High Speed Rail Planning – a combined strategic model with supporting tactical model components

Hugo M. Repolho *

Laboratory of Geographic Information Systems (LASIG),

École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

António P. Antunes

Department of Civil Engineering,

University of Coimbra, Coimbra, Portugal

Richard L. Church

Department of Geography,

University of California Santa Barbara, Santa Barbara, California, USA

* Email: hugo.repolho@epfl.ch

1 Introduction

Railway transportation planning is a highly complex process that, with respect to planning horizons and objectives, can be divided in three major phases: strategic, tactical and operational. Each phase can be further decomposed into a hierarchical planning process formed by sub-problems [1, 2]. However, within the existing literature the integration between the three major phases and even between the sub-problems of the hierarchical railway planning process is limited. The sub-problems are usually solved separately in the same hierarchically order using available optimization models and calculation methods. Strategic issues, particularly the ones related to infrastructure, have not been dealt with adequately through optimization models, being modeled without taking into account important information regarding the future services provided by the railway operator [3, 4].

This study aims to integrate and optimize simultaneously all strategic issues related to infra-structure and the subsequent sub-problems (line planning and train scheduling) that may influence optimal investment decisions at a strategic level, such that the economic viability of the investment may be evaluated with more accuracy. We present an optimization model for assisting planning railway investments. The mixed-integer optimization model proposed determines the optimal number and location of intermediate stations, determines the fleet characteristics, designs the line system and a master timetable and quantifies the volume of ridership such that social net benefits are maximized. The model takes into account the sensitivity of rail ridership to time losses due to stops at intermediate stations, as well as (static) competition from other modes. Various stop-scheduling patterns are included in the analysis. The model is then applied to a real case study.

2 Problem description

The most demanding investment on a railway network is related to infrastructure (lines and stations), rolling stock acquisition and operation. The success of the railway investment is highly dependent on rail ridership [5, 6], which relies not only on the existing infrastructures and train units but also on the level of service provided by the railway network system (there is a bidirectional relationship between demand and the operated railway service [3, 4]. A goal worth pursuing is then to integrate and optimize all features that may influence optimal investment decisions at a strategic level. Four main aspects are handled in this study: travel demand, infrastructure, service provided and rolling stock.

We consider a set of High Speed Rail (HSR) corridors between two endpoints (given the small number of possible corridors, they are studied separately and then compared). The infrastructure problem is then to select for each corridor the optimal intermediate stations location from within a given set of possibilities. The number and location of stations influences (and is influenced by) the ridership captured to the railway service. Each additional station increases local demand – less access time to railway services – but diminishes global (long distance) demand – additional travel time for users already inside the train [7].

The decisions to be made regarding the service provided are the service frequency (number of trains serving the route) and the stop-schedule patterns (the subset of stations along the railway line at which a train stops). The service provided is also dependent on the rolling stock fleet. Thus, upon the generation of a master timetable, the fleet characteristics (type and size) required to assure the service planned are determined. Moreover, the units and types of rolling stock are assigned to each train trip planned, based on the system's availability for each interval and departing station.

3 Optimization model

The model we introduce here combines the station location problem (part of the network planning problem), the train scheduling problem and the rolling stock management problem. The new railway service competes with the modes that use the existing transportation network. The problems in hand are formulated through a mixed-integer optimization model whose objective function maximizes the social net benefits given by the difference between travel costs savings and the investment made to build stations and acquire the rolling stock fleet. Three types of trips are considered based on the site where traffic is originated, the access station where passengers take the train and whether or not it occurs on the desired time interval.

4 Case study application

The usefulness of the model in real-world situations is illustrated with a case study involving a HSR line expected to be built in Portugal in the near future: the Lisbon-Porto line. The areas crossed by the new HSR line are served by a dense and very good road network which will compete with the HSR mode. Railway stations are to be chosen between 17 possible locations. The travel costs through the existing road network are computed assuming three components: vehicle operating costs, time costs, and tolling costs. The travel costs through the new HSR line are computed assuming the ticket price and time costs (in-transit time, time loss in intermodal exchange, time loss associated with each intermediate stop). We consider four types of rolling stock units with the following passenger capacity 1000, 800, 600 and 400. The eligible stop-schedule patterns are designed with zero, one, two or three intermediate stops at most. For each type of trip described, travel demand is estimated using an unconstrained gravity model that uses a power-form impedance function. The planning horizon is analyzed on a day-to-day basis, where each day is divided in fixed time intervals. Demand is distributed homogenously along the day except for three peak periods (morning, lunch and afternoon).

The optimal solution locates three intermediate stations and implies the acquisition of four trains of 800 passengers and three trains of 600 passengers. The trains average load factor is 74 percent. The optimal master timetable is illustrated in Figure 1.

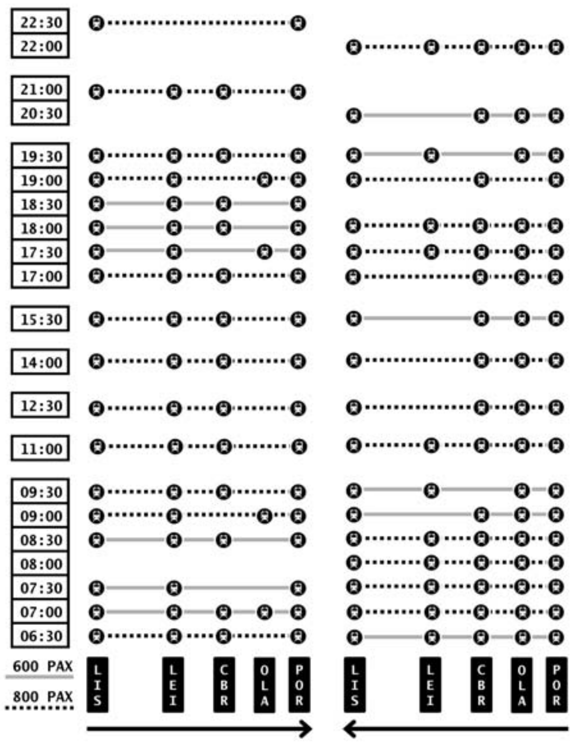

Figure 4 – Optimal master timetable

Furthermore, the solution found was validated through a sensitivity analysis to two key factors (value of time and estimated demand) and to the effect of the level of investment upon the optimal solution.

5 Conclusions

The integrated model developed proved to be a useful decision-support tool with regard to long-term railway planning. Indeed, by considering several tactical issues the expected service, the demand captured and consequently the economic viability of the investment can be defined with more accuracy.

References

[1] Ghoseiri, K., F. Szidarovszky, M.A. Asgharpour. 2004. A multi-objective train scheduling model and solution. *Transportation Research Part B* **38**(10) 927-952.

[2] Huisman, D., L.G. Kroon, R.M. Lentink, M.J.C.M. Vromans. 2005. “Operations research in passenger railway transportation.” Statistica Neerlandica **59**(4), 467-497.

[3] Zhou, X., M. Zhong. 2005. “Bicriteria train scheduling for high-speed passenger railroad planning applications.” *European Journal of Operational Research*, **167**, 752-77.

[4] Caprara, A., L.G. Kroon, M. Monaci , M. Peeters , P. Toth. 2007. Passenger Railway Optimization. In C. Barnhart & G. Laporte (Eds.), Handbooks in Operations Research and Management Science, Elsevier, Amsterdam, **14**, 129–187.

[5] De Rus, G., G. Nombela. 2007. Is investment in high speed rail socially profitable? *Journal of Transport Economics and Policy* **41**(1) 3–23.

[6] Campos, J., G. De Rus. 2009. Some stylized facts about high-speed rail: A review of HSR experiences around the world. *Transport Policy* **16**(1) 19-28.

[7] Repolho, H.M., A.P. Antunes, R.L. Church. 2012. "Optimal Location of Railway Stations: The Lisbon-Porto High Speed Rail Line." *Transportation Science*, accepted for publication on 1 April 2012.