



## OPTIMISATION OF RAILWAY TERMINAL DESIGN AND OPERATIONS USING VILLON GENERIC SIMULATION MODEL

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**Abstract.** Railway service terminals (nodes) are the places of a railway network equipped with costly technology based on high complexity technological procedures demanding a high degree of coordination and control skills. Great effort is therefore exerted to find an optimal configuration of infrastructure to extensively exploit technical and human resources and to effectively organize technological procedures. Due to the complex system, 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 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 utilisation. The tool supports tactical (middle-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, design, optimisation, Villon.

### 1. Introduction

The transportation process is composed of transfer that uses transport ways (e. g. rails, roads) and of manipulation tasks (service processes) applied to transportation vehicles and commodities transported inside transportation terminals (nodes). The following text is only concerned with the processes inside such terminals.

We can define a railway terminal as a transportation terminal with predominant railway infrastructure and respective service resources. Nevertheless, these can be supplemented by infrastructure and resources that belong to different transportation modes or manipulation devices (e. g. roads, cranes). For the sake of simplicity, in this paper, we will limit our scope only to the railway transportation elements.

The below presented examples of railway terminals are common problems that may appear concerning design, planning and traffic control:

*Marshalling yards* usually contain only rail paths and the prevalent activities are transformation operations for rail vehicles (coupling, uncoupling, sorting, various kinds of shunting etc.).

*Passenger railway stations* are also equipped with rail paths but the prevalent activities are service operations (entering and leaving carriages, cleaning etc.). The

elements subject to provide services are passenger carriages and passengers in the entrance hall.

*Industrial railways* are often combined with road transport, thus they contain infrastructure, service resources and elements subject to service of both types. In heavy industry plants, the set of tracks may be extremely large and even contain an independent train forming part. In this case, complex operations are characteristic, namely complicated manipulations and loading and unloading of different substances.

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

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

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

In general, the problem of railway infrastructure planning inside the terminal can be understood as a

need to answer the question ‘Which elements the infrastructure should be composed of and how to integrate these elements into the system?’ The question is important concerning the implementation of long-term strategic plans and taking an effort to make the existing terminal operation more efficient.

The problems of infrastructure design and operation obviously cannot be separated – infrastructure is based on the effectiveness of operations executed on infrastructure.

Simulation is supposed to be the most (and possibly the only one) suitable method for evaluating the efficiency of processes in such complex and mostly stochastic systems. The main principles of simulation and possible utilization to solve the problems of railway terminals are discussed in Chapter 2. To consider specific problems, further text concentrates on the simulation tool Villon and the features and experience obtained during the process of tool exploitation.

## 2. Utilizing Simulation

Simulation presents a technique that supports the analysis, proposal and optimization of real systems (Kavička *et al.* 2005; Kavička and Klima 2005; Jennings 2001) in the following steps:

- 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 s/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 cooperational feature of the simulation tool also proves to be very advantageous in training managing staff.

*Management of crisis situations.* The railway network and its junctions 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.

### 3. 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.

In comparison with other available simulation tools used for modelling railway operation like RASIM (HACON n.d.), RailSys (Benfeldt *et al.* 2000) or OpenTrack (Nash and Hürlimann 2004), Villon offers the users more precise modelling and visualization of infrastructure (no schematic approach), a detailed modelling of personnel and engine activities 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.

### 4. Building a Simulation Model

The elements of the railway terminal can be divided into three subsystems according to their role in the system: resource subsystem, customer subsystem, control subsystem. The same structure is also reflected in the Villon simulation model.

#### 4.1. Resource Subsystem

*Stable (fixed) resources* are all sources not changing their location in the process. This subsystem is also called infrastructure. A set of tracks, a signalling system and an interlocking system can be distinguished as the parts of modelling infrastructure.

The set of tracks consists of the track sections of different lengths (tracks and switches). We can further distinguish between tracks used for attending trains (service tracks, fixed servers) and exchange tracks that serve for connecting service tracks (e. g. switches).

Signalling and interlocking systems are modelled accurately and have the same function in the model as in the real terminal.

The model of infrastructure subsystem is created by the user in RED editor utilizing AutoCAD, DXF files or scanned paper plans as an input (Fig. 1). The model reflects the real shape and placement of the elements inside the terminal i.e. it is not a schematic plan. The definition of infrastructure is a crucial part of input data for the simulation programme.

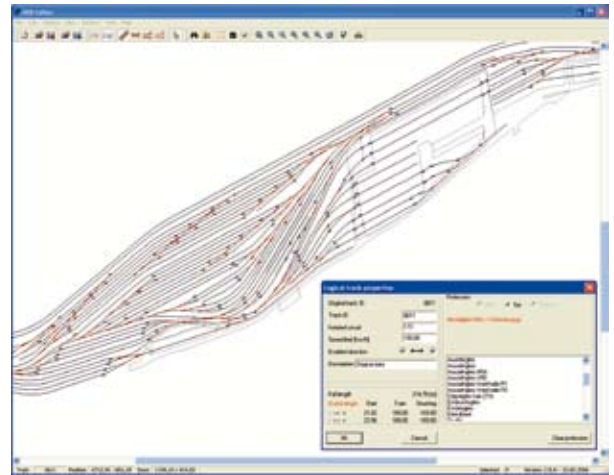


Fig. 1. Definition of infrastructure in RED editor

*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.

#### 4.2. Customer Subsystem

The elements (objects) to be served are represented in the model by trains or by the parts of trains. The service they are subject to is for example technical inspection, shunting of a set of wagons etc.

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.).

#### 4.3. Control Subsystem

Finally, 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.

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 Kavička *et al.* (2007). This architecture allows the definition of decision making mechanisms by means of specialised coloured Petri nets (Žarnay 2004).

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 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 (Fig. 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.

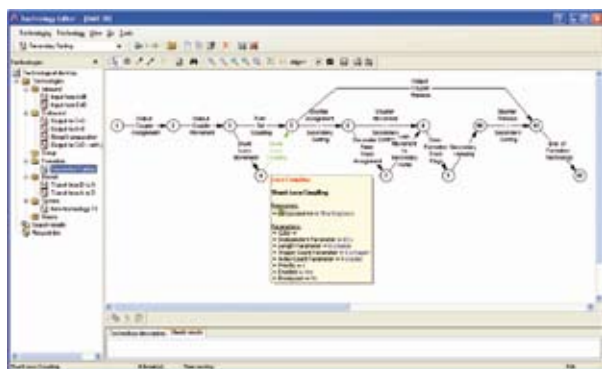


Fig. 2. An example of a flowchart defining the procedure of serving a customer

## 5. Experimentation with the Simulation Model

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 pro-

gramme modification and permits investigating the system at different levels of detail including the highest ones.

Villon enables a close interactive cooperation between the model and the user – experimenter, mainly in decision making. Graphical output and the possibility of animation (in 2D or 3D view) are supported. The model supplies the user with the information on the state of the system and its statistical development during the simulation run. Also, a broad palette of post-simulation statistical and other information on the system is given and the possibility of adding new items to the palette is offered.

### 5.1. Setting a Scenario for the Simulation Run

Setting generalized parameters for a real terminal is called setting a scenario for a simulation run (Fig. 3). The user can easily do it choosing one item of each kind from the menu of terminal elements. The scenario that was created by the user is named and stored in the database of scenarios. Each simulation run then follows a selected scenario.

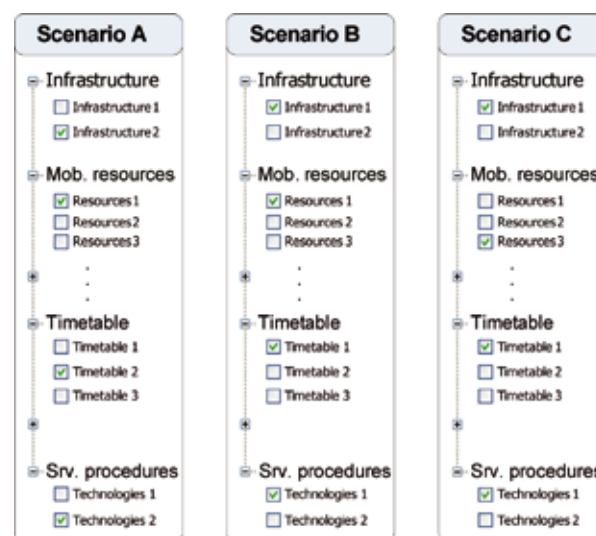


Fig. 3. The structure of the railway terminal simulation scenario

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).

### 5.2. Output from the Simulation Model

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 (Fig. 4).

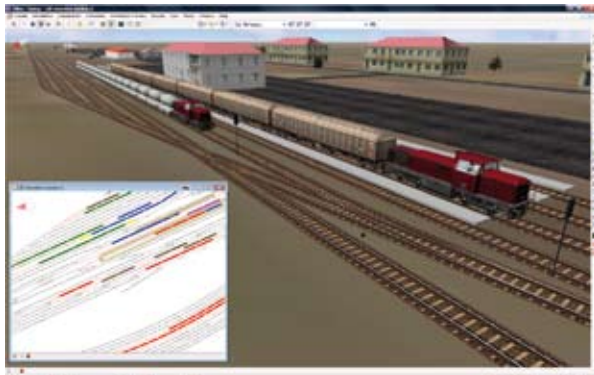


Fig. 4. The example of 3-dimensional and 2-dimensional animation

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 (called graphical protocols, Fig. 5) 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. Besides, the graphical presentation of simulation results and statistical evaluations is provided in the form of tables, graphs and charts. Villon also offers the chance to export all collected information to the XLS file for further processing using spreadsheet editor.

### 6. Applications of the Villon tool

In Chapter 2, 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 success-

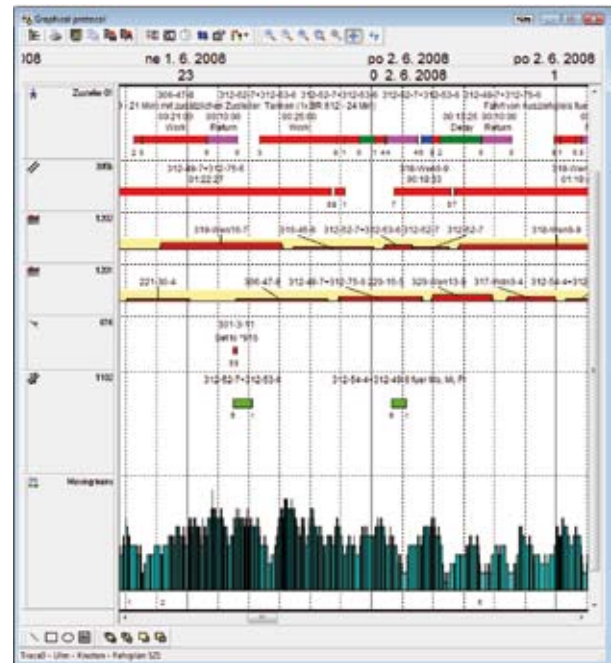


Fig. 5. The example of graphical protocol and statistics

fully 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 trackage 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 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 Kavička *et al.* (1999) 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 the Czech Republic as well as in one passenger railway station that belongs to Beijing railway node in the People’s Republic of China (Xu *et al.* 2003).

Industrial railways must be flexible enough to be capable to cope with an increase or decrease in company’s 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 pa-

per production plant SCA Laakirchen, Austria, steelworks Corus Teesside in the UK and in the infrastructure modification process in the giant chemical plant BASF Ludwigshafen, Germany (Edinger *et al.* 2005).

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.

## 7. Conclusions

1. The substantial decisions in the field of transport, respecting the contemporary level of information technologies and simulation methodologies, should not be adopted without modelling their consequences. For planning connected with railway terminals (infrastructure layout, resource dimensioning and scheduling, service technologies, decision-making strategies, reactions to the networks change etc.) it is essential to apply modelling techniques in order to investigate the proposed measures and solutions. Simulation methods enable not only to investigate the consequences of the adopted decisions but also (by means of the reasonable sequence of experiments) to provide the best solution and save financial resources.
2. Villon is a complex simulation tool able to support decision-making process connected with the design and optimisation of railway terminal infrastructure as well as with its operational processes. The proper utilization of the tool and the exploitation of a broad range of its features can help with achieving considerable financial savings for the owner and operator of the terminal.

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