Network effects within railways

Lars Wittrup Jensen & Alex Landex
Technical University of Denmark, Department of Transport,
Bygningstorvet 116B, 2800 Kgs. Lyngby, Denmark, e-mail: lawj@transport.dtu.dk

Background and purpose

Every railway timetable is constructed subject to passenger and operator demand together with constraints for the given infrastructure and rolling stock. These constraints induce interdependencies in the given timetable and the railway network. This essentially means that a timetable change in one location on the network may induce a change in another location in the network due to the timetable interdependencies. A local change may therefore propagate throughout the timetable and may become a change across a wider geographical area. An initial change that propagates throughout the timetable to other locations is known as a network effect. Network effects occur both in the planning of timetables as well as in delayed operation. In the timetabling process, network effects results in consecutive timetable changes, even far away from the original changes. In delayed operation a primary delay may propagate, due to network effects, and generate secondary delays. Even seemingly local changes may have widespread effects.

In this paper the definition and measurement methods of network effects are investigated through new research in the area, supplemented by a comprehensive review of practical case studies and scientific research studies.

Methodology

The study constitutes of three parts. First, the various factors, which impose constraints on the timetable, are described. The different types of initial changes that cause network effects in the timetabling process are then identified on the basis of the constraints.

Second, an analytic method is presented on a synthetic network illustrating the propagation of an initial timetable changes on the different railway lines in the network. The synthetic network is shown in figure i.

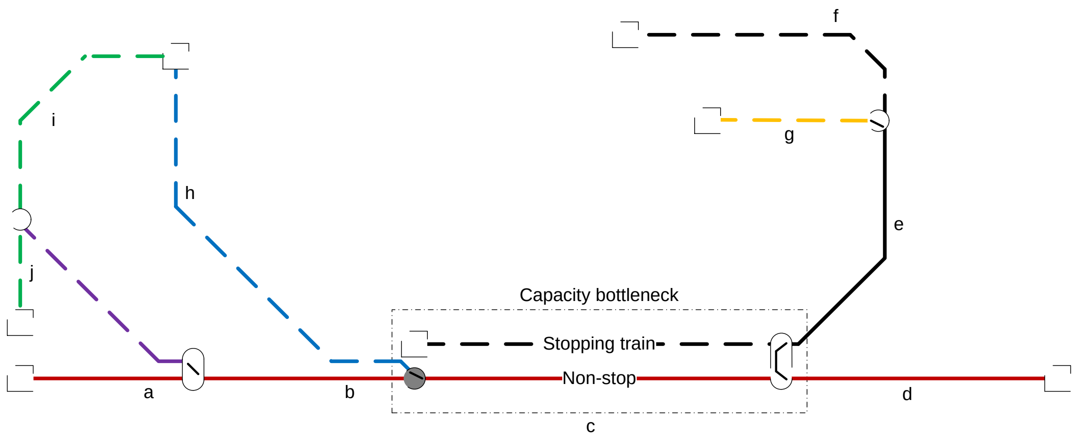

Figure i – Synthetic network. Circular shapes: transfer or couple (grey fill) constraints, squares: turn-around constraints, dashed lines: single track & continuous lines: double track. Trains are operated every 15 minutes on the black and red line, and 30 minutes on the remaining lines.

Finally, methods for measuring the magnitude of network effects are presented. This is important as it enables one to analyze to what extent a local initial timetable change propagates throughout the timetable for the whole network.

Results

The paper shows how the infrastructure, rolling stock and procedures together with demands from passengers and operator(s) form the constraints and preconditions that form the basis for a timetable. E.g. stops (and dwell times), minimum running time, connections, synchronizations of trains, minimum headway, etc.

This paper proposes that initial changes to a timetable are divided into the following three categories: running time changed, new transfer/coupling constraint(s) or new departures/train lines. If these initial changes propagate to other railway lines (defined as a section between terminal/junction stations) in the network, network effects have occurred from the initial change. If the initial change only propagates to the same line, this paper proposes that this is defined as a line effect and not a network effect.

For a long train line passing through most of the network such as an InterCity line, a change that affects this train line may induce a lot of changes other places in the network (network effects). This is caused by the fact that such train lines typically have a high priority, thereby affecting other train lines connecting to or being synchronized with high priority train lines. But the number of network effects is also dependent on whether the initial timetable change is done at the beginning/end of the train line or in the middle. Furthermore, a timetable change on a line with capacity problems will induce (more) network effects if the timetable change increase capacity consumption on the line. In case of a secondary train line connecting to one higher priority train line, there will not be any network effects, as a change made to the timetable on the secondary line will not induce changes to the higher priority train line. The change will only induce changes to the line itself, in this paper defined as line effects (as opposed to network effects).
Real world examples of the above are the Danish InterCity network to which many regional lines are connected (with lower priority). A change in the InterCity network will therefore propagate to the most of Denmark if connections have to be fulfilled. A change to a secondary line like Nærumbanen in Northern

Zealand will however not affect the S-train network, to which it is connected, as the S-trains have higher priority.

A network with many direct (and long) train lines is more prone to network effects than a network with short train lines with a lot of connections. However, this type of network is not desirable from a passenger standpoint, as passengers prefer direct routes. Furthermore, it is important to note that passengers may experience network effects, regardless of network, in delayed operation as a planned transfer connection may be lost when a train is delayed. It is therefore also important to distinguish between network effects for trains and for passengers/freight only.

Whether the local change to the timetable is seemingly small or large, caused by infrastructure or rolling stock changes, passenger or operator demand, the total consequences in the timetable are difficult to estimate. Using the analytic method presented it is fairly simple to show if a little change on one train line affects the rest of the network. However, it is difficult to estimate the magnitude of changes without the use of simulation.

Literature suggest that scheduled waiting time (SWT) can be used as a measure for network effects. SWT occurs in the timetable process due to e.g. congestion (limited capacity) and planned connections, and can be compared to delays (waiting time) in delayed operation. It is important to note that not all SWT in a timetable is caused by network effects. Therefore, one should compare a basis timetable with a candidate timetable where one initial change is implemented. If possible the SWT should be categorized by cause to gain better resolution in the results. The timetables can be constructed by the means of simulation, where the only difference is the initial change, alternatively it is also possible to use advanced queuing models to estimate the change in SWT.

Discussion/conclusion

Network effects are largely dependent on where the initial change is made and if the train line(s), initially affected, is running through large parts of the network or only on a secondary line. In the first case the risk of network effects is high, while it will rarely be the case for the secondary line. To capture the consequences effectively and the magnitude of network effects, timetable simulation models have to be used. Existing scheduling software can be used for this, but it will be more time consuming as consecutive timetable changes must be done manually. Furthermore, simulation makes it possible to evaluate different timetable variations by SWT and other KPIs.

A simulation model that makes it possible to evaluate effects of initial changes on a network scale will help timetable planners in TOCs and IMs to fast and easy estimate network effects, compared to methods and models available today. This is especially the case In Denmark where almost all regional train lines are constrained to the nation-wide InterCity network and the capacity consumption is high. This type of system allows for direct connections between the major cities in Denmark, and smaller stations can typically be reached by only one transfer at an InterCity-station.