Designing railway terminals using simulation techniques

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Abstract: *Railway service terminals are the places of a railway network usually equipped with costly technology based on highly complicated technological procedures demanding a high degree of coordination and control skills. Design of these systems and the organization of their operation should facilitate reaching to the required capacity together with high quality of service processes as well as minimal costs of resources. Due to the complexity of such systems, a simulation model seems to be the only suitable tool for performing investigations under realistic conditions. The paper focuses on the possible utilization of simulation methods to support the design and optimisation of infrastructure, operation, and process control algorithms in railway terminals. The paper also deals with the most important properties and possibilities offered by the simulation tool Villon and comments on the experience gained during its utilization. The tool supports tactical (mid-term) and strategic (long-term) planning usually related to infrastructural or operational proposals which are supposed to guarantee the optimal (or at least effective) behaviour of the modelled terminal.*

Keywords: *simulation model, simulation tool, railway terminal, infrastructure design, Villon*

1. Introduction

The transfer process is composed of a *movement* along the transportation route and of necessary *manipulations* (service processes) applied to transportation means and to transported commodities at specialised locations called (transportation) *terminals*. At the terminals, individual entities may arrive, depart, and be subjected to service or to transformation. Several kinds of elements are distinguished in the terminal structure:

- *Stable resources* - infrastructure (transportation paths, security and information elements, buildings and other static equipment, e.g. platforms, parking lots, etc.);
- *Mobile service resources* (human resources, transport, and manipulation devices, etc.);
- Elements subjected to a service - *customers* (cars, railway carriages, containers, passengers, etc.) and
- *Control system* for service and movement processes.

Undoubtedly, the most complicated situation from the point of view of manipulation and process control occurs in terminals, where the infrastructure is composed mostly of set of tracks, where the mobile service resources are mostly locomotives and where the elements under service are also mostly railway vehicles. The terminals with these characteristics are in the focus of our attention.

2. Transportation Terminals

Some examples of railway terminals, where the common problems concerning the infrastructure design and planning and the traffic control appear, and where also the similar approach to their solution is applicable, are described hereunder:

Marshalling yards contain usually only the railway infrastructure and the prevalent activities are transformation operation with the rail vehicles (coupling, uncoupling, sorting, various kinds of shunting, etc.).

Passenger railway stations are also equipped mostly with railway infrastructure, but the prevalent activities are the service operations (entering and leaving the carriages, cleaning, etc.). The elements subjected to a service are passenger carriages and also passengers in the entrance hall.

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Industrial sidings often combine railway transportation with road transportation and they contain respective infrastructure, service resources and elements. In heavy industry plants, the set of tracks may be extremely large and may even contain an independent yard for train formation. Complex operations, such as manipulations or loading and unloading of different substances are typical for such terminals.

Specialized railway logistic centres - railway depots serve usually for maintenance, reparations, cleaning and other services as well as for completion of train sets.

Terminals for multimodal transport (e.g. container terminals) contain also a heterogeneous infrastructure and various types of elements (railway, road, water transportation elements).

Transport nodes, which from the point of view of infrastructure problems and traffic operation problems, should be understood in a broader sense as an integration of several types of terminals that are interconnected by rail lines or roads.

3. Problems

The management of railway terminals deals with a number of complicated problems during the process of terminal design, i.e. process of designing, building, reconstruction and operation. These problems can be divided into two main categories – infrastructure planning (designing) and operational processes planning including the management of resources.

In general, the problem of terminal design can be understood as a need to answer the questions:

- Which elements the infrastructure should be composed of and how to integrate these elements into the system?
- Which alternatives of decision strategies and operation control to choose, in order to reach the maximal process effectiveness and the minimal resource utilization?

These questions are important for the implementation of long-term strategic plans as well as for the effort to increase the efficiency of existing terminal operation.

Among strategic aims are namely:

- Decision to construct a new terminal or a new part of a terminal.
- Technical reconstruction of a terminal infrastructure, usually followed by modernization of its elements.
- Enlargement of infrastructure with the aim to increase its capacity, if the service increase is expected.
- Decision to reduce the active infrastructure if the service depression is expected.
- Decision to concentrate investments into modern and well equipped large terminals and to suppress operations in other terminals.

From the operational problems in infrastructure planning, we can mention following:

- Terminal operation is too costly or terminal is working below required capacity while solutions via optimisation of mobile resources and via optimisation of technological processes are exhausted.
- It is evident that the infrastructure is not correctly balanced, i.e. some parts are insufficiently dimensioned and are causing operational bottlenecks while other parts are over dimensioned and are not sufficiently exploited.

Any solution of optimisation of terminal design should observe the following facts:

- Realization of an accepted solution is typically extremely costly and thus the solution should be a long term one. It is practically impossible to make additional corrections in the case of a wrong decision.
- Infrastructure is only a resource, which serves the goal – traffic operation. Configuration of an infrastructure is satisfactory only if the operation on it is efficient. Therefore, if we want to judge the suitability of an infrastructure, we have to know and to describe in detail (make a model) the traffic realized on it.

- The traffic operation of a terminal is an extremely complex system. It is a dynamic system with complex relations among its elements where the service processes are mutually intertwined mostly with stochastic interactions.

The question is what can be done from the management side to ensure the most objective decision and to avoid an erroneous decision.

Due to the complexity of the system and its stochastic behaviour, the use of exact mathematical methods is significantly limited. Classical planning methods, on the other side, use simplified models of traffic operation which do not take into account the stochastic features of the system and do not involve detailed behaviour of mutually dependent dynamical technological processes. Instead, mean and normative values are used together with expert knowledge based on past experience. Frequently, the result is a solution which, confronted with a real traffic, appears to be unsuitable.

Where can we find a way out of this situation? The only feasible way is to accept a good suboptimal solution and to find it in an environment, which is capable to reflect satisfactorily the complexness of the infrastructure and of the operation and at the same time it is capable to produce understandable solutions based on verified arguments. Experimental environment which satisfies these conditions is a simulation model of a terminal, embodied in hardware and software form as a substitute for a real or designed terminal, which respects exactly the infrastructure composition and describes in detail all operation processes in their complexity. Simulation model is used as an experimental environment with the objective to evaluate all consequences of proposed terminal design. Evidently, the efficiency of the operation is a criterion of the evaluation.

The problems of infrastructure design and operation design obviously cannot be separated – the infrastructure is dependent on the efficiency of operations executed on the infrastructure and vice versa.

4. Using Simulation

Simulation presents a technique that supports the analysis, proposal and optimization of real systems in the following steps [1], [2]:

- substitution of the real system by the simulation model;
- experimentation on the simulation model through discovering its properties, behaviour and reaction to different conditions;
- application of the obtained results to the real system (existing or planned).

The following issues belong to the most typical problems of railway terminals being solved utilizing simulation techniques:

Changes in inbound flows. Using a simulation model, terminal operation can be determined and evaluated before the inbound flows of trains, wagons, goods or passengers have been actually changed. Changes in the inbound flows usually result from modifications to the railway network or terminal surroundings that can be described as follows:

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

Cost savings through an optimum use of resources. The allocation of staff and shunting engines can be optimised using simulation techniques. Not only capacity utilisation can be considerably improved but also the amount of resources can be reduced.

Rationalisation of technological processes. A possibility of optimizing terminal operation without the need for expensive infrastructural measures is the introduction of new technological procedures (e.g. the simultaneous formation of outgoing trains or parallel humping in a marshalling yard) as well as the execution of a higher number of operations in parallel. Using simulation, the effectiveness of these procedures can be investigated before implementing them in reality.

Infrastructure maintenance planning. Simulation is suitable for preparing necessary operational modifications during the maintenance of a terminal and scheduling maintenance work.

Reconstructing and configuring terminal infrastructure. The reconstruction of infrastructure is a very complicated and expensive intervention in the process of operating a terminal. Reconstruction activities may comprise the reduction, exchange or amplification of tracks, retarders or safety equipment. Today, it is hardly conceivable that management takes a decision on infrastructural adaptations without investigation into resulting consequences using a simulation model. Simulation is an effective and tried-and-tested tool for an objective verification of decisions. If the decision on reconstruction has already been taken, the individual stages can be planned and the operational processes affected by the infrastructural measures during each stage can be examined through simulation experiments. Certainly, the above discussed information can also be attributed to the configuration and installation of a new terminal.

Verification and improvement of operation control strategies. A valuable feature of some simulation models is their capability to co-operate with the user during a simulation run. The user (e.g. the dispatcher) can define problems she/he wants to solve on his/her own during the simulation of operation. The simulation model should permit him/her to trace and evaluate the consequences of made decisions. Therefore, the user is able to examine the suitability of different operational control strategies. This co-operational feature of the simulation tool also proves to be very advantageous in training managing staff.

Management of crisis situations. The railway network and its nodes may also be exposed to different critical situations (crises) not ascribable to certain management decisions but to the failure of human or technical factors or natural events. Such crisis situations may affect a part of or the entire railway terminal and result in considerable changes in the inbound flows or affect infrastructure, reduce the availability of resources or impose changes in the operation control of the terminal (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. The simulation tool is an ideal mean for evaluating similar 'scenarios' to determine operation control strategy for individual exceptional situations to be expected.

Villon is a universally suitable, proven simulation tool that supports the creation of simulation models used for finding solutions to the above mentioned problems encountered in the railway terminals. The following part of the text discusses some features of the Villon simulation tool and the process of creating the simulation model.

5. Simulation Tool Villon

Villon is a generic simulation model that supports the microscopic modelling of various types of transportation logistic terminals containing railway and road infrastructures (e.g. marshalling yards, railway passenger stations, factories, train care centres, depots, airports etc.). When applying Villon, the users are able to create the detailed simulation models of terminal operation, define simulation scenarios, make experiments on the model and evaluate the results of simulation runs in one integrated user-friendly environment.

5.1. Resource Model

Steps leading to the construction of an infrastructure model are best explained on the example of building the model with the most complicated infrastructure, which is a railway (track) infrastructure. The infrastructure model (Figure1) is created by transformation of a map (plan) which is available either on paper or in electronic form. The obtained infrastructure model guarantees an absolute accuracy of the fit. Thanks to it, an accurate, not only simplified model of railway infrastructure is used in the simulation and therefore we can evade distortions caused by rough approximations of distances and their influence on movements of mobile elements in the simulation model.

Transformation of original plans constitute so called physical level of an infrastructure model. It means that a infrastructure composed of basic elements, tracks, simple switches, cross switches, track crossings, is available to the model builder (tracks can be divided into sections corresponding to the infrastructure organisation or into isolated sections for the signalling system). In this level, however, professions of individual tracks are not yet defined.

The notion "profession" means the purpose for which the tracks serve in the infrastructure, e.g. arrival of terminating trains, connecting tracks to depots for uncoupled train locomotives, hump tracks, sorting tracks, etc. Information on the track profession is important for the model building in the phase of technology definition and definition of technological activities of the service of train sets. For example, in the technological activity „Transfer of shunting locomotive to the train set", profession of track, used for this transfer, must be defined. Professions are assigned to individual track in accordance with the track professions in the infrastructure of the real infrastructure. Assignments of professions constitute a logical level of the infrastructure model.

After physical level of the infrastructure model, list of track professions and logical level of the infrastructure are defined, routes for the mobile elements are created. Moreover, also

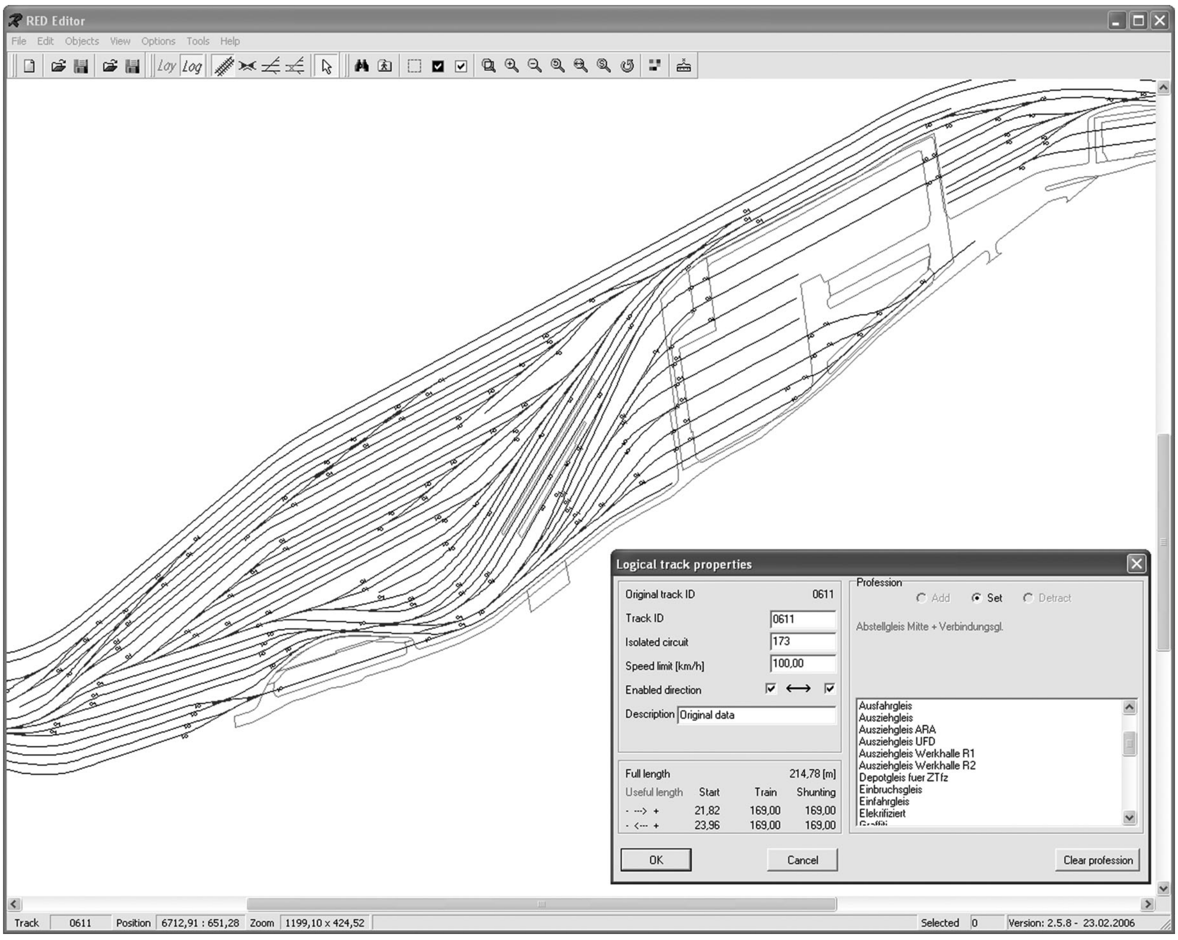

Fig. 1. User interface of the infrastructure editor presenting a detail depot infrastructure and a track properties dialog box.

dynamically ad hoc created routes may be used, which are found automatically during the simulation experiment, where an actual availability of tracks is considered.

Mobile resources of a railway terminal are the elements able to change their location in time. The examples of mobile resources are shunting locomotives and personnel. When shunting locomotive transfer sets of wagons, the personnel execute various tasks such as technical inspection, brake inspection, coupling, commercial traffic inspection etc.

Resources specialize in different professions – each of those represents the ability of a resource to execute a defined task. An integrated editor of mobile elements permits the user to define all important properties of any resource as well as their composition corresponding to real terminal configuration.

5.2. Customer Model

The elements (objects) to be served are represented in the model by trains or by the parts of trains. They are subject of service, for example technical inspection, shunting of a set of wagons etc. We use term “customer” in our paper.

The arrival of customers into the terminal is modelled by the input generator allowing the modification of parameters corresponding to the time schedule and to train composition. The documents needed for acquiring necessary data are timetable for goods trains and the wagon lists of the inbound trains. The data can be statistically processed and probability distribution tables can be created for each relevant train characteristic. Another way of modelling the input flow is to precisely reflect the real situation by means of the exact definition of every train composition and parameters (arrival time, train groups, type etc.).

5.3. Operation Model

The control subsystem consists of the elements modelling the following activities:

- decision making activities of dispatchers in the terminal;
- execution of obligatory technological procedures in customer’s attendance.

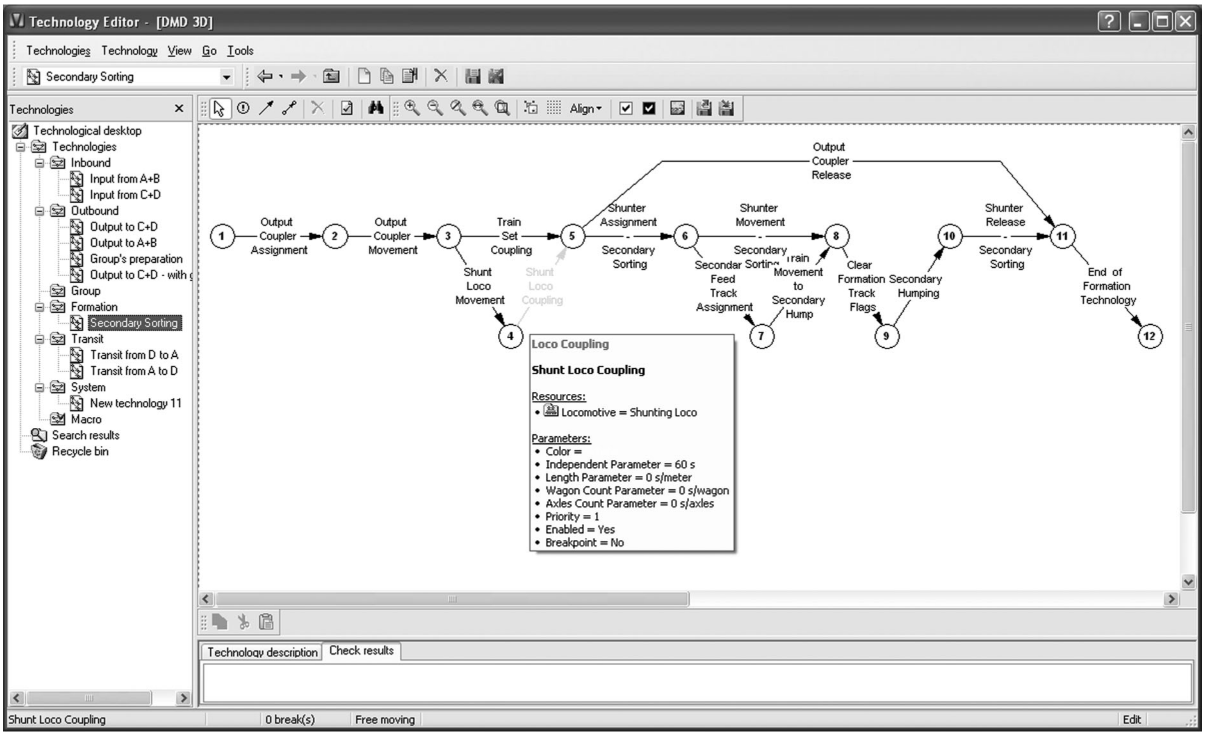

Fig. 2. An example of a flowchart defining procedure of serving a customer

Modelling the decision making activities of dispatchers is a very complicated problem belonging to the field of artificial intelligence. The decision making algorithms should simulate work of an intelligent dispatcher and be ready to easily change them. For this purpose (among others), the authors have developed an agent based simulation architecture ABAsim, a detailed description of its properties of which can be found in [3]. This architecture allows the definition of decision making mechanisms by means of specialised coloured Petri nets [4].

The technological procedures of serving customers are defined in a form of a flowchart by the user while creating a model. Flowcharts are composed of activities that represent single tasks executed during serving of customers (e.g. loading, resource assignment, brake testing etc.). Flowcharts define the succession and mutual dependence of activities in the service process. The defined parameterized activities are reusable and can be used in a more than one flowchart. Flowcharts are created in a comfortable graphical editor (Figure 2) with support for automatic validation of the entered flowcharts (guarding required succession of some activities and appropriate resource handling). The ready flowchart is then assigned to a customer (e.g. a train or truck). Once defined, the flowchart can be reused – the same flowchart can be applied to different customers with the same attendance procedure.

6. Experimentation with Villon

The properties of the model are derived from the needs which are supposed to be satisfied by using it. The model may serve for investigating the variants of infrastructure configuration, service resources, technological procedures, decision making and even control strategies. This means that the model allows investigating terminal properties under any circumstances (conditions, parameters) defined as a scenario. It permits to evaluate the changes in the environment of railway terminal (seasonal influence, exceptional situations due to e.g. strikes or weather, cancelling or changing capacity of other terminals etc.).

The model is capable to serve for investigating any railway terminal a high degree of flexibility of which supplies the user with the possibility of modelling a broad scope of situations without the need for computer programme modification and permits investigating the system at different levels of detail including the highest ones.

7. Setting Scenario

Setting generalized parameters for a real terminal is called setting scenario for a simulation run. The user can easily do it choosing one item of each kind from the menu of terminal elements. Scenario created in such a way is given a name and can be stored in the database of scenarios. Each simulation run then follows a selected scenario.

A degree of freedom in scenario setting characterizes a degree of model flexibility. This is one of the most appreciated properties of the model and therefore a special attention has been paid to it. First, the user can select any variant of infrastructure as a basis for modelling dynamic processes in the prepared simulation run. Similarly, a particular set of locomotives and personnel can be selected.

Besides, a particular input flow situation is chosen, for example, we may set the statistical characteristics of inbound trains for any day of a week. By selecting a technology procedure into the scenario, a user chooses the way of different types of trains. For example, in the marshalling yard, one technology procedure attends departing trains on sorting tracks whereas the other looks after departure tracks.

The simulation programme contains tens of decision algorithms. Any of those can be contained in the database in several variants. Any variant can be chosen by using the scenario. Decision algorithms are grouped with respect to the area they control (e.g. all algorithms for controlling the operation of shunting locomotives belong to the same group). The group as a whole can be selected into the scenario. It means that a strategy of control in an area is chosen (e.g. the strategy of shunting locomotives operation control).

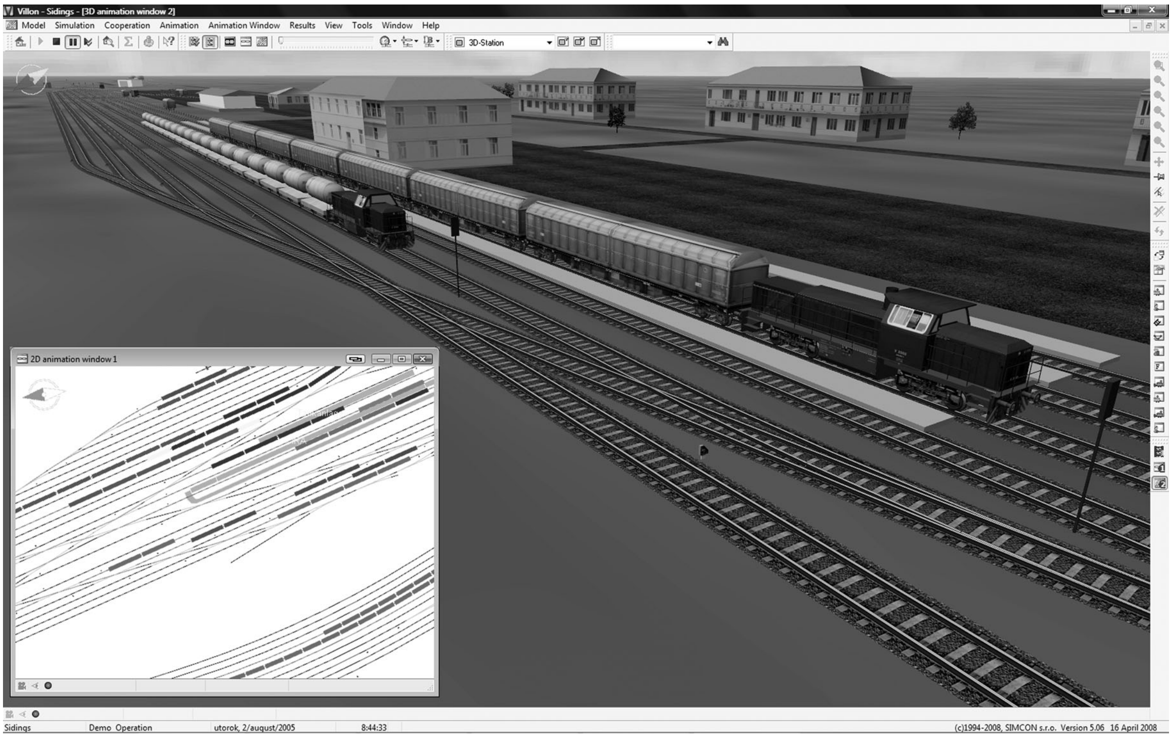

Fig. 3. The example of 3-dimensional and 2-dimensional animation

8. Outputs

During the simulation run, the animation of all train movements, sets and locomotives as well as the animation of other mobile resources is presented to the user. The user can choose between two or three dimensional view of the scene (Figure 3).

During the simulation run, the user can follow a 'live' development (change of values) of the selected characteristics in graphic presentation (e.g. the utilization rate of a selected locomotive).

Another type of output information is the overall information retrievable after terminating the simulation run. Therefore, a detailed protocol of simulation is generated during the simulation run. These protocols can be separately processed and information sought can be retrieved from them like statistics and detailed time-dependent reports (Figure 4) on the utilization of resources (locomotives, reception tracks, etc.).

Various types of statistics are obtainable from the palette of the pre-defined evaluations. The palette is open for adding new items according to the wish of the user. Reports on the utilization of resources can be produced in graphical presentation either for individual resources or in a consolidated form. Villon also offers the chance to export all collected information to the XLS file for further processing using spreadsheet editor.

9. Applications of Villon

In the previous sections, the typical problems of infrastructure planning and process control were presented, and thus a simulation technique may be an efficient tool for reaching the required solution. The simulation tool Villon successfully assisted in finding solutions to the majority of these problems, always with a significant economic profit.

Villon was used, for example, for infrastructure planning and verification of traffic operation in the train set depot in Ulm, Germany. Here, the problem of railway infrastructure configuration was complicated by the problems of locating and configuring the individual service modules of the depot (internal and external cleaning station of train sets, fuel supply device, repair and maintenance facilities etc.). Changes

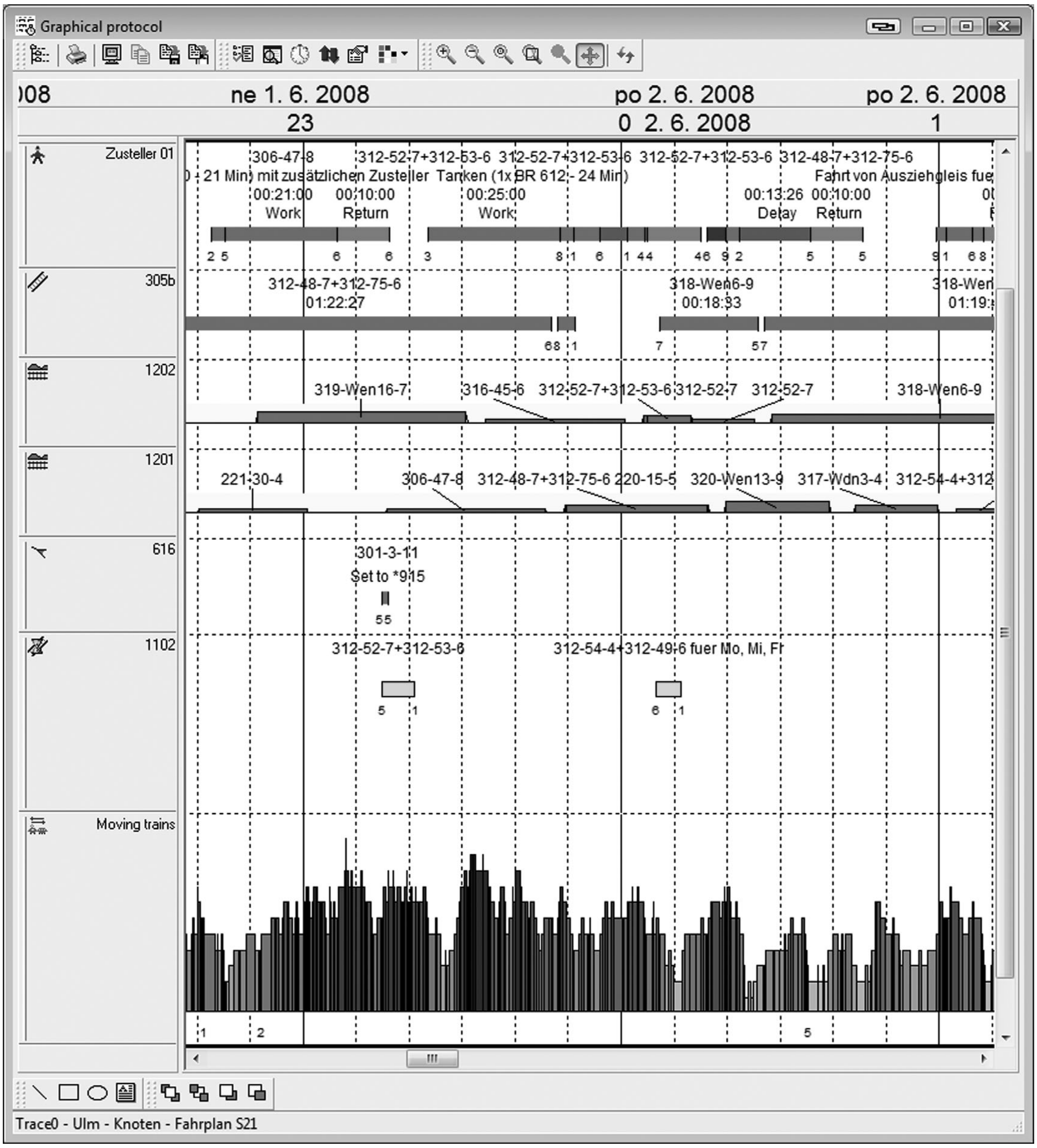

Fig. 4. The example of graphical protocol and statistics

in organizing train forming system in Austrian and Swiss railways led to cancelling several small marshalling yards and modernisation and enlargement of greater and more efficient ones. Consequently, the customer flows originally processed in the cancelled stations had to be redirected into the remaining marshalling yards. Villon was used for verifying the suitability and efficiency of the new infrastructure solutions in Linz (Austria), see [5] and Basel and Lausanne (Switzerland).

Attention was also paid to infrastructural and technological changes connected with traffic operations of passenger railway stations. Villon was successfully applied for investigating planned traffic operations in Prague, Masaryk railway station and Brno (design of a new railway station), both in Czech Republic as well as in one passenger railway station that belongs to Beijing railway node in the People's Republic of China [6].

Industrial railways must be flexible enough to be capable to cope with an increase or decrease of company production which immediately reflects the intensity of transport activities. However, geographical conditions or financial reasons often limit the modification of infrastructure in which the tool Villon was successfully employed and worked towards finding solutions to the problems following the production increase in the companies like paper production plant SCA Laakirchen, Austria, steelworks Corus Teesside in the UK and in infrastructure modification process in the giant chemical plant BASF Ludwigshafen, Germany [7].

For a complex and detailed investigation of the infrastructure of some terminals, the interaction between railway transport and other transport modes (e.g. road transport) should be considered. Villon was utilized to verify different configurations of road and railway infrastructure in Volkswagen Bratislava plant. The entire internal transport was modelled including trucks, cars, trains and pedestrians. Austrian steel works VOEST Alpine Linz needed a simulation study of road infrastructure reconstruction in the interaction with railway and road traffic inside the plant area.

Once built, verified and validated a model of a terminal can be used repeatedly for seeking different solutions. For example, an originally developed simulation model as a tool for an optimal reconstruction of a terminal (strategic goal) can be useful during a real process of reconstruction to work out solutions to the problems caused by planned closings due to reconstruction.

10. Results and Discussions

Properties and possibilities offered by the simulation tool Villon have been presented in the paper. We described our experience gained during its development and utilisation in real-life simulation studies. In comparison with other available simulation tools used for modelling railway operation like RASIM (HACON n.d.), RailSys [8] or OpenTrack [9], Villon offers users more precise modelling and visualization of infrastructure (no schematic approach), a detailed modelling of personnel and engine activities (shunting movements, dividing of trains to the blocks and merging of car blocks to the trains, etc.) as well as the possibility of modelling railway and road traffic in a single model to examine mutual interference. On the other hand, due to its focus on modelling terminal operation, Villon lacks support for modelling large-scale railway networks or timetable creation abilities.

11. Conclusion

Due to the enormous amount of money invested, the planning of the railway terminals infrastructure and its optimization cannot be done without detailed and objective examination of effects of taken decisions. Suitability of planned interventions to infrastructure cannot be objectively evaluated without detailed observation of terminal's operation after the planned change. Due to the high level of infrastructure and operation complexity at railway terminals, simulation may be the only efficient technique to examine the consequences of taken decisions.

12. Acknowledgement

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