SYNCHRONOUS RAILWAY SIMULATION OF SHUNTING YARDS

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ABSTRACT
Capacity analysis using simulation tools is an important factor to support strategic decisions in railway operation and infrastructure development. This work describes a railway simulation tool for shunting yards using a synchronous approach. Latter includes movement generation in simulation real-time and is essential for reduced set-up times, a flexible application for different yard layouts and various shunting strategies. An adequate network graph design was used for automatic routing decisions and methods for deadlock avoidance were implemented. The available approach results in an executable model to be validated with real data.

Keywords: shunting, synchronous simulation, railway simulation

1. INTRODUCTION

Ongoing optimization of railway infrastructure and its operations are important factors to strengthen the competitiveness of railway operators compared to other modes of transport. Investment decisions – especially in the field of railway transportation – tend to have long planning and lifecycle times, respectively and result in high costs for planning, development and maintenance. In many cases such planning problems have to consider the complexity of variables, input parameters and their variability. Due to the complex interactions between the infrastructure to be planned and the shunting processes simulation is seen as a reliable method and planning tool. Nevertheless, nowadays the available simulation tools for shunting yards cannot cope with capacity analysis on a fast and fairly aggregated level. Sufficient set up times are required for scenario analysis, which results in high costs and long cycle times for specific shunting yards. This research closes this gap, as with SimShunt an innovative simulation model structure has been developed that is ready to use for different shunting yards with short set-up times and fairly easy to handle (Hüttler, Gronalt, and Zazgornik 2011). Set up times deal with the infrastructural investigation, flows of incoming and outgoing trains and wagons as well as routing and scheduling within the yard according to shunting strategies and resource allocation.

The existing tools do not allow a strategic network wide view. Currently, the Austrian Federal Railways (ÖBB) who are developing partner use the simulation tool NEMO, but as it only deals with the arcs of a rail network, it is not possible to use it for capacity analysis. The software tool RailSys can be used in combination with NEMO (Kettner, Sewcyk, and Eickmann 2003) and tackles the simulation from an asynchronous point of view. It is possible to simulate planned and delayed train schedules and it allows rescheduling automatically to compare and validate decisions made in reality. Simulation software VILLON can be used for simulating logistic nodes, like plants, ports, railway stations or shunting yards (Kavicka et al. 1999; Adamko and Klima 2008). Sufficient data set up is needed and several months of work are required. Besides this, Marinov and Viegas (2009) work with simulation models for analyzing operations at shunting yards. Deadlock avoidance in synchronous railway simulation is the main aspect in Pachl (2007) and Pachl (2011). Cui (2009) deals with a hybrid simulation model for semiautomatic dispatching of railway operations. The focus is set on processing the synchronous simulation including a solution of the deadlock problem for railway operations. The publications of van Wezel and Riezebos (2005) as well as Riezebos and van Wezel (2009) deal with computing k-shortest paths (Eppstein 1994) for shunting yards. These algorithms are the basis for operational processing of shunting operations and are also used in the SimShunt model. Eggermont et al. (2009), Dahlhaus et al. (2000) and Dahlhaus and Systel (2011) describe sub-problems that occur at a shunting yard. Their work defines problems and their complexity from a mathematical point of view and can be seen as a basis for developing algorithms for practical usage. More complex problems that include more than one sub-problem including mixed integer programming models can also be found in He et al. (2003), Bektas et al. (2009) and Bohlin et al. (2011). Finally, Boysen et al. (2012) present a literature review on shunting yard operations.

The goal of this research is the development of a new simulation approach for capacity analysis of shunting yards using synchronous simulation technique. This method allows building up a generic model with the desired properties of short set-up times, easy scenario variation and various shunting strategies. The time consuming development of a predefined timetable of shunting movements according to strategies is replaced by an automatic real-time decision system.

2. PROBLEM DESCRIPTION

Several characteristics of shunting yards have a direct impact on yard's capacity: Infrastructural equipment, infrastructural resources, their allocation and shunting strategies. In order to take into consideration the most relevant parameters for yard's capacity, the high number of interdependent shunting movements in the complex railway network has to be rebuilt in the model. Therefore, asynchronous railway simulation models use a complete a priori scheduling process. In contrast to that, the SimShunt model realizes a synchronous approach, where every movement is defined in simulation real-time (see Pachl 2007). The benefits are extremely short scenario setup times, easy variation of input parameters and a flexible implementation and use of strategic algorithms. During realization two problems arise: The routing and the even more important deadlock problem. The proposed routing method is based on the k-shortest path algorithm (Eppstein 1994) and needs a special network-graph design to fulfil the requirements for shunting movement modelling. Most relevant characteristics of shunting processes are the great number of reversal movements dependent on train length and signal infrastructure as well as their interdependencies. Furthermore, the movements are bounded to a yard's rail network with short track lengths, large number of switches and tracks of solely bidirectional usage.

Deadlocks can occur for several reasons, like violation of movement sequence and conflicts because of inaccurate routing decisions. Pachl (2011) points out that "*With increasing size and complexity […] the deadlock problem has become more and more evident. Known strategies against deadlocks known for decades from computer science and operations research do not really fit to the specific needs of railroad operations simulations.*" Shunting yards belong to the most complex rail networks, with a very high number of tracks with bidirectional operation. Therefore, the deadlock-problem is a very serious issue and one of the most important facts to provide a fully functional simulation. Our approach, solving the deadlock-problem is to combine synchronous simulation with an asynchronous dispatching logic by means of implementing optimization algorithms.

3. METHODS

Proper routing solutions and deadlock avoidance are the key factors for a successful implementation of a synchronous shunting yard simulation. The methodical approach is described in the following and results in an executable simulation tool using the Software 'AnyLogic' that is ready for validation.

3.1. Network Definition

A network graph is defined consisting of nodes and arcs and is needed as a basis for the automatic generation of shunting movements of train units with variable length. Therefore, the whole track layout is implemented true to scale and exact signal positions and their orientation are included as well. All possible movements on shunting yards are usually available from their operators and documented for terms of security and switch standing. This information is used to generate elementary movements, which represent the arcs in the graph and link the nodes, which are signals, together. The arcs are weighted by the track lengths that the elementary movements contain. Reversal movements are not needed to be listed in real operation, because of their manual treatment by the signal operator. In fact they are dependent on the length of the moving train unit. To include them in the graph, the already existing movements are supplemented by adding a set containing two types of elementary reversal movements. Thus, directional movements are defined and can be triggered by defining the permitted movement types in case of restrictions. Those are required due to the fact, that movements can have defined directions for leaving start signals and reaching target signals, respectively.

3.2. k-Shortest Path Implementation

Based on the network graph defined above, a k-shortest path algorithm (Eppstein 1994) is used to define required routes from start to target signal with additional requirements concerning movement direction, orientation and length of the train unit that has to be transferred. During shunting operations tracks and signals have to be excluded from routing algorithm, because of resource assignments to other operations or occupation by other train units. Furthermore, in some cases it is necessary to overrule the finding of the shortest path or enforce the use of a particular track sequence. Maybe Loop tracks have to be used for changing train orientation in the system or the correction of long distance routes is required in case of arrivals and departures. For example latter occurs in a curved yard layout, as the shortest routes are the ones containing tracks near the inside radius, which possibly leads to conflicts with other operational instructions. Hence, modifications were made in terms of restraints defining optional signals to be included in the route and signals to be removed from graph. Besides that, the weight of a route has to be modified dynamically according to the train length and a variable penalty to charge the effort of reversals. For complexity reduction reasons some simplifications are made concerning track occupation and assignment to signals. In the present model every non moving train unit in the system is assigned to a signal and has to be coupled logically to those assigned to the same signal. Accordingly there is just one train unit located at a signal and assigned to each signal besides shunting engines.

3.3. Deadlock Avoidance Strategy

To avoid deadlock occurrence at first stage, a route reservation strategy was implemented. Because almost every track in the shunting yard is of bidirectional use, they have a high potential of conflicts, leading to deadlocks in the simulation system easily. One possible solution is to guarantee movement execution from start to target signal and avoid stops in between. Therefore, tracks are classified into two types. Capacity tracks are able to allow train units to stop at their signals, which act as start and target signals. The remaining ones are connecting tracks, where stopping is prohibited besides reversals. Their signals are used for routing purpose only. To guarantee conflict free operation and correct sequence of task execution on capacity tracks, a second reservation procedure is applied. Operational tasks according to the shunting process need to reserve capacity tracks involved in their movements included in their execution process. Depending on their explicit action, this reservation has to take place at task start-up or during operation successively. This reservation procedure turned out to be too restrictive in terms of capacity loss because of too long periods of pre-reservation, especially during long distance moves. To face this problem, an optimization based algorithm is implemented in the model. A mixed integer programming model (MIP) was formulated, to add an asynchronous despatching logic scheduling movements in waiting position. It guarantees a conflict free dispatching. Since this method is used within the simulation a fast computation is needed, which is often in conflict with the combinatorial complexity of such models. Therefore, an iterative approach was chosen and the MIP-model is solved repeatedly every time a new movement is ready to dispatch and results in assign- and reassignment of movement start times

3.4. Control Unit Further Research

Shunting movements have to be generated out of the running simulation in real-time. Therefore, decisions for track allocation and humping sequence have to be taken into account. This is done by using optimization methods, namely exact and heuristic ones, which are developed and embedded within the simulation model. Two steps are performed to develop the complete simulation framework. First, heuristic rules are developed for the test shunting yard to validate the model with current best practice. Second, more advanced decision rules are implemented to allow generic decisions, independently for different shunting yards and layouts.

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