The Train Departure Process and its Impact on the Rail Network Performance

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Abstract

Switzerland's rail network is operated at its capacity limits. Building new tracks is very cost intensive and thus only possible in exceptional cases. Adding new services to satisfy growing demands therefore can only be implemented with reducing given buffer times for both train headways and technical running times. This condensation improves the amount of dependencies between trains and finally results in a loss of stability. Consequently, new methods and ideas are required, to improve the capacity without losing of stability. As part of the development of a new advanced rail traffic management system combined with process optimisations, one approach is to increase the production accuracy for both, running trains and departing trains in stations.

The paper focuses on optimisation possibilities and impacts of the departure process. First, workflow and coherences of the departure process, temporal quantifications including stochastic analysis based on more than 200 measurements and improvement opportunities are described. In a second step, using a microscopic rail operation simulation tool, impacts of the production accuracy and rail traffic density on the stability are evaluated for the specific case of the area around Lucerne's dead end station.

Keywords

Railway Operation, Departure Process, Simulation, Capacity, Stability

1. Introduction

Punctuality is one key element for the successful rail public transport in Switzerland. Buffer times between trains and running time supplements ensure, that initial delays from a single train are promptly reduced and the propagation of secondary delays is small. Buffer times therefore stabilise a train network system, increase the punctuality level, but limits the overall capacity.

Growing demands causes a more efficient use of the existing network. Consequently, buffer times have to be reduced. In order that the punctuality level of the trains is not decreased, new technologies, strategies and methods for planning and operation are needed.

One strategy, developed in the Netherlands, considers inaccuracy in production and optimises the rail traffic flow in bottleneck areas with the help of a dynamic traffic management system [SCHA07]. Characteristics of this method are:

- Trains are handled according to the actual sequence (first come first serve) and not to the schedule;
- A flexible use of platforms at stations;
- Almost no scheduled connections in the bottleneck;
- Unnecessary waiting times by scheduling trains early are avoided in the bottleneck;
- If necessary, trains have to wait in the buffer zone outside the bottleneck;
- Different timetables for working (e.g. drivers) and public

A similar program, called PULS 90, is developed in Switzerland by the Swiss Federal Railways (SBB AG) in cooperation with the Swiss Federal Institute of Technology ETH Zurich [LAU07], [LUE07a], [LUE07b], [STA03], [WUE06]. Key element of this method is to eliminate buffer times within bottleneck areas and therefore maximise the capacity within these areas. An important difference between the two approaches is the philosophy, that in PULS 90 each train always has a valid timetable and acts within a given tolerance band. Specific reasons for this decision are the large numbers of interactions (itineraries and connections) between the trains in bottleneck areas.

In order that the PULS 90 method is applicable, two essential requirements have to be fulfilled:

- New production plans (timetables) have to be calculated within shortest time after a delay or event (real-time rescheduling); and
- The production has to follow very precisely to the given, dynamically changeable production plan. Precise production consists of two components: precise driving and on-time departure.

Thereby, the departure process was identified as a critical process to satisfy the target accuracy level. An enhanced analysis and study was needed to identify the critical parts and effects of inaccurate production.

Section 2 of the paper describes the today's departure process including temporal quantifications. Section 3 gives an overview of the interconnections between capacity, buffer times, production accuracy and stability for rail networks. Results of a microscopic rail simulation for the specific area around Lucerne to evaluate the impacts on production accuracy on stability is described in section 4 and section 5 present conclusions.

2. Departure Process

The train departure process is a common reason for delays on train networks. Beside external delay reasons as waiting for late connecting trains or blocked routes, late passengers, blocked doors, or delays caused by employees are examples for the unpunctual departure of trains. To improve the quality of the departure process, the actual departure process was analysed and measurements were done to quantify the various processes.

2.1 Process analysis of today's departure process

A train can depart from a station if the following conditions are fulfilled:

- The route has to be set (signal is green),
- The departure time is past,
- The driver is ready,
- The main boarding and alighting process is finished, and
- Train preparation (which is normally done in dead-end stations) is completed.

When the last condition out of the list is satisfied, closing and locking of the doors is possible (state *s0*). The different processes and connections to the completion of the conditions are showed in the Figures 1 and 2 for through and dead-end stations. The subsequently departure process, after satisfied departing conditions, is illustrated in Figure 3.

Figure 1 Departing conditions for a through station.

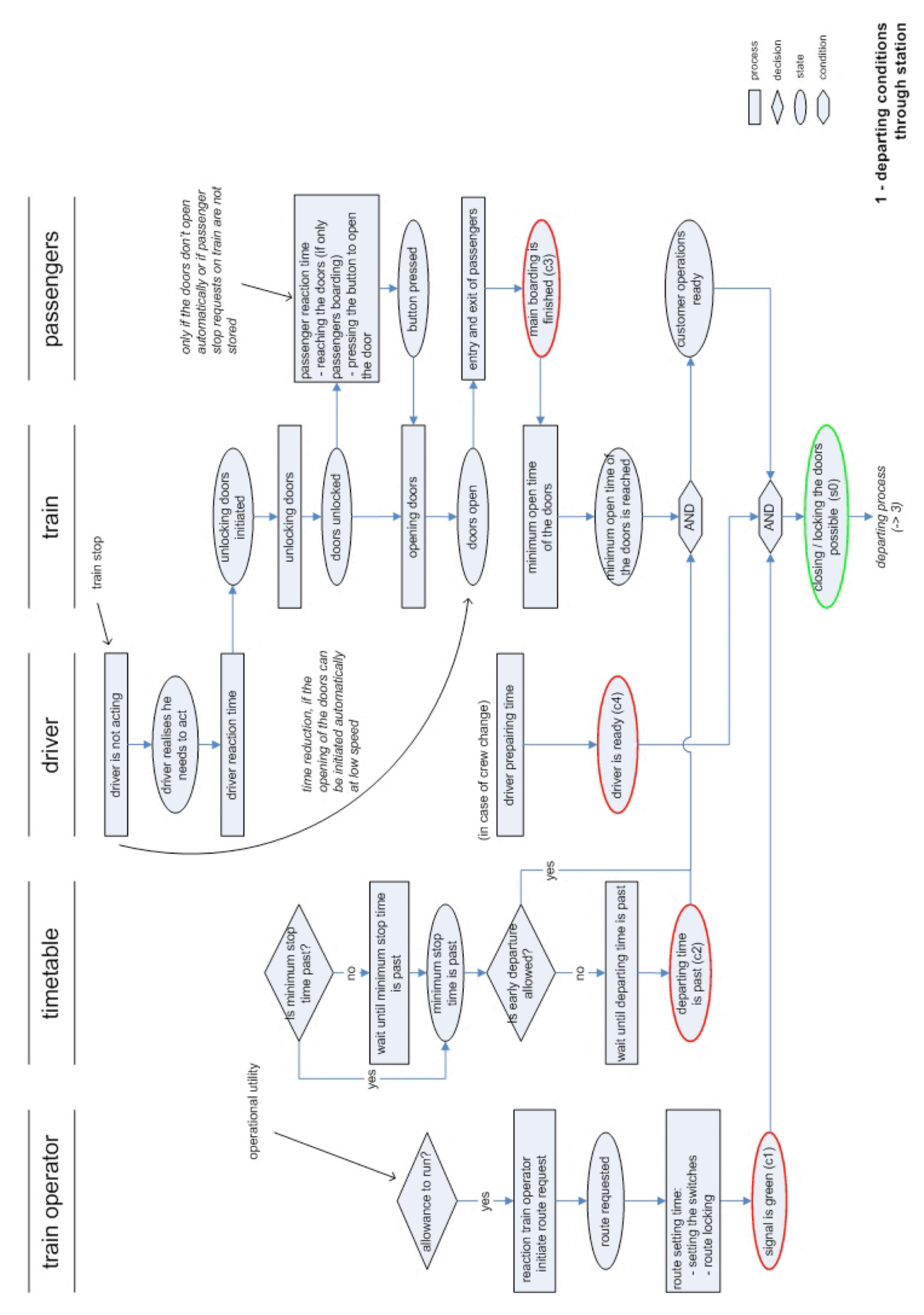


Figure 2 Departing conditions for a dead-end station.

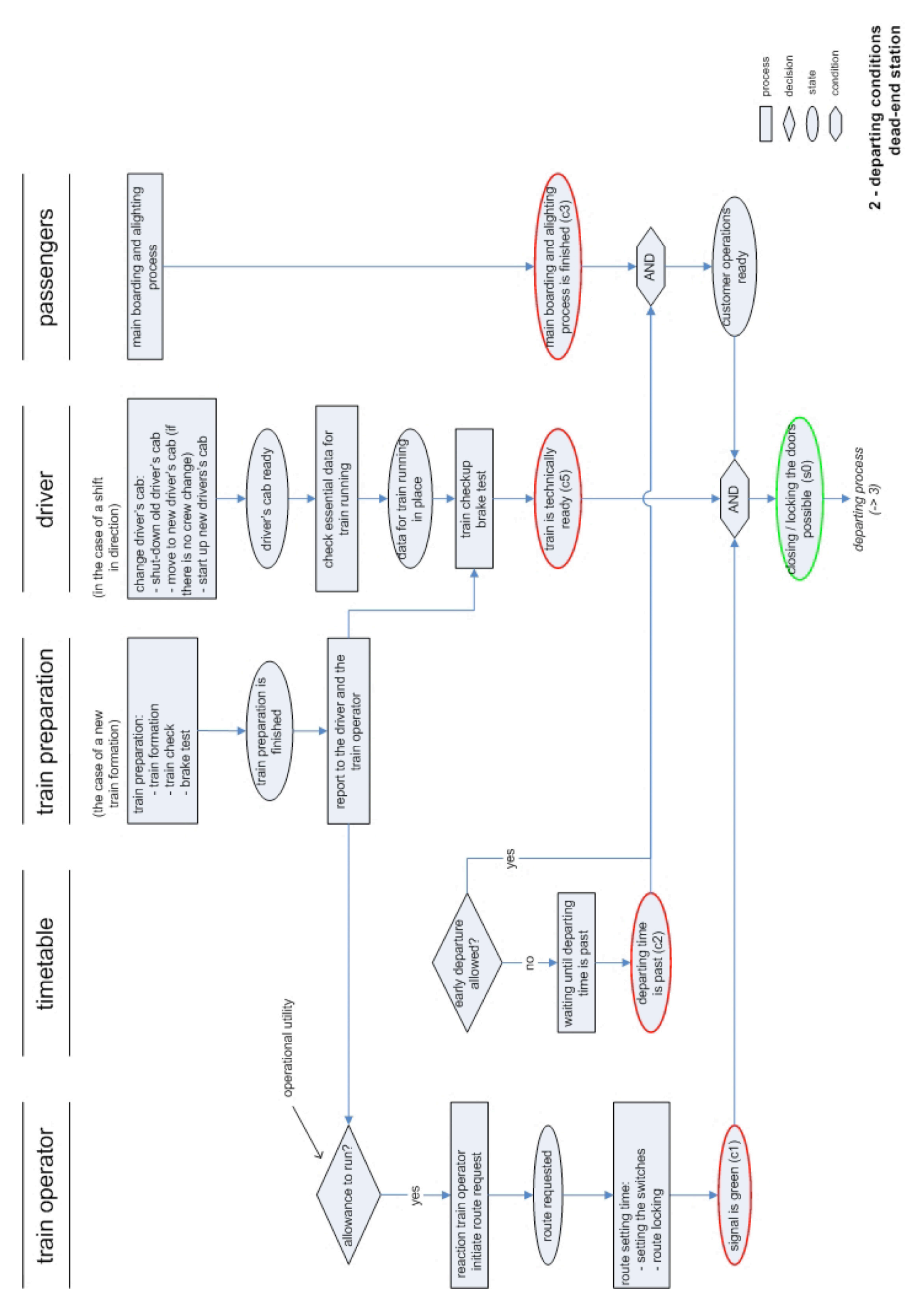
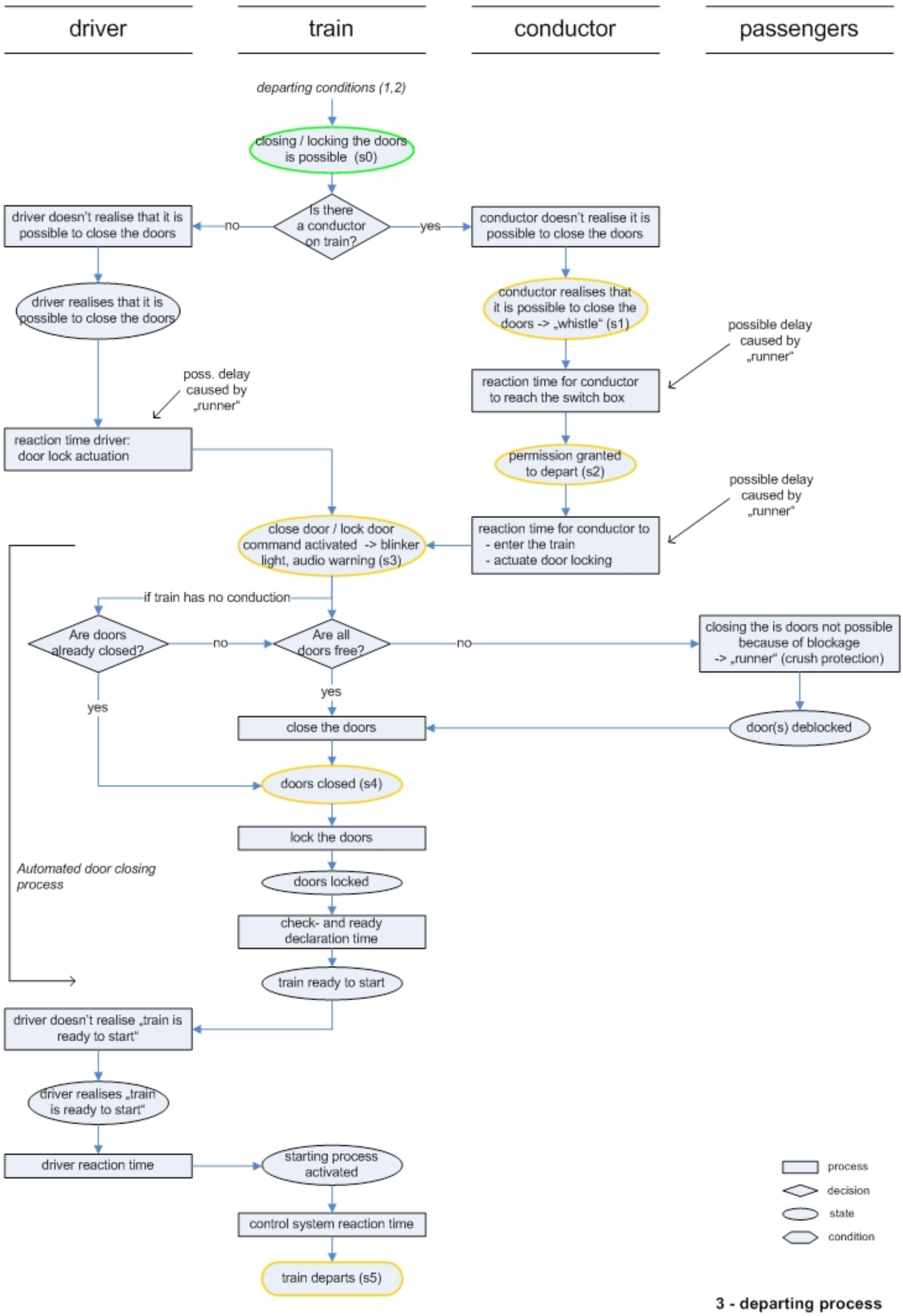


Figure 3 Departure process after achieving all departing conditions.



The departure process after satisfied departing conditions differs on principle between trains who run with and trains who run without a conductor. On conducted trains, the conductor is responsible for closing the doors and giving the final departing permission. This means, that as soon as the closing and locking of the doors is possible, he has to announce the imminent departure with a whistle and a hand signal or in the darkness with a pocket lamp. After that, he moves to the switch box to grant the permission for the departure. Subsequently, he enters the train and activates the door locking by using the UIC switch. After that, all doors of the train will be closed and locked. As soon as the driver gets the information “doors locked” transmitted to the driver’s cab, he can speed up the train. After a short delay because of the control system’s reaction, the vehicle is accelerating. Depending on the rolling stock or the station, the described processes can be executed with some minor changes. For example the dispatching can be executed by the station staff and not by the conductor. In this case, the moving time to the switch box and back to the door can be eliminated.

On trains without a conductor (for example the S-Bahn Zürich) the driver is of full responsibility. As soon as the departing conditions are fulfilled and the driver realises this state, he can activate the close door command. Thereby, the flashing light and the audio warning were activated. At the same time, the running board contact is switched off and the light barrier and the push-button were deactivated on the doors. Only the security elements of the crush protection and the differential pressure switch stay active. Nevertheless, the driver should keep a minimum time to consider the entry and exit of passengers before he activates the door close command to prevent big delays caused by passenger deviance. This entire process of the door locking is automated. This means, the driver actuates only the “door lock button”. When the doors are locked, the information is showed in the driver’s cab and the driver can accelerate the vehicle. With the S-Bahn Zürich rolling stock, it is possible to set the speed command for the departure already before the door locking process is finished. That means, the train accelerates automatically immediate after the locking. Consequently, the driver’s reaction time is eliminated and it remains merely the control system, which causes a certain delay.

2.2 Temporal quantification

Measurements were executed to answer the following questions:

- How long takes the departure process?
- What are the main causes that hinder trains to run more precisely?

Altogether, 267 train departures at the stations of Zurich and Winterthur were recorded. Train departures were measured at dead-end and through stations and for trains with or without conductors. Thereby, the states *s0–s5* (see Figure 3) were all recorded with the accuracy of a second for each train.

Figure 4 shows the different distributions of the whole departure process (from state *s0* to *s5*). It is obvious, that the shape of the distribution curves for conducted trains at dead-end stations as well as at through stations are very similar; with the difference that trains in through stations have in average about a 5 seconds smaller total departure delay in comparison to dead-end stations. Another insight of the measurements is, that the departure process for conducted trains takes in average 10 seconds longer than non-conducted trains. This difference is mainly caused by the final permission command done by the conductor. It is even more obvious, when the process step from the moment where the locking of the doors is possible (*s0*) with the moment where the lock door command is activated (*s3*) is analysed [JOH07]. The main reason for the large number of delays for non-conducted trains are interruptions caused by passengers hastening on the train short before the departure. Because of this, train drivers therefore sometimes wait with activating the door-lock command. On the other side, late arriving passengers can block the door even if the door locking command is already activated. This influence can be seen in the process step *s3–s4*. This sub-process takes only some seconds for conducted trains (mainly the system's door locking time), whereas for non-conducted trains process durations for over 30 seconds were sometimes observed.

Summarized, with today's departure process, it is not possible to run trains with an accuracy of 15 or 30 seconds.

Figure 4 Distributions for departing delays after satisfaction of all departure conditions (*s0-s5*).

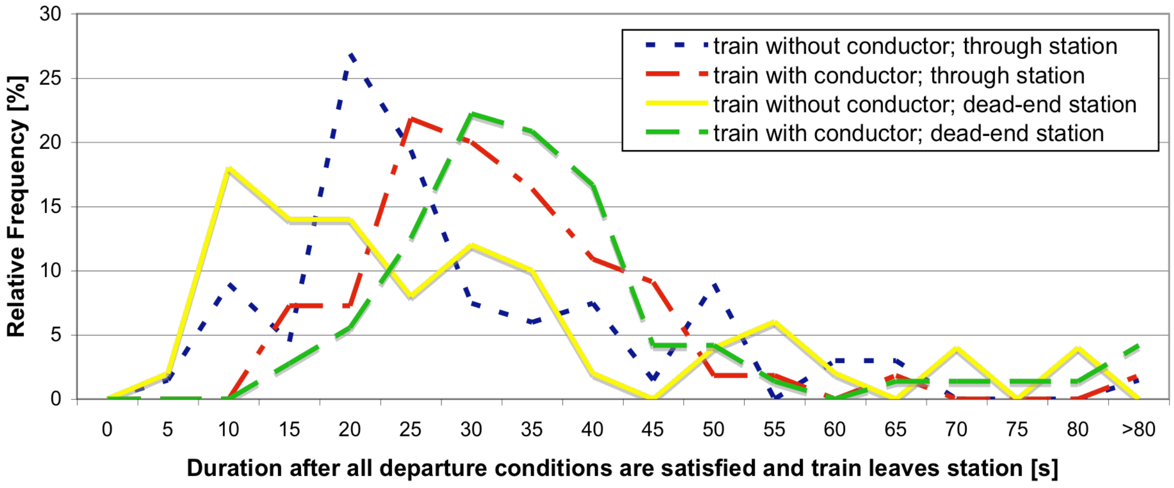


Table 1 Departing delays after satisfaction of all departure conditions (s0-s5).

	Through Station		Dead-end Station	
	With Conductor	Without Conductor	With Conductor	Without Conductor
Percentile P10	19.4 s	11.2 s	22.0 s	9.0 s
Median	30.0 s	23.0 s	32.5 s	22.0 s
Percentile P90	43.0 s	48.4 s	50.9 s	54.2 s

2.3 Possible Improvements

The measurements showed, that after satisfied departing conditions, the departure process can causes delays of up to one additional minute. To reach the target maximal value of 15 or 30 seconds, technical improvements and changes in the process are needed.

A parallelisation of the processes is one possibility to reduce the duration [LAU04]. As a result out of this, some actions have to be executed before the planned departing time is achieved. An example for this would be, that the door locking process is initiated before the route is set. To avoid passengers waiting in front of closed doors – which in fact would be very unpopular – the train drivers and conductors need accurate and up-to-date information when the route for departure will be set.

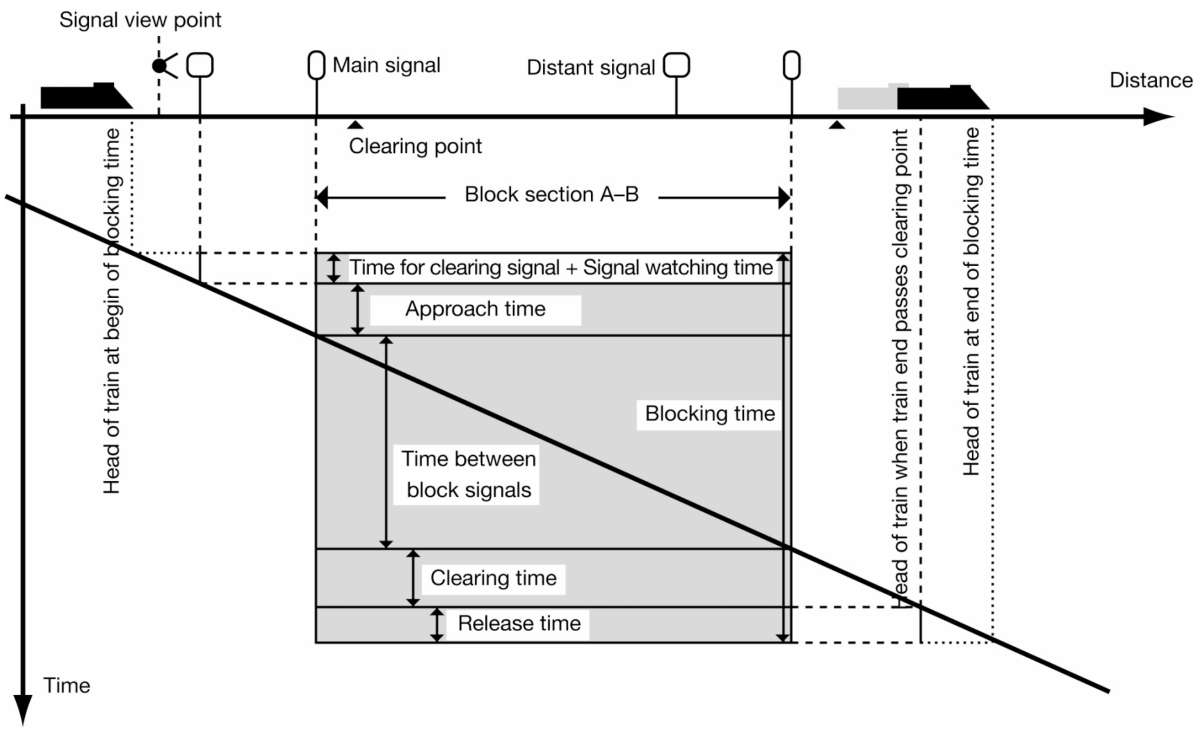
Another possibility is reducing the duration and variation for all sub-processes. Staffs on platforms or new technologies – for example dynamic passenger information systems, handhelds for conductors or advanced door closing systems – are needed to achieve higher accuracy and lower delays.

Beside the possibilities to reduce the departure process time, basic requirement for on-time departure remains that all departing conditions have to be satisfied at the planned departing time. Only in 40% of all measurements these requirements were fulfilled. Therefore, measures are needed such that the transfer of secondary delays is minimised.

3. Capacity and Buffer Times

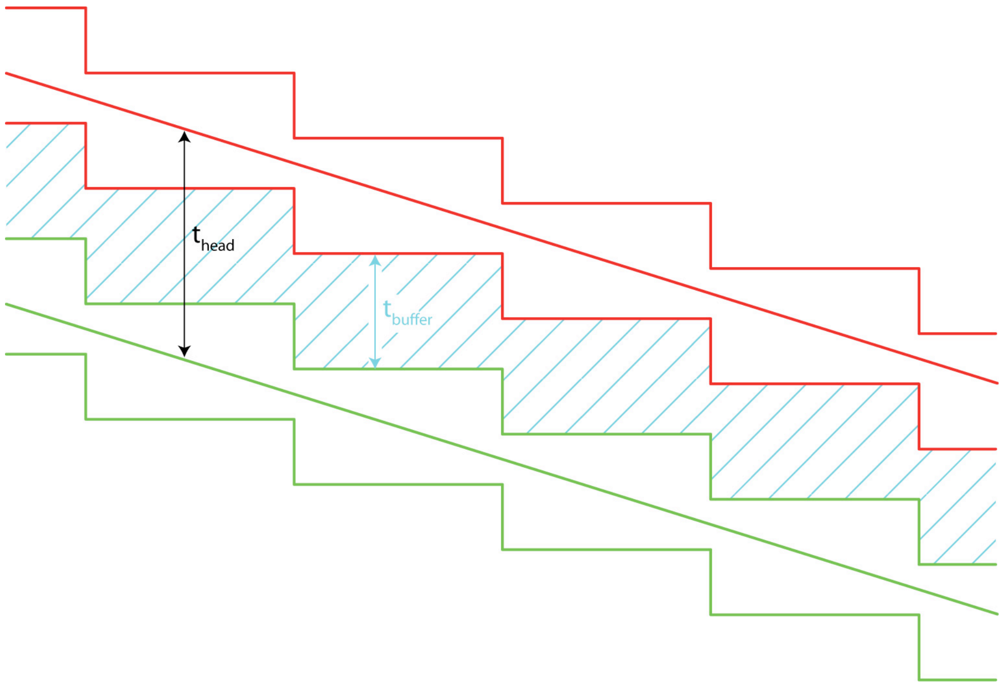
For capacity analysis, the time used on a line with fixed block systems, called blocking time, is needed. The blocking time is the time in which a given track section is allocated exclusively to a single train. The blocking time is a summation of several time intervals, illustrated in Figure 5 [PAC02].

Figure 5 Blocking time elements.



Connecting the blocking times for all sections that are passed by a train, the so-called time-distance blocking time stairway, is produced. The buffer time between two trains then can easily be determined with the blocking time stairways (see Figure 6). Using the blocking time stairways, it is obvious, that buffer times reduce the capacity. On the other hand, it is also evident that buffer times reduce the possibility of conflicts.

Figure 6 Blocking time stairways and buffer times between two following trains.

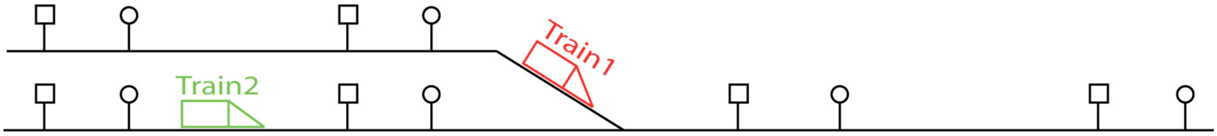


For merging two lines on a single track section (see example in Figure 7) a conflict exists if the difference of the delay of the first train $t_{del\text{-}train1}$ minus the delay of the second train $t_{del\text{-}train2}$ is larger than the scheduled buffer time t_{buffer}:

$$t_{del_{train1}} - t_{del_{train2}} > t_{buffer} \quad : \text{ conflict}$$
$$t_{del_{train1}} - t_{del_{train2}} < t_{buffer} \quad : \text{ no conflict.}$$

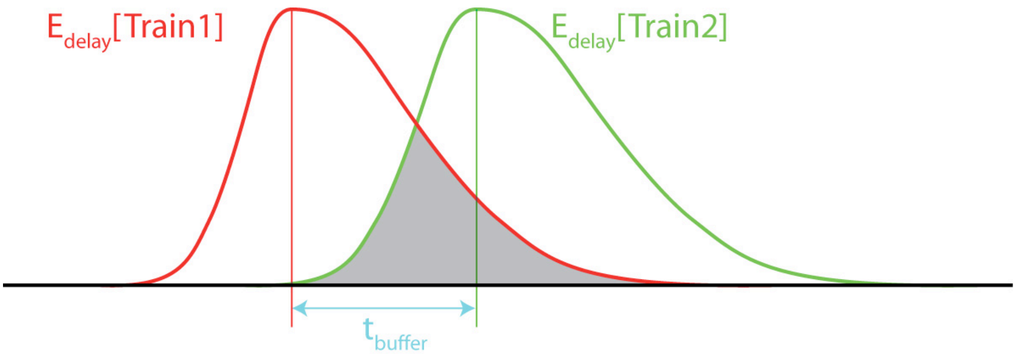
This dependency is also valid for two-way conflicts or in station areas when a train leaves or arrives late with overlapping train itineraries.

Figure 7 Train following conflict on single line section.



Surveys [LUE05], [YUA04] showed, that in most cases the distributions form of arriving and departing trains are log-normal or log-logistic (Figure 8). Conflicts and thus secondary delays occur, when the curves are overlapping. Reducing the width of the delay distribution therefore causes fewer conflicts and results in a more stable and punctual production.

Figure 8 Delay distributions for two consecutive trains.



Analysing secondary delays, train dynamics with stopping and accelerating actions have to be taken into account. Trains that have to slow down or stop because of a routing conflict, lose additional time because of deceleration and acceleration. An example, where the first train is late on a line that merges into a single section and causes the second train to stop, is illustrated in Figure 9.

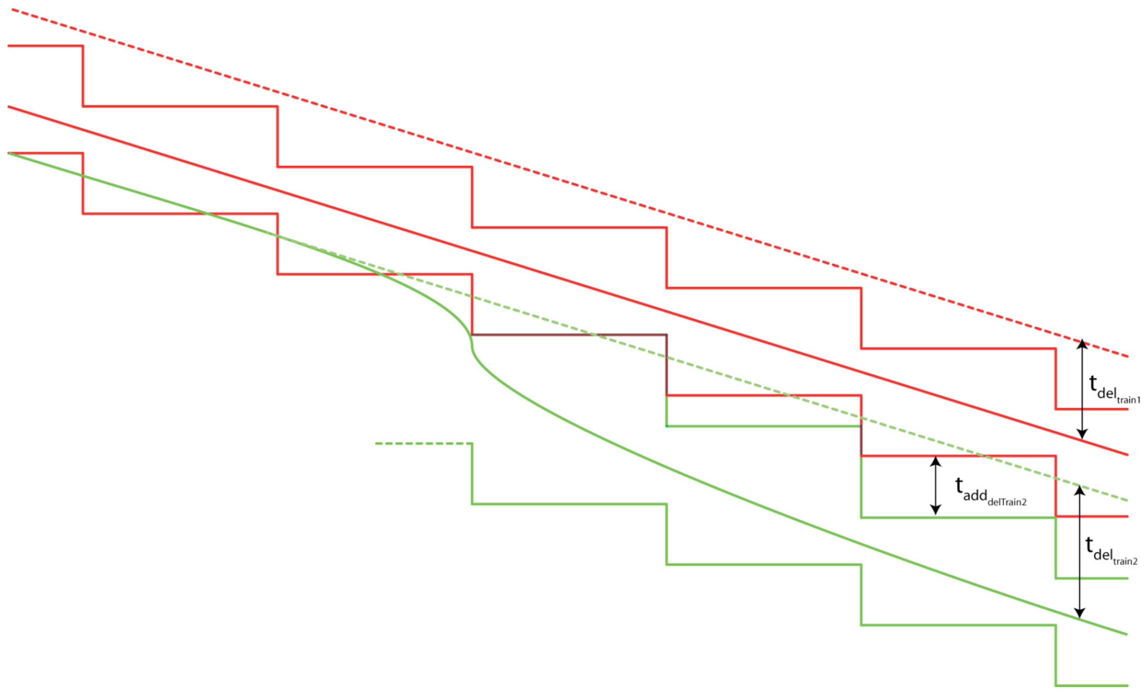
The final delay of the second train $t_{final\text{-}del\ train2}$ then can be calculated as:

$$t_{final-del_{train2}} = t_{initial-del_{train1}} - t_{buffer} + t_{add_{delTrain2}}$$

with $t_{initial\text{-}del\ train1}$ as the initial delay of the first train and $t_{add\text{-}delTrain2}$ as the time lost due to deceleration and acceleration of the second train.

Therefore, secondary delays are not only a direct transfer of the delay of a first train. The additional time lost because of deceleration and acceleration can be up to several minutes, depending on the train dynamics, the desired speed and the signalling system. In station areas, additional delays are because of the low speed only between 10 and 30 seconds.

Figure 9 Delay propagation and delay growth because of stopping train.



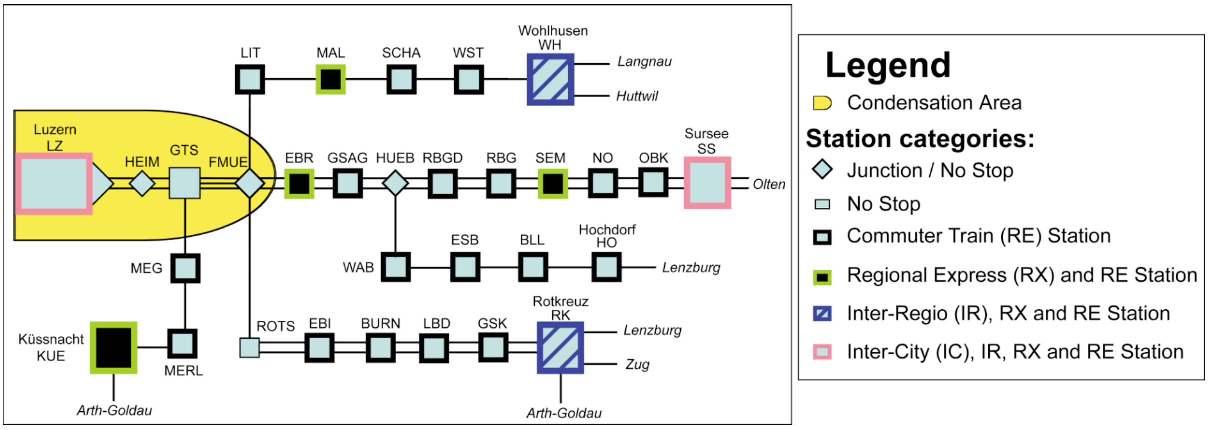
4. Simulation

4.1 Method

In order to evaluate the effects of the production accuracy, simulations of the Lucerne station area were executed. The complete area of Lucerne (illustrated in Figure 10) has a range of about 25 – 40 kilometres. The considered bottleneck zone of Lucerne with a range of about 5 kilometres consists of a dead-end station with 10 platforms and is linked only with two tracks heading to 5 different directions. Narrow gauge trains were not treated because almost no interactions with standard gauge trains exist.

The simulation was completed using OpenTrack [NAS04a]. OpenTrack is a microscopic railway simulation program, which uses the exact track topology (including the signalling system), train characteristics and timetable as input for the calculations. Various analyses and graphics are possible with this tool.

Figure 10 Aggregated topology of the network around the dead-end station in Lucerne.

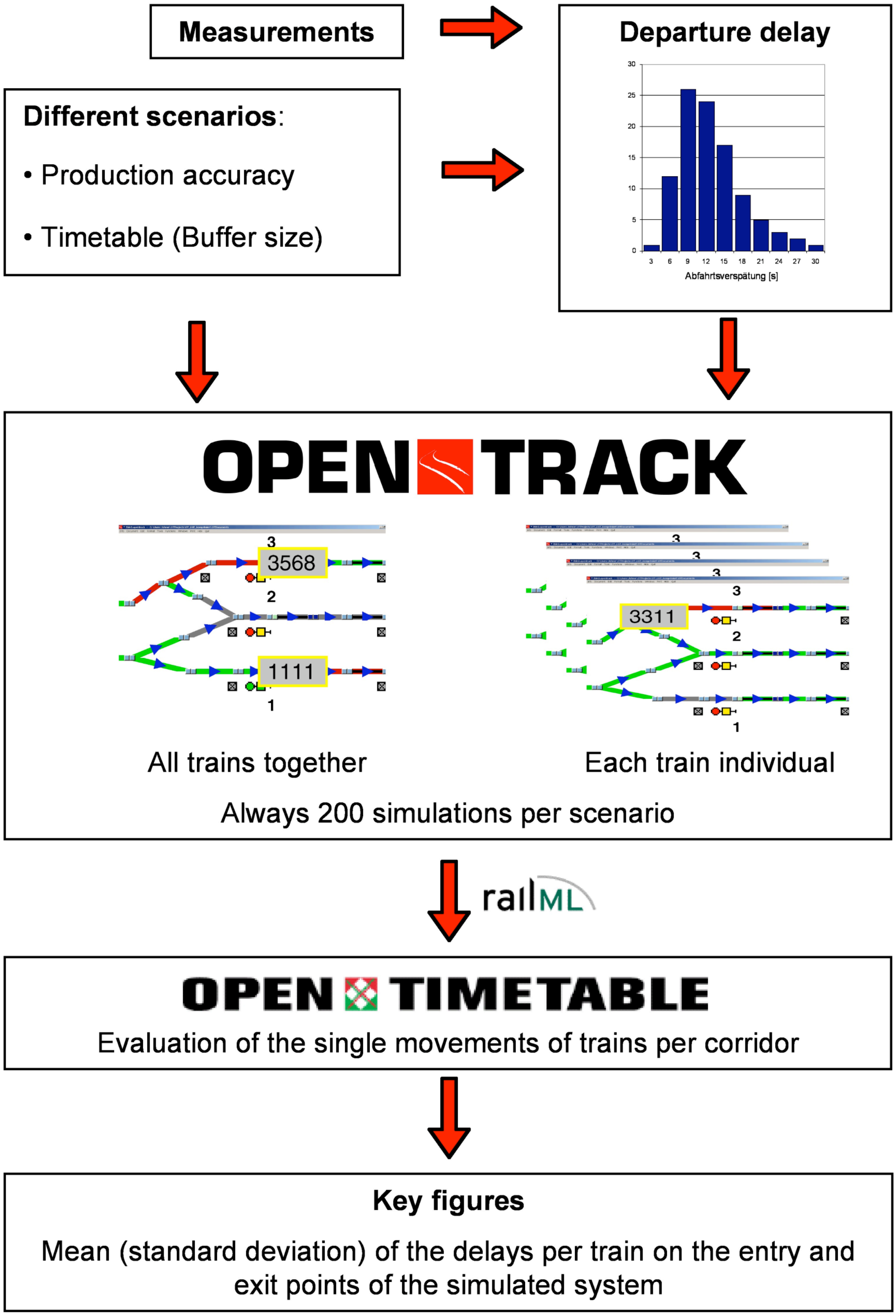


To compare the consequences of the production accuracy, trains were simulated with two different timetables. The 2006 timetable was the basis and was adjusted by varying the buffer times between trains. The other input parameter was the production accuracy, which was modelled as an initial delay with a uniform distribution and a varying width of 30 or 60 seconds.

For each scenario (timetable/buffer size and production accuracy), 200 simulation runs with random initial delays (based on the predefined distribution) were executed in OpenTrack. Using RailML, a standard data format to exchange railway data based on the XML-Scheme [NAS04b], the data was analysed with OpenTimeTable.

OpenTimeTable [NAS04c] is a computer program, designed to analyze train-operating data. This could be for both, real or simulated train running. In contrast to OpenTrack, OpenTimeTable is optimized to handle a lot of data from different train running over a along period of time or large amount of simulations in one step. With OpenTimeTable, the simulations were evaluated and specific parameters as mean delay or numbers of affected trains with secondary delays were calculated. The detailed proceeding of the simulation study is illustrated in Figure 11.

Figure 11 Proceeding of the simulation study.



4.2 Simulation results

At first view, results of the simulation show that the production accuracy has not a big temporal impact on secondary delays (Table 2). The main reason is that additional delays because of stopping and accelerating are very low. This is because the permitted speeds in the bottleneck area around the station Lucerne where conflicts between the trains occur are low. Nevertheless, it should be noted that in all scenarios, 30 to 90% of all trains were affected with secondary delays.

Table 2 Effects of inaccurate production on delays

	Small Headway 30 sec Accuracy	**Large Headway 30 sec Accuracy**	**Large Headway 60 sec Accuracy**
Mean secondary delay of all trains	22.1 sec	0.8 sec	6.4 sec
Percentage of trains affected with secondary delay	91 %	34 %	52 %

The scenarios were based on the assumption, that all trains have only small delays because of inaccuracy. However, the impact of inaccuracy on secondary delays would strongly increase, if one or more trains arrive or leave with larger delays. In this case, trains have to be rescheduled (new routings, new train orders). Because of inaccuracy, dispatchers can make suboptimal decisions with significant impact on the total delay. As a result out of this, train conflicts occur not only in the bottleneck area with low speed. Also on the single line track sections, which connect the station Lucerne with the rest of the network, conflicts can occur. In these sections, higher speed is permitted and therefore, secondary delays will increase significantly.

Accurate production, which results in a better predictability of the future behaviour, therefore is needed for dispatchers to minimise the secondary delays. Especially for dense rail traffic where a lot of rescheduling possibilities are available, consequences or delays can differ for varying measures.

It should be noted, that freight trains were not considered within this simulation. Freight trains would increase secondary delays because of their poor train dynamics. To improve the production accuracy of freight trains, different processes would be needed and are topic of ongoing research.

5. Conclusion

Inaccurate production causes uncertainty in the prediction of the future behaviour of trains running on a network. Simulation results showed, that as long as all trains run on-time within a given uncertainty bandwidth, the effects because of inaccurate departure is limited. However, as soon as the delay of one single train exceeds a threshold, making an optimal dispatching decision cannot be guaranteed. Because of this, unnecessary secondary delays occur. Thus, the level of accuracy achieved during the production limits the potential benefits of the next generation's traffic management system. Consequently, rail networks stability and capacity are unnecessarily limited by inaccurate production.

To improve the production accuracy for running trains, Driver-Machine Interfaces are under development to ensure, that temporal deviations are minimised, even for dynamically changed schedules. The departure process, another important source for inaccurate production, is a complex, sequential process and is in addition subject to various disturbances. Passengers and also involved stuff (conductors, drivers, infrastructure operators) were identified as the primary delay reasons during the process analysis and measurements.

To reduce the inaccuracy during the departure process, which is up to one minute at the moment, modifications and enhancements on technology and process is needed. The parallelisation of processes to reduce the duration for departure and new passenger information systems have to be developed and tested on their effectiveness.

To summarise, increasing capacity without significant infrastructure investments and punctuality losses is therefore only possible, when production accuracy is improved. In particular, changes in the departure process are essentially needed to achieve the target accuracy.

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