RAIL TRAFFIC FLOW OPTIMISATION BY KRONECKER ALGEBRA FOR IRISH RAIL

Andreas SCHÖBEL¹
Jelena AKSENTIJEVIĆ²

Abstract – Within the by H2020 founded project DESTination Rail, a task is dedicated to the development of a tool for rail traffic flow optimization in terms of maintenance work. On a single track line priority is set for as much work as possible to be done in one time slot between two trains. Sometimes, the timetable is even modified to allow more efficient maintenance work. On a double track line all traffic has to run over the remaining track, where typically a slow speed zone is established to protect working staff. For this bottleneck section, it is very important to have an efficient usage of capacity. Therefore, it is necessary to optimize the speed profile of approaching trains to let them pass the bottleneck section exactly at the allowed speed limit to keep occupation time as short as possible.

Keywords – Kronecker algebra, rail traffic flow optimization, rescheduling

1. INTRODUCTION

Rail infrastructure managers are responsible for safety measures and investments within the infrastructure network. Their choices are usually not only based on poor data availability, but also on the visual assessment of infrastructure conditions. Unfortunately, there is enough evidence that visual analysis shows indications for needed actions very late in the deterioration infrastructure process, or not at all. Consequently, the objective of the EU project DESTination RAIL [1] is development of a Decision Support Tool, which relies on reliable data, for rational decision making of infrastructure managers to offer safer, reliable and efficient rail infrastructure. The idea of developing a flexible decision support tool enables possibilities to use it across a range of asset classes, such as: bridges, earthworks, tunnels, switches, and tracks. Rail traffic flow optimization represents a priority in cases of restricted network availability. It is a part of a four-step process, which infrastructure managers face in their decision-making processes. Namely, location and identification of risky assets before they fail, then real-time safety assessment of existing infrastructure; furthermore, evaluation of safety and assignment of scarce resources and finally, choosing the optimal rehabilitation techniques. Using Kronecker algebra, which showed good results in dealing with bottlenecks a case study for optimization of rail traffic flow during maintenance work at Boyne viaduct in Ireland (Fig.1) was conducted. Kronecker product and Kronecker sum form Kronecker algebra. The Kronecker product can be used to model synchronisation while Kronecker sum calculates all possible interleavings. The application of Kronecker Algebra enables a deadlock free railway operation [2].

Fig.1. Boyne viaduct, Irish Rail

2. RAIL TRAFFIC FLOW OPTIMISATION TOOL

The focus of this paper lays in the fourth stage of the flow optimization, namely, the analysis of the possible infrastructure maintenance or renewal strategies. Application of microscopic simulation of railway operations based upon a physical and mathematical model of the railway system is the state of the art in railway traffic operations. Such tools output indicators for the operational performance (e.g. delays). These have a series of shortcomings, most
notably that optimisation is typically predefined by
the user of the tool and introduced into the simulation.
This common practice allows the user to find
solutions for bottleneck management and planning of
maintenance work. However, it often misses the
opportunity to find the optimum solution. It is,
therefore, not fully capable of solving dispatching
questions or handling headway conflicts. To close this
gap in future railway operation with increased traffic
flow, algorithms have to be applied which consider all
train runs at the same time. Within DESTination
RAIL, microscopic simulation tool will assess the
impact of maintenance and renewal proposals.

3. DATAFLOW MODEL

The input data used for the traffic flow
optimization tool is defined by two components: first,
the current characteristics of the rail system will be
supplied. Second, the infrastructure manager will
indicate a desired assessment of a change in the
network. Those two components will be merged using
simulation tool OpenTrack [3] for the visualization of
the data, and further processed into the concrete
syntax of the input files needed by the optimization
tool. This workflow is shown in the Figure 2:

![Fig.2. Dataflow model](image)

As it can be seen in the Figure 2, in order for
Traffic Flow Optimization process relying on
Kronecker algebra approach to deliver Output data, a
number of input data is needed. First, and most
important, is the set of Infrastructure, Rolling Stock
and Timetable characteristics, which represent the
base of future calculations. Secondly, infrastructure
manager’s identification and assessment of consequences of whether it be restricted availability of
infrastructure assets, of operational incidents.

4. DATA REQUIRED

The level of details and accuracy directly
influences the quality of output. As it can be seen
from the Figure 1, two types of sources are used for a
complete input data. First represents the crucial
elements for the operation of the railway network.
Second, the desired change in the network must be
indicated. These two components will be merged
using lightweight visualization tool before being
further processed into the concrete syntax.

4.1. Input Data: Infrastructure, Rolling Stock
and Timetable

Infrastructure data comprises information about
tracks and operation control points, as well as all
related information. The rolling stock data concerns
physical characteristics of trains that are part of the
traffic system under consideration. The timetable data
provides information about planned train routes and
their associated time schedules.

4.2. Input Data: Infrastructure Manager
Assessment Request

Infrastructure manager can analyze different
possible changes in network. First, consequences of
restricted availability of infrastructure assets can be
assessed. The aim of this is to reduce the impact of
restricted availability of infrastructure assets. The
incident can be maintenance work on a given track
section, which leads to a reduced speed limit for that
section or on the neighbouring track, as a protection
measure for the staff. Furthermore, consequences of
operational incident can be assessed. An interruption
event can be a result of the broken down train or
unavailability of the track section due to external
factors, for example, flooding of a bridge. For both
above mentioned cases, the following data has to be
provided by the infrastructure manager:

- affected track or track section (reference:
  infrastructure & timetable input)
- speed change [km/h]
- time period (begin [hh:mm:ss] – end [hh:mm:ss])
- thresholds for delays of affected trains [hh:mm:ss]
- costs of delay per minute for different train categories
  (regional, intercity, freight) and for the passenger
  transport information about differences in costs
  depending on the day of the week.

Finally, there is a possibility of assessment of
benefits from infrastructure enhancement. Examples
of infrastructure enhancement can be the construction
of an additional cross over on a highly frequented line
or construction of an additional bridge. The
following data has to be specified by the infrastructure
manager:

- location of the planned section and connections to
  existing tracks (reference: infrastructure input
  [track::id] and position on the track [meters])
- length of the planned section [meters]
- speed restriction on the selected section [km/h]
- gradient on the selected section (if changed) [%]
- set of affected trains (reference: timetable)
costs of delay per minute for different train categories (regional, intercity, freight) and for the passenger transport information about differences in costs depending on the day of the week.

5. USE CASE OF IRISH RAIL

Within DESTination Rail project, Irish Rail network, more precisely, the Boyne Viaduct (shown in Fig.1.), is used as a case study for the development and analysis of a rail traffic optimization tool.

OpenTrack [3], a software for simulation of railway operations, offered visualization of railML input data by converting them into graphic representation of infrastructure (Fig.3), where Boyne Viaduct represents the test (maintenance work) zone between Drogheda and Dundalk, obtained from the Network Statement of the Irish Rail [4].

![Fig.3. Infrastructure: Boyne Viaduct](image)

Rolling Stock data includes IC and Cargo trains using class 201 and DART traveling only to Malahide. Finally, timetable data (only for passenger trains) is shown in Fig. 4.

![Fig.4. Timetable: DUBLIN-DOGHEDA-DUNDALK](image)

Figure 5 shows a train graph, whereas in Figure 6 the optimized train run is displayed, both presenting an output of Kronecker algebra use. Clearly, the optimized train runs do not run at the maximum allowed speed, since Kronecker algebra approach offers solutions for avoidance of deadlocks. Further information and detailed outline of the function of the Kroencker algebra can be find in [5]. The solution offered by this approach shows the optimal way for passing bottleneck sections at exactly allowed speed and given time, in order to keep the occupation time at the given section as short as possible without unnecessary energy consumption due to, for example, braking for signal.

![Fig.5. Output from Kronecker algebra: Train Graph](image)

![Fig.6. Output from Kronecker algebra: Optimised Train Run](image)

Finally, Figure 7 lists delays and the energy consumption for all trains involved.

![Fig.7. Output from Kronecker algebra: Delay and Energy consumption](image)

6. CONCLUSION

In conclusion, development of rail traffic flow optimization tool enables infrastructure managers to base their decisions on reliable data without output surprises. In other words, optimal solutions will ensure high level of efficient use of, very often scarce, resources and optimal process flow. This tool will enable one to set clear priorities based on reliable data and ensure minimal loss of operations, and more importantly, energy.

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