



Distributed multi-train simulation using real components

M. Meyer zu Hörste, I. Weber, I. Illgen, H. Schrom & E. Schnieder
*Institut für Regelungs- und Automatisierungstechnik, Technische
Universität Braunschweig, Braunschweig, Germany.*

Abstract

In this paper we show the distributed simulation for multiple trains where every train and the trackside system are modelled with Petri nets and represented by separate simulators. The operation systems are influenced by additional components (mobile communication and location) which may be exchanged with real components. The simulation of an operational scenario will be shown as an example.

1 Motivation and purpose

The paper presents results of a study for a train control system with low complexity called SatZB (German "Satellitengestützter Zugleitbetrieb"), which is a specific type of a satellite-based train control system. It is a low cost system without safety responsibility for secondary lines [2, 6]. The particular part of the project, which is funded by the Research and Technology Centre (German "Forschungs- und Technologiezentrum") of the Deutsche Bahn AG, reported here had two different aims. Firstly the functionality of the trackside and trainborne subsystem has to be evaluated and secondly the performance of different hardware layouts, like different components for communication or localisation has to be checked.

2 The train control system based on a satellite location system

The SatZB is a study for a low-cost system for the simplified train control on secondary lines to improve safety and reduce costs. The specification of the system was developed in 1998 [2]. The general architecture of the system is shown in the Figure 1. This system has been chosen for this case study because of its suitable complexity: the behaviour of the system is not trivial, but the complexity is still manageable. The system consists of two units: the trackside controller and the on-board system.

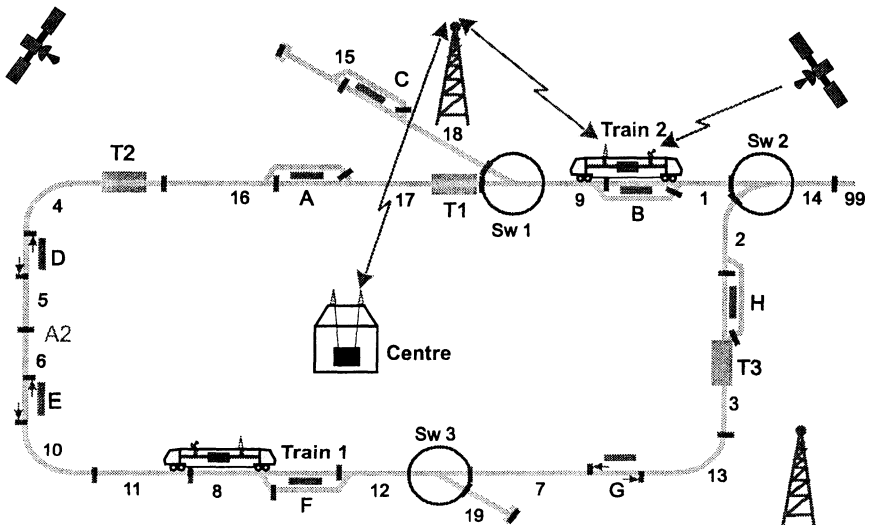


Figure 1: The Train Control System based on satellite location

2.1 Trainborne subsystem

The movement and the position are supervised by the on-board subsystem. GPS (Global Positioning System) is used to localise the train. When the train approaches the border of its current section, the on-board subsystem sends a request for the next section to the trackside subsystem. The communication between both systems is performed with GSM.

2.2 Trackside subsystem

The trackside subsystem manages a database of the track sections and supervises their states. The permission to proceed into a defined section is given to the requesting train. The complete track between two stations



consisting of one or more track sections will be blocked against oncoming trains as soon as a train occupies the first section of this track. In case of a violation of a track section by a train the train that correctly uses this section receives a request to stop.

2.3 Reduction to two trains

The movement of a train is determined by the next train in front of the train and the train may not drive into the next section until this section is again free. This leads to an independent dynamic behaviour of two trains which are separated by a third train, so that it is possible to split operational scenarios with more than two trains into a corresponding number of scenarios with two trains.

3 Modelling of the real components

The system described in section 2.1 and 2.2 interacts by communication, location and train dynamics.

3.1 Communication

The communication is realised by a separate computer using serial interfaces. The program simulates the GSM – based data transfer including modem functionality between the trainborne and trackside systems because the correct communication is including delays of connection loss of connection and errors in the telegrams.

When a train approaches the border of its current section, the onboard system sends a request for the next section to the trackside system. After receiving entry permission the train moves to the next section and notifies the trackside system about leaving the old section. After the trackside system has acknowledged the notification, the connection is closed because there will probably be no more communication necessary for a long time due the length of the section. Following statistical properties of connection are related to results of GSM tests [5] and can be changed during the simulation run:

- delay of connection establishment (expected value: 15 seconds, using SMS 90 seconds),
- probability of loss of connection (default: 49 minutes)
- bit error rate in messages/telegrams (default: 0.3 % at 9600 Bit/s)

The specific protocol for the SatZB has been realized.



3.2 Location

Each second the train position is determined using differential GPS. A uni-dimensional positioning is used in this model. The positioning inaccuracy is described by a Gaussian distribution with a parameters defined by DGPS.

The satellite visibility is not given when the train is situated in a tunnel. In this case the positioning inaccuracy will be increased by the distance which the train can drive in the positioning time intervall. Additionally an information about the incorrect positioning signal is sent to the trainborne system.

When the train is situated in a switch, a stop or a station, no track selectivity is available. In this case the location module informs the trainborne system that the location information is not confirmed. [3, 7, 4]

3.3 Train dynamics

The train dynamics is described by a discrete time approach using the physical relationships between acceleration a , velocity v and position s . Using the discrete time steps ΔT , these relationships can be written as follows:

$$t_{n+1} = t_n + \Delta T \quad (1)$$

$$v(t_{n+1}) = a(t_{n+1}) \Delta T + v(t_n) \quad (2)$$

$$s(t_{n+1}) = -\frac{a(t_{n+1}) \Delta T^2}{2} + v(t_{n+1}) \Delta T + s(t_n) \quad (3)$$

The simulation operator controls the acceleration using the keyboard. For simulation time steps $\Delta T = 0.1 \text{ s}$ or 0.2 s are used. The train dynamics module keeps track of the current position of each train and sends the value to the location and visualisation module.

4 Simulation

4.1 Test track

The track shown in Figure 1 has been designed for simulation because several scenarios (see section 4.3) have to be realised. The track consists of the following elements: 20 sections, 3 tunnels, 3 switches, 5 stations (A, B, C, F, H) and 3 stops (D, E, G).

4.2 Simulation environment

The validation of the behaviour of the system by means of simulation has been performed in two steps: in the first one the logical behaviour has been validated by means of a monolithic simulation of both subsystems in one

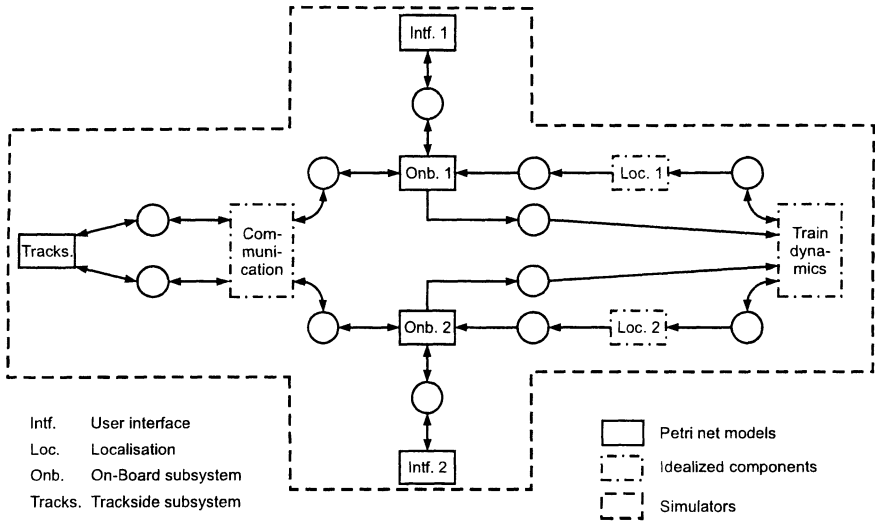


Figure 2: Logical structure of the monolithic simulation

Petri net model without influences from the real environment. The components behave in an ideal way. In the second step the simulation of the mobile communication, the satellite positioning and the train dynamics have been refined to a disturbed behaviour as in a real environment.

The tool Artifex by ARTIS s.r.l. Torino (ARTIS and Artifex are trademarks of ARTIS Software Corporation) is used to edit, simulate and especially to implement the Petri net models. The basis of the decision to use it was a careful evaluation of different tools, which was performed in the first phase of the project [2]. The set of criteria for this evaluation are independent from the current project and have been used in tool evaluations with different scope [8]. This tool decision results from the good possibility to construct and distribute processes through an object-oriented class concept. A second very important reason was the ability of Artifex to generate source code for different operating systems and hardware platforms. In the monolithic simulation only the modelling and validation modules of Artifex were used, in the distributed simulation compiled code was executed.

Monolithic Simulation

In the first step the logic behaviour of the system has been validated with a simulation shown in Figure 2.

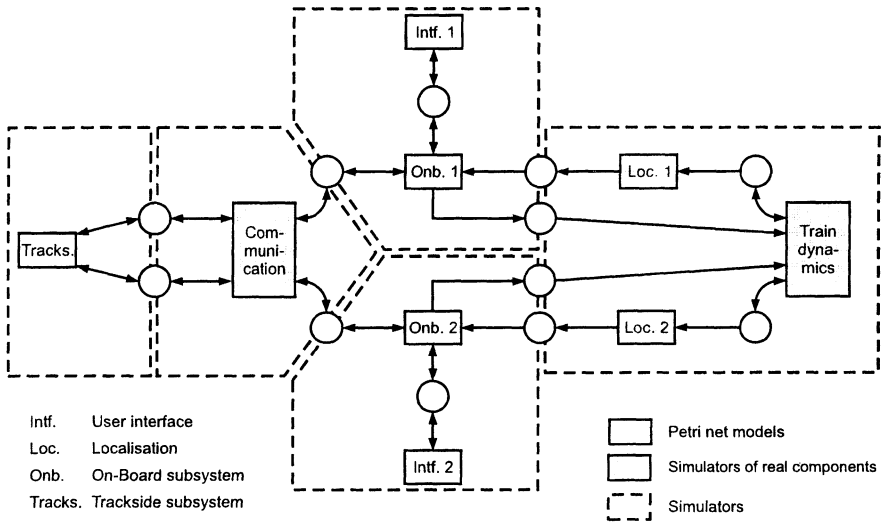


Figure 3: Logical structure of the distributed simulation

Distributed Simulation

For the validation of the complete system the simulation has been divided into five separate simulators (see Figure 3). Two of the simulators are identical trainborne system, which differ only in their specific parameters. Another simulator is the trackside subsystem. The communication is made by another simulator and the last one simulates the train dynamics and the location inaccuracy with noise, and visualizes the train position on a screen or monitor. This simulation has been used for the evaluation of the performance of the system under real conditions.

4.3 Simulation scenarios

For the evaluation a set of 24 scenarios was defined. Eight of them are related to the movement of one train without influences of another train. Eight further scenarios are related to the coordination of two moving trains. The first group contains aspects as listed in the following and their combination.

- normal running
- switch off / switch on
- shunting
- reversing in stations

The second group of eight scenarios is related to the coordination of two trains in sidings and following each other.

- A distributed simulation for multiple trains was developed to reach two goals: the evaluation of the logical behaviour and the performance under



Telegram (2: Train→Centre 3: Centre→Train)	Statement No.	Train ID	Time Stamp	El. ID (0: unknown)	Last El. ID	Direction of train
Testscenario: 11, Version: 1, Date: 280300						
Train 1 switch on	2	0 0 8 7805	10 0 0 0 0 0 0 0 0 0	0	0	0
Stored position: El. 10	3	0 0 8 7805	10 6 0 0 1 0 0 0 0 0	0	0	0
Train 1 requests El. 10	2	0 0 1 7805	20 10 6 0 1 0 0 0 0 0	0	0	0
Permission for El. 10	3	0 0 1 7805	20 10 6 0 1 0 0 0 0 0	0	0	0
El. 10 occupied by Train 1	2	0 0 2 7805	100 10 6 0 1 0 0 0 0 0	0	0	0
Request for El. 11	2	0 0 1 7805	110 11 10 0 1 0 0 0 0 0	0	0	0
Permission for El. 10	3	0 0 1 7805	110 11 10 0 1 0 0 0 0 0	0	0	0
El. 11 occupied by Tr. 1	2	0 0 2 7805	120 11 10 0 1 0 0 0 0 0	0	0	0
Train 2 switch on	2	0 0 8 7812	10 0 0 0 0 0 0 0 0 0	0	0	0
Stored position: El. 10	3	0 0 8 7812	10 12 0 0 0 0 0 0 0 0	0	0	0
Train 1 requests El. 10	2	0 0 1 7812	20 8 12 0 0 0 0 0 0 0	0	0	0
Not allowed	3	0 0 2 7812	20 8 12 0 0 0 0 0 0 0	0	0	0
El. 10 free	2	0 0 3 7805	130 10 6 0 1 0 0 0 0 0	0	0	0
	2	0 0 1 7805	140 8 11 0 1 0 0 0 0 0	0	0	0
	3	0 0 1 7805	140 8 11 0 1 0 0 0 0 0	0	0	0
	2	0 0 2 7805	150 8 11 0 1 0 0 0 0 0	0	0	0
	2	0 0 3 7805	160 11 10 0 1 0 0 0 0 0	0	0	0
	2	0 0 1 7805	170 12 11 0 1 0 0 0 0 0	0	0	0
	3	0 0 1 7805	170 12 11 0 1 0 0 0 0 0	0	0	0
El. 8 free	2	0 0 3 7805	180 8 11 0 1 0 0 0 0 0	0	0	0
Permission for El. 10	3	0 0 1 7812	20 8 12 0 0 0 0 0 0 0	0	0	0
	2	0 0 3 7805	190 12 8 0 1 0 0 0 0 0	0	0	0
	2	0 0 9 7805	200 8 11 0 1 0 0 0 0 0	0	0	0
	3	0 0 9 7805	200 8 11 0 1 0 0 0 0 0	0	0	0
El. 11 occupied by Train 2	2	0 0 2 7812	150 8 12 0 0 0 0 0 0 0	0	0	0
	2	0 0 1 7812	160 11 8 0 0 0 0 0 0 0	0	0	0
	3	0 0 1 7812	160 11 8 0 0 0 0 0 0 0	0	0	0
	2	0 0 2 7812	170 11 8 0 0 0 0 0 0 0	0	0	0
	2	0 0 3 7812	180 8 12 0 0 0 0 0 0 0	0	0	0
	2	0 0 1 7812	190 10 11 0 0 0 0 0 0 0	0	0	0
	3	0 0 1 7812	190 10 11 0 0 0 0 0 0 0	0	0	0
	2	0 0 2 7812	200 10 11 0 0 0 0 0 0 0	0	0	0
	2	0 0 3 7812	210 11 8 0 0 0 0 0 0 0	0	0	0
	2	0 0 1 7812	220 6 10 0 0 0 0 0 0 0	0	0	0
	3	0 0 1 7812	220 6 10 0 0 0 0 0 0 0	0	0	0
	2	0 0 3 7812	230 10 11 0 0 0 0 0 0 0	0	0	0
	2	0 0 3 7812	280 6 11 0 0 0 0 0 0 0	0	0	0
Train 1 switch off at El. 10	2	0 0 9 7812	290 10 11 0 1 0 0 0 0 0	0	0	0
Switch off acknowledge	3	0 0 9 7812	290 10 11 0 1 0 0 0 0 0	0	0	0

Figure 5: Log file of test run communication

real conditions. Every trainborne subsystem is represented by one simulator and the trackside subsystem by another, which are all modelled with Petri nets [6]. A study of the operational scenarios showed that for this specific system all operational situations can be split in several situations which concern only two trainborne subsystems. The communication simulator connects the trainborne and the trackside subsystems with each other and takes into account the influences of the mobile communication (e.g. transmission errors, delay and loss of connection). The environment simulator computes the train dynamics. Once per second it sends a location telegram to every trainborne subsystem. In addition errors caused by the localisation sensors such as GPS and odometer can be generated (e.g. to figure out the effects to using GPS or DGPS). All simulators are connected



via serial interfaces of the different computers. The serial interfaces of the trackside and the trainborne subsystem are related to the real interfaces, to make an exchange of the simulators with real components possible. The real-time aspects are fulfilled in this case, too.

5.1 Perspective

The visualisation of the trainborne display and the environment simulator will be made accessible with internet technologies, to support a decentralised simulation [1]. Due to the use of interfaces, which are corresponding to the interfaces of the target subsystems, a migration to a prototype implementation is possible without major changes in the subsystems.

Acknowledgement

The project *Modelling and Simulation of the SatZB* is funded by the Research and Technology Centre of the Deutsche Bahn AG.

References

- [1] G. Bikker and S. König. Developing and implementing a framework for CASE tool coupling - object orientation upon tool level. In *ECEC'2000, 7th European Concurrent Engineering Conference*, Leicester, UK, 2000.
- [2] Deutsche Bahn-AG. *Satellitengestützter Zugleitbetrieb (SatZB) - Funktionales Lastenheft. Version 1.00, 20. Februar 1998 (in German)*. Deutsche Bahn-AG, Munich, Germany, 1998.
- [3] K. Klinge and E. Schnieder. Concept of a modular degradable trainside localisation module. In *1st European Symposium on Global Navigation Satellite Systems*. Deutsche Gesellschaft für Ortung und Navigation e. v., 1997.
- [4] K.-A. Klinge. *Konzept eines fahrzeugautarken Ortungsmoduls für den spurgebundenen Verkehr*. PhD thesis, Technical University of Braunschweig, 1998. (in German), Shaker Verlag, Aachen.
- [5] K.-D. Masur. GSM-Datenübertragung bei kleinen, mittleren und sehr großen Fahrgeschwindigkeiten. *Nachrichtentechnische Zeitschrift - NTZ*, pages 16–23, 1996. (in German).
- [6] Meyer zu Hörste, M. and Schnieder, E. Formal modelling and simulation of train control systems using petri nets. In J. Wing, J. Woodcock, and J. Davies, editors, *FM'99 - Formal Methods, Volume II, LNCS 1709*, page 999, Berlin u.a.o., 1999. Springer.



- [7] S. Röver, M. Schroeder, and E. Schnieder. Satellite based locationing in guided traffic. In B. Mellit, R. J. Hill, J. Allan, G. Sciutto, and C. A. Brebbia, editors, *Computers in Railways VI*, Southampton, 1999. WIT Press.
- [8] E. Schnieder. *Methoden der Automatisierung*. Vieweg, Braunschweig, 1999. (in German).