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SIMULATION OF ACTUAL NETWORK PERFORMANCE USING KRONECKER ALGEBRA FOR OPTIMIZATION OF TRAFFIC FLOW

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Abstract: *Within the project Global SAFEty Management Framework for RAIL Operations 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 micro-level simulation tool OpenTrack will be used for enabling capacity optimisation in order to maximise the availability of the transport network and minimise environmental impacts. Moreover, with this modelling tool, traffic model will be developed that will use multi-criteria optimization algorithms to address complex requirements, for both passenger and freight transport. By employing algorithm for optimization and software's application programming interface (API) in the case study network Zagreb – Rijeka in Croatia, which is a part of the TEN-T network, the behaviour of actual network performance will be simulated as a proof of suitability of solutions provided by the provided optimization algorithm. Finally, an expected impact of the advanced traffic model using scheduling algorithm is a 40% reduction of delays in long-distance traffic.*

INTRODUCTION

Rail infrastructure managers are responsible for safety measures and planning within the infrastructure network. Although the railway transport mode is considered one of the safest modes of transport [1] with 0.16 fatalities per billion passenger km's there is a number of infrastructure failures that have happened in recent years. Unfortunately, the number is expected to rise in the future, mainly due to ageing railway network and stronger climate changes.

Consequently, the objective of the Shift2Rail project Global SAFEty Management Framework for RAIL Operations [2] is 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. As already mentioned above, there is a low number in failures on the infrastructure network, which consequently 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 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 [3], which showed good results in dealing with optimization scenarios in railway traffic flow, especially avoidance of bottlenecks and conflicts, simulation of actual network performance on the line between Zagreb and Rijeka in Croatia will be performed.

MOTIVATION FOR SIMULATION

The first step in using computer models in the railroad planning is to calibrate the base case model. This should accurately replicate observed railroad operations with the existing infrastructure, rolling stock, and schedules. Once the model has been calibrated it can be used to investigate many issues including estimating the stability of new timetables, determining the minimum infrastructure requirements for a given timetable, or evaluating the impact of rolling stock changes. A significant benefit of models is their ability to evaluate the impact of incidents or time-based network changes (e.g. maintenance) on railroad operations.

Computer simulation is especially valuable for railroad planning since, once developed and calibrated, models can be used for the comparison of the benefits, impacts, and costs of various different improvement packages. To analyse more than a few improvement packages by hand would be prohibitively time consuming. Thus, effective railroad simulation models enable planners to identify and evaluate more alternatives, ultimately leading to more creative and comprehensive problem solutions.

While computer simulation is an excellent tool for analysis and planning of railroads, railroad network simulation programs have the following limitations:

- Programs must be validated to actual conditions.
- Yard operations must be modelled separately.
- Resource constraints such as crew scheduling are largely ignored (although some specialized software does address resource constraints).
- Simulations only include the modelled study area.
- Simplifying assumptions generally create an inherent optimism about overall congestion, schedule adherence, and recoverability [5].

Given these limitations, especially the last one, it is critical that all simulation results be carefully reviewed, discussed and compared to reality.

OPENTRACK RAILWAY SIMULATION SOFTWARE

OpenTrack is a microscopic synchronous railroad simulation model. As such, it simulates the behaviour of all railway elements (infrastructure network, rolling stock, and timetable), as well as all processes between them. It can be easily used for many different types of projects, including testing the stability of a new timetable, evaluating the benefits of different long-term infrastructure improvement programs, and analysing the impacts of different rolling stock. Figure 1 illustrates the three main elements of OpenTrack: data input, simulation, and output.

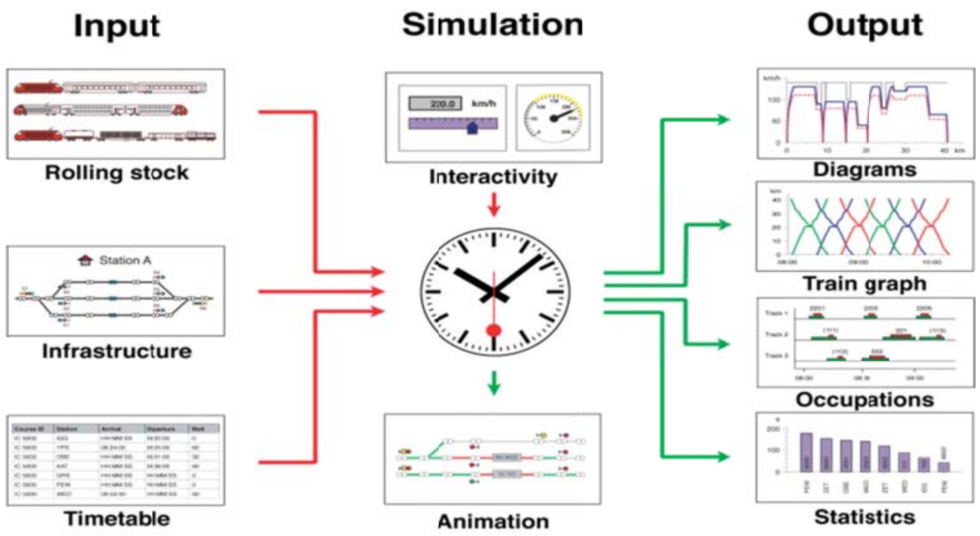

Fig.1 Data flow in simulation of railway operation
Source: [7]

Input Data

OpenTrack manages input data in three modules: rolling stock (trains), infrastructure, and timetable. Once data has been entered into the program, it can be used in many different simulation projects.

Train (locomotive and wagons) and timetable data is entered into the OpenTrack database with easy to use forms, which include shortcuts that enable data input to be completed efficiently. For example, users can designate hourly trains that follow the same station stopping pattern an hour later for the timetable input data. Infrastructure data (e.g. track layout, signal type/location) is entered with a user-friendly graphical interface; quantitative infrastructure data (e.g. elevation) is added using input forms linked to the graphical elements. Since OpenTrack uses the railML [8] structure, timetable data, train and infrastructure data can be directly imported from railML data files.

Another advantage of OpenTrack is that it enables users to adjust many variables that impact railroad operations. For example, users can simulate the impact of weather on traction by specifying the adhesion scenario (good, normal, bad).

Simulation

In order to run a simulation using OpenTrack the user specifies the trains, infrastructure and timetable to be modelled along with a series of simulation parameters (e.g. animation formats) on a preferences window. During the simulation, OpenTrack attempts to meet the user-defined timetable on the specified infrastructure network based on the train characteristics. OpenTrack uses a mixed continuous/discrete simulation process that allows a time driven running of all the continuous and discrete processes (of both the vehicles and the safety systems) under the conditions of the integrated dispatching rules.

Output

One of the major benefits of using an object-oriented language is the great variety of data types, presentation formats, and specifications that are available to the user. During the OpenTrack simulation each train feeds a virtual tachograph (output database), which stores data such as acceleration, speed, and distance covered. Storing the data in this way allows users to perform various different evaluations after the simulation has been completed.

OpenTrack allows users to present output data in many different formats including various forms of graphs (e.g. time-space diagrams), tables, and images. Similarly, users can choose to model the entire network or selected parts, depending on their needs. Output can be used either to document a particular simulation scenario or as an interim product designed to help users identify input modifications for another model run [7].

OPENTRACK AND API

The Open Track API (application programming interface) is able to communicate with a 3rd party application (over the internet). OpenTrack accepts Commands (messages to OpenTrack) and sends Status Messages (Messages from OpenTrack). Most importantly, these messages are designed such that they correspond to those exchanged in a real-world railway system between trains, interlocking and dispatching units. OpenTrack Dispatcher acts as the replacement of the reality, since the same type of information is exchanged as in reality; namely, commands (messages) go to OpenTrack, whereas Status Messages come from OpenTrack [7].

OpenTrack API's application offers an unlimited number of possibilities, starting from implementation of customer-specific dispatching algorithms to in-depth evaluation of railway operations, connections between trains and circulation of train sets. However, for GoSAFE RAIL project is the possibility of development and analysis of new concepts in train control, such as optimization of energy consumption, reduction of delays and avoidance of bottlenecks and conflicts of greatest importance.

CASE STUDAY 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.

Figures 2 and 3 show examples of infrastructure from the case study. Infrastructure data has been successfully imported in OpenTrack, as it can be seen in these graphical representations of topology. For this paper, just few examples that best reflect the possibilities of OpenTrack were selected. This can be seen in Figure 2, where one can see a detailed presentation of the main railway station in Zagreb, Glavni Kolodvor, whereas the Figure 3 shows part of the preselected network for the case study Zagreb - Rijeka, namely from Hrvatski Leskovac, via Horvati, Mavracici, Zdencina, Desinec, Jastrebarsko, Domagovic, Lazina to Draganici

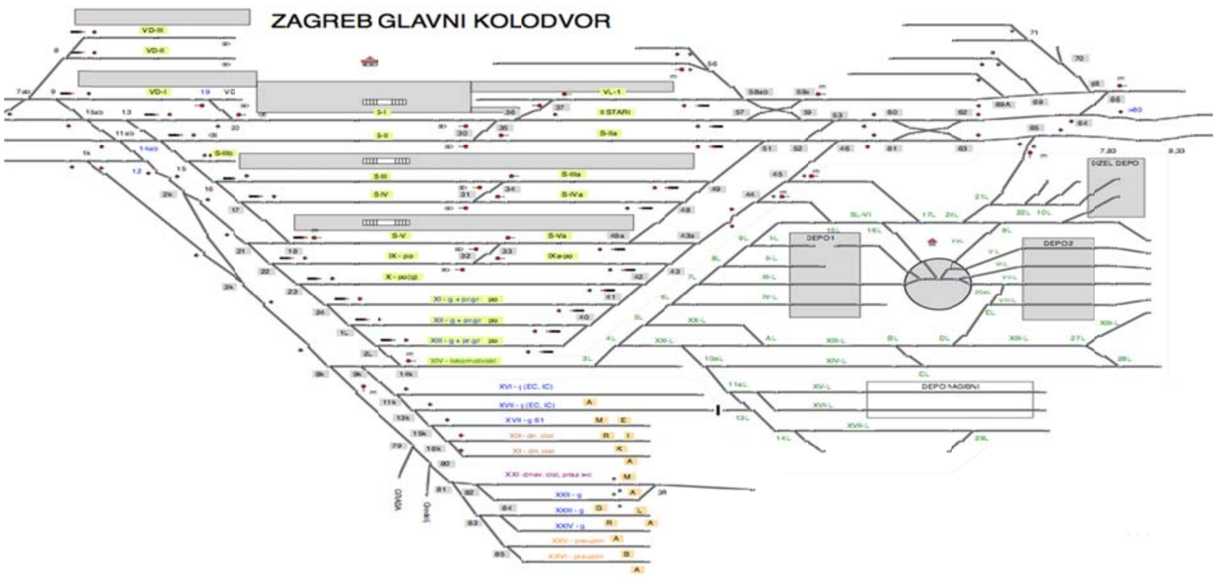

Fig.2 Infrastructure in OpenTrack: Zagreb Glavni Kolodvor
Source: GoSAFE Rail Project Documentation

Infrastructure topology includes all signals, stations and information about radius, gradient and speed profile on every kilometre point.

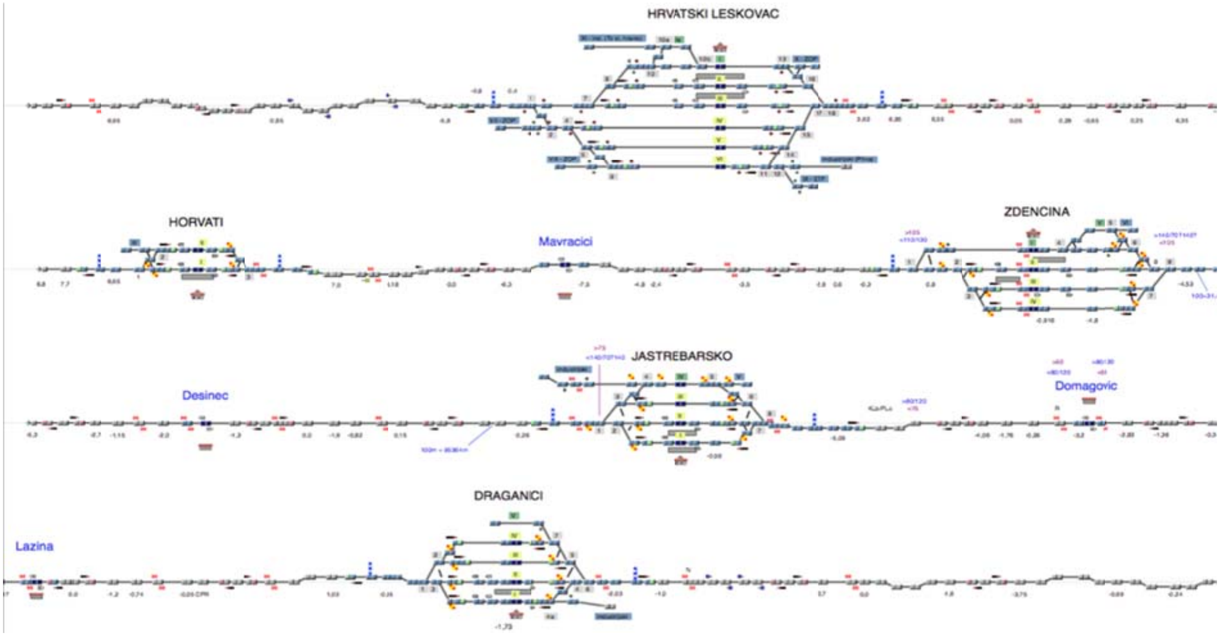

Fig.3 Infrastructure in OpenTrack: Hrvatski Leskovac-Draganici
Source: GoSAFE Rail Project Documentation

Figure 4 shows a train graph between Zagreb Glavni Kolodvor and Rijeka for different train categories between 2 PM and 11 PM. Pink colour shows fast trains, regional are represented using green and cargo using blue colour.

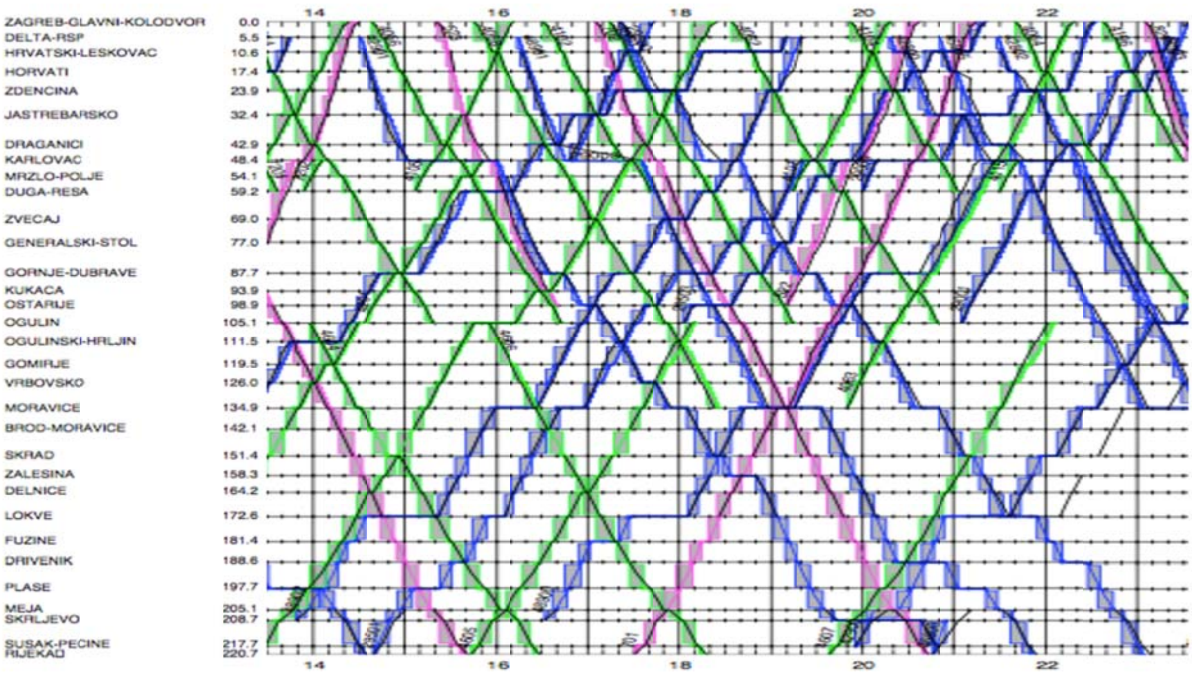

Fig.4 Train Graph in OpenTrack: Zagreb Glavni Kolodvor-Rijeka
Source: GoSAFE Rail Project Documentation

Next steps include definition of a test scenario and testing the integration of algorithm into micro-planning simulation for the chosen scenarios. These scenarios contain a track closure for maintenance in a certain time slot, or time slots; for example, when there are less trains running or more cargo and less passenger trains. Further instance can incorporate a slow speed zone due to a missing maintenance of any component, such as speed restriction on a bridge for safety reasons. These scenarios will then be tested using Kronecker algebra for the automatic optimization with the goal of minimization of delays caused by different interruptions in operations.

CONCLUSION

In conclusion, GoSAFE RAIL project will provide a means of virtually eradicating sudden infrastructure failures. OpenTrack, being a sophisticated micro-simulation model with API function, will allow the determination of impact of safety decisions on network capacity. 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. Finally, the maximization of the availability of the transport network leads to minimisation of environmental impacts, such as carbon emissions, and reduction of delays up to 40%.

ACKNOWLEDGMENT

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СИМУЛАЦИОНЕН МОДЕЛ ЗА ОПТИМИЗИРАНЕ НА ДВИЖЕНИЕТО ПО ТРАНСПОРТНАТА МРЕЖА ЧРЕЗ ИЗПОЛЗВАНЕ ТЕОРЕМАТА НА КРОНЕКЕР

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Ключови думи: *железопътен транспорт, поддържане на инфраструктурата, алгоритъм за оптимизиране, микро-симулация, модел за изчисляване на трафика, минимизиране на енергопоглъщаемостта*

Резюме: *В рамките на проект Global SAFEty Management Framework for RAIL Operations Go SAFE RAIL, финансиран по програма Хоризонти 2020 (Shift2Rail programme) и фокусиран върху постигането на Единно Железопътно Пространство (SERA), един от работните пакети е посветен на създаването на модел за интегрирана железопътна мрежа, който обхваща данни както за инфраструктурата на жп транспорт (напр. прелези, жп линии, мостове, тунели), така и за жп превози (напр. подвижен състав, влаккилометри при пътническите и товарни превози). В настоящия доклад ще бъде приложен моделът за симулации Open Track, който позволява да се оптимизира капацитета на транспортната инфраструктура, като същевременно се намали вредното въздействие върху околната среда. Освен това, този модел позволява да се развие моделът за изчисляване на трафика (пътнически и товарен) по съответната мрежа чрез използване на мулти-критериен алгоритъм. Чрез апробиране на алгоритъма посредством подходящ софтуер (application programming interface - API) за транспортния участък Загреб – Риека в Хърватска, който участък е част от трансевропейската транспортна мрежа, се доказва че предложеният алгоритъм за оптимизиране на движението е подходящ да се използва в подобни случаи. В заключение се доказва, че приложението на този алгоритъм при изчисляване на трафика води до намаляване на закъсненията на превозните средства с 40% при пътувания на дълги разстояния.*