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Publication date:
2016

Document Version
Peer reviewed version

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1 Introduction

In this paper we study the impact of the 'turn conditions' in end stations on the performance of a line plan. If trains have to turn on their platform in an end station, they occupy the platform for several minutes. A more preferred option, from a timetabling point of view, would be that a train disappears from the platform in its end station after dwelling and only appears again when departing for a subsequent trip. In this case, the train will not interfere with other trains that dwell on the platform during the time between these events. However, this option is only possible if the train can stay in a flexible and large enough shunt. Starting from a given line plan, we compare two timetables, one where trains have to turn on their platform and one where trains can turn in a shunt. We evaluate the impact on the performance of the line plan by its feasibility for timetabling, the minimum overall buffer time between trains, the sum of the buffer times and the buffer times in individual stations. A case study on the DSB S-tog in Copenhagen (Denmark) is performed.

2 State of the art

Railway network characteristics affect the performance of a railway service, for example, the use of tracks or junctions by trains in opposite directions, the number of platforms in the stations, the existence of alternative routes, the layout of the shunt in end stations, etc. In (Marín et al., 2009), an iterative approach is presented to integrate robust network design and line planning. They focus on the construction of connection links that offer an alternative in case of link failure. However, we focus on the design of the terminal stations.

Line plan characteristics also influence the performance of a railway system, for example, the number of lines that use the same infrastructure, the frequency of a line and the combination of frequencies, the trip lengths (catching up due to skipping stations), etc. Goerigk et al. (2013) analyse different line planning models by comparing typical characteristics of line plans, but also by comparing their impact on timetables and their robustness against delays. Therefore, they calculate a timetable for each line plan. In this paper, we also calculate timetables in order to evaluate line plans, but we focus on the impact of an infrastructure change and we don't compare line plans mutually.

3 Methodology

We create a set of diverse line plans. For each of these line plans we test if it is possible to generate a feasible timetable with and without turning on the platform. The majority of the initial line plans are not timetable feasible with turning on the platform. Then, we update the line planning model by including information on why timetables are infeasible. If the line plan is timetable feasible with and without turning on the platform, we find optimal (or near optimal) solutions to both timetable problems. We then compare the performance of both.

3.1 Line planning

Railway line planning is a long term planning problem which consists of the determination of the routes, stopping patterns, and hourly frequencies that should be operated in the railway network. We use a mixed integer linear program (MILP) to create line plans. Passengers are simultaneously routed, each picking a route with best estimated travel time, waiting time (estimated from headway times) and additional transfer penalties, but subject to capacity constraints. Operator line cost is estimated based on the rolling stock unit requirements and running times for the plan. A feasible line plan satisfies operational requirements and contractual service levels, satisfies conditions for feasible timetabling (though no all-embracing set of conditions is known), and provides capacity for all expected passengers. Line plans are either found by minimizing total passenger travel time or running cost, with a constraint on the other, or a weighted sum of each. We report average passenger travel time, which is similar across line plans as the majority of passenger demand is between stations that are well-served by all "reasonable" line plans but the differences are important as they are large differences for a minority of passengers. To find timetable feasible plans, additional constraints are introduced and tightened iteratively; these constraints are concerned with the shared use of end stations. Additionally, specific line combinations meeting certain unfavourable conditions for timetabling, e.g. one line that would certainly catch up with another one due to different trip lengths, are forbidden from appearing together.

3.2 Timetable model

Railway timetabling is a mid-long term planning problem, which consists of the determination of train arrival and departure times in stations. We use a MILP to build a cyclic timetable with a period of one hour starting from a line plan. The trains of a line are equally spread over the period. The goal function of this timetable model maximizes the minimal buffer time between every two trains. Reserve and release times of station areas are taken into account in the calculation of the buffer times between the trains. There is only one type of constraint that is necessary to allow for feasible turnarounds in the end stations of the lines. A train reserves the platform in its end station until the next train in the opposite direction departs from that platform (because that is the same physical train). This constraint is necessary to connect the schedule of trains in opposite directions, but it shortens the buffer time between trains of the same line in the same direction.

4 Case study

The DSB S-tog is a high frequency railway service that transports 30 000 to 40 000 passengers per hour at peak times between 84 stations. An illustration can be found on `http://www.dsb.dk/Global/STog/S%20kort%20udk%202015%233%20(3).pdf`. This network has seven terminal stations with two platforms and eight intermediate stations in which one platform is constructed as a terminal. Each train turns on the platform in its end station and thus occupies this platform for several minutes. A train's occupation time of this platform is bounded below by the minimum time needed to turn and bounded above by the time until the arrival of the next train. The DSB S-tog network is designed so that trains crossing in opposite directions, with a few exceptions, only affect each other in an end station. We assume that trains occupy every station area on their trip for 60 seconds. Trains of the same line are equally spread over the period of one hour.

The results of the case study can be found in Table 1. The first line plan was previously used by DSB S-tog. The second line plan is designed to be better for the passengers than line plan 1, the third line plan to have a better operator cost than line plan 1 and the fourth line plan to outperform on both characteristics. The upper part of the table shows some general information on the line plans. The passenger and operator cost are estimated by the line plan model. The number of interactions are the number of train pairs that share a platform in at least one station. In the lower part, we report four indicators on the spreading of the trains in time. All the timetables are constructed with a calculation time

Line plan	1			2		3		4	
# lines	9			8		8		7	
# interactions	1434			1362		1434		1434	
passenger cost	1172			1158		1198		1171	
line cost	679			829		653		665	
Turn restrictions	DSB	yes	no	yes	no	yes	no	yes	no
Min buf time (min)	-1 [1]	0,178	0,667	0,250	0,5	0	0,250	0,355	0,667
(upper bound)		(0,667)	(0,667)	(0,583)	(1)	(0,250)	(0,250)	(0,467)	(0,667)
#stations with min buf time	1	12	52	34	29	24	10	19	19
#stations with buf time ≥ 2	64	53	30	21	31	43	46	50	47
$\sum$ buf times (min)	18 450	18 969,6	20 196	17 985,2	19 086	19 085,8	20 166	19 180,9	20 308
(upper bound)		(21 066)	(21 786)	(19 602)	(20 298)	(20 580)	(21 306)	(20 214)	(20 946)

Table 1: The minimal buffer times improve if the infrastructure allows to turn in a shunt.

limit of 5400 seconds. We see that the minimal overall buffer time (Min buf time) and the sum of the minimal buffer times ($\sum$ buf times) improve if turning on the platform is not required. The values of the number of stations with a buffer time bigger than two minutes or equal to the minimum buffer time (which itself increased) show no clear trend, but they show that the turn restrictions affect the buffer times in the whole network. Optimal values give railway companies the information on how much the performance could be increased if flexible large enough shunts would be built in end stations.

5 Conclusion and future research

We analysed the effect of train turn restrictions on railway service performance. We conclude that for different kinds of line plans, the probability of propagation of delays can significantly be improved if the terminal stations have an appropriate shunt so trains don't need to turn on (and occupy) their platform. Moreover, with our approach we can calculate the magnitude of this performance improvement. Furthermore, we found that information on trip lengths and frequency combinations in end stations is useful for finding line plans that are feasible for timetabling with train turn restrictions. Future research consists of further integration of line planning and robust timetabling.

References

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[1] One station has overlapping occupation times. This allows for bigger buffer times in other stations.