approach requires dealing with more complex mathematical models and requires high resolution data. In the future, these approaches need a new generation of behavioral models for railways and they require the design of specific algorithms to deal with large problems in practice.

References

Binder, S., Maknoon, Y. and Bierlaire, M. (2016). The multi-objective railway timetable rescheduling problem, *Technical Report TRANSP-OR 160530*, Transport and Mobility Laboratory, Ecole Polytechnique Fédérale de Lausanne.

Danalet, A. (2015). *Activity choice modeling for pedestrian facilities*, PhD thesis, Ecole Polytechnique Federale de Lausanne.

Frejinger, E. (2008). *Route choice analysis: data, models, algorithms and applications*, PhD thesis, Ecole Polytechnique Federale de Lausanne.

Jespersen-Groth, J., Potthoff, D., Clausen, J., Huisman, D., Kroon, L., Maróti, G. and Nielsen, M. N. (2009). Disruption management in passenger railway transportation, *Robust and online large-scale optimization*, Springer, pp. 399–421.

Nikolić, M., Bierlaire, M., Farooq, B. and de Lapparent, M. (2016). Probabilistic speed–density relationship for pedestrian traffic, *Transportation Research Part B: Methodological* **89**: 58–81.

Robenek, T., Azadeh, S. S., Maknoon, Y. and Bierlaire, M. (2016). Hybrid cyclicity: Combining the benefits of cyclic and non-cyclic timetables, *Technical Report TRANSP-OR 160510*, Transport and Mobility Laboratory, Ecole Polytechnique Fédérale de Lausanne.

Robenek, T., Maknoon, Y., Azadeh, S. S., Hang, C. J. and Bierlaire, M. (2016). Passenger centric train timetabling problem, *Transportation Research Part B: Methodological* **89**: 107–126.