Simulation as a support for infrastructure design and planning processes within railway junction

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Abstract

Nowadays there is paid an essential attention to modernisation and reorganisation of railway companies in the field of freight and passenger traffic with the goal to assure the high level of effectiveness. The railway junctions play very important role within the mentioned process of railway modernisation. There is usually needed to invest into the new technical equipment, to rationalise the work of service resource, to modify railway processes, to react to the changed flows of incoming trains etc. Hence, in order to adopt the essential decisions connected with reengineering of railway junctions it is necessary to study the consequences in advance within the frame of suitable virtual environment. Computer simulation represents an appropriate modelling technique, which enables to study many different variants of the complex system operation. This paper deals with the simulation software VirtuOS that is specialised in the detailed simulation of railway junction operation. There are described also examples of the mentioned software utilisation in real projects and emphasised its application capabilities.

1 Introduction

Railway junctions, especially marshalling yards, are parts of the railway network equipped with expensive technical devices where complex technological processes take place. In order to meet the exacting demands of such systems, a highly efficient management and top-quality administration and co-ordination decisions are required. Hence, an optimum configuration of infrastructure, maximum exploitation of technical and human resources as well as use of efficient technological processes are of vital importance.

2 Simulations as a support for the management

A railway junction is to be managed so that high system performance and process quality on the one hand and minimum infrastructure and operating costs on the other are ensured. This can be achieved in different ways, e.g. by adapting the infrastructure, incorporating new infrastructure elements, using other types of resources, improving resource planning, changing processing techniques, modifying decision strategies or completely reengineering the system. Of course, all these points are also applied to the configuring of new junctions.

The question is now what can be done by the management to take decisions as objectively as possible and to prevent wrong decisions from being made.

Owing to the already mentioned complexity of such transportation system and their stochastic behaviour, the application of exact mathematical solutions is very restricted. Classical expert studies do not comprise sufficient objective elements, which would make many decisions easier for the management and could avoid the frequently observed indecision or even aversion to whatever decision.

The application of an objective tool, which might also contain elements of exact solutions to subproblems, is the obvious choice as a solution to this situation. Its response and results must be so understandable and convincing that both the specialist-consultant and the management can consider them an objective aid to decision-making processes and an argumentative basis.

Such a tool is the simulation model of a railway junction, which replaces an existing railway junction or one to be in a design stage by a computer model. This model is used to graphically reproduce and animate the system to be modelled and its processes true to reality. The findings of such a model may provide the basis for many decisions using output statistical data as well as animated operational processes and events. The consequences of such decisions can be traced and evaluated.

The simulation of systems is a research method supporting the analysis, design and optimisation of real systems in the following three steps:

- Replacement of the real system by a simulation model.
- Experimentation with the simulation model with the aim to determine its properties, behaviour and reactivity to changed conditions.
- Application of the results obtained to the real system (existing or to be configured).

The simulation model must be as true to reality as possible in order that the findings of the experiments can be transferred to the real system. On the other hand, there is a limit to the truth to reality of the model, which should not be exceeded. Simulation must be considered an approximate (not exact) method. The simulation model is situated in an experimental environment and simulation is an experimental method.

As a railway junction is a highly complex system, the application of simulation techniques seems to be the only possible solution.

3 Simulation tool VirtuOS

Let us briefly mention the main facts about simulation tool VirtuOS. This tool was developed in order to enable to build a simulation model, which reflects the whole complex system of a railway junction i.e. marshalling yard (Klima[1,2]), passenger station, private sidings etc. The essential motivation was based on the need to be able to realise simulation experiments, the results of which could be applied to the real railway yards and help to:

- design a suitable layout of tracks infrastructure within the yard,
- propose the needed amount and composition of mobile service resources,
- create efficient train service technologies and
- verify convenient control and decision making strategies.

However, VirtuOS itself does not provide automatic solutions of the problems, which occur within the yard. It represents an experimental environment (a laboratory) within the frame of which it is possible to study many variants of a studied yard operation, topology of tracks etc. Principally it is possible to say that using VirtuOS the user-experimenter can answer the questions: "*What will happen if...?* " Therefore it is expected that VirtuOS is handled by the well trained railway technologist who, in addition, co-operates with the management of an investigated yard.

The work with VirtuOS can be divided into three basic stages:

- Input data collection from a real yard (or prognostic data definition for a new designed yard) and the building of its model.
- Iterative process of simulation experiments (the runs) on the model.
- Recommendations for the yard operation and infrastructure layout based on the results of simulation experiments and their analysis.

In order to build up the above mentioned model it has to be collected the data about:

- *Infrastructure* (tracks) - there is scanned and vectorised the paper documentation of a yard (physical infrastructure) and then the function of each of track is defined (logical infrastructure).
- *Mobile service resources* (personnel and shunting locomotives) - there are defined the numbers, professions and working shifts for all these resources.
- *Trains* - the information about train flows (incoming and outgoing) has to be defined and it is also needed to get the statistics about incoming trains composition.
- *Technological processes* - there are defined the train *service technologies* (in the form of network graphs) after train arrival and before train departure, train *sorting* and train *forming processes* (simultaneous train formation, primary and secondary humping, sorting using a hump or flat humping etc.).

- *Control* and *decision making strategies* - there are set up the managements of service resources, the decisions of changes of simultaneous train formation schema etc.

When the building of a model is finished, there is made its verification and validation. After that it is possible to start process of making simulation experiments which investigate the yard operation under the required different conditions.

The simulation run can produce the different kinds of outputs. During the simulation run it is possible to see on the screen the animation of all movements of trains and service resources and also on-line statistics about utilisation of service resources are on the shelf. On the other hand the post-simulation outputs can be used. The simulation run reports its evolution into the simulation protocol (file on the disk). Afterwards, using the specialised tool, it is possible to obtain from the mentioned protocol any required statistics and the graphical protocols (using time scale) of the realised work of any service resource, any track occupation etc. In addition, it is possible to offer the customers the software called *VirtuOs-Viewer*. That software enables to have a look at the whole simulation run using animation outputs.

The results of simulation experiments are analysed and studied by the local technologists. Then there are made the concrete proposals of the real yard operation changes or the results show the need of additional experiments. It is possible to say that the adduced working procedure requires an iterative approach, which usually leads to the solution of some specific problem.

4 Problem solutions using VirtuOS

4.1 Methodological approach

The quality of operations control in a station/marshalling yard (meeting of criteria such as low operating costs, compliance with the timetable, defined annual throughput of wagons processed, etc.) depends on the properties of the station/yard. These properties can be formally described by a hierarchical parameter structure.

The example below shows a parameter structure based on yard properties. Parameter **P** stands for all yard parameters. The set of parameters with a subscript is the distribution of all parameters **P** to the groups $\mathbf{P_1}, \mathbf{P_2}, \ldots$, where each group contains related parameters. The lowest level of the descending hierarchy comprises *elementary* parameters already being *value parameters*, i.e. parameters with a specific value. From this point of view, the parameters of the upper levels only have a logical, formal character and designate the group of parameters on the lower level.

P : properties of the yard
- $\mathbf{P_1}$ **:** flows of incoming trains
- $\mathbf{P_2}$ **:** track configuration
  - $\mathbf{P_{21}}$ **:** configuration of arrival tracks
    - $\mathbf{P_{211}}$ **:** number of arrival tracks
    - $\mathbf{P_{212}}$ **:** length of arrival tracks
      - $\mathbf{P_{2121}}$ **:** length of arrival track No. 1
      - $\mathbf{P_{2122}}$ **:** length of arrival track No. 2
      - ....
  - $\mathbf{P_{22}}$ **:** configuration of departure tracks

....

P_3 : track discipline

P_4 : staff available

....

P_i : train processing technology

P_{i1} : technology of processing incoming trains

.....

P_n : strategy of engine allocation

....

The system user (i.e. the person who has to solve the problems when configuring a new junction, reconstructing an existing one or rationalising operations control) formulates the problems in the form of questions.

The example below encompasses a number of questions whose structure corresponds to the parameter structure of a specific yard. Each question can be formulated as follows: What value is to be assigned to the parameter or parameter group? Question $\mathbf{Q_{ij}}$, for instance, is a question about the optimum value of parameter or parameter group $\mathbf{P_{ij}}$.

Q : What properties must the yard have to ensure optimum operation?

Q_2 : What is the most favourable track configuration?

Q_{21} : What is the most favourable configuration for the arrival tracks?

Q_{211} : How many arrival tracks are required at least?

....

Q_{212} : What is the most suitable length for the arrival tracks?

Q_{2121} : What is the most suitable length for arrival track No. 1?

Q_{2122} : What is the most suitable length for arrival track No. 2?

....

Q_{i1} : What is the best technology for the incoming trains processing?

......

All the questions are intended to optimise the parameters (they ask for optimum parameter values). The simulation, however, is an *experimental* method not directly suitable for the solution of optimisation problems. It is rather a method by means of which the behaviour of a system at its outputs can be determined as a function of its input variables. If the permissible value range of a parameter **X** is $< \mathbf{X^1} \ldots \mathbf{X^k} >$, the determination of the optimum value $\mathbf{X^{opt}}$ is based on the following procedure. We express the assumption that $\mathbf{X^i}$ is its optimum value. Next, a *simulation run* is started using this value for determining the system behaviour. The next assumption is that $\mathbf{X^j}$ is the optimum value, and the simulation is repeated. After a sequence of such simulation runs (also called a *simulation experiment*), the assumption with which the system showed the optimum behaviour is accepted (value $\mathbf{X^{opt}}$). As a rule, all complex questions must be broken down into elementary questions.

If, e.g., the answer to question $\mathbf{Q_{212}}$ about the length of the arrival tracks is to be found, the procedure described above results in the examination of several "reasonable" combinations of parameter values $\mathbf{P^i_{2121}}, \mathbf{P^j_{2122}}, \ldots$ The examination of each one of the combinations of parameter values is equivalent to the performance of a simulation run.

This relatively detailed description of the simulation procedure was intended to emphasise that a single simulation run is not sufficient (as frequently supposed by the user) to give a direct answer to an optimising question. On the contrary, such an answer (and not the exact answer but an answer determined by experimental means only) cannot be obtained by the user before he has carried out a complete experiment comprising several simulation runs. Such a procedure requires expert knowledge and is very time-consuming but probably the only possibility regarding the complexity of a railway junction. On the other hand, a finally implemented model of a junction provides a lasting and relatively universal environment for further problem solutions.

4.2 Problem solving

VirtuOS is a universally suitable simulation tool, which supports the creation of simulation models used for the solution of many local problems of railway junctions. It is also suitable for the solution of problems arising from changes in the surrounding railway network.

In the following, some typical problems from these fields will be described.

4.2.1 Changes in flows of incoming trains

Using a simulation model, a junction operation can be determined and evaluated before the flows of incoming trains have actually been changed. Changes in the flows of incoming trains usually result from modifications to the railway network, which can be described as follows:

- Reduction, increase or structural changes in the flows of incoming trains due to customer interests.
- Changes in the network technology by the introduction of a new timetable. A typical task for a simulation model in this context is the modelling and examination of operational conditions in a junction before introducing a new timetable.
- Changes in the network infrastructure (e.g. decisions on the discontinuation or restriction of work in another junction) can also result in changes in the flows of incoming trains and make necessary the examination of the operational processes in a junction.

4.2.2 Cost savings by optimum use of resources

The allocation of staff and shunting engines can be optimised using VirtuOS. Not only capacity utilisation can be improved considerably, the amount of resources can be reduced as well.

4.2.3 Rationalisation of technological processes

One possibility of a junction operation optimisation without the need for expensive infrastructural measures is the introduction of new technological procedures, e.g. the simultaneous formation of outgoing trains, parallel humping, concentration of humping activities in a shorter time interval as well as the performance of more process operations in parallel.

Using the VirtuOS-based simulation model, the effectiveness of these procedures can be investigated before their implementation in reality.

4.2.4 Planning of infrastructure maintenance

VirtuOS is suitable for preparing necessary operational modifications during the maintenance of a junction and scheduling maintenance work.

4.2.5 Reconstruction and configuring of junction infrastructure

The reconstruction of infrastructure is a very complicated and expensive intervention in the operation of a junction. Reconstruction activities may comprise a reduction, exchange or amplification of tracks, brakes or safety equipment. Today, it is hardly conceivable that the management takes a decision on infrastructural adaptations without investigating the resulting consequences using a simulation model. VirtuOS is an effective and tried-and-tested tool for an objective verification of decisions. If the decision on a reconstruction has already been taken, the individual stages can be planned and the operational processes affected by the infrastructural measures within a phase can be examined through VirtuOS.

Of course, the above said also applies to the configuring and installation of a new junction.

4.2.6 Verification and improvement of operation control strategies

An important feature of VirtuOS is its capability to co-operate with the user during a simulation run. The user (in this case e.g. the dispatcher) can define problems he wants to solve on his own during the simulation of operation in advance. The simulation model permits him to trace and evaluate the consequences of his decisions. By doing so, the dispatcher is able to examine the suitability of different operations control strategies. This co-operation feature of VirtuOS also proves to be very advantageous in the training of managing staff.

4.2.7 Management of crisis situations

The railway network and its junctions may also be exposed to different critical social situations (crises), not ascribable to certain management decisions but to the failure of human or technical factors or an Act of God.
The following crisis situations are conceivable:

- Acts of God (e.g. floods, earthquakes, epidemics, etc.).
- Technical events (collision of trains, power failure, etc.)
- Social events (strike, military conflicts, etc.)

Such crisis situations may affect a part of or an entire railway junction and result in considerable changes in the flows of incoming trains or affect the infrastructure, reduce the availability of resources or impose changes in the operations control of the junction (e.g. by changing priorities).

A typical property of the above-mentioned crisis situations is that they can only be dealt with after their occurrence and the financial damages are high. VirtuOS is an ideal means for the simulation of such "scenarios" for determining an operations control strategy for the individual exceptional situations to be expected.

5 Examples of real applications

5.1 Project Linz Vbf

The main goal of Linz project (realised in the co-operation with the General Directorate of Austrian Federal Railways in Vienna /GD ÖBB Wien/ within the years 1998-1999) was to investigate the concentration of train forming processes in marshalling yard Linz Vbf after the proposed yard extension (Kavička [3]). In order to manage all processes it is necessary to modernise technical equipment and technological procedures in Linz yard.

The most costly part of marshalling yard is represented by infrastructure of tracks. Therefore it was paid essential attention to the design of a tracks dimension within the frame of which the future operation will be realised.

The simulation experiments verified gradually the capacities of:

- reception siding,
- hump tracks,
- sorting siding,
- departure siding,
- loop track (which enables the direct train departure from sorting siding to the opposite direction) and
- individual developments of switches.

At the beginning we started to test the maximal variant of track infrastructure, which respected the required yard capacity, technological requirements and also the local limitations.

At first we were focused on reception tracks. The investigation of reception siding capacity had to include the problem of opposite train movements. These movements essentially influence the utilisation of a hump. Therefore the development of switches between reception siding and hump tracks was designed (and verified by simulation experiments) in the form which enables big number of parallel movements – the train arrivals to reception siding from the hump direction and humping of trains at the same time.

When the simulation experiments connected with reception siding were finished there was paid attention to sorting and departure siding. In order to propose the capacity of sorting siding mainly these factors had to be considered:

- number of humped wagons,
- technical equipment of sorting siding (wagon positioners, brake compressors etc.),
- interlocking system on a hump (that influences the humping speed) and
- possibility of train set transfer to departure siding.

There were realised simulation experiments, which studied various humping speeds and also the occupation of departure tracks. At the end of this stage the numbers of sorting and departure tracks were proposed.

Because of capacity limits of railway network and operational effectiveness it is convenient for the distribution of wagons to form group trains within marshalling yards. The same requirement was defined also for the modernised yard Linz Vbf. The group trains were supposed to be formed using simultaneous approach. The secondary sorting during the simultaneous train formation was to be made on the secondary hump. There were studied those requirements within the several simulation experiments. The results of those experiments showed, that the process of secondary sorting was not feasible on the proposed tracks.

Hence, there were made, on the base of mentioned results, the changes of:

- emplacement of secondary hump,
- topology of departure siding and
- development of switches in sorting and departure sidings.

New track infrastructure design causes only the minimal interference between the secondary sorting process (as a part of group train formation) and the other train movements.

The individual simulation experiments showed (during solving essential problems) also some smaller inconveniences in the construction of switches developments that were caused by missing or bad located track connections.

After investigation of all tracks proposals there were studied within the further simulation experiments the numbers and compositions of shunting locomotives and personnel. The rest of simulation experiments paid attention to the prognostic flow of incoming trains which was sufficiently increased in order to verify the reserves of the new designed infrastructure of tracks.

The project was finished with the encouraging results, which showed the feasibility of effective yard operation after its extension. Nowadays GD ÖBB Wien is supposed to make decision (also on the base of our project results) about the investment to Linz yard reconstruction.

5.2 Other projects in a nutshell

There are several already realised projects and couple of current ones using simulation software VirtuOS. Let us enumerate at least some of them.

Project *Hamburg Alte Süderelbe* (1998) - simulation study for investigation of track infrastructure capacity in the station Alte Süderelbe (City of Hamburg area), in connection with anticipated increase of incoming train flow rate, outlook to the year 2010. The project was realised in co-operation with company Haas Consult Berlin and City of Hamburg.

Project *Mainz Bischofsheim* (1999) – customisation of software product VirtuOS for the special needs of DB Cargo (German Cargo Railways). There was modelled marshalling yard Mainz Bischofsheim. On this project we co-operated with Siemens Braunschweig and DB Cargo Mainz (Germany).

Nowadays we have been working on two current projects, which are focused on the economisation of big marshalling yards:

- Central marshalling yard of Vienna (Wien ZVBF) – with the co-operation of the Austrian Federal Railways. (GD ÖBB Wien), Austria.
- Marshalling double-yard Oberhausen-Osterfeld (Germany) – with the co-

operation of Siemens Braunschweig, Germany.

The main goal in both cases is to modify and improve the railway processes (technologies) within the yards without the need (if possible) to invest into the track infrastructure reconstruction.

6 Conclusions

The substantial decisions in the field of transport, respecting the contemporary level of information technologies and simulation methodologies, should not be adopted without the modelling of their consequences. Hence, it is essential also for planning connected with railway junctions (track infrastructure layout, resource dimensioning and rostering, service technologies, decision-making strategies, reactions on the networks changes etc.) to apply the modelling techniques in order to investigate the proposed measures and solutions. The complex and in practice verified simulation tool VirtuOS enables not only to investigate the consequences of adopted decisions but also by means of the reasonable sequence of experiments to choose the best solution and to save the financial resources.

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