ANDREAS SCHÖBEL, Priv.Doz. Dipl.-Ing. Dr. techn. [1]
Corresponding author: andreas.schoebel@opentrack.at
CHRISTIAN SCHÖBEL, Dipl.-Ing.[1]
christian.schoebel@opentrack.at
JOHANN BLIEBERGER, Univ.-Doz. Dipl.-Ing. Dr. techn.[2]
blieb@auto.tuwien.ac.at
STEFAN MARK, Dipl.-Ing. Dr. techn.[3]
stefan.mark@ait.ac.at
[1] OpenTrack Railway Technology GmbH
Kaasgrabengasse 19/8, 1190 Vienna, Austria
[2] Vienna University of Technology, Institute of Computer Engineering, Automation Systems Group
Treitlstraße 1-3, 1040 Vienna, Austria
[3] Austrian Institute of Technology, Center for Energy, Electric Energy Systems
Gieffinggasse 2, 1220 Vienna, Austria

BENCHMARK OF DELAYS SIMULATED BY OPENTRACK AND CALCULATED BY KRONECKER ALGEBRA ON ZAGREB-RIJEKA LINE

ABSTRACT

Within the project GoSAFE RAIL, funded by the H2020 Shift2Rail programme with focus on achieving Single European Railway Area (SERA), one work package is dedicated to the development of an integrated rail network model that will incorporate both infrastructure asset (e.g. crossings, tracks, bridges, tunnels) and traffic (e.g. vehicle, freight and passenger movement) data. Furthermore, the existing OpenTrack model of Zagreb – Rijeka line is used as an input for optimization algorithm based on Kronecker Algebra. Therefore, infrastructure topology is exported in IVT format to cover infrastructure attributes like speed limit, gradients and main signals (home, exit, block). Additionally, the annual timetable is exported in OpenTrack format to create for each train the Kronecker operations. Finally, the simulated output from OpenTrack is compared to results from Kronecker algorithm. Main indicator is the graphical timetable as well as delays of trains in their final destination.

KEY WORDS

rail traffic flow optimization; scheduling; Kronecker algebra;

1. INTRODUCTION

One of the objectives of the Shift2Rail project Global SAFEty Management Framework for RAIL Operations is the development of an evolutionary Decision Support Tool that self-learns (evolves) based on machine learning algorithms and artificial intelligence with the main goal of offering safer, reliable and efficient rail infrastructure. Due to a low number in failures on the infrastructure network, this leads to a lack of data crucial for machine learning. This will be solved by implementation of Near-Miss Concept; in other words, low-consequence events will be also included in the model and enable use of statistically significant data for model training. Furthermore, a new train mounted multiple sensor system for Object Detection will be developed.

Moreover, with OpenTrack [4] micro-simulation modelling tool, traffic model will be developed that will use multi-criteria optimization algorithms to address complex requirements, for both passenger and freight transport. Using Kronecker algebra, which showed good results in dealing with optimization scenarios in railway traffic flow, especially avoidance of deadlocks, simulation of the line between Zagreb and Rijeka in Croatia has been performed as well as an optimization based on Kronecker Algebra.

2. Kronecker Algebra for Railway Operation

One of the constantly present problems in railway systems is the problem with deadlocks especially on single track lines or during rehabilitation work [5] on a double track line and around dead end hubs. Since there were no applicable solutions in the middle of 20th century, computer scientists tried to solve this problem by implementing Kronecker algebra in the analysis [3].

Before going into solving deadlock issue, a proper definition is needed. Stallings [6] defines Deadlock as 'an impasse that occurs when multiple processes are waiting for the availability of a resource that will not become available because it is being held by another process that is in a similar wait state'. There are four preconditions for a deadlock to occur according to Coffman [1]; in other words, if one of these conditions is not met, there will not be a deadlock. There is a mutual exclusion, where a resource can only be used by one process at a time. Second, hold and wait includes processes already holding resources and requiring additional resources held by other processes. Third, the so called no preemetion, no other than the process itself can release the resource. Finally, the circular wait that requires at least two processes to form a circular chain in which each process waits for a resource that is being held by the previous process in the chain. Clearly, these four conditions can be applied to railway systems.

After defining conditions for deadlock occurrence, possible ways to deal with deadlocks can be identified. These are deadlock prevention, or removing one of the above mentioned conditions in order to prevent deadlock from even occurring; deadlock avoidance, or decision about resource allocation in advance; and finally, after deadlock detection, termination and restart of the process. For the railway systems, only deadlock avoidance is applicable [3].

Kronecker algebra is a mathematical model that consists of Kronecker Sum and Kronecker Product. For the explanation of these two operations, set of matrices (1) is defined

$$\mathrm{M} = \{\mathrm{M} = (\mathrm{mi,j}) \mid \mathrm{mi,j} \in L\} \qquad (1)$$

where L denotes a set of labels with $\langle \mathrm{L}, +, 0 \rangle$ being a commutative monoid and $\langle \mathrm{L}, *, 0 \rangle$ a monoid (Mittermayr and al., 2012). For this case, only matrices $M \in M$ with o (M) referring to the order of matrix. Additionally, n-by-n (2) matrices will be used.

Zn = (zi,j) where ∀ i,j:zi,j = 0 (2)

Kronecker product is denoted by A ⊗ B and results in mp-by-nq block matrix, as it can be seen in (3). Matrix A in this case being m-by-n and matrix B p-by-q matrix. As already mentioned above, Kronecker product is used for modelling synchronisation.

$$A \otimes B = \begin{pmatrix} a_{1,1}B & \cdots & a_{1,\mathrm{n}}B \\ \vdots & \ddots & \vdots \\ a_{m,1}B & \cdots & a_{\mathrm{m,n}}B \end{pmatrix} \qquad (3)$$

Kronecker sum of matrices A of order m and matrix B of order n, denoted by A ⊕ B (4), is a matrix of order mn defined by

$$A \oplus B = A \otimes In + Im \otimes B \qquad (4)$$

where Im and In (n-by-n matrix with ones on the main diagonal and zeros elsewhere) denote identity matrices of order m and r, respectively.

Application of Kronecker algebra in optimization of railway traffic flow lies in its functionality to detect and avoid any deadlocks within the whole analysed railway system, not just on one section. To put it differently, it can is represented as a matrix that includes all possible train movements in a system. In other words, deadlock-free solutions are overall best calculated solutions that take schedules, delays and different types of restriction on the tracks into account [7]. Whereas Kronecker Sum calculates all possible interleavings of all trains not using the same track section, Kronecker Product ensures that those using common track sections can sequentially enter only free sections, namely, sections previously released by another train. Kronecker Algebra delivers results as a matrix. However, these can be represented as a graph, especially time-speed diagram.

3. Case study Zagreb – Rijeka Line

As already mentioned, line Zagreb – Rijeka was chosen for the case in collaboration with Croatian Railways. First reason is its importance within domestic traffic network; second and more important reason, it being part of TEN-T corridor.

Figure 1 shows planned timetable (black lines) and simulated timetable (pink for fast trains and green for regional trains) for all passenger trains on Zagreb – Rijeka line.

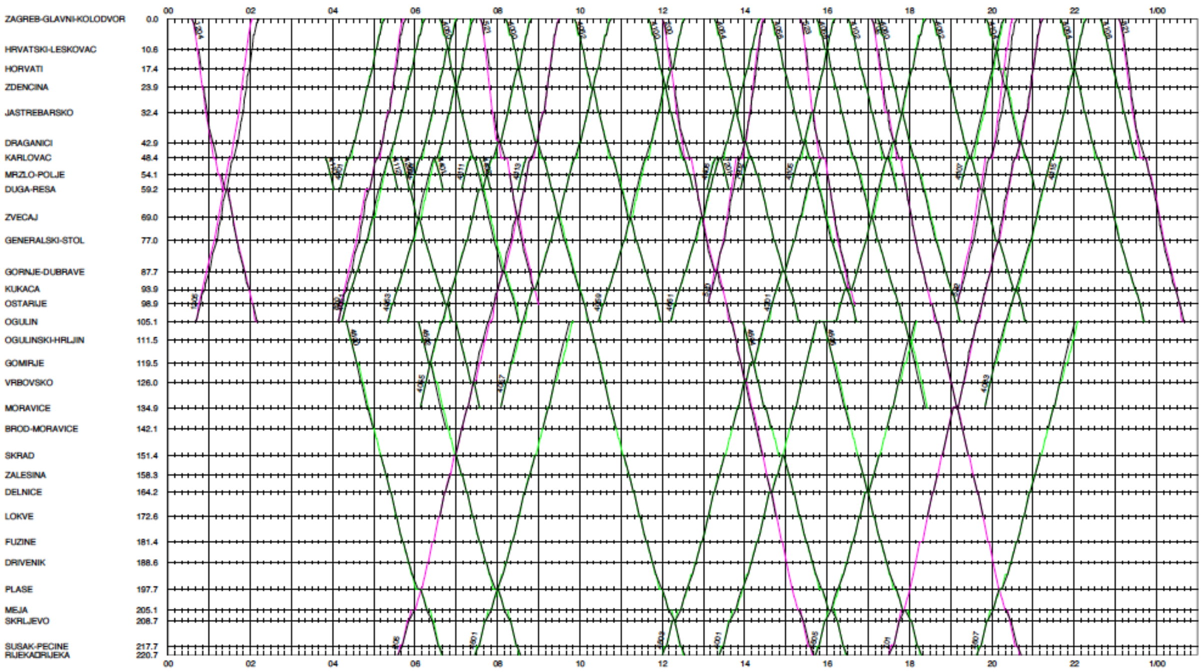

Figure 1 – Train graph of all passenger trains on Zagreb – Rijeka line
Source:[2]

As a benchmark for the Kronecker algorithm delays of all passenger trains are used according to figure 2. Delays are indicated by train ID and station ID in seconds. Obviously, majority of trains has a lot of reserve in running times and therefore arrive earlier at their final station. Of course, crossings with cargo trains are excluded in this simulation which require additional time. On the other hand, maximum delays are below 5 minutes.

Table 1 – Benchmark of earliness and delays simulated in OpenTrack and calculated by Kronecker Algebra [2]

Position	Earliness in OpenTrack	Earliness in Kronecker	Delays in OpenTrack	Delays in Kronecker
Sum of Delays in Seconds	-3143	-2779	1407	514
Number of Trains causing Earliness or Delay	42	35	14	19
Average Value in Seconds	-75	-79	101	27

Table 1 compares earliness and delays from simulation in OpenTrack of all 57 daily passenger trains using the entire or parts of the Zagreb-Rijeka line with calculated values by Kronecker. While trains arrive earlier in sum in OpenTrack simulation, delays are reduced by application of Kronecker in sum and in average. Further investigations will be carried out on the level of each single train run to validate the calculations of Kronecker by simulations of OpenTrack. Additionally, all daily cargo trains will be included as well. Thereby, the recommendations from Kronecker can be used as input for the actual performance of each single train.

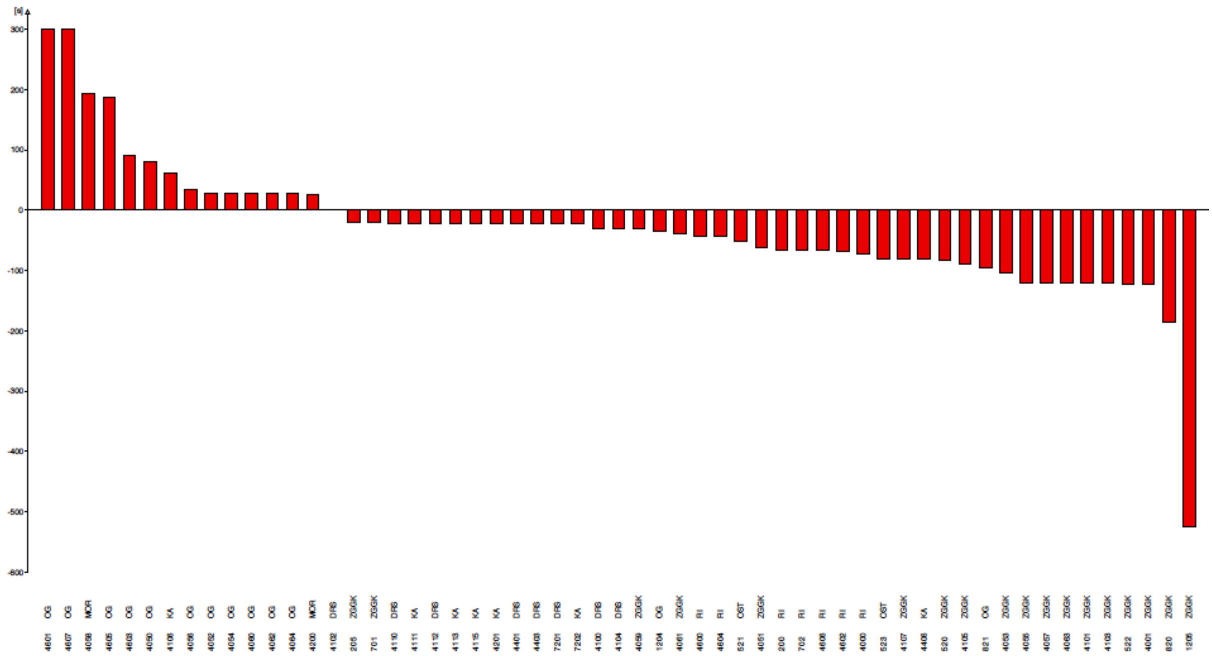

Figure 2 – Delays of all passenger trains on Zagreb – Rijeka line at their final destination
Source:[2]

5. CONCLUSION

OpenTrack, being a sophisticated micro-simulation model allows the determination of impact of safety decisions on operational network performance. Thus, by incorporating both infrastructure asset (e.g. crossings, tracks, bridges, tunnels) and traffic (e.g. vehicle, freight and passenger movement), effective delivery of maintenance or new works while maximising the connectivity and adaptability of the overall surface system will be enabled. As a performance indicator for Kronecker Algebra the delays of trains at their final station are used as a benchmark criteria. Latest test runs on the railway line from Zagreb to Rijeka show a reduction of delay of more than 60 % in sum and 70 % in average. Therefore, results from Kronecker Algebra are suitable for reducing delays. Furthermore, these recommendations should be implemented into daily operation.

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REFERENCES

[1] Coffman, E. G. J., Elphick, M. J. and Shoshani, A.,1971. System deadlocks. ACM Computing Surveys. Vol. 3, No. 2: 67-78.
[2] www.gosaferail.eu

[3] Mittermayr, R., Blieberger, J. and Schöbel, A., 2012. Kronecker algebra-based deadlock analysis for railway systems. In Promet – Traffic & Transportation: 359-369.

[4] www.opentrack.at

[5] Schöbel, A., Aksentijevic, J., Stefan, M., Blieberger, J., 2017. Optimization of rail traffic flow using Kronecker algebra during maintenance on infrastructure, In Transportation Research Procedia 27 (2017): 545-552.

[6] Stallings, W., 2001. Operating Systems. 4th Ed., Upper Saddle (21) River, New Jersey: Prentice-Hall

[7] Volcic, M., 2014. Energy-efficient Optimization of Railway Operation: An Algorithm on Kronecker Algebra, Dissertation at Vienna University of Technology