D8.4 Demonstration Scenario 3 - Iron Ore Line

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Revision control / involved partners

Following table gives an overview on elaboration and processed changes of the document:

Revision	Date	Name / Company short name	Changes
1	09/10/2014	Bengt Sandblad/UoU	Draft
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Following project partners have been involved in the elaboration of this document:

Partner No.	Company short name	Involved experts
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Executive Summary

The overall aim of the ON-TIME project is to improve railway customer satisfaction through increased capacity and decreased delays both for passengers and freight. This is achieved through new and enhanced methods, processes and algorithms.

A key objective of the project was to demonstrate the research results with real life examples and situations.

The purpose of this document is to describe simulations performed for the Iron Ore Line (IOL), in order to test and evaluate the systems for operational traffic re-planning in case of perturbations. The simulator Hermes has been used for the simulations, with input data describing the IOL. When the simulator has been found valid for the IOL, a number of perturbations scenarios have been used for evaluation of the ON-TIME modules for perturbation handling. The Perturbation Management Modules (PMM) have been connected to the simulator system. The PMM detects perturbations and the need for re-planning and calculates a new real time traffic plan (RTTP), which is automatically executed to the (simulated) traffic control system.

Two different scenarios have been used for evaluation studies. One with a delayed loaded iron ore train and one with speed restrictions between two stations.

The evaluation studies have resulted in the following conclusions:

- The Hermes simulator can simulate the traffic on the IOL, for undisturbed traffic as well as for traffic with certain perturbations. However, with a number of limitation.
- The developed systems for automatic re-planning, the PMM modules, are able to handle the perturbations specified in some scenario for the IOL.
- That evaluations show that a number of additional requirements must be fulfilled, if the systems are going to be used in real traffic control on the IOL.
- That the results give us a good basis for future research and development.
- It will be necessary to perform more advanced evaluations, in order to specify additional requirements in detail.

Final remarks are, that the results so far are very interesting for future development in Sweden. Important will be to integrate the PMM modules with a fully interactive environment. The present control system in Boden, with STEG and CATO, can profit from efficient tools for optimal re-planning and decision support. The human controllers' tasks must then be coordinated with the more automated functions and their user interfaces must visualize important aspects of the PMM actions.

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Table of abbreviations

CATO	Swedish system (Computer Aided Train Operation)
DAS	Driver Advisory System
IOL	Iron Ore Line
ONT	ONTIME project code
PMM	Perturbation Management Module
RECIFE	A PMM module

ROMA	A PMM module
STEG	Swedish system (Control using Electronic Graph)
TC	Traffic Controller
TCC	Traffic Control Centre

1 PURPOSE OF THE EVALUATION STUDY

The Iron Ore Line simulations illustrate the traffic on a single track line with a border crossing. The traffic between Kiruna in Sweden and Narvik in Norway is simulated. The purpose is to evaluate ON-TIME systems for optimal re-planning, in case of minor perturbations.

Some perturbation scenarios for the Iron Ore Line have been identified and used for simulations. The scenarios have been specified based on an investigation of most common perturbations in real traffic situations. The main scenarios are:

- One fully loaded iron ore train delayed from original station.
- Extra train added, on short notice.
- Long distance freight train, entering the iron ore line, delayed.
- Speed restriction due to maintenance work between two stations.
- Infrastructure problem. Point out of order at one station.

The operational re-planning and the solutions to perturbations are extra challenging here. The iron ore line is a long single track line, there are few and sometimes too short stations available for meetings and the loaded iron ore trains are extremely heavy. This means that non-optimal re-planning can cause severe disturbances, long delays, high energy consumption and high costs.

The results concerning how the re-planning algorithms (perturbation management modules, PMM) developed in the ON-TIME project, WP4, can solve problems in connection with traffic perturbations, are here especially interesting. Such algorithms will in the future be a part of new traffic control systems in Sweden.

2 BACKGROUND

2.1 The Iron Ore Line

The Iron Ore is a single track railway line between Narvik in Norway and Boden in northern Sweden. Characteristics of the traffic are very heavy iron ore trains (up to 8 500 tons), long trains (750 m) and mixed traffic. The mixed traffic, and special requirements for the iron ore trains, makes the optimality of planning and handling of perturbations extremely important. Delayed or cancelled trains are associated with very high costs. The section studied in the Iron Ore Line demonstrator is from Peuravaara (Kiruna) in Sweden to Narvik in Norway. On this line there are 20 stations/meeting points. The iron ore trains cannot meet at all stations, since some of them are too short. Stations are being rebuilt.

Figure 1. The location of the Iron Ore Line, and the section studied in the scenarios.

Figure 2. An Iron Ore Line train. (Source: http://www.bahnbilder.ch)

The capacity utilization is high. Normal capacity conflicts are single track conflicts with meetings between trains and conflicts between fast passenger trains and slow iron ore trains. The length of a station is between 500 m and 750 m. Iron ore trains are 750 m long.

Iron ore trains have in many aspects the highest priority. The second priority has long distance freight trains and passenger trains. The iron ore trains operate over 24 hours. There are several railway companies involved. LKAB Malmtrafik AB run iron ore trains Kiruna - Narvik, 750 m long and run at 60 km/h (loaded) or 70 km/h (empty). Green Cargo AB (Northland), run iron ore trains from Svappavaara via Kiruna to Narvik. CargoNet and Green Cargo run 100 km/h container trains, 1000 ton or 1800 ton, between 500 and 600 m long, between Oslo and Narvik. There are local passenger trains from Narvik, which run at 160 km/h and a couple of long distance passenger trains running at 160 km/h.

In the table below the Iron Ore Line's structure is described. Between Kiruna and Riksgränsen there are short meeting stations, where iron ore trains cannot meet. Between Riksgränsen and Narvik, short meeting stations are Rombak and Björnfjell.

Station name	**Abb.**	**Distance km**
Kiruna	*Kmb*	0
Krokvik	*Kv*	9
Rautas	*Rut*	20
Rensjön	*Rsn*	30
Bergfors	*Bfs*	39
Torneträsk	*Tnk*	50
Stenbacken	*Sbk*	60
Kaisepakte	*Kpe*	69
Stordalen	*Soa*	81
Abisko Ö	*Ak*	92
Björkliden	*Bln*	101
Kopparåsen	*Kå*	110
Vassijaure	*Vj*	118
Björnfjell	*Bjf*	130
Katteratt	*Kat*	141
Rombak	*Rom*	148
Straumsnes	*Sms*	156
Narvik	*Nk*	165

Table 1. The Iron Ore Line

2.2 Boden TCC

From the traffic control centre (TCC) in Boden, traffic on the iron ore line and all other train traffic in northern Sweden, is controlled. Boden TCC is a centre for development, test and evaluation of future systems for traffic control in Sweden. A new system, STEG[1] has been deployed, that supports traffic controllers to re-plan traffic using an interactive time-distance graph. The continuously updated real time traffic plan (RTTP) is automatically executed to the traffic control system. For communication with the train drivers another test DAS (driver advisory system) system, CATO[2], has been developed and implemented.

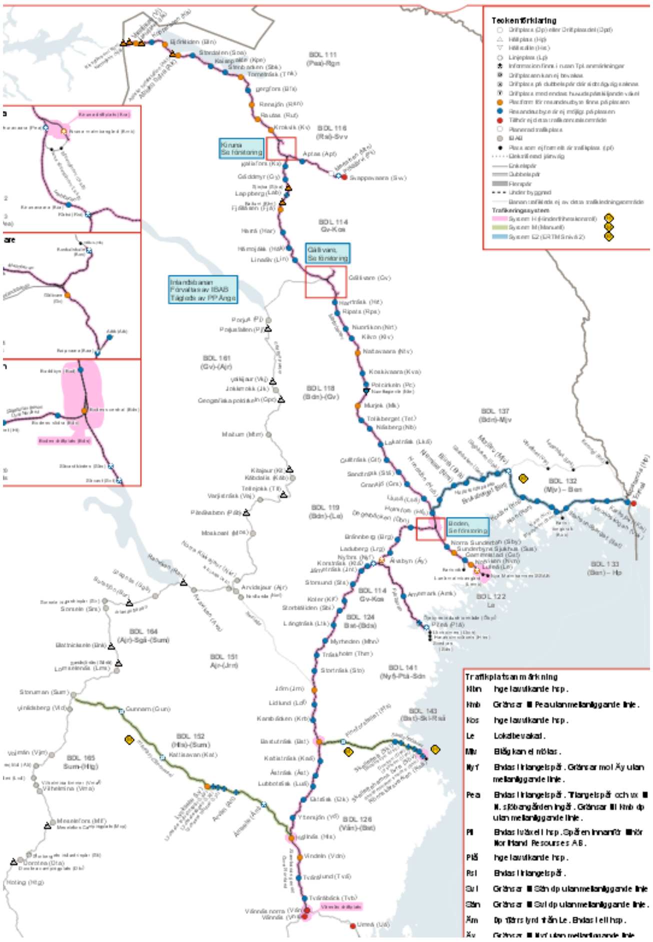

Figure 3. Traffic control area for Boden TCC.

[1] B Sandblad, A W Andersson, A Kauppi, G Isaksson-Lutteman. Development and implementation of new principles and systems for train traffic control in Sweden. Computers in Railways XII, WIT-press, 2010, pp 441-450.

[2] Yang, L., Lidén, T., & Leander, P. (2013). Achieving energy-efficiency and on-time performance with Driver Advisory Systems Success factors when going from research idea into production phase. In ICIRT (pp. 13–18).

3 THE PERTURBATION MANAGEMENT MODULE (PMM)

The design of the ON-TIME system for perturbation management is visualized in the following figure. The functionality of the PMM and related systems are described in detail in the document D4.2 from the ON-TIME project.

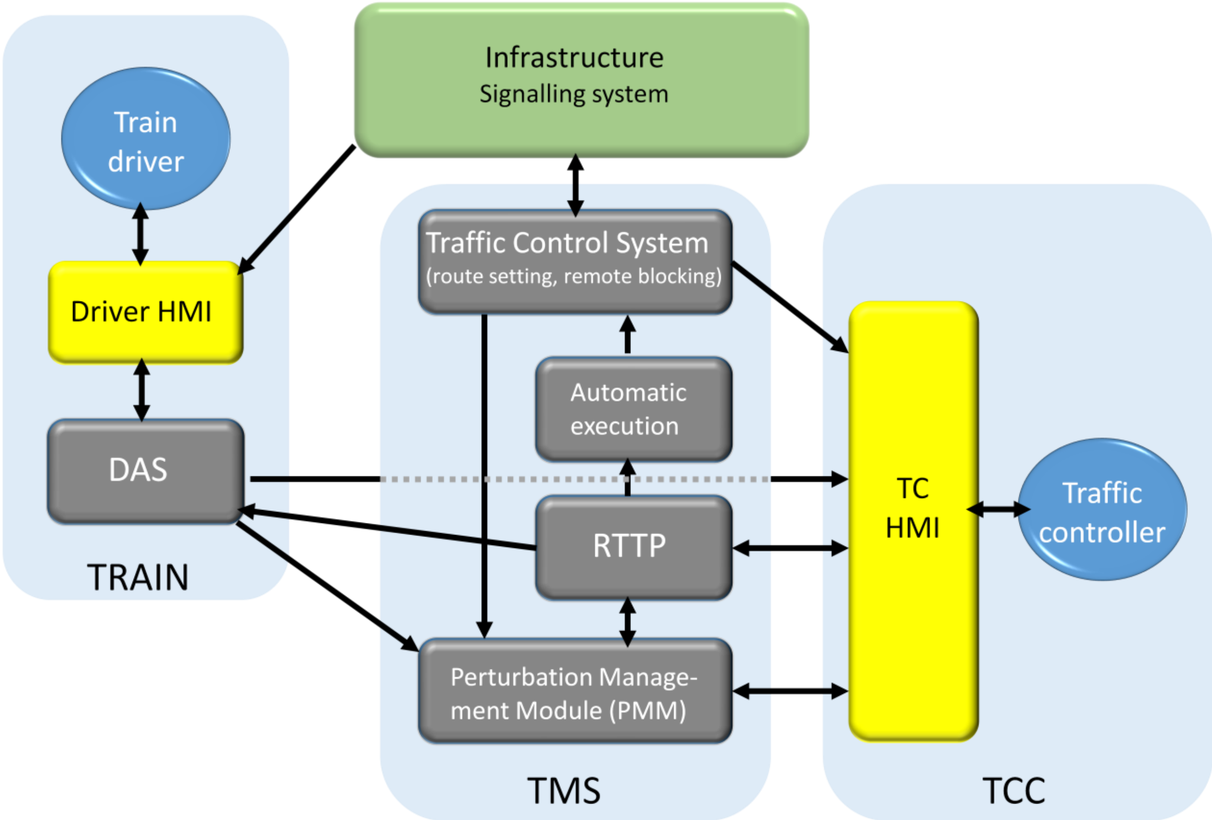

Figure 4. The structure of the ON-TIME systems for perturbation handling and train driver support.

The PMM detects the need for re-planning and calculates a new optimal RTTP (real time traffic plan). The RTTP is automatically executed to the traffic control system.. When required, the human traffic controller can perform re-planning tasks. The new plan is via a DAS (driver advisory system) sent to the train driver.

It can be noted that the present control system in Boden, the STEG system, is designed according to the same main principles. The difference between the STEG system and the ON-TIME solution is the existence of the PMM. In STEG, the human operators are responsible for the re-planning and a PMM is not implemented there today. For the iron ore train, there exist a DAS, CATO, which has the same role as the DAS system developed in the ON-TIME project. In the ON-TIME system, designed according to the figure above, the interactive role of the human controller is planned but not implemented today. For future research and development in Sweden, the result from ON-TIME is of great interest.

4 DELIMITATIONS

In the demonstrator for the Iron Ore Line, the interactive HMI for the traffic controller is not implemented. However, in the STEG implementation in Boden, a fully interactive system is in full operation. Future research will combine these two innovations: the interactive system and the supportive optimization algorithms (PMM) developed in ON-TIME.

For the evaluation studies presented in this document, the focus is on the operational re-planning performed by the PMM, and the connections to the DAS and train drivers has not been studied.

Not all specified scenarios have been evaluated in the simulator and demonstrator system. Some typical scenarios have been selected for more detailed analysis. See below.

The evaluation is based on the following system structure:

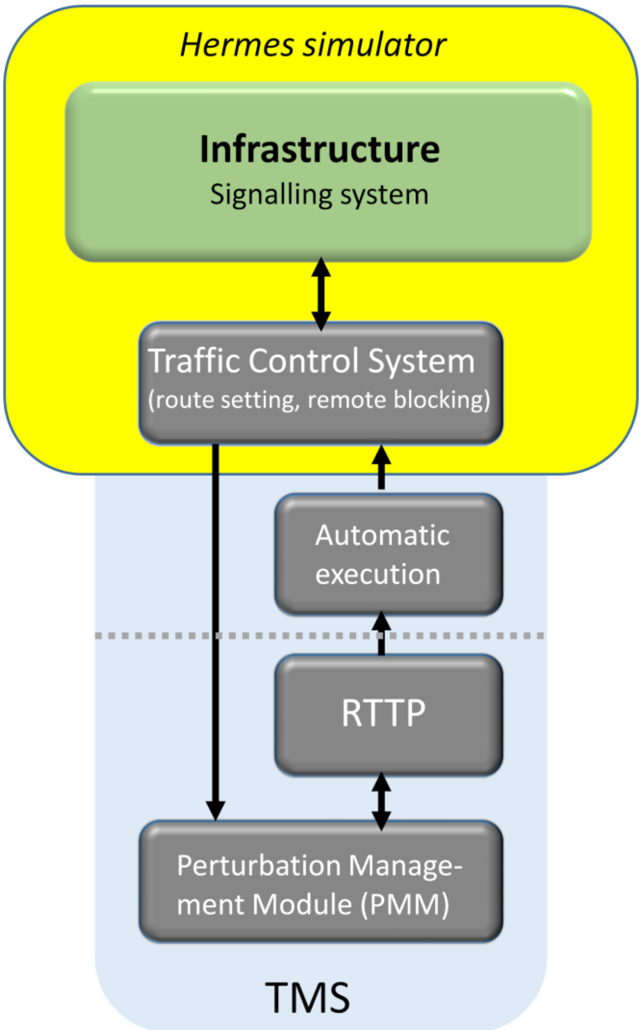

Figure 5. The Hermes simulator simulates the infrastructure, the traffic control system and the train traffic for the specified scenarios.

5 PERTURBATION SCENARIOS

The following perturbations scenarios have been specified. The specification is based on an investigation of common perturbations on the iron ore line. The scenarios have also been selected in relation to the planned evaluation of the PMM, developed in WP4 of the ON-TIME project.

Basic scenario data

Day and time to simulate: Monday Oct 21, 2013. The original timetable is used.
Area to simulate: From Peuravaara (PEA) to Norway/Narvik (NO-NK)
Number of trains: During the day: Eastbound: 22, Westbound: 19.

Scenario 0

Title: Baseline simulation
Description: No perturbations. All trains run according to timetable.
No infrastructure problems.

Scenario 1

Title: One Iron Ore Train delayed
Description: Train 9910 delayed 40 min from PEA. Ready to leave at 09.40.
No infrastructure problems.

Scenario 2

Title: A long distance freight train added and delayed
Description: New train added to original timetable. Delayed at entrance.
No infrastructure problems.

Scenario 3

Title: Speed restriction
Description: Speed restriction due to maintenance work.
Max speed between Rensjön (RSN) and Bergfors (BFS) 40 km/h.
Duration of speed restriction: Whole day
No infrastructure problems.

Scenario 4

Title: Infrastructure problem. Point out of order.
Description: Point out of order at station Stordalen (SOA).
Side track cannot be used.
No trains can meet at this station. Duration: Whole day.

As mentioned above, not all of these scenarios have been implemented in the test simulations. The tests and evaluation has been concentrated on some typical scenarios. See below.

6 TIME-TABLE DATA

The timetable graph for the simulated day has the following contents:

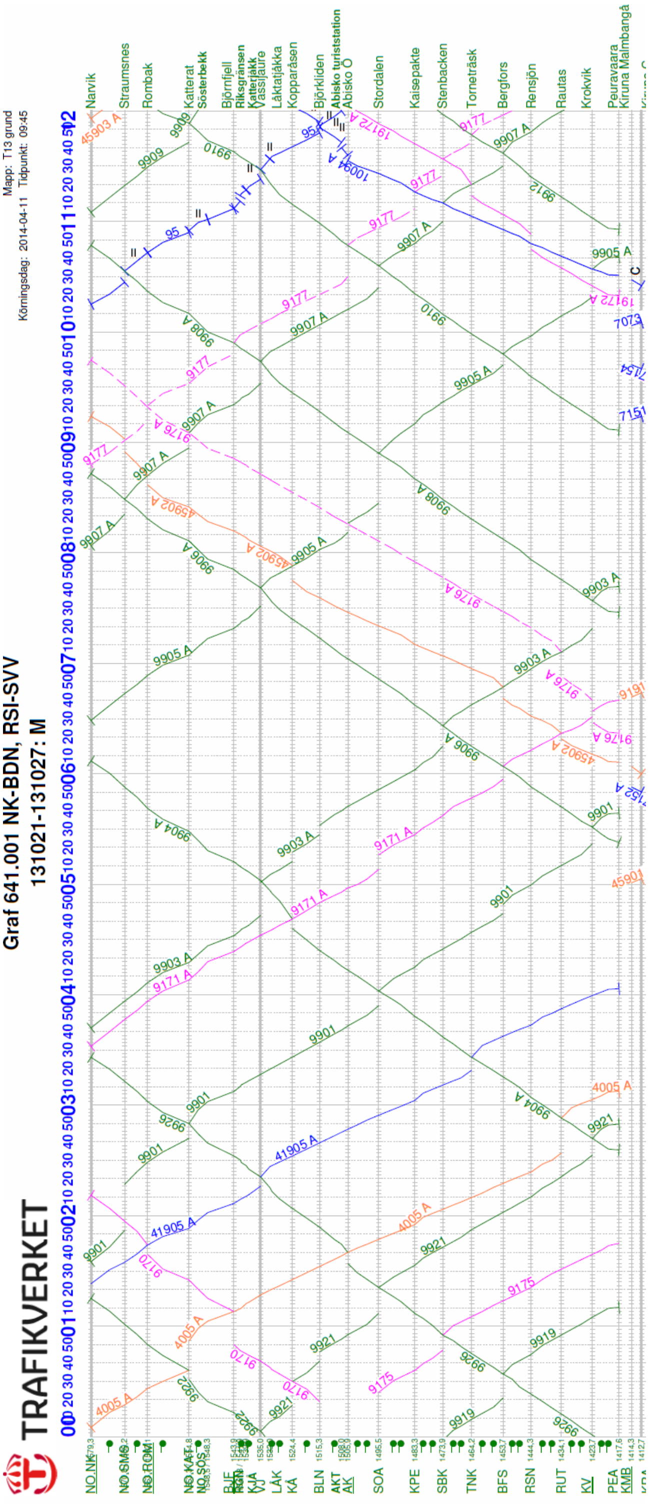

Figure 6. Time table graph for the simulated day, 0h – 12h.

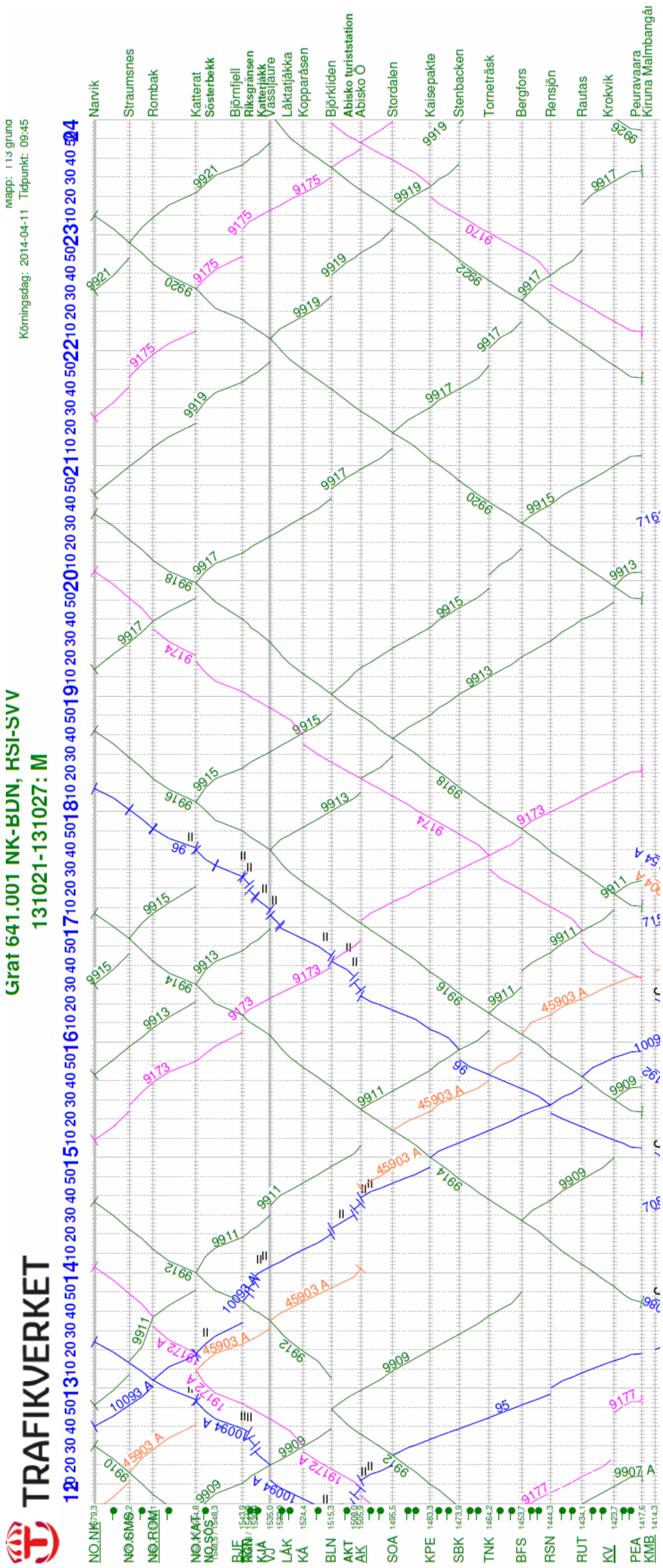

Figure 7. Time table graph for the simulated day, 12h – 24h.

7 EVALUATION METHOD

The evaluation consists of several different parts.

1. Evaluation of the simulator system Hermes, to verify that the traffic on the Iron Ore Line is correctly executed. This evaluation of the simulator system as such has mainly been performed in other parts of the ON-TIME project. Here some additional comments are given.
2. Quantitative evaluation of the simulated scenarios, using the Matlab-based evaluation tool developed in the ON-TIME project. Here some specified aspects of the quality of the re-planning, performed by the perturbation management module, are calculated and analysed. For more information about the quantitative evaluation, c.f. document deliverable D4.3 from the ON-TIME project.
3. Qualitative evaluation of the new real time traffic plan (RTTP) generated by the PMM. Here the new solutions are evaluated, based on a qualitative analysis of the generated time-distance graphs.

7.1 Quantitative evaluation

The Matlab based tool uses log-files generated by Hermes for calculation of quantitative measures for specified key performance indicators (i.e. journey time, resilience, punctuality, energy consumption, resource usage....). The result can also be visualized in form of a number of diagrams. See examples below and in the document D4.3 from the ON-TIME project.

7.2 Qualitative evaluation

This is based on analysis of the time-distance graphs. The re-planning performed, and the simulations based on the execution of the new RTTP, can be studied. In a first step the analysis and evaluation are made by the researchers. In a later step the quality of the re-planning decisions will also be evaluated by experienced traffic controller from the TCC in Boden.

8 THE HERMES SIMULATOR

The HERMES (Holistic Environment for Railway Modelling, Evaluation and Simulation) rail simulation platform is used by the On Time project to provide a real time model of railway traffic and to provide a source of static data defining the network, the rolling stock and the timetable to operate over the network.

The simulator has been adapted to provide access to internal functionality through a Java based API, accessed through a user developed plug-in module. This module conforms to a functional interface that provides access to the internal data and provides requests to change the internal state of the simulation. Although this can only be considered as a prototype at this stage, the API, namely HERMES API provides an initial specification of the generic functional properties of railway operations.

The project required simulations to be performed on a number of disparate networks, each highlighting a particular problem of capacity and punctuality. Early in the project, Iron Ore Line network was constructed based on the given timetable, through a data format extracted from the RailSys format used by Trafikverket. Subject to the area of interest, the Iron Ore Line network was limited to the area between stations Peuravaara (Kiruna) and Narvik (see Figure 8):

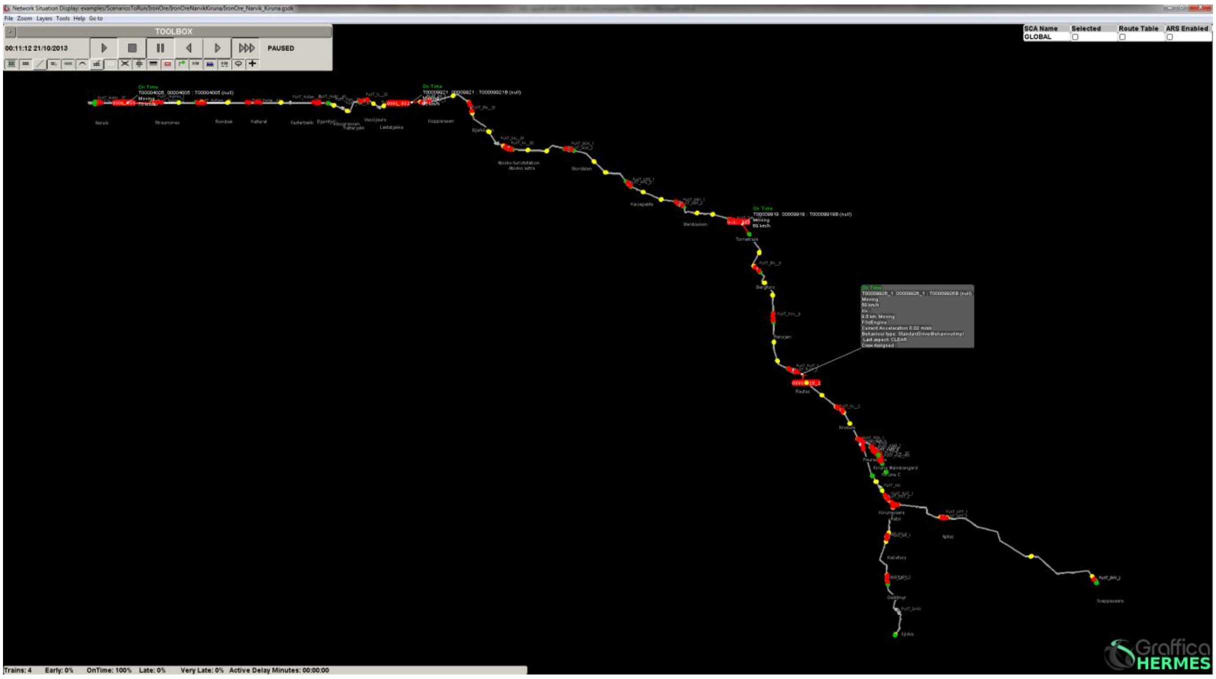

Figure 8. The overall Iron Ore Line constructed on Hermes Simulator

The HERMES API allows access to both static and real time information from the running simulation such as changing the speed of the simulation, tracking a specific train, and/or visualizing related graphs or text information for different actors, i.e. specific trains, tracks, or signals. For close-up view from a meeting point on the Iron Ore Line see Figure 9:

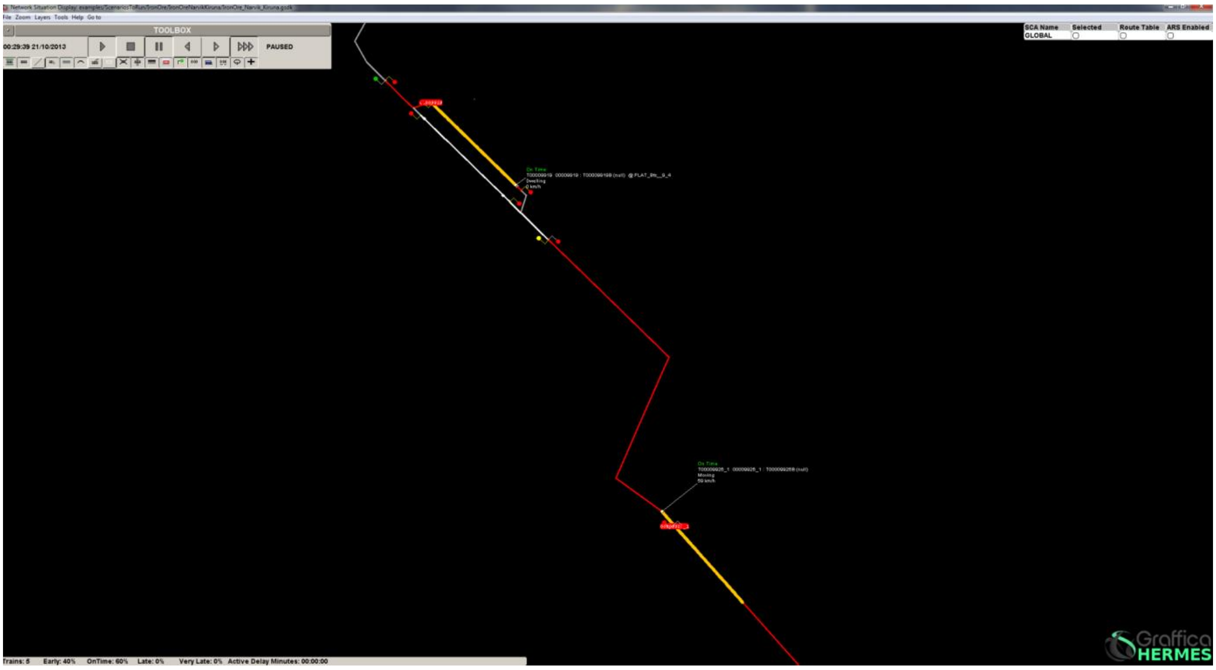

Figure 9. Meeting point on the Iron Ore Line

HERMES API forms the external interface that connects the simulator to the WP7 web services that convey the information from HERMES to the respective work packages, and to pass the requests generated by these work packages back into the simulator. For more details on HERMES API see document D2.3 from the ON-TIME project.

HERMES has been modified through a series of incremental changes and releases to the On Time partners, who have then connected to the simulator to validate and verify the content of the HERMES output. On account of the characteristics of the Iron Ore Line network, the traffic and the special requirements for the iron ore trains the network has been challenging for the built-in dispatching algorithm (that is a simple First Come First Served model) available in HERMES. A series of problems were encountered throughout the process of generating a conflict-free baseline scenario. Therefore, for the evaluation studies, the baseline scenario of the Iron Ore Line has been generated by using the route table that gives the passage order given by the timetable. On the Iron Ore network it was not possible to use the HERMES dispatching algorithm, since this was producing deadlocks which would have prevented a correct evaluation.

Through direct access to the data structures, the information is made available to third party programmers where a variety of generic network disruption scenarios are generated. Each disruption is of a given type, affecting a specific element of infrastructure or rolling stock and is scheduled to start and end at defined times. Different disruptions can be introduced to the system i.e. dwell time disruption, points failure, service cancellation, signal failure, train speed disruption. See Figure 10 for an illustration of point out of order disruption on the Iron Ore Line where the side track is highlighted in red, indicating that the particular meeting station cannot be used throughout the simulation.

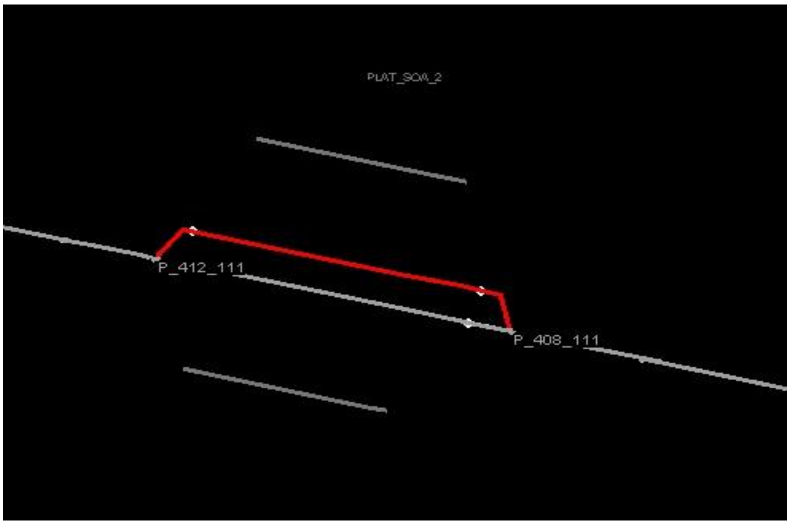

Figure 10. Point out of order, meeting station cannot be used.

During the project we have encounters problems to run relevant simulations without dead-locks and unexpected behaviour of the simulated trains.

The baseline scenario, generated by HERMES deviates from the original timetable due to the restrictions originating from HERMES-based rules. Since the simulated trains run at their maximum speed allowed, most of the services end their journeys approximately 20 minutes earlier than the scheduled end-times in the generated baseline scenario.

In order to avoid such consequences, along with other practical reasons, the simulations are limited to 7 hours, starting at 00.00 h and ending at 07.00 h.

9 SIMULATIONS

For studying perturbations, two different perturbation scenarios have been used for the evaluation simulations.

9.1 Scenario A

One iron ore train delayed.

Train 9904 delayed 40 minutes, from its start in Peuravaara (PEA).

For this scenario three different simulations have been made:

- Without PMM
- With the PMM model ROMA
- With the model RECIFE

9.2 Scenario B

Speed restrictions between two stations.

Speed restriction to 20 km/h between Rensjön (RSN) and Berfors (BFS), for the whole day.

(Speed restriction to 20 km/h is not common for the IOL, but has been used for test purposes)

For this scenario three different simulations have been made:

- Without PMM
- With the PMM model ROMA
- With the model RECIFE

9.3 PMM algorithms

The ROMA and RECIFE algorithms are described in documents from ON-TIME WP4, see deliverables D4.1 and D4.2. The differences between the two modules are mainly the following:

ROMA, developed by TU Delft, is an alternative graph method based on branch-and-bound techniques.

RECIFE, developed by IFSTAR, is a mixed integer linear programming technique.

Both algorithms work in a "closed loop" configuration, which here means that they are continuously monitoring the present situation and recalculates the RTTP.

10 RESULTS

10.1 Scenario A – without PMM

A number of simulations have been performed, in order to validate that the model is executed correctly. This reference simulation, below referred to as the baseline simulation, is a simulation without any perturbations and without any PMM module active. The baseline simulation is done with the Hermes simulator system, running according to the original timetable, from time 00.00 until 07.00.

10.2 Scenario A – ROMA model

Some tables and diagrams generated by the Matlab based tool from the results of the quantitative evaluation of Scenario A are briefly described and exemplified below, for the resilience KPI (see Figure 11).

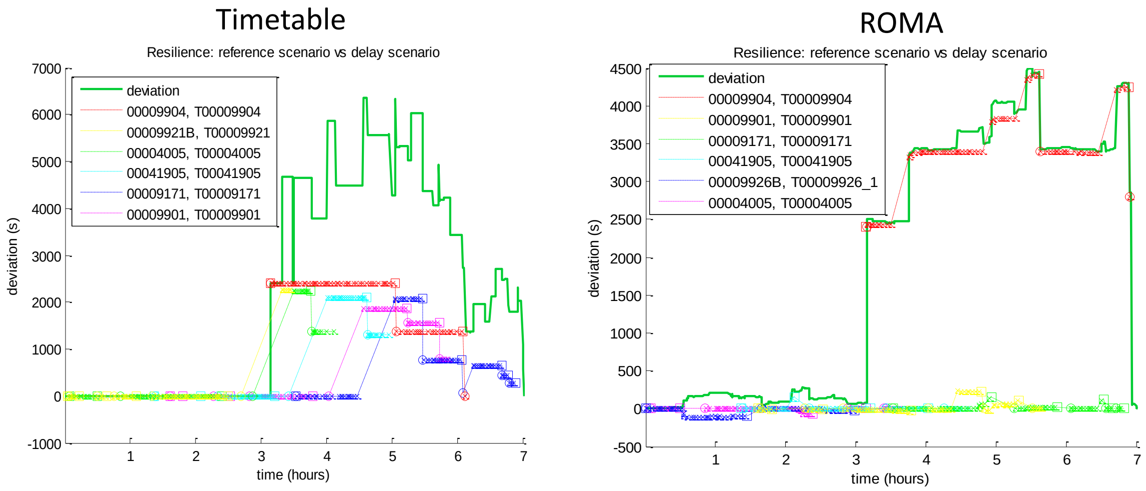

Figure 11. Iron Ore line Scenario A: Comparison between the timetable and ROMA in terms of resilience

RS	Timetable	ROMA
Deviation area [s^2]	5.509e+07	4.849e+07
Maximum delay [s]	6354	4497
Time to recover [s]	13840	13540

Table 2. Quantitative values calculated from the simulation.

The three measures of the resilience KPI are the *maximum deviation* during time period T [seconds], the *time to recover* [seconds], and the *delay area* [seconds^2]. The ROMA algorithm has a rescheduling interval of 2 minutes and a prediction horizon of 2 hours. For an observation period of 7 hours based on the quantitative evaluation results, in general the algorithm is able to strongly reduce the deviation area with respect to the case in which trains follow the scheduled passage order. Figure 11, along with the above given table, clearly illustrates that a positive effect is achieved in terms of resilience since the application of the ROMA algorithm reduces the deviation area, the maximum delay as well as the time to recover the delay.

Detailed analysis of the quantitative evaluation results are described in detail in documents from ON-TIME WP4, see deliverable D4.3. In this document we will mainly focus on the *qualitative* evaluation, i.e. the quality of the RTTP calculated by the used PMM.

Figure 12 shows the result of the simulation using ROME for this scenario, compared to the simulation without PMM.

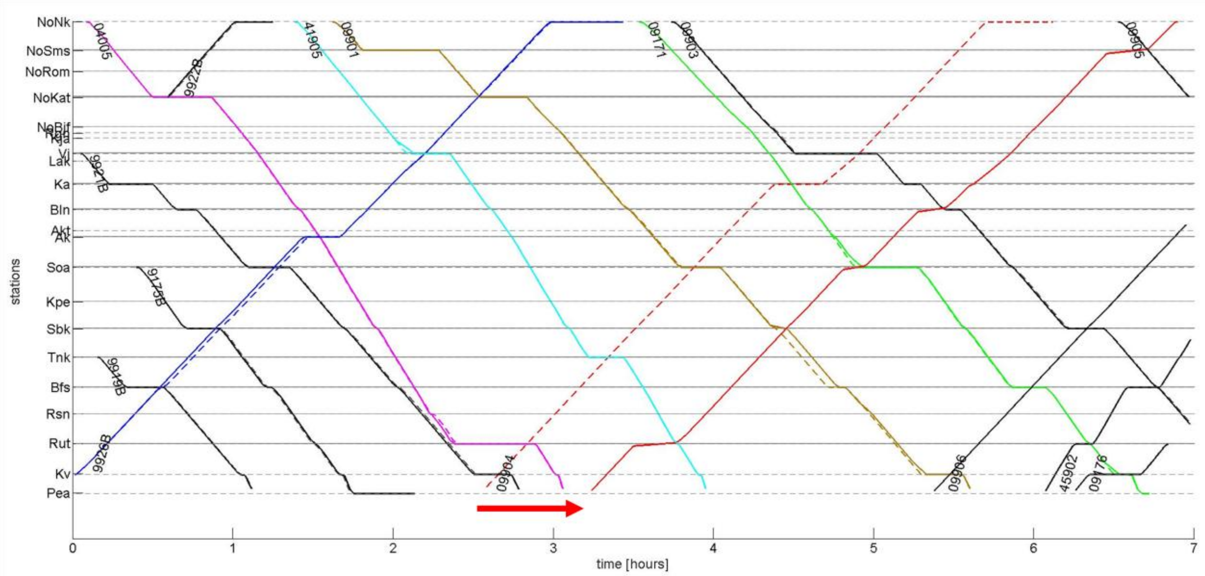

Figure 12. Scenario A, one train delayed, simulated with the ROMA PMM module. The delay, train 9904 delayed 40 minutes from Peuravaara, is indicated by the red arrow. The dashed graph lines represent the baseline simulation, and the solid lines represent the simulation results for scenario A using the ROMA PMM module.

10.2.1 Qualitative analysis

The following analysis is based on the simulation results available so far. The detected limitations in the results can most probably be overcome, if the specifications and the input data to the algorithms are further developed. The following analysis is important for generating new requirements. It is our intention to continue the work, so that the relevance for implementation into operational practice can be completely evaluated.

10.2.1.1 Headways

The analysis shows that the headways calculated are too short. See fig 13. On a single track line headways for consecutive trains in the same direction must be given larger margins, in relation to the present structure of the signalling and interlocking system. This must be corrected in the input parameters. Different trains also have different properties, e.g. weight, acceleration etc., and need different headways.

10.2.1.2 Removal of unnecessary stops

Both the baseline simulation and the simulations with perturbation and PMM modules show a number of unnecessary stops that are not removed, see fig. 14 and 19. This indicates two different problems:

- The original timetable is not optimized
- The PMM model is not implemented for different types of stops. Planned stops for passenger trains are fixed and cannot normally be cancelled. Planned stops for iron ore and freight trains are scheduled only for meetings, and should be eliminated if a meeting has been cancelled or moved to another station.

To solve this, the systems must be able to fulfil the following requirements:

- The time-tabling systems and processes must remove unnecessary stops and optimize the original timetable before the start of the operational phase. Today some stops still remain in the timetable, mainly because there are scheduled stops there on other days.
- Different types of stops must be defined and implemented in the PMM models. Stops where no transport tasks exist must be eliminated if they are no longer needed. Stops for e.g. passenger trains at stations cannot be removed.

10.2.1.3 Priorities between trains

The present models have not used the possibilities to specify priorities between trains. The concept of priority is complex. Different types of priorities exist and they are also sometimes dynamic and context dependent. Both the models and input data for the specific context must be specified.

For the iron ore line the following basic priority rules exist today:

- Loaded iron ore trains have high (highest) priority, even if they are delayed.
- Iron ore trains and freight trains have high priority if they are close to an important dead-line (miss important events).
- Trains on time have priority over delayed trains.

Also other rules exist, e.g. concerning maintenance work etc.

For the analyzed scenarios, see fig 15, 16. 20, 21, we can see examples of priorities that are not according to these rules. Trains with high priority are not given priority, which leads to many stops, long delays for these trains and high energy consumption.

A test, where a human traffic controller was asked to solve the presented scenario, showed that if they removed unnecessary stops and used relevant priority rules that achieved the following:

- All loaded iron ore trains arrive at destination (Narvik) on time
- All other trains, except one, arrive on time.
- One train (41905) will be a few minutes late.

Probably, and this must be verified in future experiments, the PMM models can solve this problem if adjusted and supplied with relevant input data.

10.2.1.4 Optimal meetings on single track lines

The problem to plan for optimal meetings must be further studied. Models for running times, signalling and interlocking parameters, margins etc must be evaluated.

10.2.1.5 Driver behaviour

The present model for driver behaviour must probably be further developed. Now the drivers do not drive according to the plan, but according to maximum allowed speed. This means that they are often ahead of schedule, arrive too early, get speed restrictions and as a consequence loose much time!

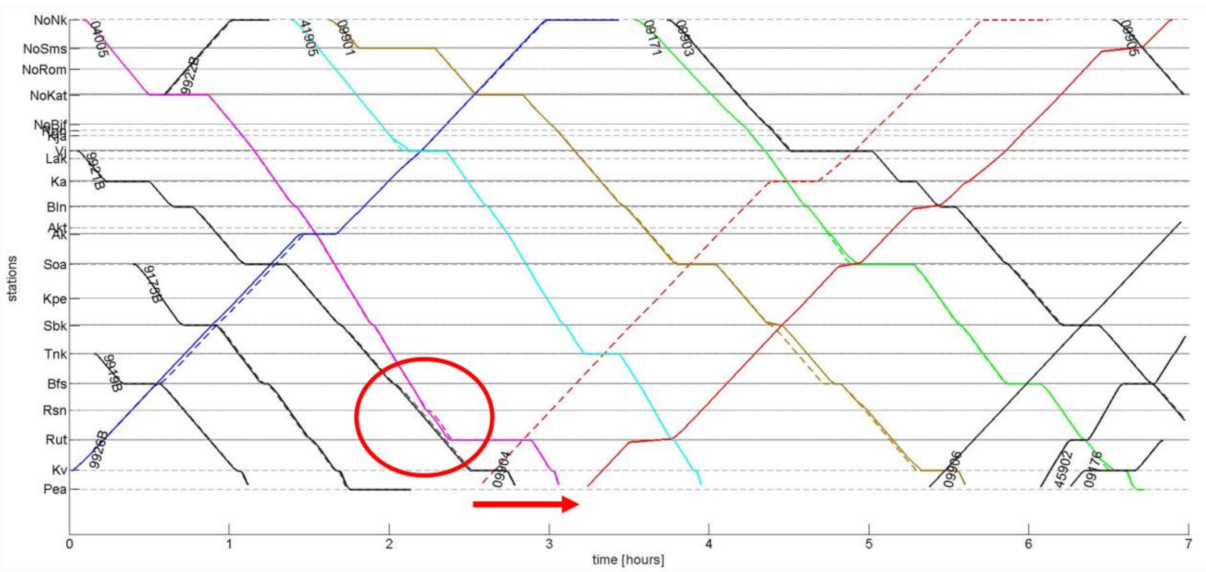

Figure 13. Some of the headways generated by the simulation are not realistic for the IOL.

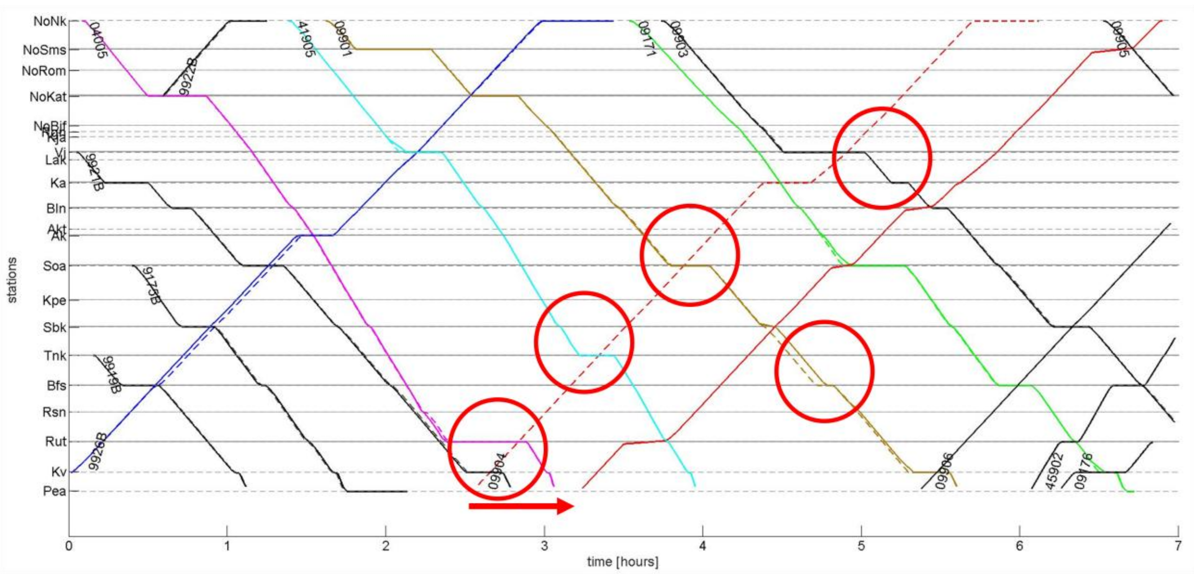

Figure 14. Unnecessary stops are not eliminated by the PMM.

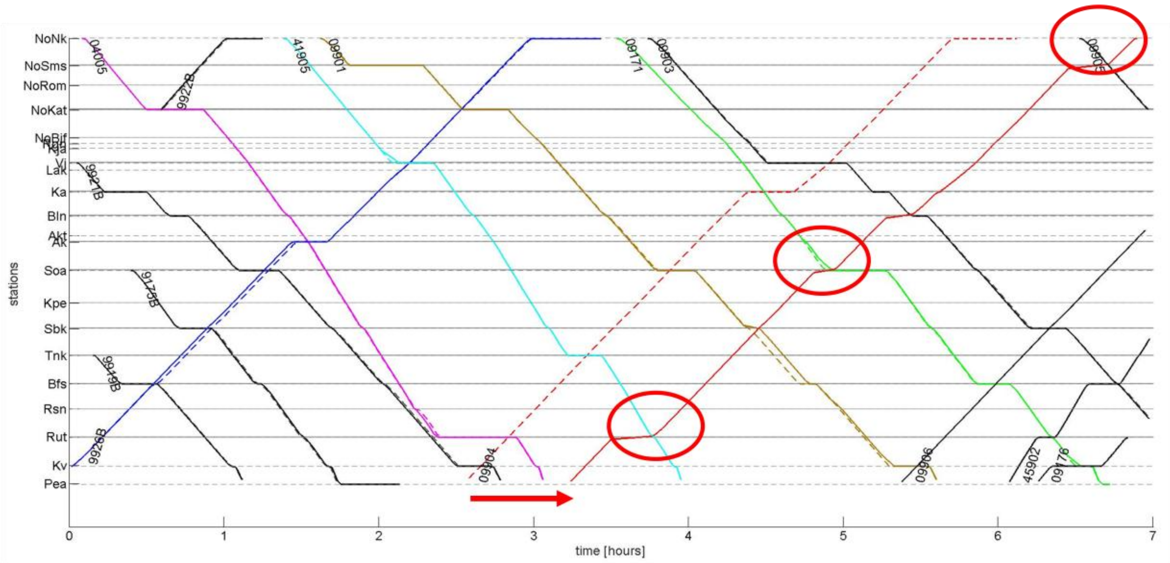

Figure 15. Loaded iron ore trains are not given priority, which means that they often have to stop for e.g. unloaded iron ore trains. This is not according to normal operation at the IOL. The iron ore trains are forced to more stops, are delayed and use more energy.

10.3 Scenario A – RECIFE model

Figure 16 shows the results from the simulations using the RECIFE PMM model, compared to the simulation without PMM.

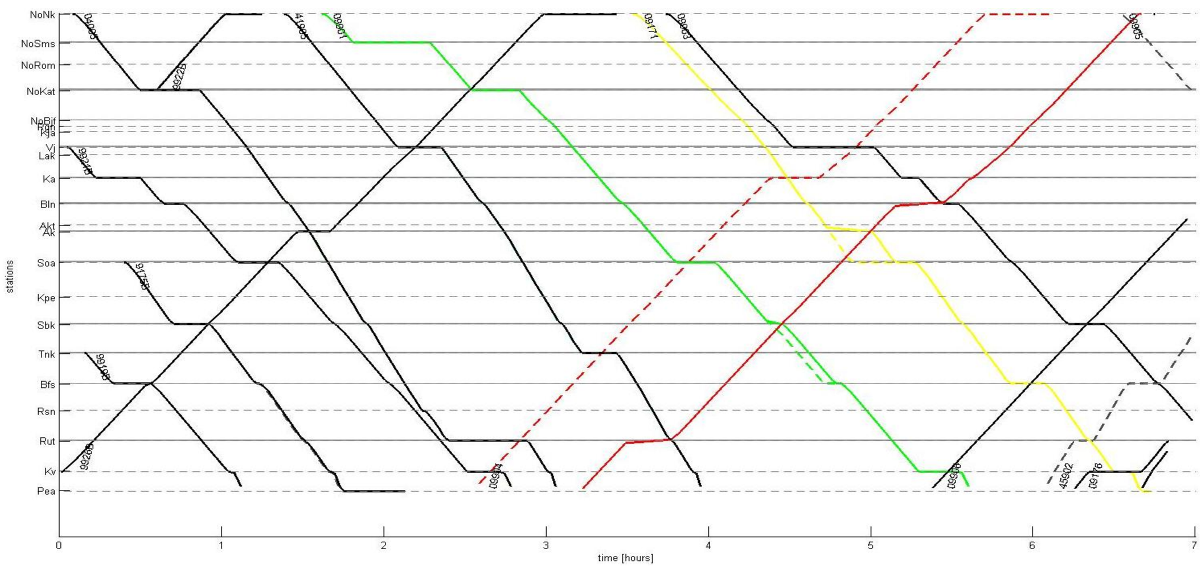

Figure 16. Scenario A, one train delayed, simulated with the RECIFE PMM module. The delay is the same as for the ROMA case above. The dashed graph lines represent the baseline simulation, and the solid lines represent the simulation results for scenario A using the RECIFE PMM module.

10.3.1 Analysis

The analysis here is the same as for the ROMA model. We can see that there are small differences in the result, but it is not relevant to analyse this further here. Discussions about the differences between the models can be found in document D4.3.

10.4 Scenario B – without PMM

This simulation is the baseline simulation, and identical to the baseline simulation for Scenario A.

10.5 Scenario B – Roma model

Fig 17 shows results from the simulation for scenario B, compared to the baseline simulation without PMM.

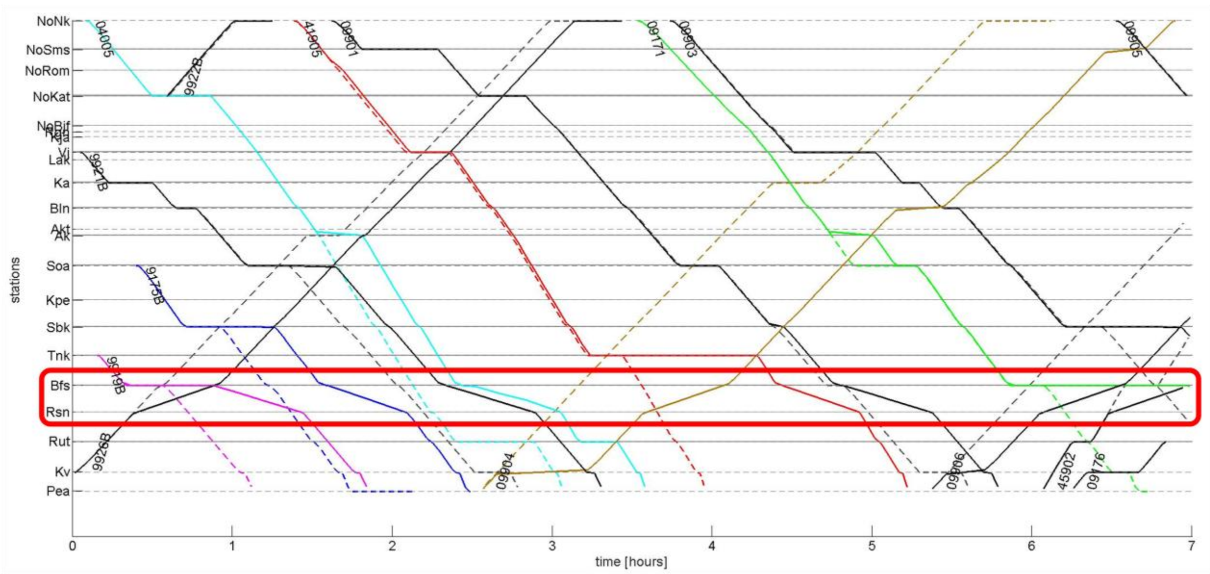

Figure 17. Scenario B, speed restrictions to 20 km/h between Rensjön and Bergfors. The dashed graph lines represent the baseline simulation, and the solid lines represent the simulation results for scenario B using the ROMA PMM module.

10.5.1 Qualitative analysis

The analysis is parallel to the analysis for scenario A.

The two PMM models, ROMA and RECIFE, both solve the perturbation, but with the same principal limitations as for scenario A.

In fig. 18 we can identify the headway problem.

In fig. 19 the problem of not eliminated unnecessary stops is illustrated.

In fig. 20 we see that also here the limitation regarding priorities cause too long delays for loaded iron ore trains. Here the solutions from ROMA and RECIFE differ, e.g. regarding some of the loaded iron ore trains. The reasons for this must be further evaluated.

Also for scenario B we tested how a human traffic controller would solve the scenario. The result, based on the same conditions as for scenario A, showed the following:

- All loaded iron ore trains arrive the destination (Narvik) on time.
- One empty iron ore train and two other freight trains will be delayed
- All other trains will be punctual.

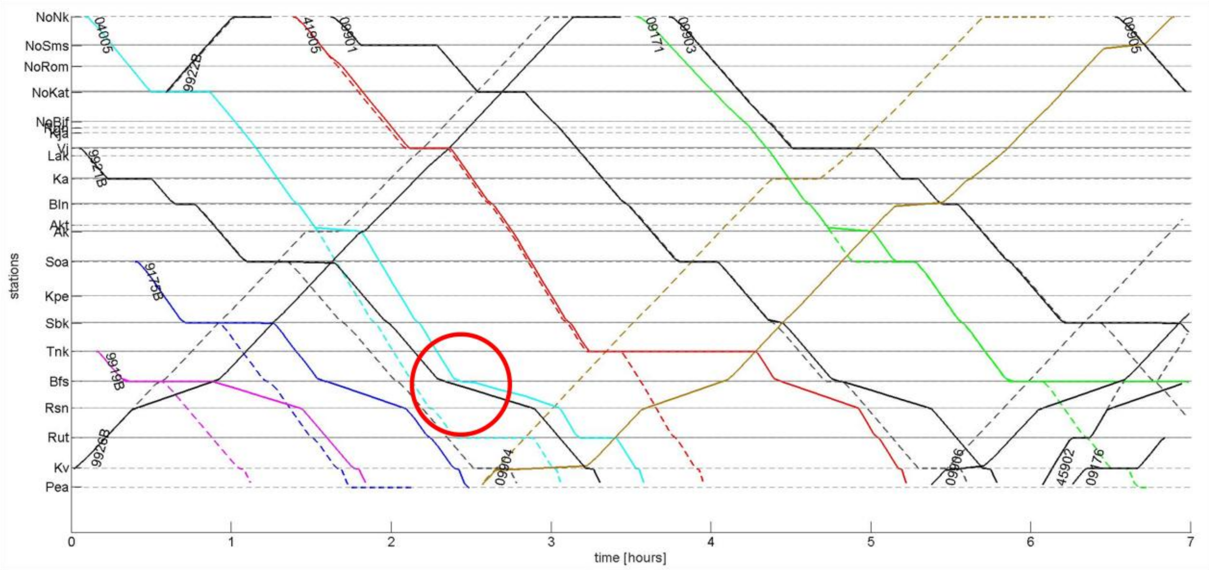

Figure 18. Too short headways are generated by the PMM.

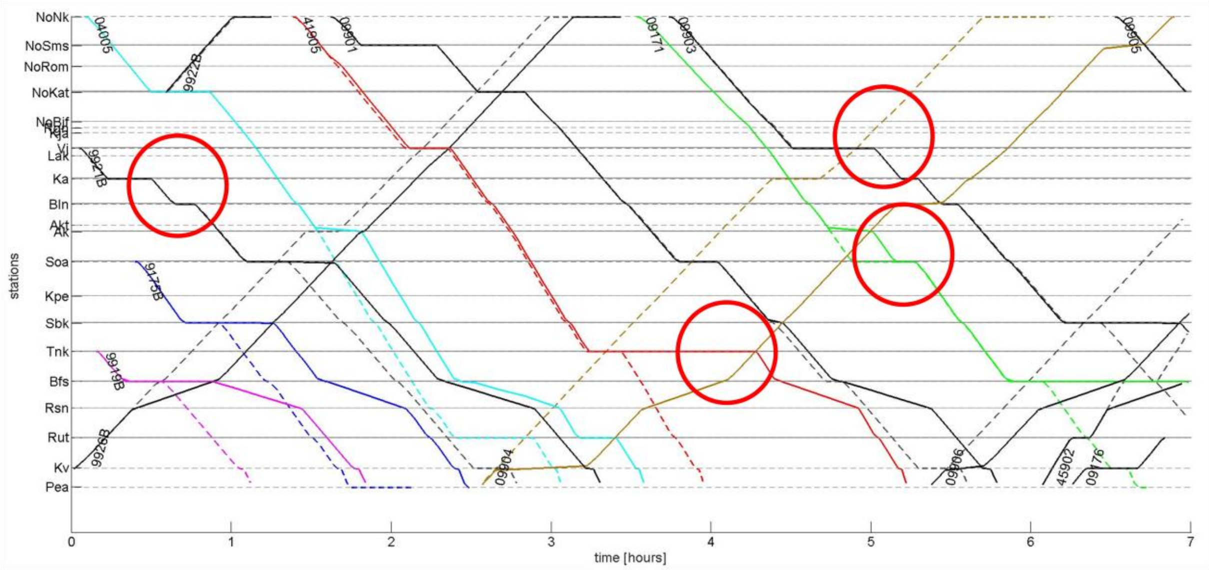

Figure 19. Unnecessary stops are not removed.

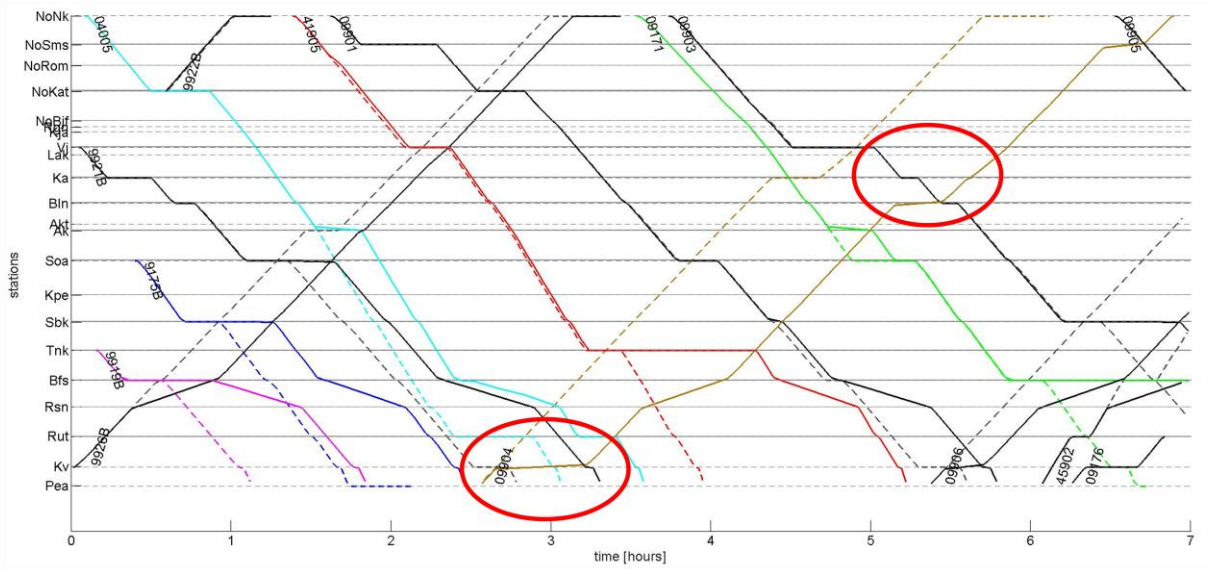

Figure 20. Priorities are not specified for the trains. This makes the loaded iron ore trains stop and they are further delayed, and consume more energy.

10.6 Scenario B – RECIFE model

Fig 21 shows results from the simulations for scenario B, using the RECIFE model, compared to the simulation without PMM.

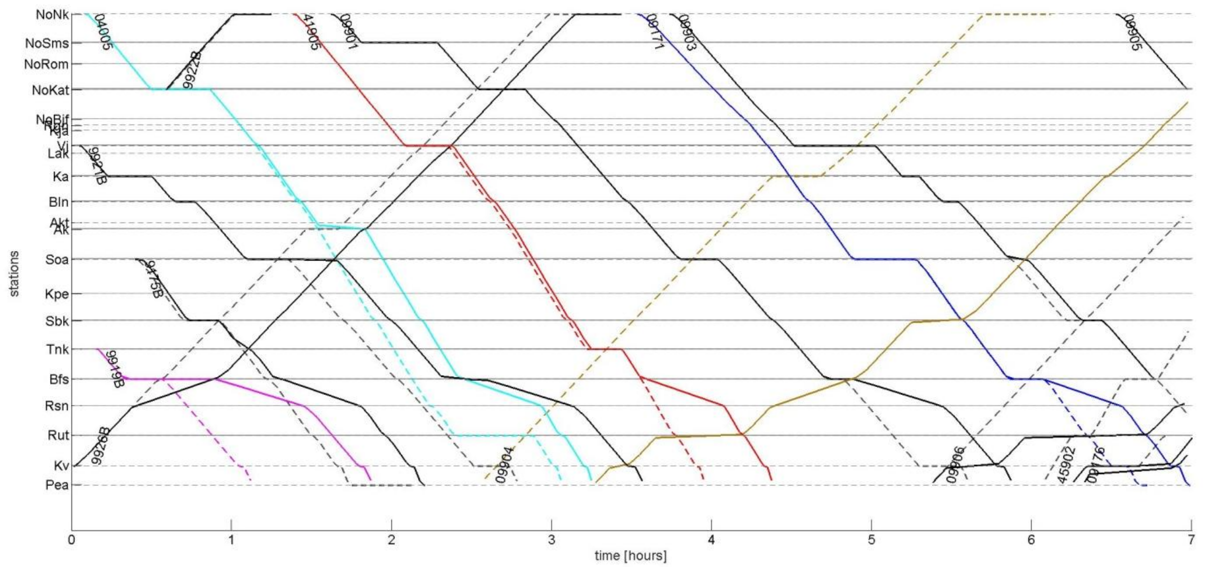

Figure 21. Results for scenario B, using the RECIFE model.

11 CONCLUSIONS

We can conclude that:

- The Hermes simulator can simulate the traffic on the IOL, for undisturbed traffic as well as for traffic with certain perturbations. However, with a number of limitation, as discussed above.
- The developed systems for automatic re-planning, the PMM modules, are able to handle the perturbations specified in some scenario for the IOL.
- That evaluations show that a number of additional requirements must be fulfilled, if the systems are going to be used in real traffic control on the IOL.
- That the results so far give us a good basis for future research and development.
- It will be necessary to perform more advanced evaluations, in order to specify these additional requirements in detail.

We have not been able to evaluate the robustness and resilience of the produced results in detail. This would require more data from the IOL, which is not available today.

One problem encountered is that the original timetable contains errors that should be removed prior to simulations and evaluations.

12 FUTURE RESEARCH AND DEVELOPMENT

For Swedish railways, the results from the ON-TIME project in general, and from the experiments on the IOL in particular, are of great interest and importance.

The TCC in Boden, today controlling the IOL using the control system STEG for operational re-planning and control, and the DAS system CATO for train drivers, will be a platform for future development and evaluations, based on the ON-TIME results.

Even if we now see many limitations in the developed systems, e.g. in the PMM modules, these can probably be eliminated. More evaluation studies and an iterative development of more detailed and precise methods will be of high value in the future.

Finally, the most important future development is to integrate the PMM modules in a fully interactive environment. The present system in Boden, with STEG and CATO, can profit from efficient systems for optimal re-planning and decision support. The human controllers' tasks must be coordinated with the more automated functions and their user interfaces must visualize important aspects of the PMM actions. The controllers must also have the possibilities to specify conditions for the automatic modules, so that dynamic requirements can be specified, e.g. regarding priorities, train order, track usage etc