D2.1: Review of capacity restrictions, railway planning, problem description and existing approaches

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Executive Summary

This document describes the work done in WP2 to produce a set of prioritised capability requirements to guide the efforts of work packages 3, 4, 5, 6 and 7. Research was carried out to identify the problems that infrastructure managers (IM) experience with timetable planning and traffic control. The problems were then used to infer a set of system capability requirements. The set of requirements was too large to be of use in guiding the work packages, so further work was carried out to create a prioritised list; prioritisation was on the basis of the number of IMs identifying each problem. Finally, work was carried out to relate each of the prioritised requirements to the relevant work package and innovation topic. The final list of requirements, work packages and innovation topics is shown in Table 15 of this document.

Additionally, as part of WP2 research was carried out to produce a set of IDEF0 diagrams for each IM, providing a representation of the functionality of the timetable planning and train control processes. High-level system diagrams have also been produced showing how infrastructure managers and railway undertakings interface throughout the timetabling/traffic control process.

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1 INTRODUCTION

As world-wide demand for passenger and freight transport increases across all modes, main line railways in Europe are experiencing ever more intensive use of their services, particularly in urban areas. This is leading to higher levels of congestion, and an increasing incidence of delays and disturbances. One solution to this problem is to build more railway capacity; however, constructing new railways is expensive, takes time and faces a number of environmental constraints. Therefore, the **ON-TIME** project is investigating new ways of managing existing capacity that will allow more services to operate more reliably than is currently the case.

The **ON-TIME** project has nine objectives as follows:

Objective 1: Improved management of the flow of traffic through bottlenecks to minimise track occupancy times. This will be addressed through improved timetabling techniques and real-time traffic management.

Objective 2: To reduce overall delays through improved planning techniques that provide robust and resilient timetables capable of coping with normal statistical variations in operations and minor perturbations.

Objective 3: To reduce overall delays and thus increase service dependability through improved traffic management techniques that can recover operations following minor perturbations as well as major disturbances.

Objective 4: To improve the traffic flow throughout the entire system by providing effective, real-time information to traffic controllers and drivers, thus enhancing system performance.

Objective 5: To provide customers of passenger and freight services with reliable and accurate information that is updated as new traffic management decisions are taken, particularly in the event of disruptions.

Objective 6: To improve and move towards the standardisation of the information provided to drivers to allow improved real-time train management on international corridors and system interoperability, whilst also increasing the energy efficiency of railway operations.

Objective 7: To better understand, manage and optimise the dependencies between train paths by considering connections, turn-around, passenger transit, shunting, etc. in order to allocate more appropriate recovery allowances, at the locations they are needed, during timetable generation.

Objective 8: To provide a means of updating and notifying actors of changes to the timetable in a manner and to timescales that allow them to use the information effectively.

Objective 9: To increase overall transport capacity by demonstrating the benefits of integrating planning and real-time operations, as detailed in Objectives 1-8.

The objectives are being addressed by a number of work packages across six innovation topics; however, the problem is large and complex and the work packages require guidance on where they should concentrate their efforts.

To provide that guidance, WP2 has investigated the state-of-the-art of timetable planning and traffic control, as well as current technologies and innovations in those areas. The results have been synthesised to create a set of prioritised capability requirements related to work package and innovation topics, and some descriptions of system functionality. This document describes that work and presents the results.

The document begins with a review of current technology and innovations in timetable planning and traffic control. This is followed by a description of existing processes, reported problems and strategic developments, based on a questionnaire sent to **ON-TIME's** IM partners. Knowledge of current problems is used as the basis for eliciting the IMs' requirements and identifying the most important. Process information is summarised using IDEF0 notation, to provide a formal description of current process functionality. Finally, prioritised requirements are synthesised with Work Package tasks and **ON-TIME's** innovation topics to produce a recommended focus for the work of WP3, WP4, WP5, WP6 and WP7. In addition to that work, IDEF0 diagrams have been developed to show existing timetable planning and traffic control functionality in a formal way; high level system diagrams have been developed to show the interfaces between infrastructure managers and railway undertakings throughout the timetable/traffic control process.

2 REVIEW OF TECHNOLOGICAL DEVELOPMENTS AND TECHNOLOGY READINESS LEVELS

2.1 Review of technological developments

In this section, the technological developments in Traffic Planning and Timetabling, Railway Traffic Control and Management, Operational Management and the Application of Driving Advisory Systems will be reviewed in terms of system applications and research approaches. Each sub-section corresponds to each work package (WP3-WP6) respectively. The review of system applications includes relevant systems in service, on trial and under development. The research approaches mainly include the latest researches which are fairly relevant to the ON-TIME project.

2.1.1 Traffic Planning and Timetabling (WP3)

Table 1 - Systems:

System	Organisation	Description	Comments
DONS (Design Of Network Schedule)	Netherlands Railways and Railned	Developed in 1990s in Holland. In use 2007 in Holland. Objectives: • Assist the planners of Railned and Netherlands Railways in generating timetables. • Key functions: • Generating a cyclic hourly timetable • Checking timetable feasibility.	(Kroon, Maroti et al. 2008) Stochastic improvement of cyclic railway timetables (Kroon and Maroti 2008)
SIMONE (Simulation Model for Networks)	ProRail and Incontrol Enterprise Dynamics	Developed in 1990s in Holland. In use 2007 in Holland. Objectives: • Determine the robustness of a railway timetable. Key functions: • Link to DONS for simulation • Estimate the effect of a small disturbance and quantity of bottlenecks in a network.	(F., M. et al. 2007) Survey of Automated Systems for Railway Management
DONNA	Netherlands	Developed in 2000s in Holland. In use 2009 in Holland	PRORAIL, DONNA

	Railways and ProRail	Objectives: • Improve the quality of the timetable. Key functions: • Supports the planning and commitment (distribution) of the use of railway infrastructure capacity. • Train movements studied, designed, planned, applied and distributed.	http://www.prorail.nl/Vervoerders/Capaciteit%20treinpaden/Donna/Pages/Geschiedenis.aspx
Railsys	RMCon	Germany Used worldwide including Network Rail UK, DB, SNCF, TV Sweden, Austria railways, Australia railways etc. Objectives: • Integration tools for planning, timetabling, simulation, analysis and evaluation of railway systems. Key functions: • Yearly timetable and ad-hoc timetable construction • Railway infrastructure management • Railway system simulation • Comprehensive Evaluation	Fully commercial systems for railway planning, timetabling, simulation, analysis and evaluation. Successfully applied in worldwide railway industry.
OpenTrack	OpenTrack Railway Technology Ltd.	OpenTrack handles single simulation runs as well as multiple simulation runs where random generators produce different initial delays and station delays	Fully commercial systems for railway planning, timetabling, simulation, analysis and evaluation. Successfully applied in worldwide railway industry.
SOM		Holland System to construct robust basic hour timetables by combining optimisation with simulation using a stochastic programming framework.	To be included in DONS
TAM		Holland An optimisation model for rolling stock scheduling and rescheduling	Has been developed during the last 5 years
CREWS	SISCOG	Holland. In use in Holland.	Implemented. SISCOG, CREWS Datasheet

		Objectives: • Providing solutions to the problem of effective planning • Management of the work of crew members. Key functions: • Quick and efficient planning and management of staff • Provide fast responses to train and crew changes, minimises crew-related train disruptions • Provide evaluation of strategic options	
LUCIA (Lisbon Utrecht Crew Scheduling Algorithm)	SISCOG and Netherlands Railways	Developed in 2007 in Holland. In use in Holland since 2009. Objectives: • Developing an optimisation model capable of solving large-scale duty scheduling problems. Key functions: • Algorithm is included in CREWS to solve the Netherlands Railways crew scheduling problem for the whole week in a single run.	SISCOG, LUCIA http://www.siscog.eu/subarea.asp?idSubArea=38&idArea=7
LUKS		Germany The LUKS software tool is an integrated system for railway operations research.	Recent development http://www.via-con.de/development/luks
Langfrist-fahr plan		Germany Long-term schedule planning	Recent development
VIRIATO	SMA and Partner	Developed in 2001 in Switzerland Objectives: • Support strategic planning for regular trains. • Used by RFF (France) to give the possible paths for regular trains. Key functions: • Plan regular interval trains • Analysing single trains • Allows the user to determine the level of saturation of a specified line, in percentage terms.	Barber F. et al (2007)

THOR		France Used by SNCF/DCF (delegated IM) to create the paths for trains, out of the suburbs of Paris, with precision of 1 minute	In operation
CHAO		France Used by SNCF/DCF (delegated IM) to create the paths for trains, in the suburbs of Paris, with a precision of 10 seconds	In operation
HDTS (High Density Train System)		Italy A system to improve infrastructure capacity in high density line sections/nodes, by reducing the length of block sections and/or headway	Recently in operation
TOPSim	Uppsala University	Sweden A new simulator system that could contribute to improved methods for train traffic planning and operation and to create an experimental environment for the development of new control support systems and operator user interfaces.	No longer developed.
Netz21		Germany Network concept 21 century To be installed on dedicated lines, separation of traffic	Not completely accomplished
LZB		Germany Continuous train control system installed on high-speed lines and routes with a high degree of utilisation. LZB-equipment of rolling stock for regional and freight trains has been developed.	In use
MakSi		Germany Re-scheduling for maintenance works	In operation
Moses		Germany Strategic infrastructure planning	In operation
Viriato		France Used by RFF (IM) to give the possible paths for regular trains.	In operation

Trainplan		Sweden Used by Trafikverket and Green Cargo, annual timetable planning, ad hoc timetable planning	In operation
Webbansökan		Sweden Web based application of train paths	In operation
"quai obs"		France Software tool used to create the "In Stations" timetable, including the platform occupation and the vehicle movements (empty trains, locomotives, etc.)	In operation
VKL		Holland The central information system for monitoring the operational processes. This monitors the positions of trains between stations. It also has components describing the duties of rolling stock and crews. The information is integrated, i.e. if a train has a certain delay, then this is also reflected in the rolling stock and crew duties.	In operation
Europtirails	UIC project	The main objective is to improve the effectiveness and efficiency of train running on European rail corridors in the operational range through information sharing and support between IMs for Customers (RU)	In operation

Table 2 - Research approaches:

Research Approach	Author	Description	Comments
Analysing stability and investments in railway networks using advanced evolutionary algorithms	(O. and M. 2004)	In this paper a network of periodically running railway lines is considered. A cost-benefit analysis of investments is derived, where the benefit is measured in reduced waiting time for passengers changing lines. The actual mean waiting time is also estimated with simulation.	The optimisation described is proven to produce Pareto optimal timetables, with cost-benefit analysis in consideration. It also allows estimation of "turning points" for the timetable synchronisation.
Cyclic Railway Timetabling: a Stochastic Op-	(Kroon, Maroti et al. 2008)	The paper describes a stochastic optimisation model to minimise the average delay of a single	The research proved that stochastic optimisation is a useful

timization Approach		train on a number of consecutive trips along the same line. The model can be applied to find an optimal allocation of the running time supplements of the train. It can also be used to improve a given cyclic timetable for a number of trains on a common infrastructure.	approach to improve cyclic railway timetables. By re-allocating time supplements and buffer time, delays can largely be reduced.
Fast Approaches to improve the robustness of a railway timetable (ARRIVAL)	(M., D. et al. 2007)	In this paper the authors proposed and analysed four different methods to improve the robustness of a given Train Timetabling Problem solution for the aperiodic (non cyclic) case. The approaches combine Linear Programming (LP) and ad-hoc Stochastic Programming/Robust Optimisation techniques.	The robustness improvement models are evaluated in terms of validated cumulative delay. Light Robustness is proved to be the fastest method for large-scale real scenarios. It is also accurate and easy to be embedded.
Light Robustness (ARRIVAL)	(Fischetti and Monaci 2009)	In this paper a timetable optimisation model for uncertain input data is proposed. The model is called Light Robustness. It couples robust optimization with a simplified two-stage stochastic programming approach.	The model proves to be flexible, easy to use and can produce high-quality solutions with less effort and time.
Railway Timetabling with the model of the Periodic Event Scheduling Problem	(Liebchen 2005; Liebchen and Peeters 2009)	The papers summarised traditional models of the Periodic Event Scheduling Problem (PESP). An integration of network planning, line planning and vehicle scheduling is proposed for periodic timetabling, by a simple extension of PESP.	
Design of a new railway scheduling model for dense services	(Caimi, Burkolter et al. 2009)	This paper is focused on the timetabling and routing problem in condensation and compensation zones. A policy is introduced to schedule trains using a time discretisation.	Results show fast generation of timetables for large stations. The main problem is to find a balance between adequate slack time and timetable stability. The coordination between the condensation and compensation zones is also a concern.

How regular is a regular-interval timetable? An operational tool to assess regularity	Tron D., and Tzieropoulos P. (2009)	The paper describes a piece of software developed to automate the assessment process of the regularity of timetables.	The software is proved to provide some comprehensive indexes covering the whole network and services. Yet it may raise some tricky aggregations and weighing issues.

2.1.2 Traffic control and management under minor perturbations (WP4)

Table 3 - Systems:

System	Organisation	Description	Comments
AdmiRail	Systransis	Developed in Switzerland In use at Switzerland's Lötschberg basis tunnel. Objectives: • AdmiRail is an intelligent platform concept for Train Traffic Control systems and automation systems of the future. Key functions: Given a timetable and the current situation on the tracks, Train Traffic Control Systems based on AdmiRail are capable of computing the optimal order of trains, optimally adjusting the secured headways, and optimally guiding trains through the controlled area.	http://www.systransis.ch/en/products/admirail/
STEG	Trafikverket, Uppsala University	Developed in 1996 in Sweden STEG is a fully developed, deployed, tested and evaluated experimental system for operational train traffic control in Sweden. It has been in operation at two different traffic control centres in Sweden since 2008. Key functions: A complete operational system for real-time re-planning, generation of a continuously updated traffic plan and automatic execution of the plan. The user interface support re-planning tasks and identification of conflicts.	Mature system in service. Without fully close loop control.
OCCR		Holland A central control unit in the operational control processes.	Started recently.
SAP		Sweden A system for operational traffic control, based on the	In test operation since spring 2012. Under evaluation.

		"control by re-planning and automatic execution of the plan" concept. This system will support re-planning in very complex traffic areas and stations using interactive resource graphs.	
NTL (National train control system)		Sweden A project aimed at developing the next generation of traffic control systems in Sweden. Partially based on the STEG concept.	In requirements specification phase.
Decision support tools		Holland Support operational control and give speed advice to train drivers. Part of the functionality will be speed advices to train drivers.	Initiated.
CATD - Computer Aided Train Dispatching	Uppsala University	Sweden Development of models, algorithms and systems, which support optimal computer-aided train dispatching. Implemented as a minor prototype system in order to, "off-line", evaluate its possibilities and limitations concerning the dynamic aspects of train traffic control.	
ASDIS	(Jacobs 2004)	Traffic regulation tools using asynchronous simulation techniques.	Computer aided decision support system for traffic management.

Table 4 - Research Approaches:

Research Approach	**Author**	**Description**	**Comments**
The Influence of Anticipating Train Driving on the Dispatching Process in Railway Conflict Situations	(Albrecht 2007)	The paper describes the consequences of anticipating train control in Dispatching Support Systems. The circumstances under which delays will be reduced or not improved are both analysed.	Anticipating train control leads to reduction of energy consumption, improvement of passenger comfort and may lead to reduced delays. Such an advanced train dispatching system would require exact operation of trains following computed paths, which is only possible with ATO on board.

Conflict Resolution and Train Speed Coordination for Solving Real-Time Timetable Perturbations	(D'Ariano, Pranzo et al. 2007)	The paper introduced a graph model for detecting and solving conflicts in the train dispatching procedure. Safe distance headway and speed coordination between consecutive trains are considered, based on the Blocking Time Model.	The paper showed an effective system for identifying potential delays and rescheduling. The results implied the need for a detailed model for the computation of dynamic speed profiles and the advanced scheduling algorithms.
A fuzzy knowledge-based system for railway traffic control	(Fay 2000)	The paper described a Fuzzy Petri Net model for dispatching support systems in railway operational control systems.	The research showed that the model is effective and is easy to integrate to improve traffic performance, reliability, and customer satisfaction.
Railway traffic disturbance management - An experimental analysis of disturbance complexity, management objectives and limitations in planning horizon	(Tornquist 2007)	The paper described a heuristic approach HOAT for re-scheduling under disturbances and performance evaluation. It also investigated how the planning horizon of the re-scheduling process affects the network in the longer-term.	The analysis showed that the HOAT approach is widely applicable, and that it can produce optimal or near optimal solutions in a short time.
Alternative Graph formulation	(Mazzarello and Ottaviani 2007)	A conflict detection and resolution model based on Alternative Graph formulation was proposed.	
Differential Evolution Algorithm for Junction rescheduling Model	(Chen, Schmid et al. 2010)	An innovative algorithm DE_JRM based on DE was proposed for solving real time train rescheduling problems in junction areas and bottleneck sections.	
A tabu search algorithm for rerouting trains during rail operations	(Corman, D'Ariano et al. 2010)	A fast heuristic and a truncated branch and bound algorithm were introduced for computing train schedules within a short computation time, and the effectiveness of using different neighborhood structures for train rerouting was investigated.	

2.1.3 Operational management in the event of large disruptions (WP5)

Table 5 - Systems:

System	Organisation	Description	Comments
OCCR		Netherlands A central control unit in the operational control processes. Objective: ❖ In case of a disruption, the main decisions about how to react are taken here. Key Functions: ❖ Describe how the timetable can be rescheduled based on the kind of disruption. ❖ Describe how to isolate the problem area and turn the rolling stock outside of it.	It represents all stakeholders' requirements.
VKL		Holland Existing supporting system for operational processes.	Existing
VOS		Holland New supporting system for operational processes.	Being developed. This will replace the existing VKL system.
Decision support tools		Holland Support operational control and give speed advice to train drivers. Part of the functionality will be speed advices to train drivers.	Initiated.
AFAIG	Laboratory of Intermodality, Transport and Planning (LITEP) of the Swiss Federal Institute of Technology Lausanne (EPFL)	Objective: ❖ Evaluate extension and modernisation projects of the fixed installation ❖ Develop new operational strategies and structures of the new timetable ❖ Elaborate a temporary timetable when a disturbance has happened The model uses the following components to describe the system:	

		• the track network; • the safety installations; • the rolling stock; • operation schemes.	
CREWS	SISCOG	Holland. In use in Holland. Objectives: • Providing solutions to the problem of effective planning • Management of the work of crew members. Key functions: • Quick and efficient planning and management of staff, • Provide fast responses to train and crew changes, minimises crew-related train disruptions • Provide evaluation of strategic options.	Implemented. SISCOG, CREWS Datasheet
LUCIA (Lisbon Utrecht Crew Scheduling Algorithm)	SISCOG and Netherlands Railways	Developed in 2007 in Holland. In use in Holland since 2009. Objectives: Developing an optimisation model capable of solving large-scale duty scheduling problems. Key functions: Algorithm is included in CREWS to solve the Netherlands Railways crew scheduling problem for the whole week in a single run.	SISCOG, LUCIA http://www.siscog.eu/subarea.asp?idSubArea=38&idArea=7
CREWS-RTD	Portuguese company Siscog	Holland A fast algorithm to reschedule crew duties.	Implemented.
TAM		Holland An optimization model for rolling stock scheduling and rescheduling	Has been developed during the last 5 years
STEG	Trafikverket, Uppsala	Sweden	In test operation since 2008. Evaluated.

	University	A complete operational system for real-time re-planning, generation of a continuously updated traffic plan and automatic execution of the plan. The user interface supports re-planning tasks and identification of conflicts.	Implemented in two traffic control centres.
SAP		Sweden A system for operational traffic control, based on the "control by re-planning and automatic execution of the plan" concept. This system will support re-planning in very complex traffic areas and stations using interactive resource graphs.	In test operation since spring 2012. Under evaluation.
NTL		Sweden A project aimed at developing the next generation of traffic control systems in Sweden. Partially based on the STEG concept.	In requirements specification phase.
PIC	National coordinators	France Provides various functions at different levels, supports train dispatching, covers reporting and performance analysis.	
TRC	Network rail	UK Makes decisions about diverting trains, cancelling trains, etc.	
CMS(News 9 Jan 2010)	Centre for Railway Information System(CRIS)	Indian CMS automates day-to-day business functioning by monitoring crew movement in real-time, duty allocation, payment calculation and crew training in an efficient and transparent manner.	CMS was recently chosen as the 'Most Innovative Solution using Rational Software' for 'The Great Mind Challenge for Business-2009' by IBM

Table 6 - Research Approaches:

Research Approach	Author	Description	Comments
Rescheduling pattern description language R (C. Hirai)	C. Hirai, N. Tomii, Y. Tashiro, S. Kondou & A. Fujimori	Automatically rescheduling the trains with a pattern language processing system, especially for a large disruption. Establish a language to describe the patterns. Develop a language processing system to apply the patterns Construct a framework of an automatic train rescheduling system to modify the decision made by the interpreter.	This method can work satisfactorily and quickly for heavy train disruption so that it provides a stable transport service.
A heuristic based on elementary balancing possibilities & a flow-based heuristic approach (Gabriella Budai May 30, 2007)	Gabriella Budai, G´abor Mar´oti, Rommert Dekker Dennis Huisman, Leo Kroon.	The Rolling Stock Balancing Problem (RSBP), which is a usual problem faced in the short-term planning phase as well as during operations, is aimed at correcting the off-balances when the rolling stock among the stations do not fit to the allocations before and after the planning period. The paper describes two heuristic methods and compares them with each other. Finally, some insight is given into the quality of the proposed heuristics.	Both approaches are quite fast, even if the problem size is increased. It shows that both of them can be effectively used not only for solving larger size problems, but also for solving real-time rescheduling for a major perturbation.
State resources approach in a constraint-based scheduling model (Rodriguez)	Rodriguez	This article deals with a constraint-based scheduling (CBS) model of real time management of train traffic through stations, mainly by using state resources to improve the model of conflicts between trains running in opposite directions.	This approach shows very promising preliminary results in the solution performance.
Knowledge-based or Rule-based approach combined with a critical path method (Cheng	Cheng	The Knowledge-based or Rule-based approach has typically been used to solve problems that are either too complex for a mathematical formation or too difficult to be solved by optimisa-	

1996)		tion approaches. In terms of railway traffic control, a knowledge-based decision support system for real-time train dispatching can be established by setting certain rules from experienced signallers' decisions.	
Task-exchange teams (M.Lentink 2009)	David G.A. Mobacha, Erwin J.W. Abbinkb, Pieter J. Fiooleb, Ramon M. Lentinkb, Leo G. Kroonb, Eddy H.T. van der Heijdena, Niek J.E. Wijngaardsa	Agent-based crew-rescheduling is a relatively new area of research. The basic principle underlying the solution process is that of task exchange. Each driver's schedule consists of a number of tasks. If in the event of a disruption a driver can no longer perform one or more tasks due to a schedule conflict, these tasks are taken over by another driver. For exchange, this driver may have to hand over tasks that conflict with the newly accepted tasks to another driver.	This approach is an ongoing study on novel multi-agent approaches to crew rescheduling
Re-scheduling of railway rolling stock during track maintenance	(Budai, Maroti et al. 2007)	A systematic method of Rolling stock rescheduling during track maintenance operations was proposed.	
A column generation approach for the rail crew re-scheduling problem	(Huisman 2007)	The Crew Re-Scheduling Problem (CRSP) was defined and can be formulated as a large-scale set covering problem. The problem was solved with a column generation based algorithm. The performance of the algorithm was tested on real-world instances of NS.	

2.1.4 Driving Advisory System (WP6)

Table 7 - Systems:

System	Organisation	Description	Comments
Automatikfunktion (AF)	Systransis	2008 Switzerland Lötschberg basis tunnel Objectives: ❖ Avoid stops in the tunnel ❖ Gain time in cases of conflict ❖ Achieve a smooth traffic pattern in the tunnel Key functions: ❖ Provide a recommended order for trains through the tunnel's single-track section. ❖ Provide "advisory speed" to drivers approaching the single-track section.	Successful application of simple driving advisory integrated with ETCS-2 on a single track line with junctions.
Czech system AVV	AZD Prague	Since 1972 Czech Czech Railways Objectives: ❖ Achieve automatic train operation (ATO) ❖ Save energy using advanced train control Key functions: ❖ Reduces train speed or stops the train in accordance with absolute speed limits, signal indications and timetabled station stops ❖ Automatically set the vehicle to coast	Claimed achieved Energy savings up to 30%. Not only purely driving advisory, but also automatic coasting execution.
Computer Aided Train Operation (CATO)	Swedish Railways TransRail	2008 Sweden LKAB iron ore line Objectives: ❖ Achieve improved energy efficiency and optimised capacity on the network ❖ Ensure no train stops at a signal on its planned route	Good trial of integration of traffic control and driver advisory. Without a closed feedback control loop.

		Key functions: ❖ Two-part system, CATO Train and CATO Traffic Control Centre. ❖ Provide optimized target date to drivers ❖ Calculate the most efficient driving pattern	
PDA-based system of Dresden Technical University	Dresden Technical University	2008 Germany Dresden S-Bahn Objectives: ❖ help an S-Bahn driver operate his train efficiently with respect to energy consumption and downstream conflicts Key functions: ❖ Inform the drivers of the time to departure ❖ Offer drivers three driving strategies including cruising and coasting	Stand alone system with COTS products. Energy savings of between 7 and 12 percent have been measured.
Bombardier Driving Style Manager	Bombardier	Since 1999 Bombardier Objectives: ❖ Advise drivers about speed, acceleration and deceleration to minimise the energy consumption Key functions: ❖ produces an energy-optimised driving style (EODS) with the consideration of temporary or dynamic speed indications and signaling information	Integrated with ETCS DMI. Good Trials to provide unified operational system for different countries worldwide.
Energy-efficient timetabling	SNCF	Last 20 years France Objectives: ❖ Save electricity energy consumption ❖ Save investment of power infrastructure using lower peak load ❖ Extend the usage of catenary. Key functions:	Static driver advisory to provide CZs and RSZs. The project experience shows that CZs and RSZs are fairly stable for train paths.

		❖ Calculate start and end of each coasting zone (CZ) and speed within each recommended speed zone (RSZ) ❖ Provide static printed CZs and RSZs to drivers	
ESF EBuLa	DB	2002 Germany German railways Objectives: ❖ Reduce CO2 emissions ❖ Reduce energy cost Key functions: ❖ Calculate the optimal time to shut off traction power ❖ Display train driving advisory information for drivers	Deutsche Bahn saved €32 million by energy-efficient driving between 2002 and 2005.
Real-time rescheduling at SBB Puls 90	SBB ETH	2011 Switzerland Test on stub station at Lucerne Objectives: ❖ To maintain the connectivity of service pairs Key functions: ❖ Train rescheduling to maintain the OD pairs ❖ Provide drivers train advisory information to implement train rescheduling decisions	The system mainly aims to maintain railway service connections with integration of train rescheduling and control.
Fassi / EcoTrainBook	Germany regional railway Erzgebirgsbahn Umwelt und Verkehr of Dresden	2006 Germany Regional railways Vogtlandbahn Objectives: ❖ Reduce energy consumption by train driving advisory Key functions: ❖ Show the drivers different energy consumption with different driving styles ❖ Provide driving recommendations	The system provides a kind of decision making assistant for drivers on driving strategies.

FreeFloat	DB Nets AG	2006 Germany Rastatt, Germany. Objectives: ❖ Guide trains in real time to avoid conflicts so as to reduce delays and energy consumption Key functions: ❖ The system has two control loops: inner control loop and outer control loop. ❖ Generate updated rescheduling decisions for the drivers with the consideration of traffic control.	Good trials on driver advisory taking traffic control into consideration.
FreightMiser	TTG Transportation Technology Pty Limited University of South Australia	2008 Australia Australian freight networks Objectives: ❖ Improve energy consumption and punctuality of freight railways Key functions: ❖ Calculate optimal speed profiles with different journey time ❖ Calculate optimal coasting points during the journey and provide the information to the drivers	Specific driver advisory system for freight trains.
GEKKO	DSB Danish Railways	2008 Danmark Trialled at DSB Objectives: ❖ Indicate drivers to be on correct pathway. Key functions: ❖ Implemented with a PDA device ❖ Request timetable and infrastructure information to calculate optimal speed profiles for the drivers.	Demonstration of onboard PDA linked to the central server.

LEADER – Locomotive Engineer Assist Display & Event Recorder	New York Air Brake (NYAB)	2009 America American Railroads Objectives: ❖ Reduce energy consumption ❖ Reduce the in-train forces ❖ Provide optimal driving advisory strategies Key functions: ❖ Calculate train behaviours on the basis of rolling stock and infrastructure data ❖ Calculate energy efficient driving strategies for the train drivers	Good trials to include function of reducing in-train forces in driver advisory system.
Metromiser	Siemens University of South Australia Berlin Technical University	2002 Objectives: ❖ Provide energy efficient driving with energy optimized timetables. Key functions: ❖ Timetable optimizer for calculation of energy optimized timetables ❖ On-board unit to calculate and provide optimal driving advisory information	DAS for light-rail, metro and suburban systems, Provision of optimised timetables and optimised driving profiles.
RouteLint	ProRail	2003 Netherlands Trialed in 2004 Dutch Railways Objectives: ❖ Improve communications between drivers and dispatchers to acquire energy-efficient driving and improve punctuality. Key functions: ❖ High speed data link between trains and control centres ❖ Speed adjusting (acceleration, braking, coasting) according to real time train traffic information	Provide route setting information ahead to the drivers.

Train Coasting Advisory System (TCAS)	British Rail R&D Division	1986 Britain Trialed in 1986 British Railways Objectives: ❖ Make good use of train coasting to reduce energy consumption and braking maintain cost Key functions: ❖ Monitoring train running against timetable ❖ Calculate train coasting points for drivers	Initial trial for train driving advisory with simple but efficient functions.
Trip Optimizer	GE Transportation Systems	2005 USA USA freight railways Objectives: ❖ Implement energy saving driving with close loop speed regulation Key functions: ❖ Calculate optimal cruising speed and display in the cab for train drivers.	Installed in GE Evolution locomotives for freight railways. Optimal cruising speed is displayed lineside at each station.
Betriebsleitanlage der Wiener U-Bahn (BLW)	Vienna Transport (Wiener Linien)	Vienna Objectives: ❖ Energy saving driving with line-side speed indicators to drivers. Key functions: ❖ Calculate optimal cruising speed for the trains to next stops, and display line-side.	Maximum speed to next station is displayed to the drivers.

Table 8 - Research approaches:

Research Approach	Author	Description
Theory of optimal control	(Howlett, Milroy et al. 1994)	Application of optimal control theory on Metromiser system for suburban railways to achieve energy-efficient driving strategies. Claimed to achieve fuel savings in excess of 13% and dramatic improvements in timekeeping.
Generic Algorithms	(Chang and Sim 1997)	A genetic algorithm (GA) was proposed to optimise train movements using appropriate coast control that can be integrated within ATO systems.

Discrete dynamic programming algorithm	(Franke, Terwiesch et al. 2000)	Based on a nonlinear point-mass model of the train, A discrete dynamic programming algorithm was developed for the deterministic and efficient numerical solution of the nonlinear optimal control problem.
Calculation algorithm for solving real time optimal train operation problems	(Liu and Golovitcher 2003)	A calculation algorithm for energy efficient train control was developed to solve the optimal train operation control problems in real time.
Dynamic Programming	(Albrecht and Oettich 2002)	A new approach was presented to fulfill conflicting goals of dynamic schedule synchronization and energy saving, in rapid rail transit systems, with an algorithm for the dynamic modification of train running times.
Pontryagin principle	(Pokorny 2007)	Application of the Pontryagin principle and to develop the optimal strategy and to derive equations for the computation of switching times and the corresponding speed profile in the case of global speed constraints.

2.2 State of the art TRL related to ON-TIME project

Technology Readiness Levels (TRL) methodology is proposed to be applied in the ON-TIME project to verify the innovations in the project. This approach is used by NASA, the European Space Agency and many government departments around the world to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating a technological solution into a system or subsystem. The TRL definitions that will be used in the project are listed in Table 9.

Technology Readiness Level	Definition
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component validation in a laboratory environment
TRL 5	Component validation in a railway environment
TRL 6	System/subsystem simulation or prototype demonstration in a railway relevant environment
TRL 7	System prototype demonstration in a railway environment
TRL 8	Actual system completed and qualified through test and demonstration
TRL 9	Actual system proven through successful mission operations

Table 9 Technology Readiness Levels (TRL)

Table 10 shows TRL mapping of the state of the art technological developments related mainly to work packages (WP3-WP6) in the ON-TIME project. It should be noted that the TRL of specific technologies are different in terms of different system specifications, e.g. one mature system technology on TRL 9 may only be a component in a large system, so that the TRL falls to level 5.

Work Package	TRL	Comments
WP3	3	❖ Existing tools for railway planning and timetabling mainly act as a computer aid system without decision support and optimisation functions. ❖ Lack of unified understanding of capacity definitions. ❖ Lack of consistent and integrated processes to support the different levels of planning (and associated modeling). ❖ Lack of commonly accessible data standards /interfaces/ (tool chains). ❖ No unified criteria for timetabling assessment and evaluation. ❖ Currently timetable construction and simulation requires significant a priori knowledge.
WP4	3	❖ Generally quite simple algorithms with single objective optimisation have been implemented. ❖ Issues in terms of processing power with complex approaches. ❖ Significant research has been carried out in this area but little implementation. ❖ No unified standard and interfaces in system specifications for railway traffic control.
WP5	3	❖ Generally quite simple algorithms with single objective optimisation have been implemented. ❖ Lack of consistent and integrated processes to support the different levels of operational management (and associated modeling). ❖ Lack of commonly accessible data standards /interfaces/ (tool chains). ❖ Little standardisation or consistency between railway operational management systems. ❖ No integration processes between railway traffic control and operational management.
WP6	5	❖ Lots of systems implemented with different objectives and approaches at different application levels. ❖ Little standardisation or consistency between systems. ❖ Sorts of technological components have been validated in a railway environment. ❖ No system with fully close control loop for integration of railway traffic control, operational management and DAS.

Table 10 TRL mapping of technological developments

The summarised innovations proposed in the ON-TIME project are listed in Table 11. It shows the existing TRLs of innovations, together with the step change improvement that will be brought about through research and development undertaken in the ON-TIME project.

Innovation	Current TRL	Planned TRL after ON-TIME
Innovation 1: Standardised definitions and methods	**2**	**7**
Innovation 2: Improved methods for timetable construction	**3**	**6**
Innovation 3: Algorithms to either automatically provide control, or provide decision support to controllers	**3**	**7**
Innovation 4: Methods, processes and algorithms that are able to provide decision support when events occur that require the disposition of assets and resources	**2**	**6**
Innovation 5: Interoperable approaches for the communication and presentation of information	**3**	**6**
Innovation 6: An information architecture to support the communication of standardised and contextualised train control data	**2**	**7**

Table 11 Table showing the current TRL levels and the planned step changes

3 REVIEW OF PROCESS DESCRIPTIONS, REPORTED PROBLEM AREAS AND STRATEGIC DEVELOPMENTS

3.1 Introduction

Task 2.1 (Railway planning and operation process) is covered by this document and concentrates on the review of underlying railway operations management processes (strategic planning, tactical planning and operational planning). The task should also perform a functional work systems analysis and modelling (what are the normal processes, and how is tactical and operational planning done). It is also specified that traffic planning and control should be reviewed from different relevant perspectives.

In order to collect information from the different countries, a questionnaire was designed and sent out to the IM in the UK, Sweden, Germany, France and Italy. Holland was also included, although not through the IM directly as they are not a part of the project.

The complete answers to the questionnaire are reported separately, in an annex to the deliverable D2.1: Technical annex to D2.1: Questionnaire reports.

In this section, the analysis based on the questionnaire reports will be reported. The following is presented below:

Description of traffic management processes in different countries

- A description of the different countries' traffic management processes, in a form that is intended to support a comparison and analysis of similarities and differences.

Experienced problems

- Today’s problems regarding the different issues covered by the questionnaire, as reported by the IM.

Developments and innovations

- Today’s ongoing and planned development and existing innovations, as reported by the IM. This is intended to support an analysis of state-of-the-art and best practice.

3.2 The traffic management processes of Sweden, Netherlands, and Great Britain

Based on the material obtained from the IM and the time and resources available, the traffic management processes of Sweden, Netherlands and GB have, so far, been described. Remaining countries will be considered at a later date if necessary, however, through the analysis of the processes adopted in these countries it is clear that, at a high level, the processes and resulting functional requirements are similar in each country.

3.2.1 The traffic management process of Sweden

3.2.1.1 Overview

In Sweden, almost all railway traffic is controlled from traffic control centres (DLC's). With the help of train control systems, the trains along the tracks are remotely controlled and monitored through signalling systems. The introduction of centralized control has enabled large staff savings. The signal boxes along the tracks do not need to be staffed by local dispatchers. The centralisation requires that the lines are equipped with a block system and has also meant that it is possible to rationally manage trains over a larger area with improved capacity and safety.

Centralised train traffic control is managed from eight DLC's in different places in Sweden:

- Boden, mixed traffic, single track, Swedish Iron Ore (Malmbanan), border traffic to Norway, implemented STEG Graph Plan.
- Ånge, mixed traffic, single track, (ERTMS L2 on Botnia Line).
- Gävle, mixed traffic, mainly single track, some double track.
- Stockholm, very dense mixed traffic, multi-track, local commuter trains, the hub of long distance train traffic in Sweden.
- Hallsberg, mixed traffic, multi-track, border to Norway.
- Norrköping, mixed traffic, (implemented STEG Graph Plan and Track Occupation Plan).
- Göteborg, mixed traffic, multi-track, commuter traffic
- Malmö, mixed traffic, multi-track, border to Denmark, dense commuter traffic

On the technical level, centralised traffic control is implemented with three different systems:

- Argus (Ansaldo) – Boden
- Ebicos TMS (Bombardier) – Gävle, Hallsberg
- Ebicos 900 (Bombardier) – Ånge, Stockholm, Göteborg, Norrköping and Malmö

3.2.1.2 The main processes

The main processes in operational train traffic control have the following main process operations:

- Operations management. Operations management leads the proactive work by identifying and managing risk for disturbances in the operations management area. The Head dispatcher should be informed of all events affecting the operations management capabilities within their own operations management area, and overall in the other DLC´s.
- Train traffic control. The dispatcher should work proactively by implementing a plan ahead in order to identify early any future discrepancies. The dispatcher shall stay constantly updated about the traffic situation on their own and adjacent routes, as well as actively monitor trains and other devices, in order to directly observe deviations. The dispatcher ensures train routes and other manoeuvres take place in such a way that traffic is not disrupted.
- Train Traffic Information. The Traffic information officer is responsible for proactively monitoring the traffic flow at the planned location by monitoring via existing facilities and systems, and through collaboration with other operational functions.
- Power management. The power management shall proactively monitor and analyse alarms in the system.
- Infrastructure management. To proactively monitor progress in the status of the infrastructure. Change of status in the infrastructure is documented.

3.2.1.3 Systems, automation and rescheduling

Dynamic information about process status is presented in track diagrams on large distant panels and/or on several computer screens close to the individual workplace.

Dispatchers observe train movements and control train routes by remote blocking. Track usage is controlled either by ordering automatic functions or by directly executing interlocking routes for each station. Automatic functions are either implemented locally, in the centralised control systems or as a separate automatic control system.

Together with the human traffic controller, there are up to four levels of more or less autonomous automatic functions that try to partially solve the same problems. Interactions between these levels of decision making and execution are complex.

While the solutions vary between the different types of systems, reflecting a gradual development, the functionality is largely uniform. The same is true for human machine interfaces; for example, where different generations of display technologies are represented, but where the principles of presentation and interaction are largely common to the various types of systems.

In the case of disturbances, the train dispatcher creates a rescheduled timetable that is valid until the next rescheduling action. On single track lines it is normally made on paper (time-distance graph), but sometimes it is virtually non-existent, i.e. it exists only in the head of the dispatcher. On multi-tracked lines its existence is most often non-existent or is just notes on the paper (time-distance graph).

Deviations from the agreed plan are announced to the traffic service offices (RUs). Measures to handle the deviation are done in dialog with the traffic service offices.

The dispatcher announces deviations in train order to the train driver.

The existing information and decision support systems used in operational control are:

- Opera – Provides train information, e.g. current weight, length, telephone number, etc.
- Basun – System used in order to report and get information regarding deviations in timetable and causes of delays.
- ASTA – Tele communication system with queue handling, functional calls, identification of caller etc.

3.2.1.4 Railway undertakers (RU)

The railway undertakers (RUs) are responsible for rostering and vehicle planning. They have traffic service offices where controllers work, taking business based traffic decisions and rescheduling the resources in case of perturbations and disruptions.

The railway undertakers can handle the situation through new circulation strategies or by having extra vehicles ready.

With improved traffic information systems, traffic service offices will be updated on the current timetable of each train and at an early stage realise the consequences of that plan.

3.2.1.5 Process diagram

The following process diagram describes the main aspects of the Swedish traffic management process, also including a brief description of the timetable process. The symbols used are explained in detail below.

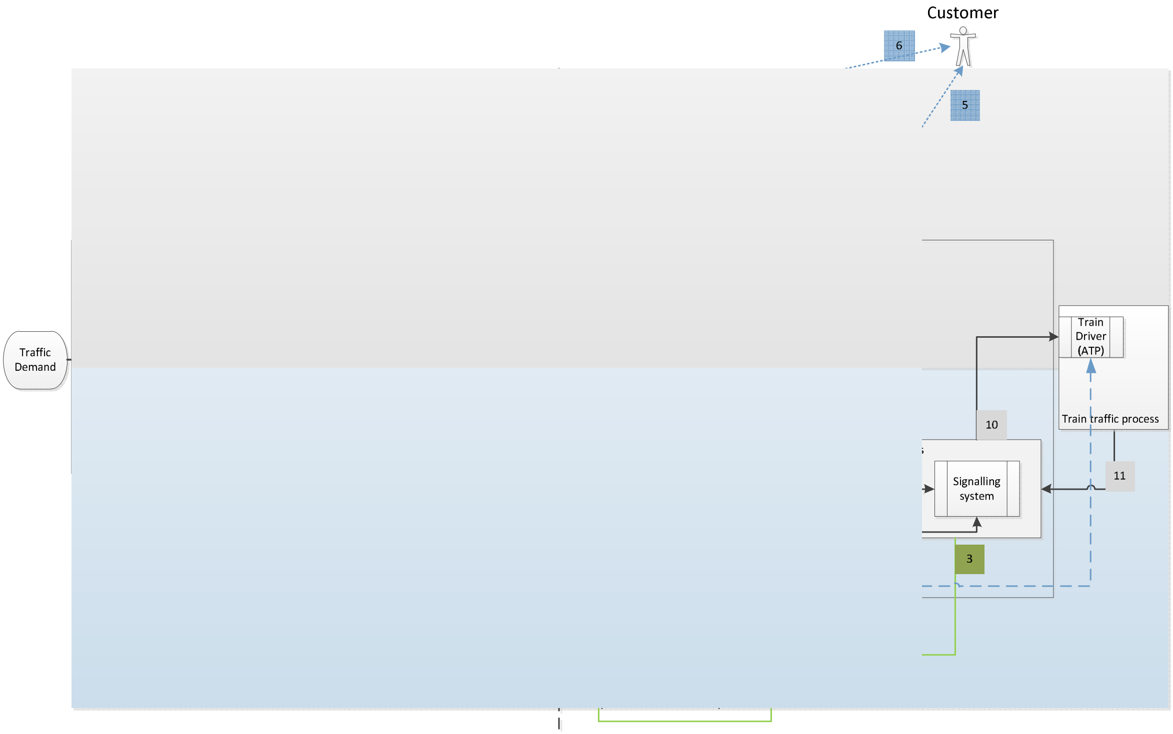

Figure 1 Swedish timetabling and traffic management process

3.2.1.6 Explanations related to the process diagram

3.2.1.6.1 General

Black line: “Flow of information” in the direction of the arrows between the sub processes.

Red line with arrow: An actor “does” something (controllability).

Green line with arrow: An actor collects information about something (observability).

Blue dashed line: Oral communication by phone

Blue line: Direct oral communication

Blue pointed line: Information to customers in different (not specified) ways.

3.2.1.6.2 “Flow of information” between the sub processes (Black arrows/lines):

1. The demand from the society is the basis for the planning of the need of timetable slots.
2. The RUs create their preliminary applications for slots and hand them over to the IM.
3. The planned slots are the basis for the RUs planning of resources (crew and rolling stock).

4. The IM slot allocation process decides the RUs final planning of resources (crew and rolling stock).
5. The allocation processes decide the "final" resource plan for the year to come.
6. The allocation processes decide the "final" timetable for the year to come.
7. The actual timetable and the resource plan is transferred (on a daily basis) to the operational process.
8. The ad hoc application for slots creates changes of the actual timetable and resource plan respectively. The planning perspective of the ad hoc slot applications are from 8 weeks to 24 hours.
9. –
10. The train traffic process in itself is controlled by the operational control process (signalling system (ATP)). The train driver uses information from the control process (signalling system) to drive the train. The train is controlled by the signalling system (ATP).
11. Information about the state of the train traffic process is collected in the operational process.

3.2.1.6.3 Selected actors' controlling of the sub processes (Red arrows/lines):

1. The RU planners handle the applications for time slots (train paths) and the planning of resources (crew and rolling stock).
2. The IM planners create the timetable based on the slot applications etc.
3. The IM planners change the timetable based on ad hoc applications for slots etc.
4. The RU planners handle the ad hoc applications for time slots and make necessary changes in the resource plans.
5. In case of disturbances, the train dispatcher creates a rescheduled timetable that is valid until the next rescheduling action. On single track lines it is normally made on paper (time-distance graph), but sometimes it is virtually non-existent, i.e. exists only in the head of the dispatcher. On multi-tracked lines it is most often non-existent or is just notes on the paper (time-distance graph).
6. The train dispatcher gives information about traffic changes to the customer information process.
7. The train dispatcher controls the traffic by executing train routes, either directly by giving route commands or indirectly, and perhaps only for a part of his area, with the help of the ARS functions of the control system.
8. The RU´s controller makes the necessary changes in the resource plan in case of perturbations or disruptions.
9. The RU´s controller gives information about traffic changes to the customer information process.

3.2.1.6.4 Selected actors' information gathering from the sub processes (Green arrows/lines):

1. The dispatcher uses information from the original timetable ((TD-diagram on paper)) when doing the rescheduling of the current timetable.

2. The train dispatcher uses the current (actual) rescheduled timetable – virtual or on paper - when controlling the train traffic.
3. The train dispatcher gets information from the operational process about the current state of the train traffic process in which there are, for example, almost always some minor perturbations.
4. The customer information process uses information from the originally planned timetable (TD-diagram on paper).
5. The customer information process gets information from the operational process about the current state of the train traffic process.
6. In case of perturbations or disruptions, the RU´s controller gets information from the daily resource plan.
7. The RU´s controller gets information from the operational process about the current state of the train traffic process.

3.2.1.6.5 Communication between selected actors (Blue arrows/lines):

1. Direct oral communication between head dispatcher and train dispatcher regarding changes in the traffic plans. The train dispatcher informs the head dispatcher about delays and other deviations from the (original) plan. The head dispatcher supervises the dispatchers and also coordinates the necessary activities together with the outside world, primarily communicating with the RU´s.
2. Oral communication by phone between the Head dispatcher and RU controller regarding business based changes. The head dispatcher informs the RU´s controller about perturbations that demand business based decisions to be made by the controller or that make it necessary to change resource plans.
3. Oral communication by phone between dispatcher and train driver. The train driver is informed about changes and/or train driver informs about, for example, technical problems with the train or other faults.
4. The RU and IM planners communicate in different ways during the process of timetable creation.
5. The customer information process informs customers about changes affecting them (mainly customers waiting at stations or customers using the web information sources).
6. The RU´s controller gives necessary information to the customers in different ways.

3.2.2 The traffic management process of Netherlands

3.2.2.1 Overview

Operational control is split between the IM and the RUs. The IM is responsible for the effective and safe utilisation of the infrastructure (route setting, signalling, etc.), and the RUs are responsible for providing rolling stock and crews for the trains.

There is one OCCR (Operational Control Centre Rail) centrally located in Utrecht, where, in principle, all stake-holders are represented: IM and the RUs. The operational processes are monitored and, in case of a disruption (e.g. temporary unavailability of part of the infrastructure), the main decisions about how to react are taken here.

Furthermore, the IM has 13 Local Control Centres, where local decisions about local processes are taken and executed. For example, route setting and interlocking decisions are executed in the Local Control Centres of the IM.

Based on the type of disruption, there are over 1000 disruption scenarios that describe how the timetable may be rescheduled. The strategy described in these disruption scenarios is how to isolate the disrupted area, and to turn the trains at the nearest stations (of the right type) outside the disrupted area. The disruption scenarios basically describe an alternative Basic Hourly Pattern that still fits, given the reduction of infrastructural capacity. The selection of a disruption scenario is a joint decision process between IM and RUs.

Serious real-time timetable changes such as cancellations of certain trains are a joint decision between the OCCR, the relevant Local Control Centres of the IM, and the relevant Regional Control Centre of NS.

3.2.2.2 Systems, processes, automation, and rescheduling

For informing all controllers of IM and RUs about the status of the trains, there is a central information system, VKL. Traffic can be scheduled in real-time. Rescheduling the timetable means that a new plan is inserted into the control system “Proces Leiding” (Process Control). In principle, the new timetable can be executed automatically, but dispatchers can also influence it manually.

Much communication between dispatchers takes place via telephone. Officially, a request from the controllers of the RUs for an additional train path (for example, for a shunting movement) should be sent to the traffic controllers of the IM via fax.

Communication between the resource dispatchers of the RUs and the train drivers takes place via telephone or “pda”. Train drivers may communicate directly with controllers of IM, for example for informing them about malfunctioning infrastructure.

All controllers have an automated overview through the VKL system of the real-time positions of the trains along the lines, including their delays. The controllers of the RUs only have this information in “textual” format. The controllers of IM also have a dynamic time-space diagram in graphical format. Delays are propagated in the simplest way: no delay absorption until the end of a train service.

The controllers of IM use the system “Proces Leiding” (Process Control) to influence the process: they can see the details of the train movements on the detailed railway infrastructure, mainly in the (environment of the) stations, and they can set routes and signals in a manual way.

However, under normal circumstances, routes and signals are set automatically by the system ARI (Automatic Route Setting). Based on the detailed timetable, ARI knows which routes and signals must be set for each train, and when this must happen. If a train makes it known to ARI at a certain location and within a certain time interval, ARI tries to set the requested routes and signals using rather simple, local rules based on FCFS. ARI can be overruled by traffic controllers of IM.

In case of delays or disruptions, the timetable is modified manually by controllers of IM, and then ARI acts according to the modified timetable. As indicated before, there are many disruption scenarios, describing the modified Basic Hourly Patterns that are to be operated in case of disruptions. These scenarios describe the timetable, and the rolling stock connections in the stations (early turning), but give no details of rolling stock or crew duties. The disruption scenarios are based on the strong periodic character of the Dutch railway timetable.

Furthermore, at the moment no decision support systems are used in the operational control process. Only in the ultra-short term planning process (i.e. today´s planning for tomorrow), there are decision support tools for modifying the rolling stock and crew duties. These may be used in case of a bad weather forecast for tomorrow. In such case a more robust timetable with less but longer trains may be operated. These decision support tools became available just recently.

3.2.2.3 Railway undertakers (RU)

The railway undertakers (RUs) are responsible for rostering and vehicle planning.

In principle all stake-holders are represented in the OCCR (Operational Control Centre Rail) centrally located in Utrecht. There the operational processes are monitored. In case of a disruption (e.g. temporary unavailability of part of the infrastructure), the main decisions about how to react are taken here.

NS (RU) has split the country into 5 areas. In each area, NS has its own Regional Control Centre, where the timetable is monitored and the operational rescheduling of the duties of the rolling stock and crews are carried out.

3.2.2.4 Process diagram

The following process diagram describes the main aspects of the Dutch traffic management process. The symbols used are explained in detail below.

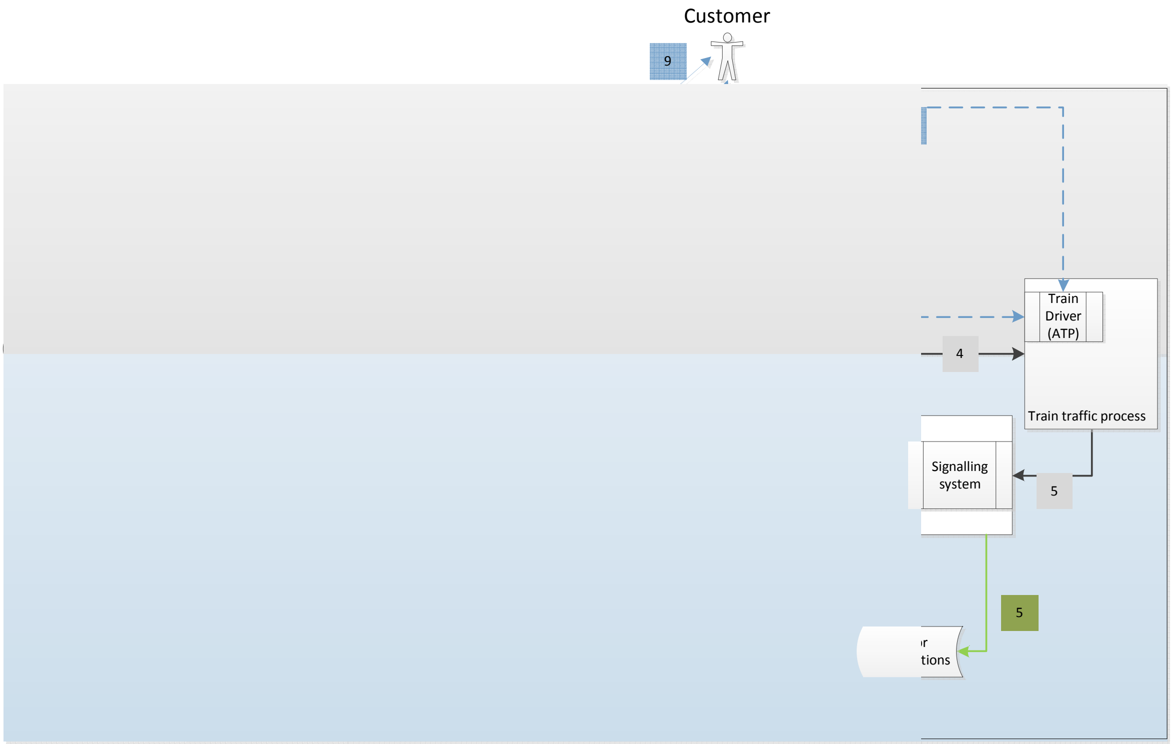

Figure 2 Dutch traffic management process

3.2.2.5 Explanations related to the process diagram

3.2.2.5.1 General

Red line with arrow: An actor "does" something (controllability).

Green line with arrow: An actor collects information about something (observability).

Blue dashed line: Oral communication by phone

Blue line: Direct oral communication

Blue pointed line: Information to customers in different (not specified) ways.

Black line: "Flow of information" in the direction of the arrows between the sub processes.

3.2.2.5.2 "Flow of information" between the sub processes (Black arrows/lines):

1. There is a daily transfer of the original timetable of the day from the timetable systems. The IM is in charge of this.
2. There is also a daily resource plan (RP) that is handled by the RUs.
3. The original timetable of the day is transferred to the control system. This is repeated after every rescheduling activity.
4. The train traffic process in itself is controlled by the operational control process (signalling system (ATP)). The train driver uses information from the control

process (signalling system) to drive the train. The train is controlled by the signalling system (ATP).

5. Information about the state of the train traffic process is collected in the operational process.
6. Information about the state of the train traffic process is continuously transferred from the operational process to the real time positions and delays process.

3.2.2.5.3 Selected actors' controlling of the sub processes (Red arrows/lines):

1. The OCCR controller can, in case of perturbations and disruptions, create a rescheduled timetable that is transferred to the operational process. This rescheduling activity is normally done in cooperation with the RU representatives in the OCCR.
2. The local head dispatcher can also create a rescheduled timetable that is transferred to the operational process. This is normally done in cooperation with the RU representatives in the RCC.
3. The local dispatcher can, if necessary, make minor rescheduling activities. The resulting routes are normally (if the train is within the time window) executed automatically. The local dispatcher can also manually execute train routes.
4. The RU´s regional controller makes necessary changes in the resource plan. In case of a disruption, the timetable, the rolling stock, and the crews must be rescheduled manually.

3.2.2.5.4 Selected actors' information gathering from the sub processes (Green arrows/lines):

0. The OCCR controllers have ready to use disruption scenarios at their disposal in case of larger perturbations or disruptions. They may be automatically transferred into a new rescheduled timetable. This is done in cooperation with the RU representatives.
1. The OCCR controllers and the local head dispatcher of the IM get detailed information about the trains from the real time positions and delays process.
2. The OCCR controllers and the regional controllers of the RU´s get detailed information about the trains from the real time positions and delays process. The regional controllers of the RUs only in textual format.
3. The RU´s regional controller uses information from the resource plan in case of perturbations and disruptions. Note that the timetable, the rolling stock, and the crews must be rescheduled manually and rescheduling the timetable and the resources is carried out sequentially.
4. The customer information process gets information from the real time positions and delays process about the current state of the train traffic process.
5. The train dispatchers in the LCC get information from the operational process about the state of the train traffic process in which there are, for example, almost always some minor perturbations.

6. The local head dispatcher uses information in the current timetable when planning the traffic.
7. The OCCR controller uses information in the current timetable when planning the traffic.

3.2.2.5.5 Communication between selected actors (Blue arrows/lines):

1. Direct oral communication between the OCCR controllers representing IM and RU´s. In case of disruptions (e.g. part of the infrastructure temporarily unavailable) the OCCR makes main decisions about how to react.
2. Oral communication by phone between OCCR controllers and local head dispatcher in LCC controllers regarding changes in plans.
3. Oral communication by phone between local head dispatcher and local dispatchers regarding changes in plans.
4. Oral communication by phone between OCCR controllers and regional controllers in RCC regarding changes in plans.
5. Oral communication by phone between local head dispatchers of IM and regional controllers of the RUs. They can discuss the effects of changes before making decisions.
6. Oral communication by phone/pda between local dispatcher and train driver. The train driver is informed about changes and/or train driver informs about, for example, technical problems with the train or other faults (infrastructure failures).
7. Oral communication by phone/pda between regional controllers of RUs and train driver. For example, time consuming communication about whether the drivers are willing to accept their modified duties.
8. The customer information process informs customers about changes affecting them (mainly customers waiting at stations or customers using the web information sources).
9. The RU´s regional controller gives necessary information to the customers in different ways.

3.2.3 The traffic management process of GB

3.2.3.1 Overview

There are three levels of control in GB in terms of roles:

1. Signallers (earlier signalmen). They are responsible for setting routes for trains (giving movement authorities). These are the “front-line operators”. They make decisions on the order of trains through junctions (regulation) for their area but take instruction from higher up if there is major disruption.
2. Shift Signalling Managers (SSM) – these are only present in larger signal boxes (i.e. boxes with at least 3-4 signallers). They do not directly control the railway but supervise the signallers and give them instruction on how to regulate trains. They speak with control (TRC) about larger issues.

3. Train Running Controllers (TRC) – these sit in a separate location from the signal box, in control centres. They work with the train companies during major disruption to make decisions about diverting trains, cancelling trains, etc. and then pass these instructions to the signal box to be implemented. In some areas they give instruction to SSMs or signallers about regulation (i.e. the ordering of trains through junctions) but this is not usual.
4. Another type of controller called an *incident controller*. These are based in control centres (with the TRC) and any faults or incidents are reported to them. They are then responsible for logging the details and organising a response team.

In terms of signalling technology there are also three main levels:

1. VDU based – these are computer based signalling schematics. Within this, there are three main types which are from three different suppliers (they all conform to a common standard but there are small differences):
    - IECC – this is the product from DeltaRail (Integrated Electronic Control Centre). It has been in place since the 1980s and has Automatic Route Setting (ARS) as standard. In technological terms, one IECC (i.e. one set of computers) can drive up to three workstations but this is a detail relevant only to the engineers. Most people would refer to the entire signal box as the IECC.
    - MCS – this is the product from GE. It is newer than IECC but has only recently had ARS implemented on it.
    - WestCAD – this is the product from Invensys. Again, newer than IECC but still working on having ARS implemented over it.
2. NX panels – these are control panel type schematics for controlling trains. They are almost exclusively manual (one has a small area run by ARS). The size of NX panel boxes range from a very small panel easily manned by one person, to very large signal boxes with up to 13 different signallers working at one time.
3. Level frames – the oldest style of signalling still in use and very manual!

3.2.3.2 Systems, processes, automation, and rescheduling

SSMs and Train Running Controllers do not have any signalling equipment. SSMs use read only schematic views in VDU-based areas. SSMs and Train Running Controllers use a couple of other tools – one is a schematic view but at a much higher level than the ones signallers use. This is called CCF and shows the trains colour-coded according to delay. They also use the central system; a DOS based system called TRUST, for viewing train timetables. NR is just starting to introduce read-only train graphs which identify conflicts.

Important notes:

- The CC in IECC is a bit misleading. They are really signal boxes. As explained above, there are a few different types of signal boxes but the general principle is that a signaller controls a portion of the network from a workstation/panel/lever frame.

- Because IECC has been around longer, and has been more advanced than MCS and WestCAD, the two other kinds of VDU box tend to get compared to it. The main difference in the past has been that IECC has ARS, but as this is now being implemented on MCS and WestCAD the differences will be much more minor.
- There still exist about 500 lever frame boxes (which tend to be single manned) and probably about 200 NX panels.
- There are no IECCs in ***Control Centres***. They are all in signal boxes. Putting signalling and control together is a future aspiration. "Control Centres" cover strategic control, major incident management, information management to other stakeholders, etc.
- The entire railway is overseen by control centres, but they do not have any ability to directly control trains. The entire railway is controlled by signallers. All track control occurs in what we might call signal boxes – even IECCs (which have control centre in the title) are signal boxes.
- There are just over 800 signal boxes altogether and around 14 control centres.

Information passed between signaller and TRC is always by telephone (sometimes via the SSM where they are present). There are plans to introduce a train graph, but it is read only, so it will not be possible to change the plan on the graph.

After the changes have happened, they will be visible in TRUST. Any changes that have yet to happen have to be communicated by telephone or fax.

Clarifying points:

- 100% of the network is actively controlled (signals set, points moved etc.) by something like 800 signal boxes (500 lever frame, 200 nx´s, the rest are vdu based (IECC, Westcad, and MCS). Occasionally, there is a slight mix in a box. So, for example, Wembley signal has 4 or 5 nx workstations, but one workstation that shares traffic with London underground is VDU-based.
- 100% of the network is strategically overseen by Control Centres (14 in total) – they make the big decisions, substantial re-planning and keep information flowing to all stakeholders (e.g. public, train operating companies) but they do not physically control anything.
- Within the railway system almost all control is distributed across regions. Interestingly, there is one central UK 'command centre' as such called NOC (national operations control) but this does not make any control decisions. They mainly exist as a central information source for senior management and possibly have an advisory role to route controls.
- NX control is not just limited to minor or outlying areas. Euston Station for example, one of the UKs busiest stations, and the lines running out of it are controlled by NX at Wembley. The upgrades from NX to VDU-type workstations typically coincide with other major infrastructure changes and upgrades.

- "Control Centres", in Network Rail terminology, are where strategic decisions are made. Also, representatives from the Train Operating Companies (TOC) are often present in the Control Centres. Usually the main TOC for that area is present. This enables the Train Running Controller to have rapid access to TOCs and there is probably room for discussion. It is interesting that it is considered appropriate to have TOCs physically alongside Train Running Controllers, but not yet signallers. Also, depending on where you are, there may be a one to many relationship between the IM (network rail) in the Control Centre, and RU (the TOCs). York Control Centre deals with East Coast Mainline, Hull Trains, Northern, Grand Central, Cross Country, and probably a couple of others (plus freight!).
- Of course the signaller (in the signal box) may do minor re-planning. Much of it may take place so rapidly that there is no perceived disruption to the service, or delay is in terms of a few minutes. This will never get escalated to the Train Running Controller, other than coming up on the displays that show general network status.
- When a major event occurs, the problem is escalated to the Train Running Controller. This person then informs and possibly negotiates with the TOC representative in the control room to discuss options such as missing out stations, cancelling trains etc. Also, they might need to contact engineering, emergency services, etc. but this would usually be the Incident Controller, not the TRC.
- Another interesting aspect of this system is that signallers (front line track control) talk to drivers (front line vehicle control) whereas controllers do not. How regularly the TOCs talk directly to drivers is unclear. Officially, TOC controls only speak to train guards but not drivers, unless the driver contacts them.
- VDU signalling equipment tends to be cheaper and much easier to install than NX panels. It also allows ARS to be implemented, which is much more difficult on NX panels. Because UK signalling control systems are directly tied to interlocking systems, they tend to only re-control during a re-signalling project. It is hoped that this link will be broken in future.

3.2.3.3 Railway undertakers (RU)

The railway undertakers (RUs) are responsible for rostering and vehicle planning. They have traffic service offices where controllers work, taking business based traffic decisions and rescheduling the resources in case of perturbations and disruptions.

Representatives from the Train Operating Companies (TOC) are often present in the Control Centres. Usually the main TOC for that area is present. This enables the Train Running Controller to have rapid access to TOCs and there is probably room for discussion.

3.2.3.4 Process diagram

The following process diagram describes the main aspects of the British traffic management process. The symbols used are explained in detail below.

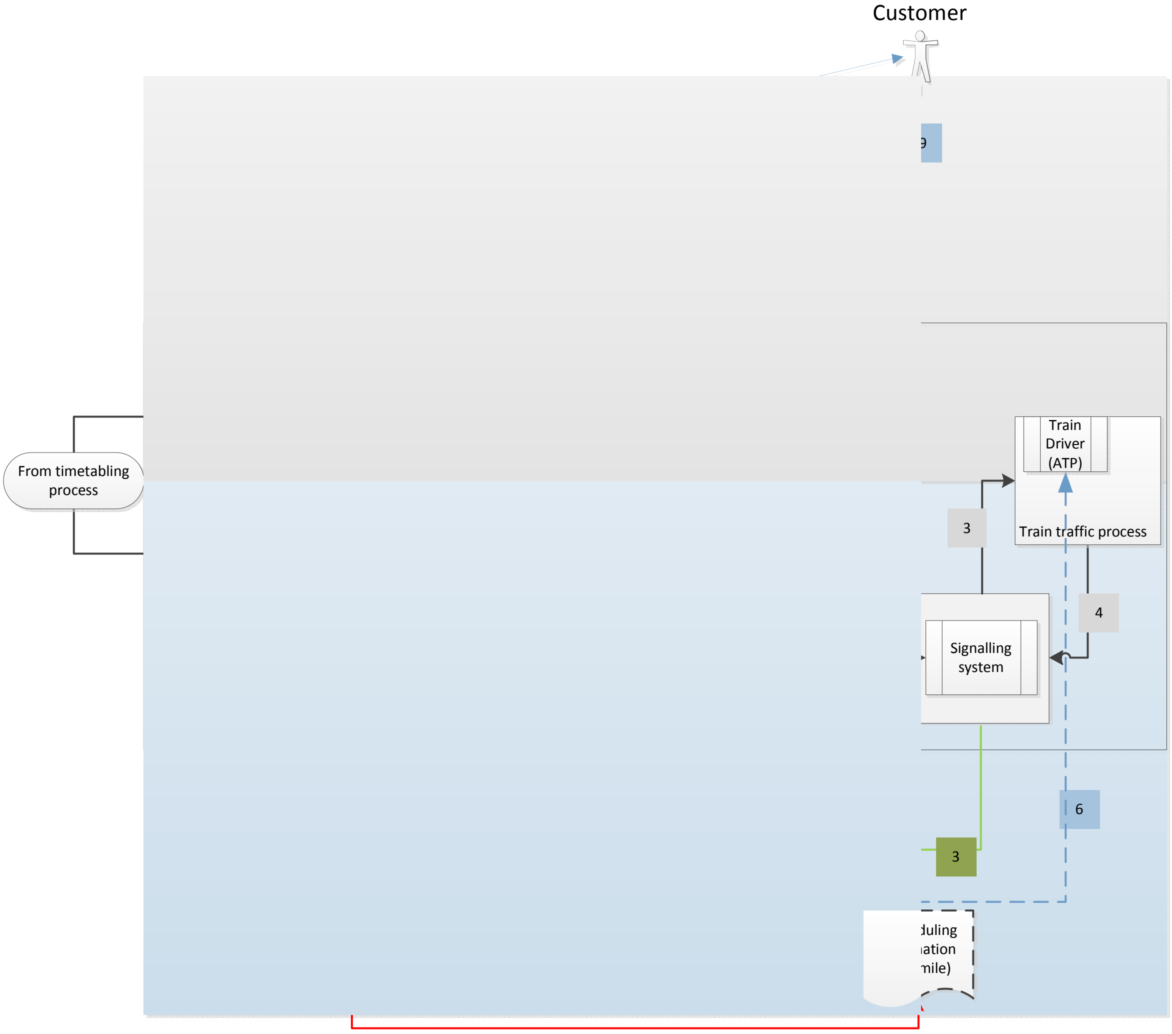

Figure 3 British traffic management process

3.2.3.5 *Explanations related to the process diagram*

3.2.3.5.1 Abbreviations

Signaller	Previously called signalman. The signaller works in a (small or large) "signal box".
SSM	Shift signalling manager, only in signal boxes with at least 3 signallers.
TCC	Train control centre. There are in total 14. Note there is no control system in the TCC. The locations of the TCCs are separate from the signal boxes.
TRC	Train running controller in TCC. They work with the train companies during major disruption to make decisions about diverting trains, cancelling trains, etc. and then pass these instructions to the signal box to be implemented.

CCF	Colour coded display that shows the state of the trains in the system. Used by TRC and SSM.
TRUST	A DOS-based system for viewing the current (actual) timetable.

3.2.3.5.2 General

Black line: “Flow of information” in the direction of the arrows between the sub processes.

Red line with arrow: An actor “does” something (controllability).

Green line with arrow: An actor collects information about something (observability).

Blue dashed line: Oral communication by phone

Blue line: Direct oral communication

Blue pointed line: Information to customers in different (not specified) ways.

3.2.3.5.3 “Flow of information” between the sub processes (Black arrows/lines):

1. The actual timetable and the resource plan is transferred (on a daily basis) to the operational process.
2. -
3. The train traffic process in itself is controlled by the operational control process (signalling system (ATP)). The train driver uses information from the control process (signalling system) to drive the train. The train is controlled by the signalling system.
4. Information about the state of the train traffic process is collected in the operational process.
5. The customer information process gets information from the operational process about the current state of the train traffic process.
6. The customer information process uses information from the originally planned timetable.

3.2.3.5.4 Selected actors’ controlling of the sub processes (Red arrows/lines):

1. The TRC make the big decisions, substantial rescheduling and keep information flowing to all stakeholders (e.g. public, train operating companies). They then reschedule the timetable.
2. The signaller (in the signal box) does minor rescheduling actions. Either directly by executing routes or indirectly by manipulating the behaviour of the ARS.
3. The SSM and/or signaller give information about traffic changes to the customer information process.
4. The TRC gives information about traffic changes to the customer information process.

5. Major changes of the timetable are transferred to SSM and/or signaller by facsimile transmission.
6. The RU´s controller makes necessary changes in the resource plan in case of perturbations or disruptions.
7. The RU´s controller gives information about traffic changes to the customer information process.

3.2.3.5.5 Selected actors' information gathering from the sub processes (Green arrows/lines):

1. TRC, SSM and signaller uses information in the current (actual) timetable when making decisions and rescheduling.
2. SSM and signaller receive information concerning major timetable changes from TRC by facsimile.
3. TRC, SSM and signaller gets information from the operational process about the current state of the train traffic process in which there are, for example, almost always some minor perturbations.
4. The RU controller uses information in the current (actual) timetable when making decisions and rescheduling.
5. The RU´s controller gets information from the operational process about the current state of the train traffic process.
6. In case of perturbations or disruptions the RU´s controller may have to change the use of different resources and then uses information from the daily resource plan.

3.2.3.5.6 Communication between selected actors (Blue arrows/lines):

1. Direct oral communication between SSM and signaller regarding changes in the traffic plans. The SSM supervises the signallers and also handles communication with the outside world, primarily the TRCs.
2. Oral communication by phone between SSM (or signaller) and the TRC in TCC. TRC pass instructions to the signal box to be implemented. The SSM gives important information to the TRC.
3. Oral communication by phone. The SSM (or signaller) reports faults or incidents to the incident controller based in the TCC who logs the details and organises a response team and informs the TRC.
4. Direct oral communication between incident controller and TRC regarding changes in the traffic plans and other activities
5. TRC work with the RU controller during major disruption to make decisions about diverting trains, cancelling trains, etc. Oral communication, directly or by phone.
6. Oral communication by phone between signaller and train driver. Train driver is informed about changes and/or train driver informs about, for example, technical problems with the train or other faults.
7. -

8. The customer information process informs customers about changes affecting them (mainly customers waiting at stations or customers using the web information sources).
9. The RU´s controller gives necessary information to the customers in different ways (for example via train guards).

3.3 Experienced problems

In this section the problems in today's railway systems are summarised, as these are reported by the involved infrastructure managers (IM) in their answers to the questionnaires. The list of reported problems cannot be considered to be complete, but reflects what the respective IM consider to be important problems in relation to the objectives of the ON-TIME project.

In many cases potential solutions to the problems are also discussed.

The material is sorted under the following four headings:

- Capacity, Traffic Patterns, and Railway Infrastructure
- Traffic Planning
- Operational Train Traffic Control (including train drivers)
- Strategic Information Structures and Systems

Under each heading the reported problems are listed for the Netherlands (reported by NS Reizigers, The Netherlands Railways), Germany (DB), Sweden (Trafikverket), France (SNCF), Italy (RFI – RETE FERROVIARIA ITALIANA) and the UK (Network Rail).

3.3.1 Capacity, Traffic Patterns, and Railway Infrastructure

3.3.1.1 The Netherlands

Most capacity problems are found around the main stations, e.g. Utrecht Central Station handles about 72 trains per hour during peak hours on the North side of the station, while there are only 14 platform tracks.

There are also capacity problems on the double track lines in the western part of the country (e.g. Schiphol-Almere, The Hague-Rotterdam) and on some junctions which have a limited capacity (e.g. Den Bosch).

The very high utilisation of the infrastructure easily causes a snow-ball effect of train delays in case of even small disturbances. The limited capacity of the infrastructure is the bottleneck in the recovery process after a disruption. In particular, the limited space on major railway stations to turn trains is a serious bottleneck. Therefore, all recovery scenarios have the available infrastructure capacity as major input. Other resources follow later. The capacity issues of the infrastructure are mainly a consequence of the speed difference between Intercity and local trains. Since many stations for local trains have been added in the last couple of years (as required by local governments), capacity has decreased. The station capacity is also a bottleneck in the system, in particular in the main stations. If train frequencies are further increased, as is the intention for future years, these problems will increase.

In the information systems, cancelling a train is much easier than adding a train. Therefore the initial estimation of the duration of a disruption is usually "optimistic", often leading to rescheduling and a lot of uncertainty. (See 1.1.1.1[1])

The most serious bottlenecks in the infrastructure will be solved by 2015.

For the period after 2015, there is an ambitious plan by the government, ProRail and NS to introduce high frequency rail services. On the most important routes there will then be a need to operate 6 Intercity and 6 local trains per hour, sometimes also mixed with freight trains.

As mentioned before, the station capacity may then become a major bottleneck. In order to reduce the number of crossing train movements, fly-overs have been or will be built around some of the larger stations (Arnhem, Utrecht). (See 1.1.2.1)

The largest capacity problems are found in the Randstad, i.e. the metropolitan area including the big cities (e.g. Amsterdam, Rotterdam, Hague, and Utrecht), due to the high frequencies of trains there. The tunnel near Schiphol is also a bottleneck in the railway system.

Capacity problems are also caused by the different characteristics of the trains: inter-city trains and regional trains are running one after another and although most freight trains are running along the dedicated Betuwe freight line there are still several freight trains running between the passenger trains on the other lines.

Border crossing trains are the starting point for the timetabling process. There are not many border crossing trains: a few international passenger trains, and several freight trains. The connection of the dedicated Betuwe freight line to the German system is a bottleneck on the German side of the border.

The Dutch technical systems (power supply, safety) are rather different from the systems in neighbouring countries. Therefore, either flexible rolling stock must be used, or locomotives must be changed at the border. (See 1.2.1.1)

3.3.1.2 Sweden

On double track there is often a mix of fast and slow trains, which causes capacity problems. In Stockholm, Malmö and Gothenburg regions capacity congestion plans have been developed - the timetable structure has been developed to be efficient (many train paths) and harmonizing.

On single track lines long distances between meeting stations are consuming capacity. Lines with long trains that can just meet at special long stations give high capacity

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[1] This reference is to the relevant part of the separate report Technical annex to D2.1: Questionnaire reports, which is a compilation of all answers to the questionnaires.

consumption. Meeting stations equipped with simultaneous entrance enhance capacity, especially on single track lines. (See 1.1.1.2)

Sweden has high capacity consumption in many parts of the network. There is a strong demand for passenger traffic; local, regional, as well as long distance. There is also a demand for freight traffic. Trafikverket undertake many infrastructure investments. The purpose is to increase capacity and traffic according to traffic demand.

Trafikverket has recently found out that the Swedish railway system is old and not well maintained. There is, therefore, a need to raise the level of maintenance and reinvestment. The money for maintenance and reinvestment will be increased. The purpose is to raise the infrastructure quality and to reduce infrastructure disturbances.

Sweden has quite large capacity problems in many parts of the railway network. There is a lack of infrastructure capacity in the larger cities, and on parts of the double track lines in the triangle Stockholm-Gothenburg-Malmö and on some parts of the single line network.

Sweden has deregulated train traffic and there are many railway companies operating trains and maintaining the infrastructure. In the 2012 timetable there were 46 railway companies applying for train paths. The interaction during the annual timetable planning process, ad hoc planning process and operational process has to be developed to handle these new circumstances. There is a need to improve and formalise the interaction between Trafikverket and the Railway undertakers.

The major capacity problems – related to infrastructure factors – are:

- Bad maintenance results in bad infrastructure quality. Construction work for reinvestments (bigger maintenance) or infrastructure investments give reduced capacity during the work.
- The network has 81 % of single track lines. For many lines there is a demand for more traffic. It needs: more meeting stations, sufficient length meeting stations, simultaneous entrance, partial double track and raised speed.
- Double track line needs: more passing stations, four track sections, efficient signalling systems and traffic control, tunnels or fly-overs for crossing trains.

The major capacity problems – related to traffic patterns – are:

- On double track lines there is a mixture of slow and fast trains.
- On single track lines there is high demand for trains and a difficulty to say no to trains. On many single track lines we have a mixture of trains, heavy freight trains and fast passenger trains.

Measures in order to reduce the capacity problems caused by infrastructure characteristics and traffic patterns:

- Maintenance and reinvestments to get higher infrastructure quality.
- Double track lines harmonizing speeds and capacity congestion plans (Stockholm/Mälardalen, Göteborg region and Malmö region).

- Single track: new meeting stations, extra block sections, simultaneous entrance on single track stations, single line network harmonising by in periods driving the trains in one direction.

(See 1.1.2.2)

There are special capacity restrictions concerning the border crossing traffic: between Sweden and Denmark the power system and signalling system are different. Trains that manage both systems are required, otherwise the locomotives must be changed. (See 1.2.1.2)

There are large capacity problems at the major cities in the Stockholm/Mälardalen region, Göteborg Region and Malmö/Skåne region. There are also large capacity problems in many single track and double track areas. (See 1.2.2.2)

3.3.1.3 France

The most important traffic pattern characteristics are:

- The diversity of trains in terms of maximum speed, capacity of acceleration and deceleration which involves loss of capacity.
- In the timetable, some spaces are allocated for freight, others for local trains, or for high speed trains.

The following characteristics are regarded as most important for recoverability in the operational control processes:

In such a situation, the aim of the IM is to clear the rail section.

- The “wrong way” possibility level: is it possible to use the track in both directions? What are the restrictions by using the unusual direction (speed limit, for example)?
- The possibility to use an alternative way: Is there another way to use? Is the train able to use this way (technical aspects), and is the train driver able to use it?
- The possibility to park trains: Are there some usable sidings?
- The availability of assistance vehicles

The major capacity problems – related to infrastructure factors –are:

1. The conflict between maintenance and traffic demand
2. The capacity allowance between:
    - different RUs in some specific areas
    - Different kinds of traffic (high speed trains, regional trains, freight etc.).
    - Some areas with slopes involve limitations of the freight trains' weight and losses of capacity.

The most important capacity problem is the need to use the same route for nonstop service trains and local trains in the suburbs of Paris. There is a loss of capacity. (See 1.1.1.3)

Other major capacity problems – related to infrastructure factors – are:

1. Losses of capacity due to maintenance needed.
2. Speed differences on the same line due to traffic variety. For example, around Hendaye, some freight trains cannot exceed the speed of 70 km/h whereas the TGV speed limit is 220 km/h.
3. Some specific areas are hard to manage in terms of timetable creation:
   - Lille Europe Station
   - Lyon Part-Dieu Station
   - One way railway in the Alpes
   - The "triangle de Coubert"
   - The railway between Valenton and Massy.

Measures taken in order to reduce the capacity problems caused by infrastructure characteristics and traffic patterns:

- The "domestication du graphique": the aim is to have only local trains in the suburbs of Paris.
- A reduction in the distance between trains by decreasing the speed limits and deleting the yellow blinking indication.
- The document signed between RFF and the Ministry of transport includes a capacity investments obligation in case of area saturation.
- The experience feedback from difficult situations helps us to solve past problems in order to increase the timetable process efficiency.
- RFF created a sales department to discuss issues with RUs and handle the paths allocation process. This department's aim is to solve conflicts between RUs' path demands and increase the efficiency of the process.

(See 1.1.2.3)

Some important aspects of French capacity management:

- The French classic (high speed excluded) railway has very varied speed values.
- The railway is quite old and needs a lot of maintenance, which causes losses of capacity.
- With the 2012 timetable, a regular-interval timetables system has been developed for the French railway.
- The station capacity is now handled with a short time scope without a real method. It is based on the empirical knowledge of operators.

Capacity restrictions in the railway network:

On the French Railway network, there is a standard size for trains. This size is specified in terms of length, height, width, weight and other specific characteristics. Some trains are outside of this standard size. As a consequence, those nonstandard trains have specific speed limits which depend on the infrastructure.

Most of the French electric security systems are based on the localisation of the train by using the electric contact between the train and the rail. However, some trains are not able to make good electric contact. Those trains cannot be managed by the automatic systems and create a loss of capacity.

The borders are specific areas with specific problems to manage. There is a real difficulty in coordinating on one hand different RUs and on the other hand IMs from each side of the border to create continuous border crossing paths. (See 1.2.1.3)

Nowadays, the timetable is made using three different software tools:

1. The first one is Viriato, used by RFF (IM) to give the possible paths for regular trains.
2. The second one is THOR, used by SNCF/DCF (delegated IM) to create the paths for trains, out of the Paris suburbs, and with precision of 1 minute.
3. The third one is CHAO, used by SNCF/DCF (delegated IM) to create the paths for trains, in the suburbs of Paris, with a precision of 10 seconds.

Then the paths created by CHAO need to be added in THOR, manually, to create the timetable. This situation is a source of mistakes and gives additional work to the timetable makers. Furthermore, the stations and the nodes with crossings between Paris suburb trains and other trains are critical to manage due to the difference in precision between THOR and CHAO. (See 1.2.3.3)

3.3.1.4 Italy

The rail network saturation is a typical system effect: approximately one third of the network is loaded by c. 70% traffic (trains-km).

Three types of traffic are used, which demand capacity on main lines and nodes: high-speed and long distance passenger trains, regional trains and commuters, and freight trains. These can have very different nominal commercial speeds (variability in a range of 100-200 km/h, besides HSL). This pattern may give rise to difficult compatibility problems for timetable and operational planning. According to time windows (e.g. peak commuting hours), the regional traffic pattern can impose the most severe constraints on specific nodes and line sections, where infrastructure is not separated between types of traffic flows. Apart from some exceptions, the Italian rail infrastructure is characterized by its “natural” linear constraint, having no freight dedicated lines and limited alternate or “cross-over” routes. During night hours capacity, with higher freight demand, is constrained by current track maintenance, which can require 3-4 hours/day per section and imposes further constraints on long-distance traffic planning.

Preventive maintenance is a general requirement (constraint) for timetable planning; this may vary on different line sections and in different years (periods):

- Short term preventive maintenance can impose specific constraints on timetable re-planning for short-term demand (e.g. weekly basis or similar “rolling wave” planning period); this may be due to contingent and unscheduled events;

- Acute maintenance work can be considered as an unplanned "incidents" to regular traffic management, which must be recovered at the least cost for the railway undertakings, ideally with no train suppressions and the least possible delays. Two major and more common events which require contingent works and impact on train regularity are: traction line breakdown and automatic block (or other signalling installation) failures. When a traction line breaks down on a double track line it is a serious mishap for traffic regularity, since the operations are limited to one track and procedures to best recover are to take place. (See 1.1.1.4)

Major capacity problems – related to infrastructure factors – of today are:

The rail infrastructure has, over the last two decades, been experiencing various capacity problems which usually concentrate on some specific limitations of the network due to historical and topological constraints. These date back to the original tracing of some routes, which at the time had to follow easier and more tortuous ways, through mountains and coastal profiles. These have been overcome either through construction of new lines or incremental local improvements of existing ones. The major example of infrastructure "duplication" remains the so-called "Direttissima" high speed line (250 km/h) which parallels the traditional line from Rome to Florence and represents one trunk of the new HSL Naples to Milan. The general policy of Italian railways has been to develop an interconnected system between new and old lines, whenever possible. This also favours the "heavy" solution for new ETCS equipped HS Lines ("Sistema Alta Velocità"), which began to operate in 2006. New high-speed trains can thus be diverted to old lines in case of necessity, while vice-versa is not generally possible (since traditional trains would have to be equipped with ETCS), except Direttissima. Infrastructural bottlenecks usually remain in large metropolitan areas and nodes, where, as already outlined, mixed traffics converge and independent routes are not usually available. To relieve the operational "pressure" and increase throughput capacity on these points remains one of the main issues of the infrastructure development. Moreover, additional line sections and large investments are currently underway to increase the "node capacity" and create new independent HS crossings (e.g. long suburban tunnels and new passenger stations in Bologna and Florence).

The traditional network is still characterized by some bottlenecks which are to be overcome in the near future. These, for instance, originate from still limited single-track sections which need to be doubled, to provide homogenous double-track capacity on longer corridors.

In order to provide some planning strategies, some guidelines are in use by the Commercial and Operations Departments which relate the nominal capacities of rail lines to traffic density (i.e. trains per day or per hour) according to signalling technology. These, however, do not properly take account of traffic "mixed" patterns and other characteristics, so more specific studies (e.g. by use of simulations) are carried out on a case by case basis.

The major capacity problems – related to traffic patterns – are as already stated; the variability of train type speeds (a factor also referred to as "etero-tachycity") is usually the major problem faced today. This usually accrues as one gets near to a metropolitan terminal, as new stations originate (being sources and sinks) of additional traffic flows. (See 1.1.2.4)

The major capacity problems that the Italian railway is facing today are:

A saturation level is defined for main railway lines, according to current bidirectional traffic flows and "current" speed variability patterns. According to this, bottlenecks are identified and some capacity restrictions are to be taken into account. These levels are classified as follows:

No of trains /bidirectional	
Saturated	N > 210
Pre-saturated	210 >= N >190

Which also takes into account current levels of maintenance requirements (scheduled daily possessions). (See 1.2.2.4)

3.3.1.5 UK

The Capacity Utilisation Index (CUI) identifies parts of the network where there are significant capacity constraints. The most severe are the approaches to London, followed by capacity constraints on the main north – south routes of the West Coast, East Coast and Midland Main Lines. Then there are a number of regional hotspots centred on Birmingham and Manchester, and on the North Trans Pennine corridor. In Scotland the key constraints are in the central belt, particularly on the approaches to Edinburgh and Glasgow.

Some key junctions constrain capacity due to the need to make conflicting movements. Similarly, the number of platforms and/or track layouts at key stations can constrain capacity. Although capacity utilisation is usually lower outside the peak hours, it is not always practicable to use all of this capacity – in particular, lower utilisation during the "inter-peak"-hours is essential to ensure that the timetable for the day as a whole is sufficiently robust. Access is also required for maintenance and renewals.

This high level of utilisation constrains the ability of the industry to respond to demand for additional services, where demand is greatest. In the past, it has often been possible to accommodate growth by running more trains, but the extent to which this is possible without enhancements to the network is becoming more limited and highly location specific. Even where additional capacity is available, the ability to use this for certain freight traffic is sometimes constrained by route capability, including gauge. (See 1.1.1.5)

As a result of capacity problems, relaxing higher speed trains and obtaining a more homogenous (equal speed) traffic pattern may be the general solution; nevertheless this locally deteriorates the performance of higher speed trains.

At the planning stage, a new “best practice” was introduced years ago, to make better usage of infrastructure in case of perturbed situations and statistical performance of different trains: this regarded the introduction of the so-called “dynamic overpass”, where the precise loop station for allowing overpasses between trains is not fixed on the space-distance diagram, but the decision is left to real-time operations (controllers or signalmen). The lower speed train is provided with some buffer time to allow overpass, when it will take place. This flexibility rule also allows the scheduling of some freight trains on a diagram and line section where it would otherwise be difficult to provide a very reliable schedule.

Another method which is usually accepted to improve schedule reliability, besides operational safety, is the introduction of Centralised Traffic Controllers (signalmen) instead of local decision makers.

Capacity problems – related to traffic patterns:

Possibly the biggest challenge is to deliver greater capacity in an affordable way. To maximize existing capacity means improving operating practices, timetabling and punctuality. This means moving to a more uniform performance of trains (or families of vehicles), running to a more standardised service pattern. We need to re-think how we provide for expanding freight services, optimizing capacity by increasing the speed at which freight trains operate, allowing passenger and freight services to be timetabled more efficiently where they share main line capacity.

The NR response to these overall challenges is to develop a longer term strategy in the context of four themes:

- To improve the door-to-door journey for users of the rail system, including the challenge of reengineering our stations to make them efficient and friendly interchanges;
- An easily maintained railway, which by implication gives a step improvement in reliability;
- An energy efficient and sustainable railway by the application of new technologies and an approach of minimising whole-life costs for the system; and
- Improved capacity and capability of the network by better utilisation of the current network (e.g. reduced performance allowances), moving to differentiated routes to improve utilisation and where necessary the tactical extension of the network.

Measures taken in order to reduce the capacity problems caused by infrastructure characteristics and traffic patterns:

We have started to move from a “find and fix” to a “predict and prevent” maintenance regime and the use of train-based technology to monitor the infrastructure and, through our “Intelligent Infrastructure” project, equipping bridges and earthworks with automatic condition monitoring systems.

We believe we can deliver reduced journey time and lower energy consumption by making trains much lighter than they are today with better internal design and lighter materials. More radical steps include changing the way the system protects against train collision risk by using train protection technology controls rather than heavy crash resistant materials on the trains. Our civil engineers are also examining the use of modular bridges which can be installed at low cost and with little train service interruption. This could help us to eliminate some level crossings. Where this is impracticable, our signal engineers are developing dependable obstruction detection systems. We can reduce train bogie and suspension weight by improving track quality. This will create a virtuous circle of higher track quality, lower train weight, less energy consumption and reduced journey time.

To release further capacity within the existing network means addressing junction, station and route capacity. Our plans for CP4 start to tackle the most critical pressure points on the network in the short term. Further tactical enhancements beyond CP4 could include additional facilities, infill electrification and construction of short chords or links. For stations, we have started a programme of modular solutions for our station infrastructure. (See 1.1.2.5)

Capacity utilisation in the railway network:

- Mixed use railway – capacity constraints caused by speed differential of services;
- Journey time critical so cannot be lengthened;
- In the London suburban area – high density of traffic with flat junction crossings. Network very close to capacity;
- Limited terminal capacity with many London termini very close to full capacity based on requirements for turnaround times.

Capacity restrictions in the railway network: System capability – signalling, layout (flat junctions), platform capacity, rolling stock numbers (and type). (See 1.2.1.5)

Major capacity problems faced today: Track layout, terminal capacity, speed differences of services required to meet demand. (See 1.2.2.5)

3.3.1.6 Germany

The railway infrastructure is divided into the long-distance and mainline network [ger.: Fern- und Ballungsnetz] and the regional network [ger.: Regionalnetz]. Capacity problems exist mainly in the long-distance and especially in the mainline network.

We consider two types of infrastructure. On the one hand the lines and on the other hand large railway stations and junctions. We have capacity problems, for example, in the Rhine corridor, on the Hamburg-Hannover line, and in Cologne and Frankfurt (am Main) main stations.

Capacity problems occur due to the following characteristics:

- When mixed traffic types use the same tracks (long-distance, regional and freight trains), where problems arise due to the different driving dynamics and stop characteristics. There is a high proportion of these lines. A lower proportion have unmixed tracks (e.g. high speed lines or some S-Bahn lines).
- Due to the polycentric settlement and economy, the German railway network has many nodes and a highly interconnected net structure.
- Regional trains have an important role in the traffic usage.
- All countries around Germany have the same gauge, so different gauges in the cross-border traffic are not a problem.

On most lines, we have regional passenger trains overlaid by long distance and freight trains on the long distance network.

Most important in respect of capacity utilisation are mixed traffic types on the same track. If the trains have the same driving dynamics and the same stops, the trains can be easily bundled.

To recover from disruptions there have to be enough tracks in passenger stations and at overtaking stations to overtake or hold back slower trains. If it is necessary to turn a train before its end station there must be enough tracks and connections between the tracks at the actual station. (See 1.1.1.6)

Major capacity problems – related to infrastructure factors: these arise particularly at same level crossings and junctions, where we have higher blocking times.

Mixed traffic with different velocity and stop characteristics cause capacity consumption. The capacity problems increase with a higher line speed.

In order to reduce the capacity problems caused by infrastructure characteristics and traffic patterns, the following changes can be made:

- Extensions of tracks and stations on the infrastructure side;
- Bundle train paths for trains with equal driving dynamics (in scheduling and operation);
- Speed harmonisation (lower speed for faster (freight) trains) in scheduling and operation;
- Maintenance of tracks and switches.

(See 1.1.2.6)

Important capacity restrictions are are single-track-connections in junctions, and one-level-crossings.

Capacity restrictions concerning the border crossing traffic: there are some capacity problems due to different power supplies, safety systems and regulations, so that we must change engines and drivers at the border or use special engines and drivers, who can drive in both systems. (See 1.2.1.6)

3.3.2 Traffic Planning

3.3.2.1 The Netherlands

When there is not enough infrastructural capacity, the railway sector looks for other ways of increasing capacity. However, often the result is that the number of trains will not be increased.

Because of different systems in the planning and operational control phase, there have always been two completely separate departments. When splitting the old NS into IM and RU, the planning and operational control departments were split in another way. As a result there is currently another division of responsibilities between IM and RUs, in the planning 36 or more hours in advance, and in the last 36 hours before operation.

The VKL system contains only the most necessary information from the planning phase. Many relevant data are not available in this old system. As a consequence, the operational control departments of ProRail and NS are the weak points in the railway sector. (See 1.3.1.1)

Most problems in the Netherlands are of an organisational nature. The timetabling process is not always very well managed (this varies from year to year). Conflicts between goals result in conflicts between people from different departments and/or between NS and ProRail. Another organisational problem is the lack of timetabling planners that are good enough.

A further issue is the poor quality of the exceptions in the 7*24 timetable compared to the basic hour timetable. These exceptions have a huge impact on punctuality. Since the 7*24 timetable is not simulated beforehand, it is hard to detect the problems before operation.

A significant problem in rolling stock planning is the bad quality of the predictions of passenger flows. Another problem is the lack of a good interface between the optimisation modules for rolling stock planning and the database.

In crew planning there are no major difficulties. (See 1.3.2.1)

3.3.2.2 Sweden

The new process of timetable planning and traffic operation needs better methods and tools to analyse timetables and traffic. The analysis requires coherent work and RUs have to be handled in the same way. There is a need to improve the analysis. That means better methods and IT support systems to support analysis for planning future timetables.

Trafikverket need to develop the area timetable planning methodology and information systems, analysis of available capacity and train paths. For this there is a need for simulation systems, timetable systems and systems to follow up traffic in different aspects, such as the number of trains, punctuality, etc.

Dealing with traffic planning is complex. For this purpose the organisation, IT systems and methods have to be developed by iteration. It is also necessary to have good external co-operation between universities, Infrastructure managers, RUs, other railway enterprises and consultants. (See 1.3.1.2)

Sweden has problems with a high frequency of small and medium perturbations. The main causes of the perturbations are old and badly maintained infrastructure and rolling stock, bad plans (too optimistically optimised) for locomotives/trains/wagons, and a too high utilisation of infrastructure. Trafikverket works in co-operation with the railway companies to raise the quality in all these areas. That means more money to infrastructure reinvestments and maintenance, newer and better maintained rolling stock and more maintenance depots.

Resource planning is done by railway companies. The timetable planners and planners at the Train control centres working for Trafikverket have some knowledge about resource planning and communicate with the railway companies.

Today's timetable planning process is developing. The challenge is to get a good connection from planning to operational traffic and to close the loop. (See 1.3.2.2)

3.3.2.3 France

The difficulty in building a robust timetable is the high proportion of last minute path demands. For example, in 2011 about 800,000 path demands were made during the last week before the scheduled date for the train. Almost all of those last minute demands concern freight trains.

An important aspect of French organisation is the “In Stations” movements. We do not put on the planning any of the movements of empty trains or light engines between the storage rails and the stations. Those “in stations” movements are organised in real time by traffic operators. Furthermore, the way in which they are organised is very different from one station to another.

Maintenance causing large capacity restrictions has to be planned more than two years before the date of the restriction. From December A-2 to September A-1 the timetable is made according to the real capacity of the network, large restrictions included.

This is one of our major problems today. There is a lack of communication between the timetable planning process and operational traffic control. Safety and punctuality events are studied and adjustments can be done on the timetable to solve identified problems, but it is not efficient enough to solve all the problems.

The rules of the art are respected all along the process. We identify problem areas then make robustness studies for those areas. However, there is no control process at the end of the timetable construction process.

In France there is a problem with last minute path demands:

An RU can make 10 path demands for the same train without any fee. The operator handles all of these demands one by one. Then some of these demands are rejected due to capacity reasons, the others are accepted. Then the RU just has to use one of the accepted paths and cancel the others. The RU just pays for the used path. The problem of this situation is the number of demands handled by timetable operators at the last minute (from J-1 5pm to J). (See 1.3.1.3)

Major problems and difficulties experienced in the timetable planning process of today:

- The capacity is used for maintenance:
    - It is not easy to have precise dates of maintenance during timetable construction.
    - The coordination of different maintenance operations on the network is hard to handle. As a consequence, some maintenance operations can be carried out during the same period on two ends of the same line and double the effect on a train's regularity.
- There is a conflict between "keep quality of service" and "run the maximum number of trains".
- On one side, the French network is quite old and its evolution is slow. On the other side, the local authorities claim to have more trains and new lines.
- The complexity of our institutional system which involves:
    - 1 dominant RU;
    - 21 regional authorities claiming for trains;
    - 1 IM responsible of the timetable.
    - The decision process is complex and not stable. There is no national guideline.

The major problem of resource planning is the appropriateness between traffic demand and resource planning, i.e. between the train paths and the stations' opening hours.

The process used to define the stations' opening hours is one year long (from December A-2 to December A-1 for the year A) and includes the RUs, RFF (IM) and SNCF/DCF (delegated IM). (See 1.3.2.3)

3.3.2.4 Italy

The system currently in use is the RoMan (Route Management) platform, originally provided by Siemens PSE (Austria), with some development. The planning organisational process is essentially centralised. The system, a CAD (Computer Aided Design) solution, provides some conflict detection support and requires the operator to make the rest of the work. The current version used at RFI does not provide 'platforming' (station scheduling) or integrated node planning. (See 1.3.1.4)

The major problems and difficulties experienced in the timetable planning process of today can be summarised as follows:

- still very labour intensive;
- missing integration with quality specifications rulings;
- limited support for railway node planning and conflict management at stations;
- access to off-line or external information.

The IM is not involved in crew and vehicle planning.

Innovations and developments within the area of timetable planning:

A new upgraded version of Roman is being installed, with some new facilities, but no radical innovations have been introduced.

(See 1.3.2.4)

3.3.2.5 UK

Nothing reported

3.3.2.6 Germany

The biggest challenge of DB Netz AG: to operate a network with mixed traffic.

The normal case in Germany is a mixture of different train types on the same line, for example the line from Frankfurt – Mannheim, with:

- Long distance passenger trains
- Regional passenger trains
- Urban passenger trains ("S-Bahn")
- Freight trains.

(See 1.3.1.6)

3.3.3 Operational Train Traffic Control

3.3.3.1 The Netherlands

A main bottleneck in the operational control processes is due to the fact that several years ago the IM tasks and the RU tasks were separated into strictly different organisations. As a consequence, there is a separation between the operational control processes in the Regional Control Centres.

In order to compensate for this strict separation, the OCCR was recently set up. In the OCCR, all stake-holders are represented. However, at the regional level, the personal communication between the IM and RUs is still time consuming via telephone and fax, and usually not face-to-face.

Moreover, the fact that the execution of most operational decisions for modifying rolling stock and crew duties has been split over 5 Regional Control Centres is also a source for lots of time consuming communication between these control centres, especially for duties that cross the borders of these regions.

Rescheduling the timetable and the resources is carried out in a strict sequence.

The central information system for monitoring the operational processes is VKL. This monitors the positions of trains between stations. It also has components describing the duties of rolling stock and crews. The information is integrated, i.e. if a train has a certain delay, then this is also visualized in the rolling stock and crew duties.

However, this system does not provide any decision support. Thus, in case of a disruption, the timetable, the rolling stock, and the crews must be rescheduled manually. This is quite time consuming, especially rescheduling the crew duties. As was indicated earlier, there is a lot of communication between IM and RUs, and between the different Regional Control Centres.

Inserting a train into the process control system is a time consuming manual process. It is more complex than deleting a train. Therefore, the initial estimation of the duration of a disruption is usually optimistic, leading to several iterations of rescheduling.

Resource disposition, problems

Rolling stock: During and after a disruption there is insufficient insight into the modified passenger flows in the system. Therefore, the capacities of the trains often do not fit with passenger demand. Furthermore, the rolling stock dispatchers do not have insight in the shunting processes at the shunt yards. Therefore, they do not know whether a proposed shunting movement will be carried out or not. Each modification in the shunting processes requires a lot of communication between the regional rolling stock dispatchers, the local shunting coordinators, and the local traffic control.

Crews: Rescheduling the crews is considered as one of the bottlenecks in the operational control process in case of a disruption. Rescheduling one train, including the communication (and negotiation) with the involved crew, requires about 10 minutes on average. In a serious disruption, often dozens of duties are disrupted. Altogether, this leads to a situation where the rescheduling process is far behind the real-life processes, leading to an out-of-control situation.

Both: Rolling stock and crews can be assigned to a train
only after the train has obtained a detailed timetable. Therefore, the processes of rescheduling the timetable and rescheduling the resources must be carried out sequentially. (See 1.4.2.1)

3.3.3.2 Sweden

Major Problems in the organisation of operational control are the following:

- Major problems in the larger cities are retaining existing personnel as well as the recruitment of new dispatchers.;
- Difficult to get up staff schedules.

Major Problems and limitations in the existing information and control systems for operational control are:

The fact that there are three different traffic control systems distributed over eight traffic control centres with restricted overall information and control has the following effects:

- Prevents a flexible and common-mode operation;
- Creates technical boundaries and limitations in geography;
- Makes the operation vulnerable and critical for punctuality;
- There are high costs with multiple systems and suppliers;
- Creates inefficient staffing and management.

The major problems and limitations in the communication between train drivers and operational control are that the communication is predominantly by telephone (spoken). Both train drivers and dispatchers are forced to use spoken communication in order to inform each other of new and altered plans and conditions.

Even when a small perturbation occurs a great deal of spoken communication is needed to solve the problem. It would make things much easier if the current timetable was delivered to the train driver and if it was possible for the train driver to notify discrepancies in driving to the outside world.

On-going or planned projects for Improvement of Train Drivers' support in the Operational control Process are: CATO, Green Cargo, ETCS.

(Major problems and difficulties are experienced in the processes of resource disposition in operational control.)

The interlocking logic in the signal boxes is not available from a planning point of view. This observability problem can lead to problems when re-planning within a complex track structure.

If train number driven automatic functions are being used the dispatcher cannot really understand the reason behind certain actions such as train sequence, train routes, etc.

During disturbances, the interactions tend to be too complicated to produce predictable traffic solutions. The automatic support systems are not predictable enough to the dispatchers, because of their internal complexity. To overcome these difficulties, the dispatchers are then forced to take full control by inhibiting all automatic functions in the "disturbed" area and solve the disturbed situation "manually". Intense manual control and oral communication will result in a high workload. The result is that the dispatcher is focused on finding working solutions and cannot have the ambition to optimise the traffic.

(See 1.4.2.2)

3.3.3.3 France

In France, we use a software tool called BREHAT to do the feedback of the regularity problems. The principle of BREHAT is to connect all of the train delays created by an incident to the incident itself. For example, if a train starts with 15 minutes of delay due to a rolling stock problem, those 15 minutes are connected to the rolling stock problem. Then, if this train creates some perturbations in a node, due to its 15 minutes' delay, those perturbations are also connected to the original rolling stock problem.

This process can be inconvenient when we try to extract information and analyse the impact of different sort of incidents. The influence of the context and the situation is very important and give a chaotic aspect to the analysis.

1. Links between COGCs: Specific rules give information COGCs must exchange in case of perturbations. However, COGCs have the habit of solving problems in their own territory before they communicate with their neighbours. There is the same difficulty with foreign railways in case of border crossing trains. The development of the TCCCom project by RNE would give efficient help to improve the communication quality between COGCs.
2. Links between IM and RUs: A recent evolution has separated the IM and the RU members. In case of incident, the rules exist in the regulations but there is still work to do to apply these rules on one hand in the computer systems and on the other hand on the ground.

(See 1.4.2.3)

3.3.3.4 Italy

In particular, international freight train re-planning on European corridors can give rise to “changes of scheduled train numbers”; this causes problems in keeping links to the original scheduled number.

Generally speaking there are not yet any decision support tools in use. Past R&D experiences have not yet provided efficient and usable solutions, for different reasons:

- limited user friendliness;
- difficult to integrate with current operational systems;
- difficult to validate (on real time and on field situations);
- much too risky and costly to implement ;
- human operators unwilling to rely upon robotic, unproven solutions.

(See 1.4.1.4)

Major problems occur in large perturbations and infrastructure breakdowns. These are managed case by case relying upon past experiences and analogous behaviours.

Previously portrayed cases are examples of “recurring” operational incidents that usually impair normal operations; to recapitulate for example:

- one of two tracks out-of-service;
- temporary line interruption, with no exact forecast to rehabilitate;
- heavy slowdowns on one or two tracks;
- difficult to obtain information from bordering networks.

In addition, other impairing cases can be (RU related):

- difficult information or forecast to obtain from RU on their expected delay;
- alerting on handicapped trains;
- emergency recovery of stopped train.

The question is whether in these scenarios one could have a more organic catalogue of lessons learned and system embedded procedures which could better help operators, provide appropriate solutions in less time and improve forecasting ability.

Major problems and limitations in the existing information and control systems for operational control:

Elements of the answer to this question are already outlined in previous sections.

Moreover, one could observe that current systems do not support the new railway logic of open access to infrastructure and management of performance regime, between different RUs.

In particular:

- the ability to respond and find a solution to a specific operational problem could be driven both by the current status and the historic cases, involving the same actors;
- delay imputation and analysis could be real-time, real-time identifying causes of delays (e.g. 'snowball effect') with no or limited intervention by the human controller;
- real-time communication and recognition of some defaulting party, IM or any RU, could provide better transparency and less administrative "ex-post" workload;
- ability to simulate and re-run the operational cases with friendly tools and interfaces, in order to improve return of experience and learning organisation. (See 1.4.2.4)

3.3.3.5 UK (Network Rail)

Nothing reported

3.3.3.6 Germany

In the control centres we make an evaluation two times per year. In this way the control centre data and the decisions of the dispatchers will be reviewed and evaluated. Afterwards, feedback will be given to the dispatcher. If it is necessary the employees undertake specific training and coaching. (See 1.4.1.6)

Major problems concerning organisation of operational control have not been identified at this moment.

One problem is the age of current control centre software. The data base and data supply between the different modules do not always seem to be compatible.

(See 1.4.2.6)

3.3.4 Strategic Information Structures and Systems

3.3.4.1 The Netherlands

The VKL system contains only the most necessary information for the planning work. Many relevant data are not available in this old system. In addition, it does not have any decision support.

As a consequence, the operational control departments of ProRail and NS are the weak points in the railway sector.

3.3.4.2 Sweden

In Sweden the main challenge is to adapt the systems to better support the traffic process (from the application and planning phases via the daily production to the follow-up phase.

The current traffic information systems are defective and insufficient. One reason for this is the current use of paper based train graphs. There is a need for computer based train graphs that can – when there are perturbations and disruptions –easily be updated and thereby continuously reflect the current traffic plan.

Introducing infrastructural changes in the train control systems is today a quite slow and cumbersome process.

It is often the case that dispatchers have incorrect information or lack necessary information in the control process and therefore make wrong decisions. (See 1.5.2.1)

3.3.4.3 France

In France there are two main problems:

1. The costs of the different systems. RFF (IM) uses a lot of software and each one needs maintenance and regular updates. RFF also tries to develop new timetabling software to replace other ones.
2. Compatibility aspects between different software. Using a lot of different software creates some compatibility problems and thereby additional work load on the operators.

(See 1.5.2.3)

3.3.4.4 Italy

The main problems arise from the bottlenecks in the major metropolitan and regional node. To analyse all issues in the node in detail the simulator requires all the data of the relevant lines.

Nevertheless, an interface from the simulators to the information systems should be required. In fact, current simulation technology does not generally allow easy and straightforward access to legacy IT systems; it has the same needs for interfacing to national Timetable Systems.

A similar link should be made available to provide the statistical quality of service data (i.e. delays, propagation analysis) directly fed from the real-time control systems.

(See 1.5.2.4)

3.3.4.5 UK

Experienced problems: Data integration between systems, multiple sources of similar data (e.g. the infrastructure model), accuracy of data for consistently reliable point to point train timing calculations, system performance, system usability, ability to conduct conflict detection in a manner consistent with industry standards, ease of calculation of perturbation data. (See 1.5.2.5)

3.3.4.6 Germany

Some problems concern:

- interfaces between different databases, databases and software tools;
- partially manual input;
- updating/managing infrastructure and schedule changes in several systems;
- up-to-date (daily) schedule with adaptations to maintenance work;
- considering temporary speed restrictions in the database.

(See 1.5.2.6)

3.4 IM developments and innovations

In this section we summarise developments and innovations as these are reported by the involved infrastructure managers (IM) in their answers to the questionnaires.

In the part reported here, general visions and discussions about future developments and innovations are listed. This material is sorted by country.

In a second part, presented in Section 3.4 below, specific systems and projects are listed.

The visions are listed for the Netherlands (reported by NS Reizigers, The Netherlands Railways), Germany (DB), Sweden (Trafikverket), France (SNCF), Italy (RFI – RETE FERROVIARIA ITALIANA) and the UK (Network Rail).

3.4.1 The Netherlands

The automated planning tool DONS has been developed in recent years. This system supports the basic timetable planning process (generation of the Basic Hourly Pattern). This tool was used to generate the 2007 timetable, which was a completely new timetable generated from scratch.

Also the development of the DONNA system will make it possible to improve the quality of the timetable. Although it does not contain "generation functions", it will help to reduce the number of errors in the timetable, due to extensive conflict detection facilities.

Over the next few years, the Netherlands is planning a number of innovations and developments. For example:

- The development of an improved simulation tool for a priori evaluating the quality of a timetable.
- Development of improved tools for supporting the traffic control organisation in dealing with delays and disruptions, i.e. how to quickly modify the timetable in such cases.
- Development of improved tools for supporting the dispatching process of rolling stock and crews in case of disruptions. In particular, better tools for crew rescheduling will be helpful. This will help to reduce the number of cancelled trains in disrupted situations.

In the near future, the utilisation of the infrastructure will increase, due to the increase in the frequencies of the trains on several corridors. In order to achieve this and still have a high quality of service, reliable infrastructure and rolling stock are required. In addition, excellent organisation and supporting tools for the real-time operational processes are necessary. With an extremely high utilisation of the infrastructure, delays will quickly propagate through the system if these tools are not in place. Finally, with those improvements implemented, relatively small initial disturbances (such as late departures, longer dwell times, etc.) should be significantly reduced. (See 1.2.3.1[2])

Expected innovations and developments in the area of timetable planning for the next years to come:

- In 2012, the SOM model should be incorporated in DONS.
- We also plan other improvements in the DONS system, such as integration of the track planning and the station planning modules.
- A simulation for the 7*24 hour timetable is under consideration.

Expected innovations and developments in the area of resource planning for the next years to come:

- New models and tools to improve the prediction of passenger figures used in rolling stock planning.

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[2] This reference is to the relevant part of the separate report Technical annex to D2.1: Questionnaire reports, which is a compilation of all answers to the questionnaires.

- A new rolling stock planning tool that has a user-friendly interface with the different optimisation models developed during the last couple of years. This will also contain several modules for the shunting processes at the stations.
- Introduction of an improved version of LUCIA to solve the crew scheduling problem for a whole week in a single shot (instead of day-by-day). This should gain some efficiency.
- Rostering modules for the crew planning.

Visions concerning necessary future strategic developments within the area of timetable planning and resource planning:

We believe that it is especially important to reduce throughput times everywhere during the process of timetabling and resource planning. The world is now much more dynamic than in the past, and railway companies (both IM and RUs) should be able to react to this by quickly changing a timetable and the resources. Adequate decision support tools are required to achieve this. A good example is heavy weather. After two heavy winters, ProRail and NS decided to operate a timetable with reduced services on such days. This timetable and the related resource schedule are expected to have the regular quality, but it needs to be constructed within 1 day. This requires sophisticated tools, good planners and a good decision process. (See 1.3.3.1)

The design of a blue-print for the organisation of the operational processes, including the required information systems, has started, but is not finished yet. One of the proposed improvements is to do the rescheduling of the timetable and both resources in parallel (instead of sequential), in order to reduce the rescheduling throughput time.

The supporting systems for the operational processes will be improved. On the IM side, the VOS system is being developed. This will replace the existing VKL system. There are no concrete plans yet for adding decision support functions. However, recently the interest in developing such functions has increased within the IM.

There is an initiative to give train drivers more detailed information about preferred passing times at certain locations to improve punctuality and energy efficiency.

Recently, another initiative was started to investigate the added value of decision support tools for the traffic controllers of IM. Part of the functionality will be speed advices to train drivers. This development is still very fresh.

Within NS, the systems for real-time rescheduling of rolling stock and crew duties are being replaced by new systems. The intention is that the new systems will also include decision support functions.

Rolling stock: Currently a tool is available for off-line rolling stock rescheduling. A number of experiments have been carried out to test whether this model can also be used in the ultra-short term planning process. The tool will also be further developed so that it can be used in the real-time operations.

Crews: A fast algorithm to reschedule crew duties has been implemented in CREWS Real-Time Dispatcher (RTD), a module developed by the Portuguese company Siscog. Currently, CREWS-RTD is connected to the old VKL system. This system allows a rescheduling of the crew duties in a couple of minutes when a serious disruption happens. This should mainly help to prevent the out-of-control situations that happened during the last couple of years due to serious winter weather (heavy snowfall). In the next phase, CREWS-RTD will replace the old VKL system regarding crew dispatching.

In addition, the planning module of CREWS has been adjusted to also reschedule duties in the ultra-short term planning process (e.g. rescheduling today for tomorrow). This is mainly used to reschedule a crew schedule overnight when the decision is taken to reduce the number of trains in the timetable. That is 15 minute frequencies are changed to 30 minute frequencies. (See 1.4.3.1)

3.4.2 Sweden

The following innovations and developments have been carried out within the area of railway capacity in the last couple of years:

Better communication and co-operation between Trafikverket and the Railway companies. Trafikverket gives priority to improving communication with Railway companies from the top to the bottom. This includes timetable planning (1 year – 24 hours before traffic), the operational traffic and to follow up railway traffic outcome (punctuality, disturbances, etc.). Information systems are developed and different kinds of full scale scenarios and practices are done to improve the operational co-operation.

To improve timetable planning and traffic control the strategy is to have a good connection between strategic – tactical – operational planning and to follow up the traffic outcome. For traffic control the concept is to control by planning. (See 1.2.3.2)

Development of operational processes within the Transport Administration is on-going. This may lead to new demands for information or tasks and changes in roles.

Development is conducted with the aim of providing information and services on traffic and infrastructure services to customers and other stakeholders in the transport sector.

Development of the planning process is on-going. One goal is that a change to a new process will be in place by 2015. A basic principle is that "rough" delivery planning should be done in the early planning against agreed delivery times, but not to the complete detailed production scheduling that provides complete route plans made at a later stage. The content and format of route plans may change gradually in the process of change.

There are several systems under consideration for developments which affect the process of Operational Control:

- New traffic control systems;
- System for production planning and delivery of production data;
- A developed operational management system, including refining the data sources;
- A new train order system is being developed;
- ERTMS implementation is under way.

(See 1.4.3.2)

3.4.3 France

France has the following visions concerning the future strategic developments within the area of railway capacity estimation, utilisation, etc.

Nowadays, the timetable is made using three different software tools. This situation is a source for mistakes and gives additional work to the timetable makers. Furthermore, there is a difference in precision between systems. To solve those problems, RFF is working on the creation of one software tool which could be used instead of the 3 others. (See 1.2.3.3)

Innovations and developments within the area of timetabling:

- Local movements of locomotives or empty trains are integrated to the timetable.
- The regular-interval timetables system has been developed on our railway.
- The 2012 timetable was a revolution by changing about 85% of the hours.
- “Quai obs” is a new software tool that can be very helpful in the timetable construction process.

Innovations and developments within the area of resource planning: We work on an economic model for the timetable, including a mapping of the accessibility of different territories.

Necessary future strategic developments within the area of timetable planning and resource planning:

1. Nowadays we plan the movements between two stations and then we have a look at the stations. As a consequence, the number of the platform is not included in the path definition. We just have 20 stations listed as “structuring stations”, only the platform occupation of those structuring stations is studied during the timetabling process. We are working with this situation and the question is: could it be more efficient to look at the station organisation first.
2. We give more responsibilities to the RUs in the timetabling and with respect to the timetable. The main idea is to get a better utilisation of margins included in the path definition. The margins are not there to allow the RU to change the planned train and use a lower one or to make longer commercial stops than planned ones. The margins are there to manage on line perturbations.
3. Different jobs of the IM (maintenance, finance and timetable process) need to converge to work with higher efficiency. The different processes have to be managed together.

(See 1.3.3.3)

The process is changing. From 2006 to 2040 the control network will change from 1500 signal boxes and 21 COGC to 16 CRR including an amalgamation of the levels 1 and 2 of our traffic control process, i.e. “Agent Circulation” and “Régulateur”.

The Next Generation of MISTRAL will be ready for 2020. The main evolutions from the current version are:

- Integration of a conflict detection tool: today, the system is not able to find the conflicts. With the next generation, a tool is studied to find conflicts and alert the operator to those conflicts. Then the operator can modify the registered timetable to solve those conflicts.
- The registered timetable can be updated without any operator action in case of modification of the timetable (train cancelling, last minute train creation, last minute maintenance, etc.)
- A tool for failure handling will be integrated.
- The next generation will be flexible, i.e. the system will be able to modify the infrastructure configuration (creation of new line, point suppression…).
- The current generation cannot include more than 10 operators in the same area due to reactivity aspects. The next generation will be more powerful.

Since the end of 2010 RFF and DCF have been working on a project called ”maxi perfo”. One of the aims of this work is to improve the train driver’s support to reduce the ”stops and restarts” and the generated losses of time.

With the “CCR” prospect, there is a need for a communication system between COGC members and RU representatives: Today, each RU can have a representative in the COCG to handle large perturbations or disruptions. Tomorrow, when the CCR will be in function, there will not be any RU members in the CCR. That is, this system will replace the current software linking COCG members, RU representatives, maintenance operators, “Agent Circulation”. The study will end in 2014-2015.

(See 1.4.3.3)

3.4.4 Italy

Italy has the following visions concerning the future strategic developments within the area of railway capacity estimation, utilisation, etc:

It is anticipated that better tools and applications will be available as follows:

- integrated system (e.g. ERP) which easily provides data and algorithms to assess current capacity correlated to performance levels (data driven and extracted from real time traffic management systems);
- geographical (e.g. GIS) or topological infrastructure database, to provide studies and simulations on possible alternatives and scenarios, regarding infrastructure modifications and/or traffic pattern variations;
- impact studies and forecasting regarding economic aspects of path allocation and performance regimes;
- analysis aggregated according to various business levels and interests;
- open system architecture and standards;
- user friendly and easy to use.

(See 1.2.3.4)

The future strategic developments within the area of timetable planning can be summarised as follows:

- more efficient and less labour intensive process;
- integration with quality specifications and guidelines, concurrent with the design activities;
- integration with railway nodes and conflict management at stations;
- better integration with the requirements of open access management;
- integration with lower level (simulation) and higher level (e.g. UIC Fiche) design methods;
- integration with GIS or other more detailed descriptions of infrastructure;
- better integration with real-time operational process information systems;
- automatic assessment of level of quality.

(See 1.3.3.4)

At present we do not record formal programs engaging a better and continuous information flow between drivers and operational traffic control centres. A proposed system (using GSM-R) is to seamlessly communicate to the control centres train faulty conditions and other conditions which impair normal running.

Another project regards the provision to the driver of an electronic train sheet, which could be updated on-line with the recommended train speed, in addition to the maximum train speed, which is now static information. However, this concept has not yet reached any conclusion so far.

We would mention that any new system in this area should have close coordination and acceptance by both the IM and RUs, in addition to the National Rail Safety Agency. (See 1.4.1.4)

The main innovation project regards the HDTS (High Density Train System). This is a new system development, recently undertaken by the RFI Engineering Department, to improve infrastructure capacity in high density line sections/nodes, by reducing the length of block sections (and/or headway), which – as it is well known - is inversely proportional to line capacity. The system regards an upgraded automatic block system which overlaps on the current one and allows shorter block sections, thus increasing capacity. This new system is currently envisaged to be used on several bottleneck rail sections which are present in various railway nodes. (See 1.4.3.4)

3.4.5 UK

Nothing reported

3.4.6 Germany

Innovations and developments planned for the next years to come:

- Netzkonzeption 2030 (conceptual design of the railway network 2030 under progress);
- ERTMS/ETCS in corridors;

- Longer freight trains (835 m/1000 m);
- maximum axle load 25 t
- develop software for train dispatching and driving assistance -> speed harmonisation in operation.

3.5 Considering Human Factors

It will be necessary to consider human factors in different ways in most of the ON-TIME WPs and tasks. There are many reasons for this. The train traffic system is very dynamic and complex and humans are involved in different roles in most activities. This means that we must see the systems to be developed as socio-technical systems, i.e. systems involving both human actors and technology. Even if we see a rapid development of automatic systems and decision support systems, it will remain in this way for many years to come. In some very restricted contexts it will be possible to implement fully automated stand alone systems, but as long as we cannot completely model and control every aspect of the traffic systems, we will rely also on human efforts and human skills. Even in the case of full automation, humans will be effected by and involved in the outcome of the automated processes. The relations between automation and humans must, in other words, always be considered. No technical systems can be developed and deployed without considering organisational and human aspects.

In a complex system such as rail control, control takes place at several levels; strategic control, planning/re-planning (NB this is the activity of rea-time planning with a running service, not timetable planning), regulation (or routing) and, ultimately, execution of physical control actions. Some of these levels of control require problem solving and creativity (typically the higher level processes) which draw on the abilities of the human operator while others are best (high speed physical control actions) may be best performed by automated control systems. When we view control in this manner, rail control becomes a socio-technical system, with multiple agents (computers, and humans in a variety of roles). Together, they collaborate to deliver performance – for ON-TIME this is improved capacity. There are two potential paths to take when designing the integration of automation into complex work systems:

- Automate as much as we can and leave what remains to the human operators. When the automation fails for some reason, the human operator has to step in. The work of the humans will be a rest product of what we cannot fully automate. There is a risk that this will result in degradation of skills and reduce the possibilities for the human operators to perform with quality when this is required.
- Design new systems based on a planned balance between human activities and automation, in response to specified performance targets. This will result in solutions where human skills and automation are used in the most efficient way, seen as a whole. We strive to find the optimal mix of human work and automation. Automation is here regarded as a complement and support to human activities and skills, and contributes to solutions that the human operator could not achieve without advanced technology. This does definitely not exclude fully

automated systems, but automation must always be designed and evaluated considering the system as a whole, across different levels of control. So, fully automated physical control at the lowest level may take place in response to decisions at higher levels of control.

The two different main standpoints results in two different principles for human control:

- Control by exception. Here the human operator is normally "out-of-the-loop" and only intervene when required by the system. When the operator's involvement is required, through some system alert, the operator must evaluate the situation and decide on how to act.
- Control by awareness. Here the human operator is considered to be continuously active in the control process. The system is designed to provide high situation awareness and readiness to act whenever required. The human operator is always "in-the-loop", and has a continuous knowledge about what happens and why. Here the operator can predict what is developing and by being pro-active prevent unwanted situations.

It is the latter standpoint, control by awareness, which we basically recommend for the project. In most practical situations it is not a question of a pure control by awareness approach, but rather a combination with necessary exception handling. Crucially, both awareness and exception handling / human input must take place at the appropriate level of control. Human operators are potentially best suited to managing physical control actions at the lowest level of control, through the use of representations at a higher level of control i.e. at the regulation or planning level. This is most appropriate when physical actions are too rapid or tightly coupled to be assessed, and reacted to, on their own. For example in ON-TIME, specific control actions such as DAS advice, or specific point and signal settings may be best responded to as regulation settings or short-time amendments to an electronic timetable.

Research and experiences clearly indicate the importance and advantages of the control by awareness approach to human control and interaction with automatic systems. In control by awareness the operators build more advanced mental models of the system and develop higher skills. They are given the opportunity to be pro-active. They can control their work so that they avoid being in situations which they cannot handle. This increased awareness is also more likely to avoid the problem of automation (particularly in more unstable system coniditions eg with variable traffic, or poor weather) making sub-optimal decisions. Overall, improved awareness allows the human operator to maximise the automated control offered by technology to the point where, together, they meet the performance criteria required of the socio-technical system. For ON-TIME, this awareness will also help operators when the system, for whatever reasons, runs into major disruption and information needs to be distributed rapidly to multiple stakeholders i.e. WP5.

This also has benefits for the individual operating the system. They in control of the work situation as such and avoid the experience of being controlled by the system, something which has been shown to result in severe work environment problems. It is also an experience that if human operators are put in a situation characterized by pure control by exception, they start to generate their own solutions that allow awareness. If they are prohibited from this they will react with resignation leading to e.g. bad work environment, low efficiency and quality and less focus on safety issues. The development of local solutions can also lead to other problems and should be avoided.

The discussion above shows the importance of having a socio-technical approach to technical development. When we develop the technological systems, we must consider the organisation as a whole including the roles of the human actors, and at multiple levels of control.

There are many issues related to human factors that should be considered. We will not try to list all such considerations here, but will illustrate this with a few examples:

- Human operators, if they are acting as traffic planners, signallers, train drivers or in other roles, must always be supported so that they are "in-the-loop" (in full control, have high situation awareness). Human operators can not develop skills or perform with quality if they are only allowed to handle exceptions or if they lack appropriate information.
- Automation in systems where human operators are involved must be made in such a way that humans and automatic systems can "work together". Basic considerations and guidelines for appropriate automation in train traffic control have been discussed by e.g. (Balfe 2012) and (Sandblad 2010). An important problem reported from most train traffic systems is that automatic systems are turned off when a more complex disruption occurs, in order to not be "surprised by automation" or be "out-of-the-loop". Such situations should be avoided.
- In the design of user interfaces, for information systems generally and especially in critical systems for traffic controllers and train drivers, it is important to use appropriate methods. The functionality and visualisation will be most important for the usability of the developed system.
- It is important to "listen to the users" when support systems are designed, developed and deployed. Skilled professionals should be involved in the process. There exist much knowledge and experiences regarding user involvement that can be applied here. User centred development models and participatory design are examples.
- Another important human factors aspect concerns the work environment of the humans in different roles. A sustainable work requires a good work environment with regard to physical, psychosocial and cognitive aspects. There must be a good balance between demands, self control and social support. If this is not provided the result will not only have negative effects for the individuals, but also on their performance and can lead to low efficiency and safety risks.

Human factors research stands on a strong theoretical tradition. There are many theories and methodologies that can be applied to studies of train traffic systems. Examples are: Human perception and cognition, Human-Computer Interaction, Cognitive work analysis, Human decision-making, Human control of complex systems, Situation awareness, Human error, Resilient engineering, Humans and automation, User centred systems development, Usability engineering and evaluation and finally Cognitive work environment.

Train traffic related human factors research has grown rapidly in both quantity and quality of output over the past years. The continual influences of safety concerns, new technical system opportunities, reorganisation of the business, deregulation, urgent needs to increase effective, reliable and safe use of capacity, and increased society, media and government interest have now accelerated rail human factors research programmes in several countries. Experiences from successful research and applications of human factors in railway systems development can be found and are summarised in some central publications. Here we would like to mention the three biannual conferences organised by UoN and funded by NR and RSSB. Both the state of the art in railway human factors work and many applications can be found here. Two of these are published as a book and the third one is in the process of publication (Rail Human Factor, Supporting the Integrated Railway, 2005), (People and Rail Systems. Human Factors at the Heart of the Railway, 2007).

This more general discussion on the importance of considering Human Factors when technical systems are being developed and deployed, must be complemented with more detailed recommendations for how Human Factor aspects can and should be applied in the ONTIME project. A more detailed document, giving details about this, will be presented as a separate report. Main parts of this report will be:

- The importance of seeing the systems that are being developed as parts of a socio-technical system. The objectives of the project are to develop not only separate technical systems, but complete system solutions that will work in practice. When we develop the technical subsystems, we always must consider the organisation as a whole, including the roles of the human actors.

- A number of more specific (to each work package) recommendations that can be seen as a complement to the technical recommendations presented below in this deliverable. These recommendations will specify what must be considered and how, regarding e.g. organisational aspects, the roles of the human operators, collaboration and communication between actors, automation and user interfaces. Also aspects related to development and deployment processes will be discussed.

A more detailed presentation of relevant human factors, and guidelines for how these can and should be applied in the project, will later be presented as a separate report.

4 FUNCTIONAL PROCESS DESCRIPTIONS

4.1 Introduction

Section 2 of this document describes the results of research into the state-of-the-art of timetable planning and train control processes among the ON-TIME IM partners. It also indentifies the range of supporting technologies available to planners and controllers, together with their technology readiness levels. This section describes work to summarise the process information using a formal modelling notation IDEF0.

IDEF0 was developed during the 1970s, as part of the U.S. Air Force Program for Integrated Computer Aided Manufacturing (ICAM), which sought to increase manufacturing productivity through systematic application of computer technology. The program identified the need for better analysis and communication techniques (National Institute of Standards and Technology 1993), which it sought to achieve by, among other things, developing the IDEF0 notation for describing system functionality. The ON-TIME project is similar to ICAM in that clear and objective descriptions of existing system functionality are important foundations for the work of WPs 3, 4, 5, 6 and 7. This similarity lead WP1 to investigate, and subsequently adopt, IDEF0 notation.

IDEF0 shows process functionality in the context of associated inputs, outputs, controls and resources. It also facilitates the decomposition of high-level processes to an increasing level of detail. The highest level model is called the IDEF0 A-0 model (pronounced I DEF zero, A minus zero). WP2 has chosen to represent the railway system as a whole at this level (see Figure 4), and to assume that this model is generic to all European national railways

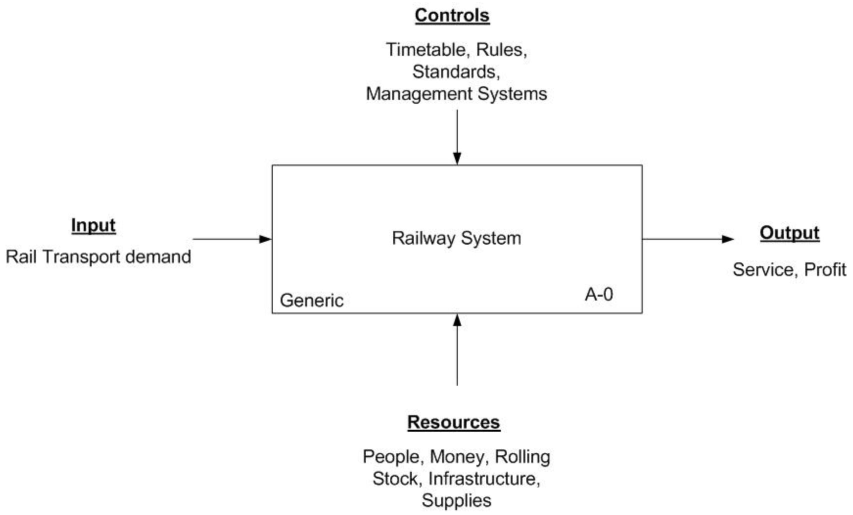

Figure 4 A diagram showing the IDEF0 A-0 view of the railway system

Figure 4 shows the railway system function in the centre box, with inputs (the demand for rail transport) coming in from the left, and outputs (rail services and financial benefit in the form of profit) exiting on the right. Coming into the box from the top are the system controls (timetables, rules, etc); the controls are the things that direct and constrain the operation of the system. Finally, coming in from the bottom are the resources (people, money, etc), which are used in the operation of the system. This arrangement is similar for all IDEF0 diagrams. Decomposing the IDEF0 A-0 diagram to the next level produces the IDEF0 A0 diagram, which is shown in Figure 5. This describes the principal functions of the railway, together with their linkages and feedback loops. Again, WP2 has assumed that this model is generic to all European national railways.

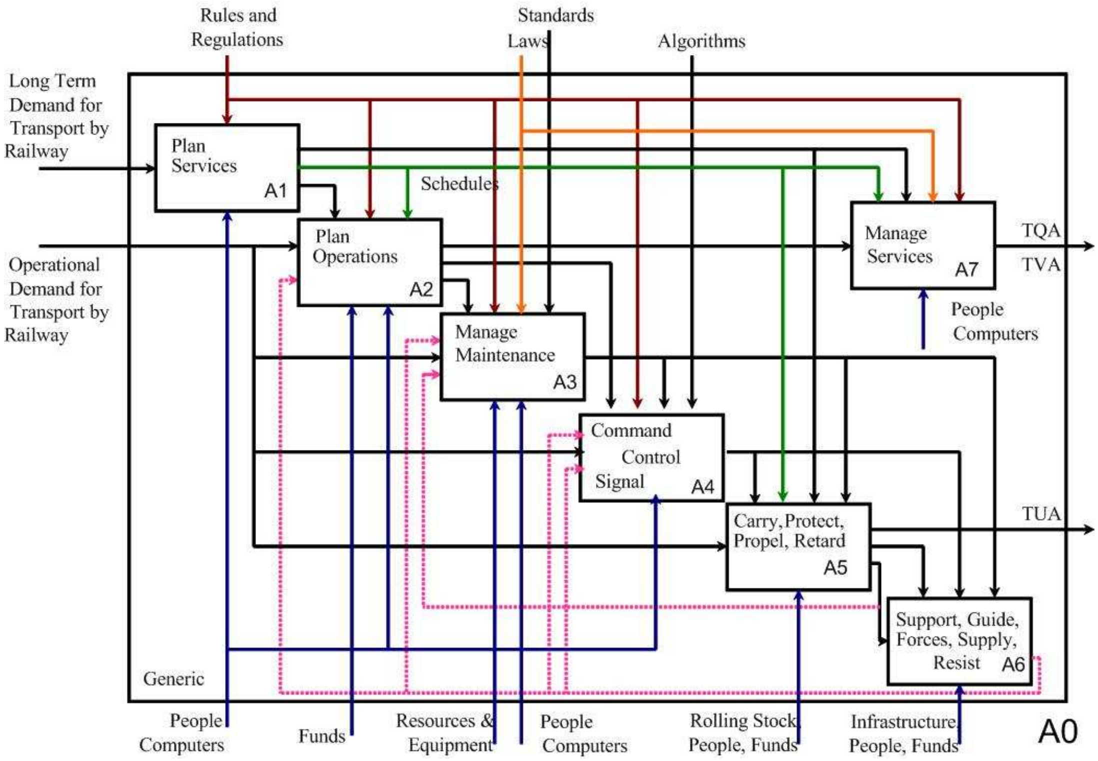

Figure 5 A diagram showing the IDEF0 A0 view of the railway system (Schmid F.)

Functions A2 (Plan Operations) and A7 (Manage Services) are the ones of most interest to ON-TIME: A2 covers the planning of timetables and rolling stock/train crew resources, while A7 covers the operation of the planned service and management of perturbations. For each of the ON-TIME IM partners, WP2 has decomposed A2 and A7 further, based on the results of the WP2 questionnaire, video-conferences with Trafikverket and more detailed research into the British case based on the following documents: the 2013 Network Statement (Network Rail 2011A); the Network Code (Network Rail 2011B), and; National Control Instructions (Network Rail 2011C). The resulting diagrams below, describe not only the functionality, but also the inputs, outputs, controls and resources applicable to each view; and in particular, the resource element shows where technologies in the form of tools are applied. Each diagram states in the bottom right-hand corner the function being decomposed; and in the bottom left-hand corner the ON-TIME partner to which it applies is identified. In cases where the diagram applies to all partners, the word generic appears in the bottom left-hand corner.

4.2 British IDEF0 Diagrams – Timetable Planning

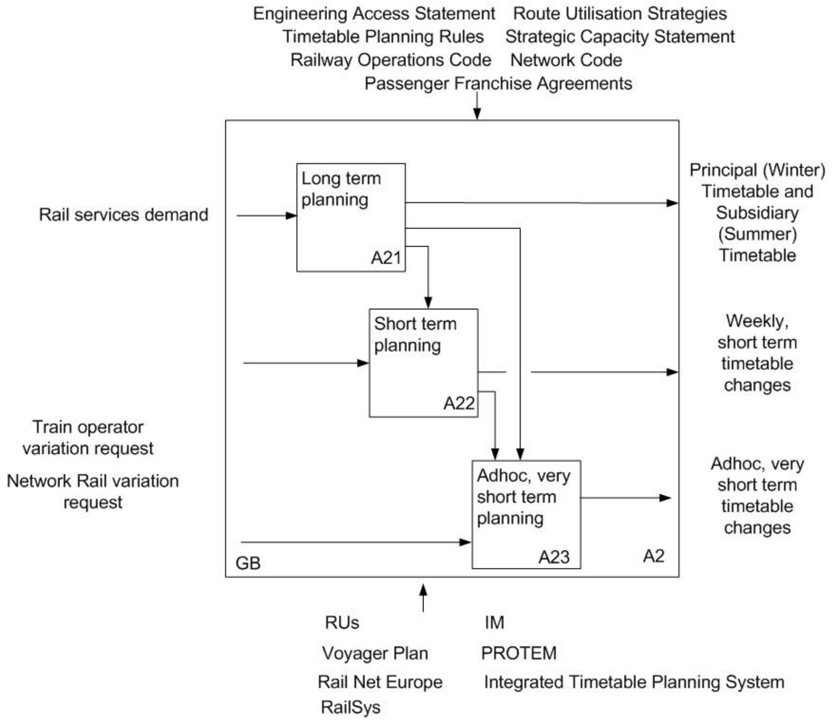

Figure 6 A diagram showing decomposition of function A2 (Plan Operations)

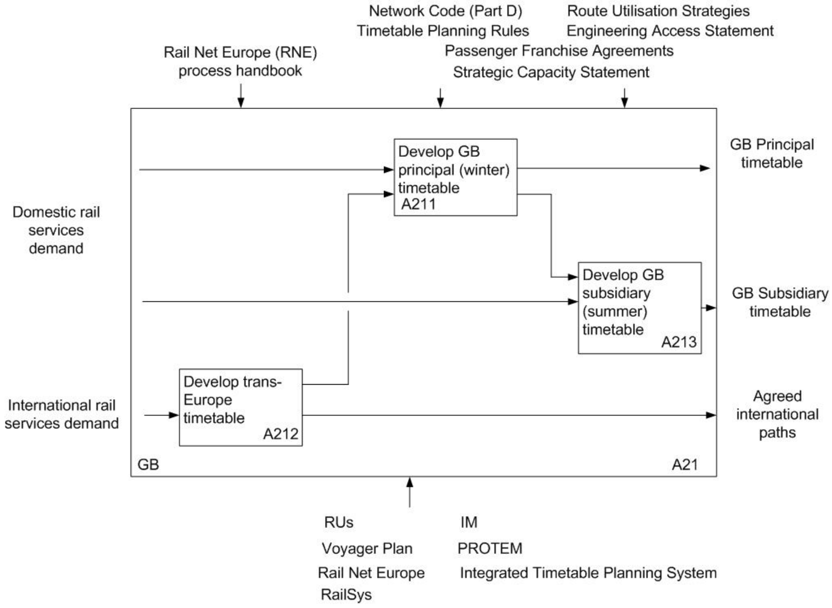

Figure 7 A diagram showing decomposition of function A21 (long term planning)

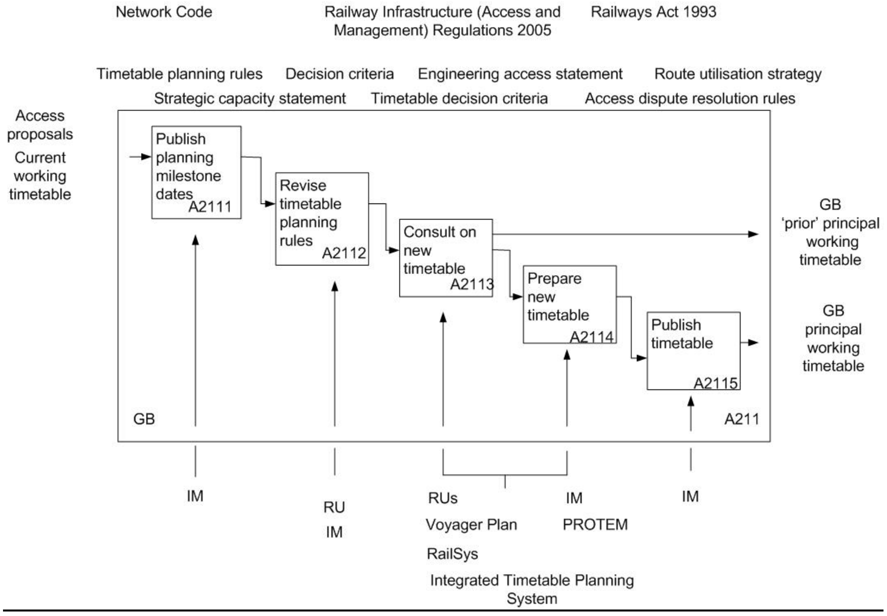

Figure 8 A diagram showing decomposition of function A211 (develop principal timetable)

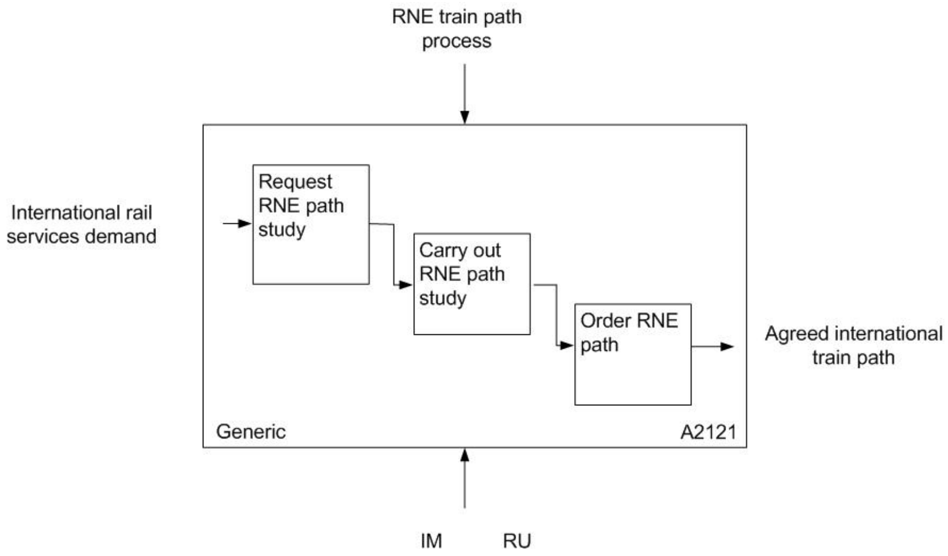

Figure 9 A diagram showing decomposition of function A212 (develop trans-Europe timetable)

4.3 British IDEF0 Diagrams – Train Control

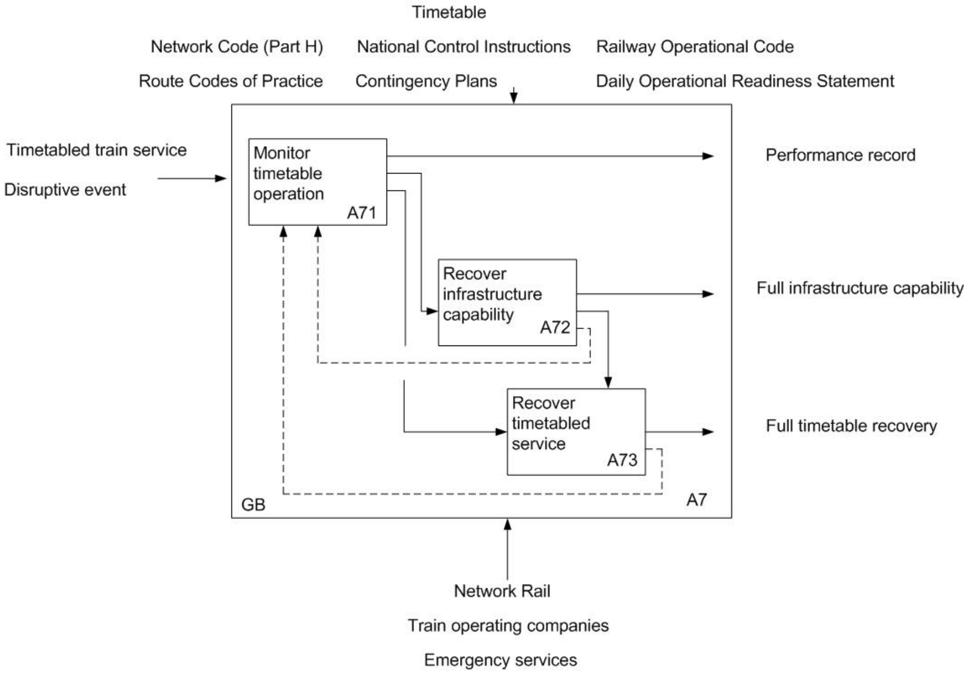

Figure 10 A diagram showing decomposition of function A7 (manage services)

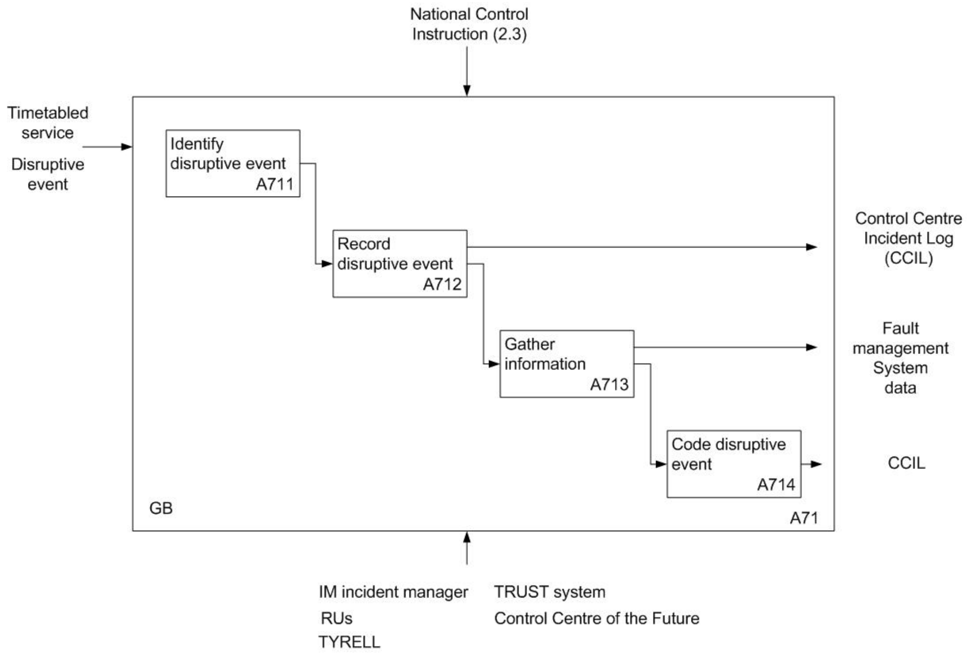

Figure 11 A diagram showing decomposition of function A71 (monitor time-table operation)

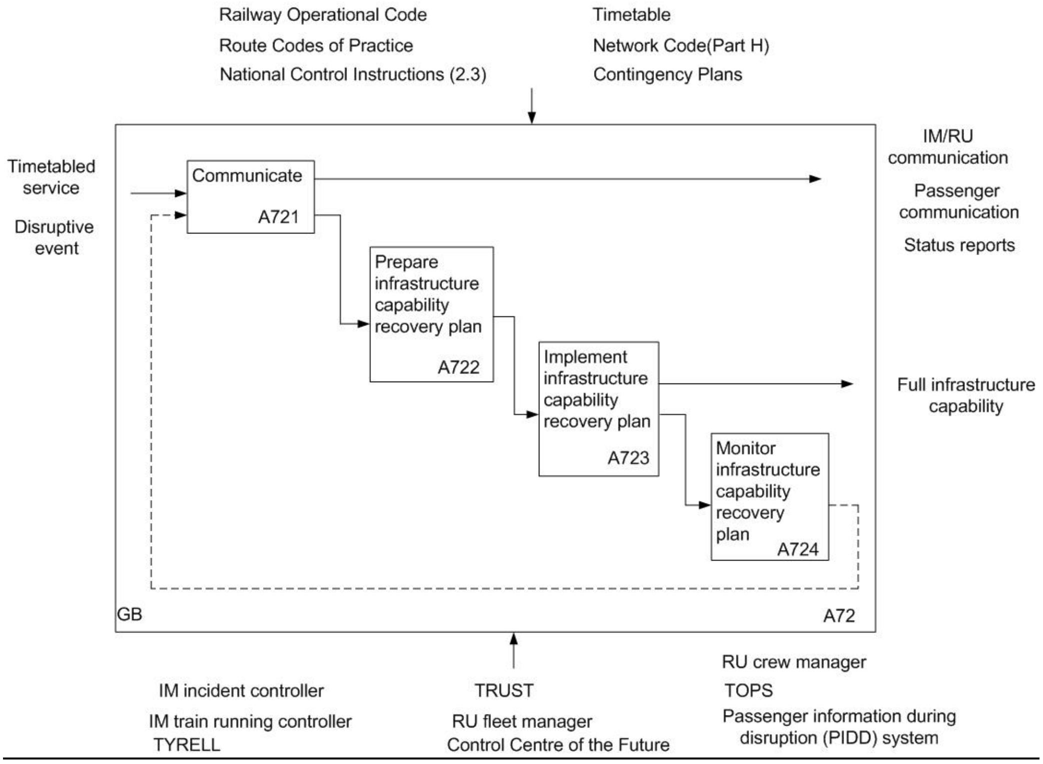

Figure 12 A diagram showing the decomposition of function A72 (recover infrastructure capability)

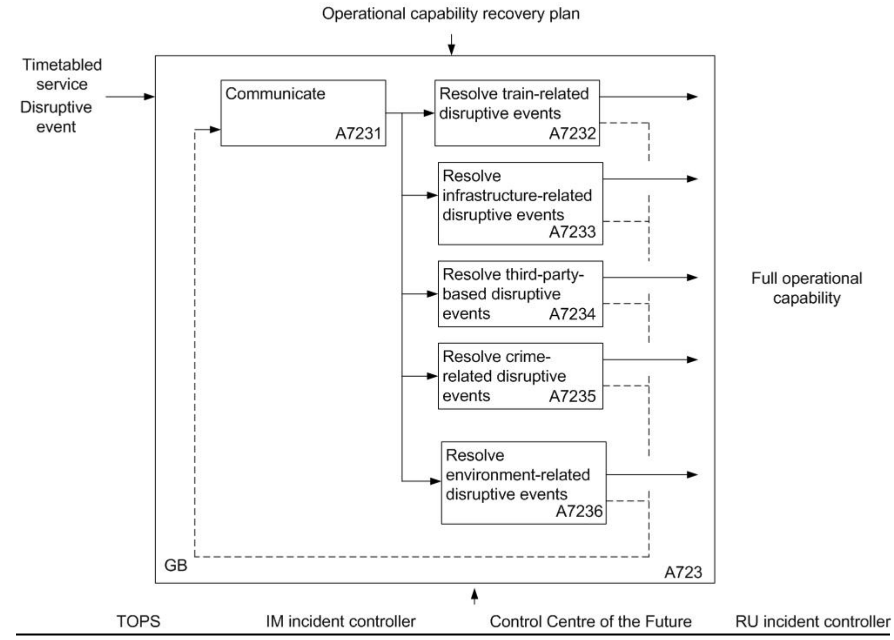

Figure 13 A diagram showing the decomposition of function A723 (implement infrastructure capability recovery plan)

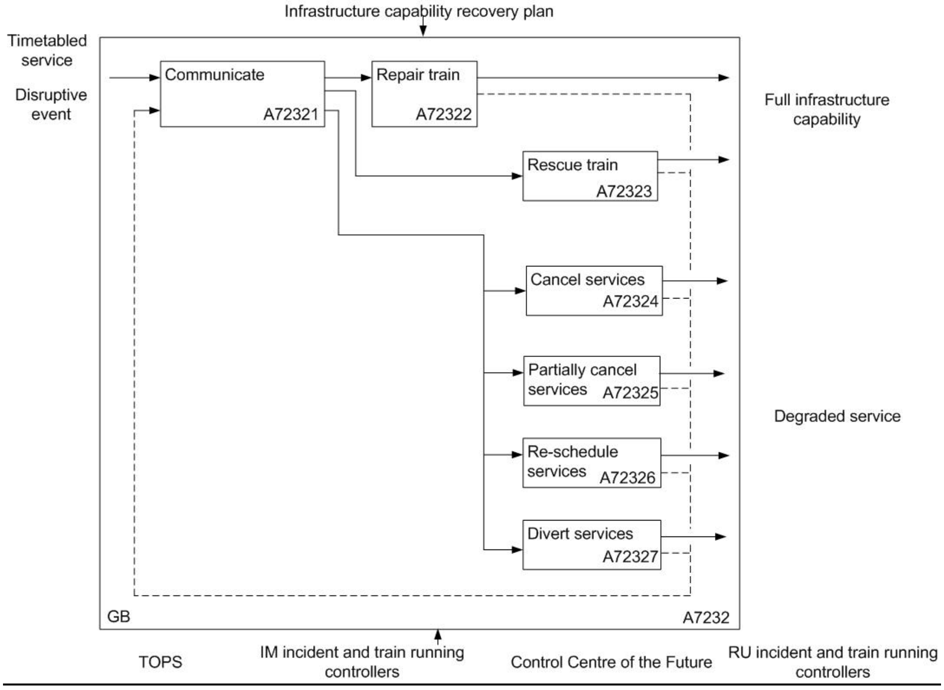

Figure 14 A diagram showing the decomposition of function A7232 (resolve train-related disruptive event)

4.4 Swedish IDEF0 Diagrams – Timetable Planning

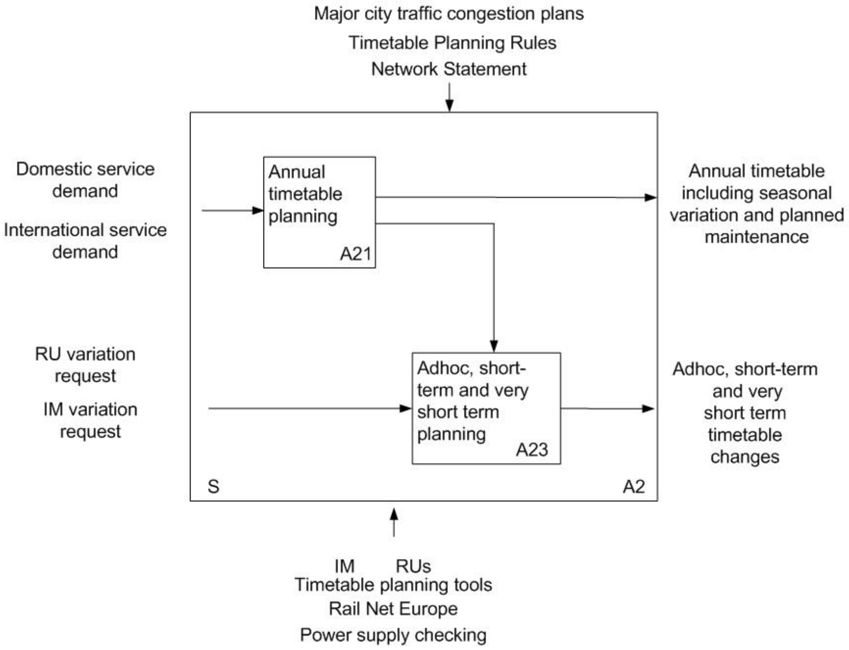

Figure 15 A diagram showing the decomposition of function A2 (plan operations)

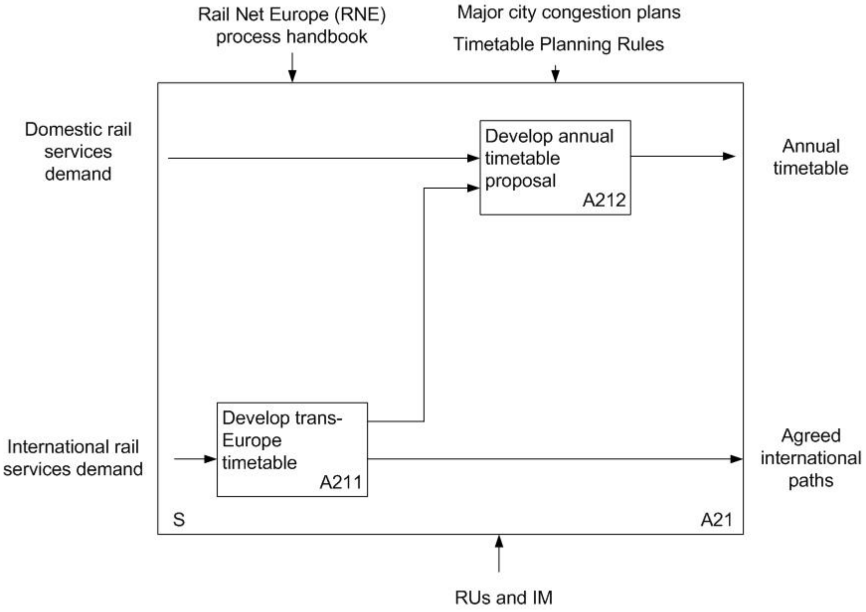

Figure 16 A diagram showing the decomposition of function A21 (annual timetable planning)

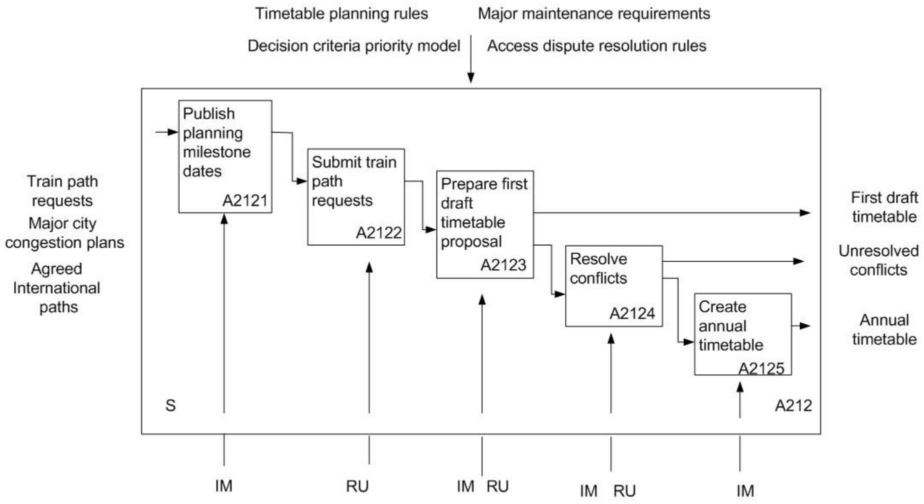

Figure 17 A diagram showing the decomposition of function A212 (develop annual timetable proposal)

4.5 Swedish IDEF0 Diagrams – Train Control

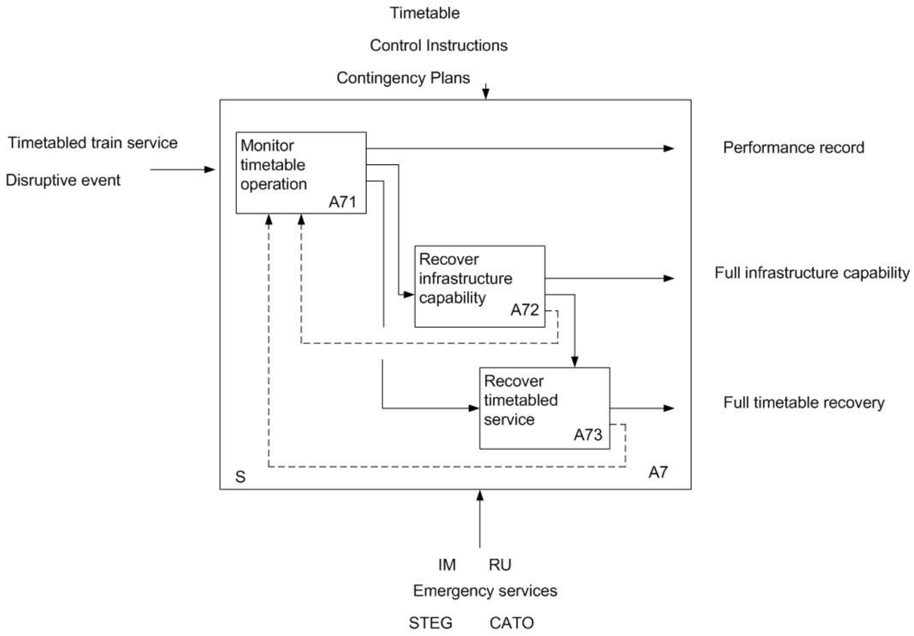

Figure 18 A diagram showing the decomposition of function A7 (manage services)

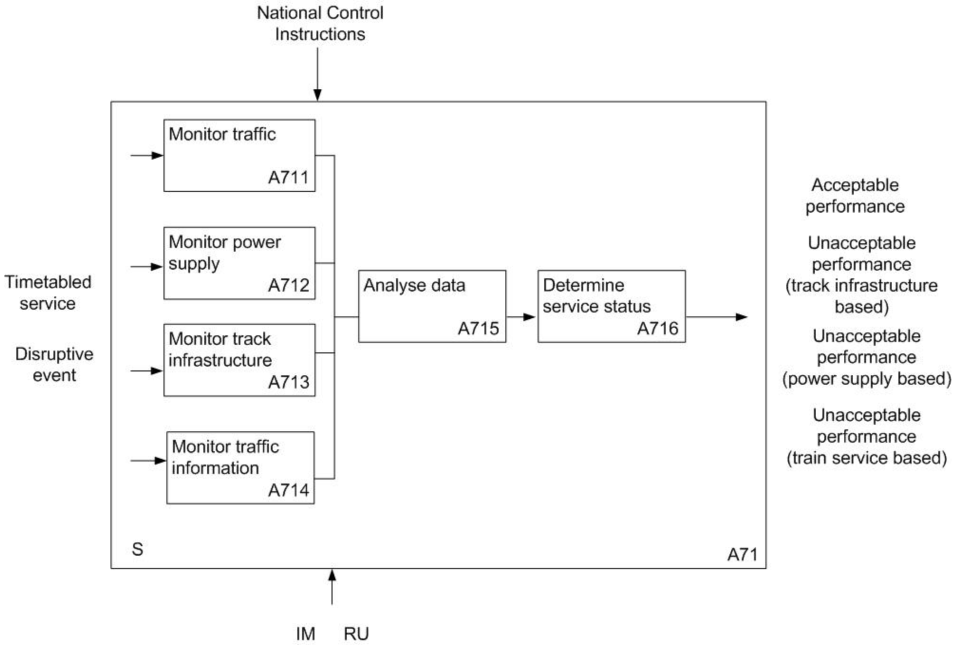

Figure 19 A diagram showing the decomposition of function A71 (monitor timetable operation)

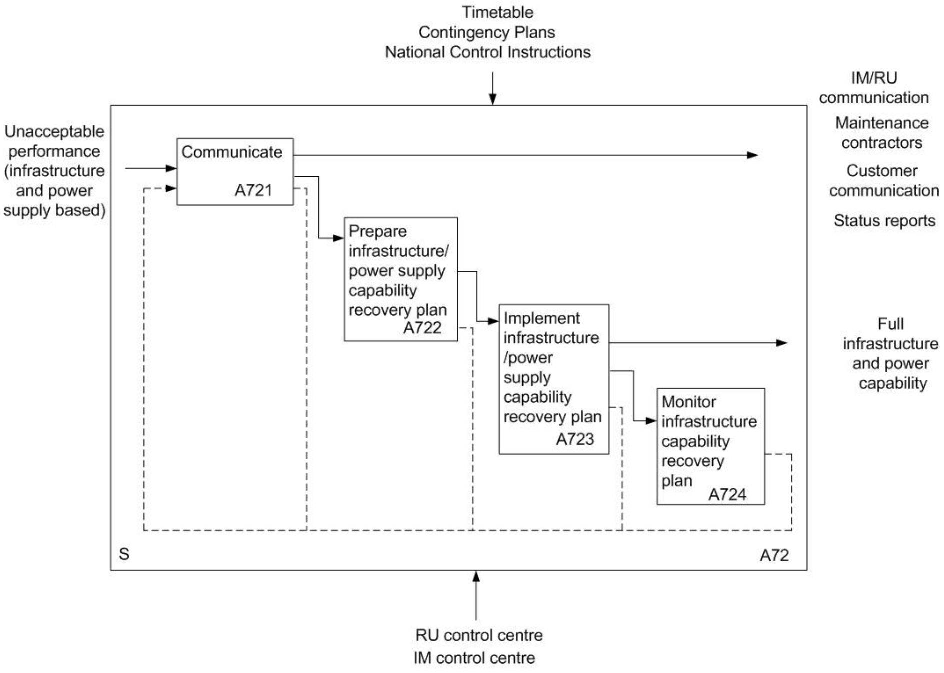

Figure 20 A diagram showing the decomposition of function A72 (recover infrastructure capability)

4.6 German IDEF0 Diagrams – Timetable Planning

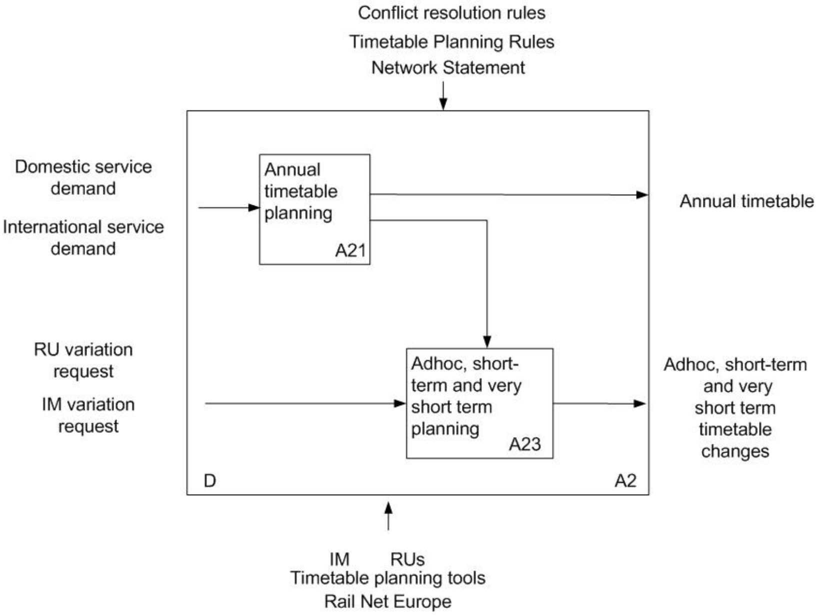

Figure 21 A diagram showing the decomposition of function A2 (plan operations)

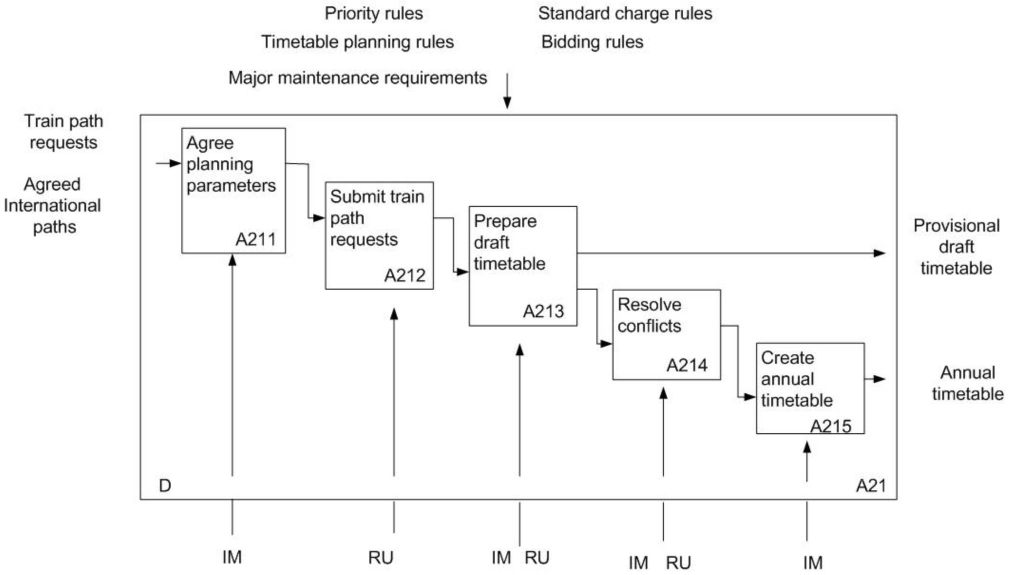

Figure 22 A diagram showing the decomposition of function A21 (annual timetable planning)

4.7 German IDEF0 Diagrams – Train Control

No data

4.8 Netherlands IDEF0 Diagrams – Timetable Planning

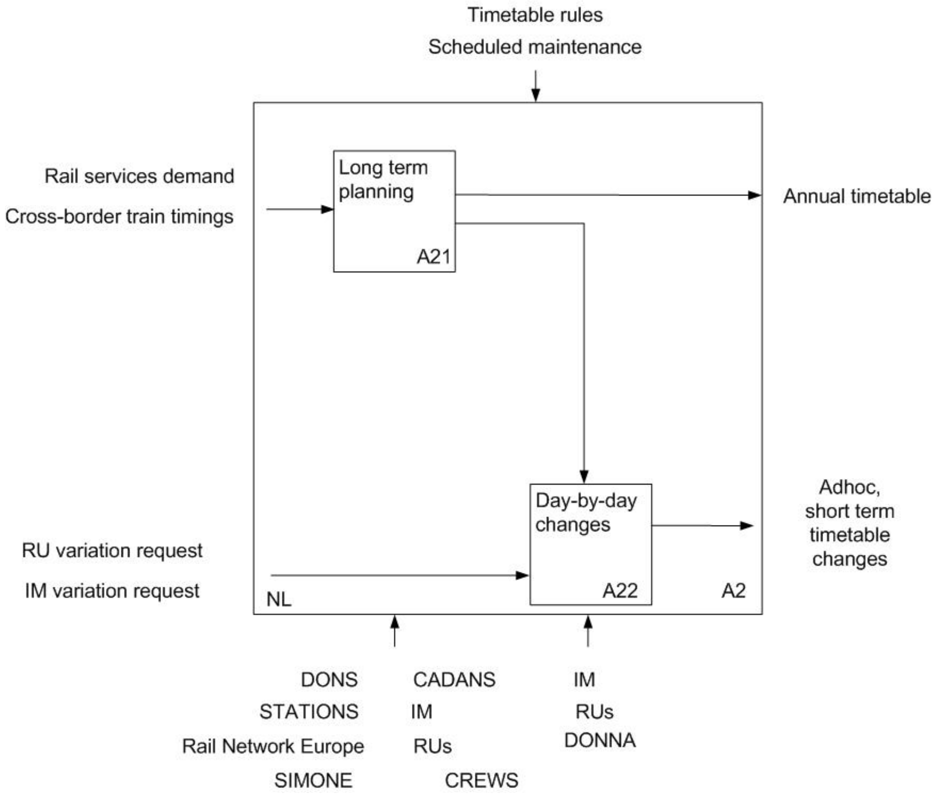

Figure 23 A diagram showing the decomposition of function A2 (plan operations)

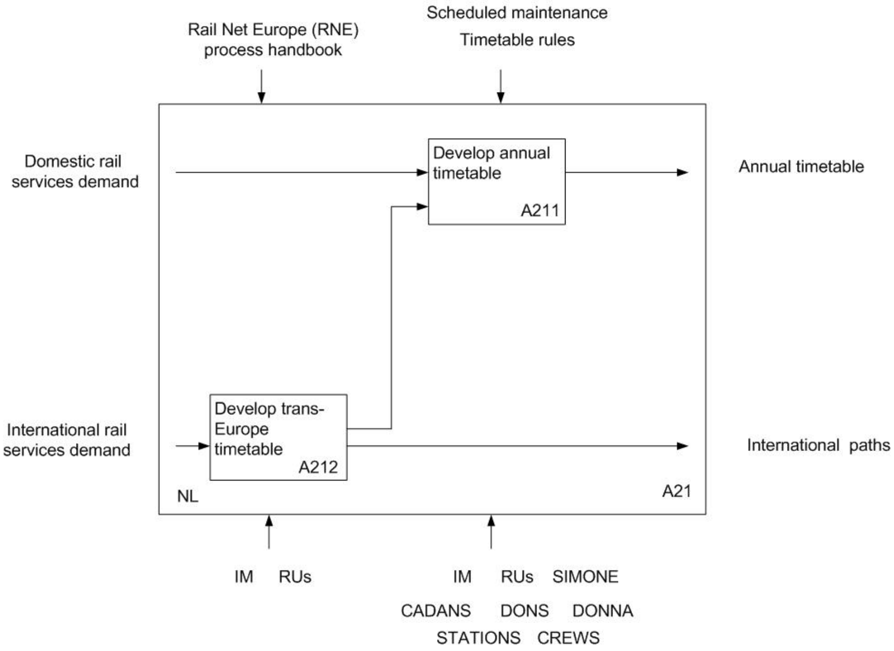

Figure 24 A diagram showing the decomposition of function A21 (long term planning)

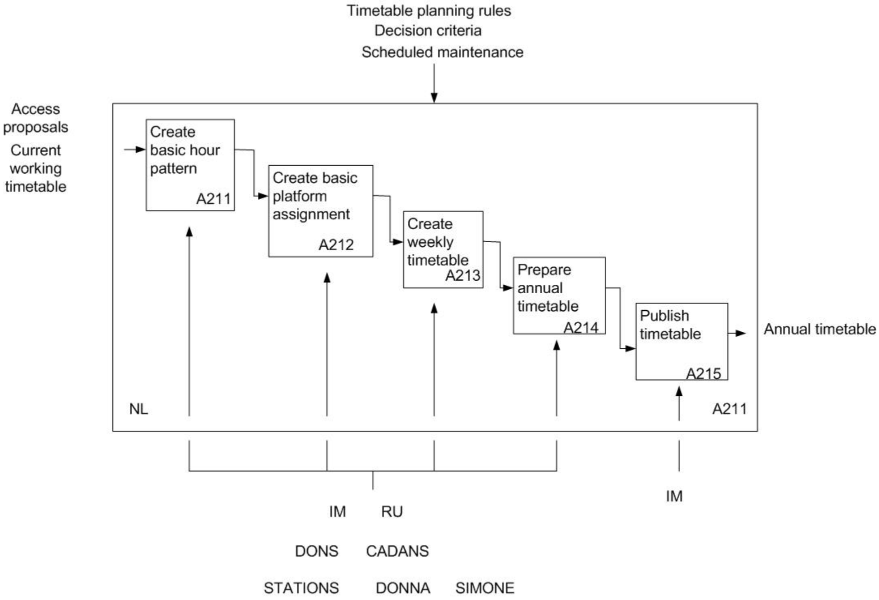

Figure 25 A diagram showing the decomposition of function A211 (develop annual timetable)

4.9 Netherlands IDEF0 Diagrams – Train Control

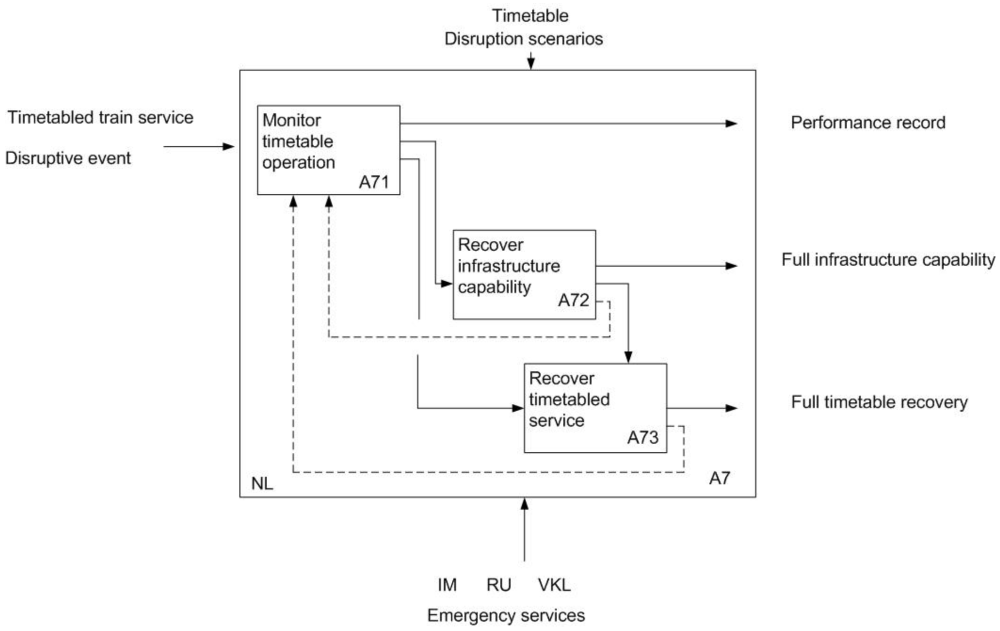

Figure 26 A diagram showing the decomposition of function A7 (manage services)

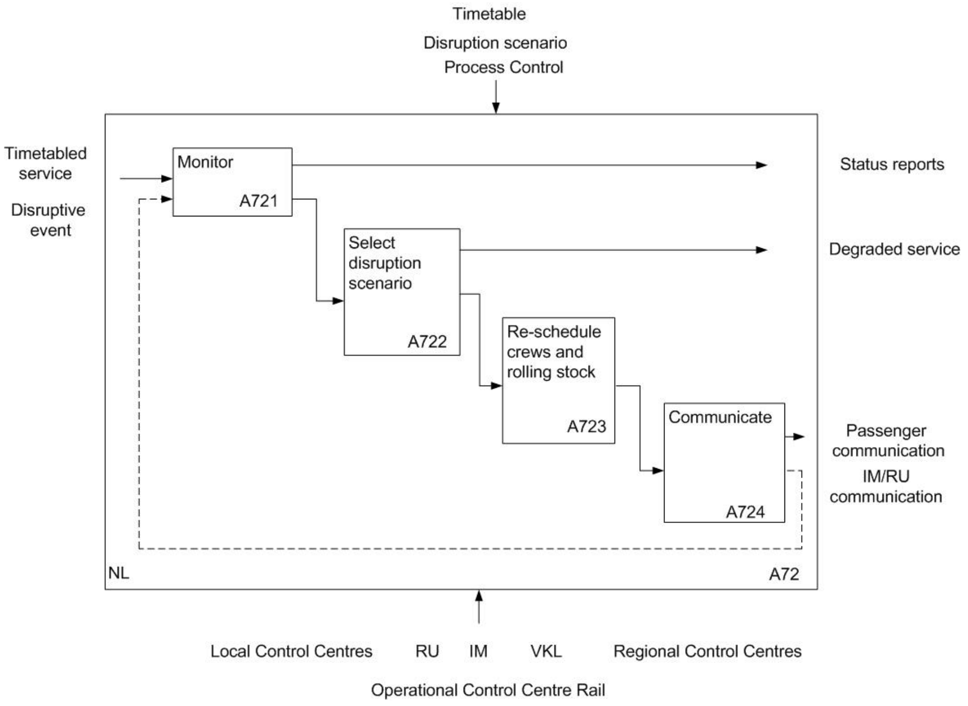

Figure 27 A diagram showing the decomposition of function A72 (recover infrastructure capability)

4.10 Italian IDEF0 Diagrams – Train Planning

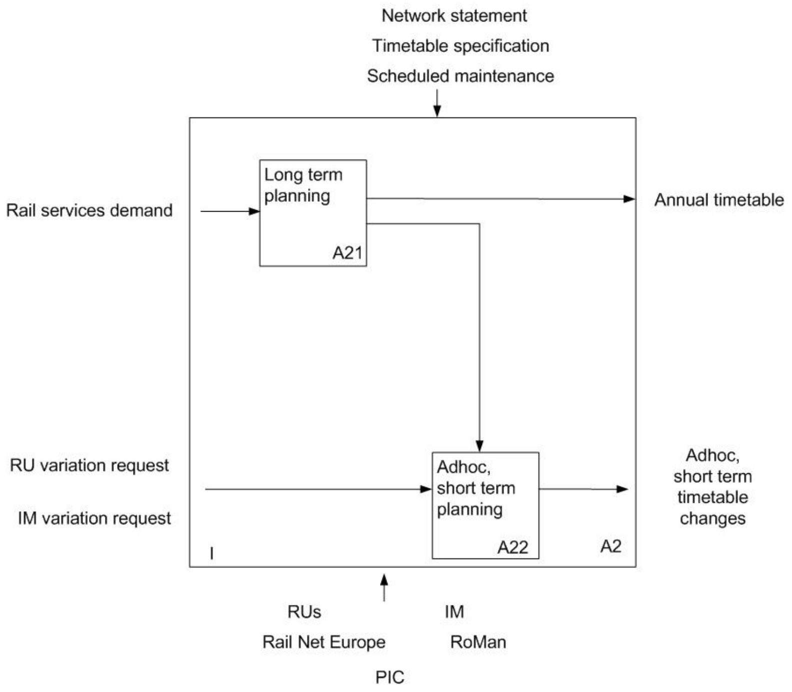

Figure 28 A diagram showing the decomposition of function A2 (plan operations)

4.11 Italian IDEF0 Diagrams – Train Control

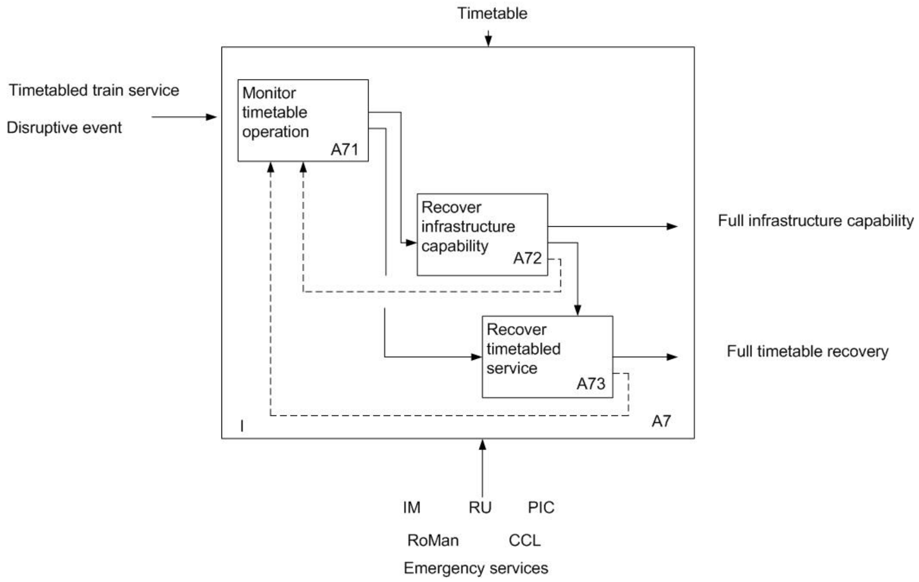

Figure 29 A diagram showing the decomposition of function A7 (manage services)

4.12 French IDEF0 Diagrams – Timetable Planning

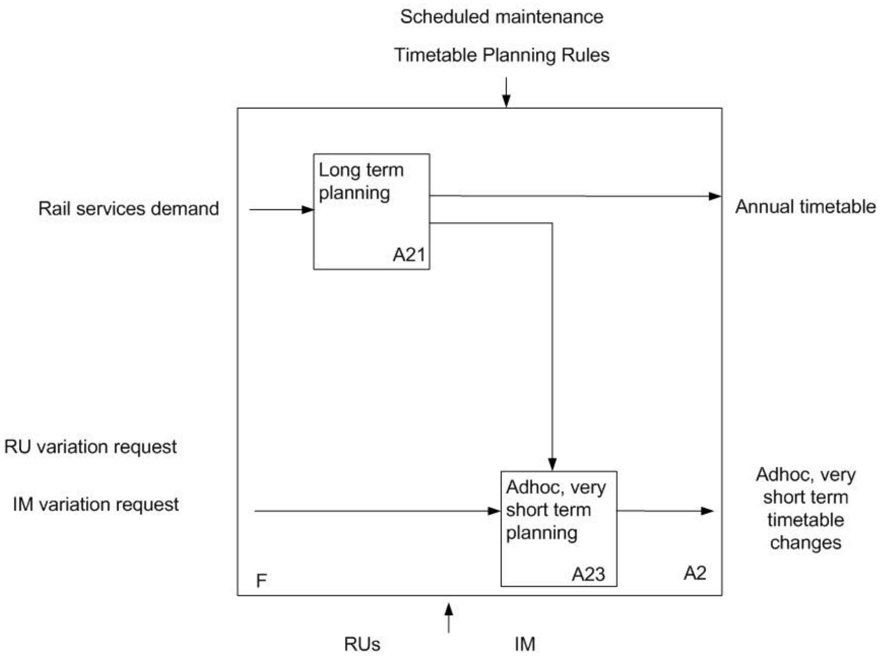

Figure 30 A diagram showing the decomposition of function A2 (plan operations)

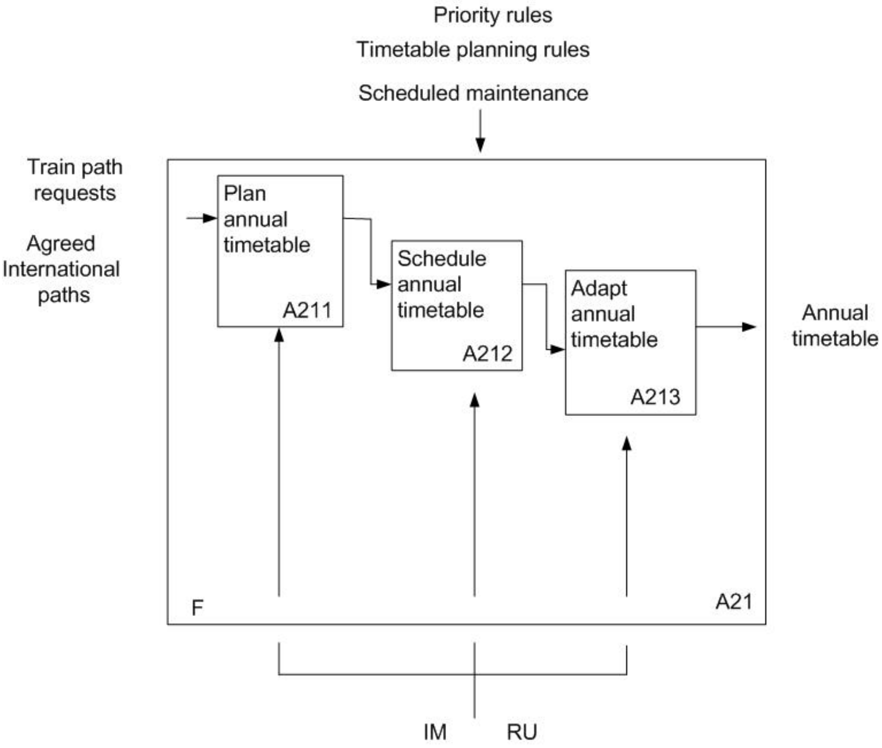

Figure 31 A diagram showing the decomposition of function A21 (long term planning)

4.13 French IDEF0 Diagrams – Train Control

No data

5 CAPABILITY REQUIREMENTS ELICITATION

5.1 Introduction

Capability requirements describe at a high-level the functions that a system is required to perform. In the case of **ON-TIME,** the aim has been to identify capability requirements for the timetable planning and traffic control systems.

WP2 sought to infer IM requirements from an understanding of the timetabling and planning environment; therefore, the WP2 questionnaire asked IMs to describe today's situation and systems, problems and developments/innovations in the areas of:

- Capacity;
- Traffic planning;
- Operational traffic control, and;
- Strategic information structures and systems.

In parallel with the questionnaire, WP1 also did some work to identify capability requirements. This involved interviews with IM timetable planners, and with IM and RU traffic controllers in Great Britain. The results of this work were presented in Deliverable D1.1 (Bouch et al, 2012), which is available on the **ON-TIME** website.

This part of D2.1 describes the results of the questionnaire in terms of the problems and requirements identified. It also combines the results of this with the requirements work of WP1, to create a prioritised list of requirements to guide the work of WPs 3, 4, 5, 6 and 7.

5.2 Problems and related requirements

Table 12 summarises the problems and requirements emerging from the questionnaire. The two columns on the far left-hand side indicate which part of the questionnaire is being referred to. The country column (third from the left) shows the country that raised the problem; the usual international symbols are used to denote the countries involved. The column third from the right lists the problems identified in the questionnaire affecting the **ON-TIME** project, and the column second from the right lists the related requirements. The column on the far right provides a requirement reference number, which is used later in Table 13.

Where a table entry shows a requirement, but no associated problem, it can be assumed that the requirement was stated in the questionnaire responses; however, where an entry has a problem and a requirement, the requirement may have been stated in the questionnaire responses, or inferred from the problem. Where a problem is stated, but there is no corresponding requirement, this indicates that the problem falls outside **ON-TIME's** scope.

Table 12: A summary of problems and related requirements developed from the questionnaire

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	**Description**				
1.2	Capacity Problems and Solutions				
1.2.1	Today's Situation and Systems	NL	Variations in speed between different types of train consume capacity	The system shall be capable of scheduling trains to optimise capacity usage and meet RU access rights	1
			Congestion in the large metropolitan areas		
		S	None		

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		F	Some trains are too large to run on some parts of the network		
		I	None		
		GB	Variations in speed between different types of train consume capacity	The system shall be capable of scheduling trains to optimise capacity usage and meet RU access rights	2
			Congestion in the large metropolitan areas		
			Limited terminal capacity		
		D	Technical compatibility problems at border crossing points		
			Disagreements between IM and RUs about capacity allocation	The system shall be capable of supporting fair allocation of capacity	3

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
1.2.2	Experienced problems	NL	No report		
		S	Congestion in city areas		
		F	No report		
		I	None		
		GB	None		
		D	No report		
1.2.3	Development and Innovations	NL		The system shall be capable of assessing the quality of a timetable	4
				The system shall be capable of rapid development of timetables to support recovery from disruption	5
				The system shall be capable of rapid rescheduling of rolling stock and crews to support recovery from disruption	6

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
				The system shall be capable of supporting real time management of intensive traffic	7
		S	None		
		F		The system shall be capable of integrating existing timetable tools	8
		I		The system shall be capable of creating timetables to meet required performance levels	9
				The system shall be capable of simulating timetable operation	10
		GB	No report		
		D		The system shall be capable of supporting the work of train dispatchers	11
				The system shall provide train speed advice to drivers	12

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	**Description**				
1.3	Traffic Planning				
1.3.1	Today's Situation and Systems	NL	None		
		S	Train planning interface between IM and RUs needs to be improved	The system shall be capable of integrating timetable input from the IM and RUs	13
			Better tools are required for timetable planning	The system shall be capable of simulating timetable operation	14
				The system shall be capable of integrating train planning and traffic control	15
			Train path conflicts	The system shall be capable of supporting resolution of train path conflicts in accordance with the rules.	16

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		F	There is a lack of communication between timetable planning and operational control.	The system shall be capable of integrating timetabling and operational control	17
		I		The system shall be capable of supporting platform scheduling	18
		GB	None		
		D	Mixed traffic railway		
1.3.2	Experienced Problems	NL		The system shall be capable of simulating timetable operation	19
		S	Many small and medium perturbations		
			Too high utilisation of the network	The system shall be capable of measuring network performance	20
				The system shall be capable of integrating planning and operational control	21

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		F		The system shall be capable of producing high performance timetables	22
				The system shall be capable of supporting an integrated planning/control decision-making process	23
		I		The system shall be capable of improving the efficiency of the timetabling process	24
				The system shall be capable of integrating important data sources	25
				The system shall be capable of optimising timetable development	26
				The system shall be capable of supporting conflict resolution	27
1.3.3	Development and Innovations	NL		The system shall be capable of integrating all aspects of timetable planning	28

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
				The system shall be capable of supporting crew and rolling stock scheduling	29
				The system shall be capable of supporting rapid development of timetables and crew/rolling stock plans	30
				The system shall be capable of supporting rapid re-scheduling of trains, crew and rolling stock	31
		S		The system shall be capable of supporting strategic, tactical and operational planning	32
				The system shall be capable of supporting effective communication between IM and RUs	33
				The system shall be capable of integrating timetabling and train control	34

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		F		The system shall be capable of integrating train movements and station platforming	35
				The system shall be capable of optimising use of operating margins	36
		I		The system shall be capable of improving the efficiency of the timetabling process	37
				The system shall be capable of optimising timetable development	38
				The system shall be capable of supporting conflict resolution	39
				The system shall be capable of integrating timetabling and train control	40
		GB	No report		
		D	No report		

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
1.4	Operational Train Traffic Control				
1.4.1	Today's Situation and Systems	NL	During disruption the timetable is altered manually	The system shall be capable of automated timetable recovery	41
			Operational control processes lack decision support	The system shall be capable of providing decision support for timetabling and train control	42
			Communication with drivers is slow	The system shall be capable of rapid communication with drivers	43
		S	None		
		F	There is no standard for communication between control and train drivers	The system shall be capable of integrating communication between drivers and control	44
			Communication with drivers produces a safety risk	The system shall be capable of supporting safe communication between control and drivers	45
		I		The system shall be capable of supporting real-time re-planning	46

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
			There are no decision support tools	The system shall be capable of providing decision support	47
		GB	None		
		D			
1.4.2	Experienced problems	NL	There is a separation between IM and RU controllers	The system shall be capable of integrating the work of IM and RU	48
			Communication between control centres is poor	The system shall be capable of improving communication efficiency between control centres	49
			Rail operations processes do not have decision support	The system shall be capable of providing decision support to train controllers and operators	50
				The system shall be capable of providing drivers with new required passing times	51
			Re-planning trains is slow	The system shall be capable of rapid re-planning of trains	52

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
			Rolling stock dispatchers do not have good information about train availability	The system shall be capable of providing information about rolling stock and crew location and availability	53
		S	Multiple systems cause problems	The system shall be capable of integrating existing systems	54
			Poor communication between drivers and control	The system shall be capable of supporting effective communication between drivers and control	55
			Manual re-planning is slow and complex	The system shall be capable of supporting rapid re-planning	56
			Planners do not have full knowledge of interlocking constraints	The system shall be capable of integrating the knowledge of planners and signallers	57
			Current automated re-planning methods are not trusted by controllers		

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	**Description**				
		F	Communication between control centres is poor	The system shall be capable of improving communication efficiency between control centres	58
			There is a separation between IM and RU controllers	The system shall be capable of integrating the work of IM and RU	59
		I	One track out-of-service	The system shall be capable of utilising pre-prepared contingency plans	60
			Poor communication across borders	The system shall be capable of communicating across national borders	61
			Poor communication between IM and RUs	The system shall be capable of facilitating communication between IM and RUs, and between RUs	62
				The system shall be capable of supporting rapid problem analysis and resolution	63
		GB	No report		

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		D	Lack of compatibility between existing control tools	The system shall be capable of integrating existing control tools	64
1.4.3	Development and Innovations	NL		The system shall be capable of providing decision support across all aspects of traffic management and control	65
				The system shall be capable of parallel development of timetable and rolling stock/crew rosters	66
				The system shall be capable of ad hoc re-scheduling rolling stock	67
		S	None		
		F		The system shall be capable of automated conflict detection during timetable development	68
				The system shall be capable of automated handling of disruption	69

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
				The system shall be capable of easy re-configuration in response to network reconfiguration and rolling stock change	70
				The system shall be capable of providing drivers with new required passing times	71
		I	None		
		GB	No report		
		D	No report		
1.5	Strategic Information Systems and Structures				
1.5.1	Today's Situation and Systems	NL	Non		

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
		S	Existing systems need better integration	The system shall be capable of integrating existing planning and control tools	72
		F	Timetabling uses three separate tools	The system shall be capable of integrating existing planning and control tools	73
		I	No fully integrated IT system	The system shall be capable of integrating existing planning and control tools	74
		GB	None		
		D	None		
1.5.2	Experienced Problems	NL	The existing system does not have decision support	The system shall be capable of providing decision support	75
		S	Existing systems need better integration	The system shall be capable of integrating existing planning and control tools	76

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
			Paper-based train graphs mean re-scheduling in response to disruption is slow	The system shall be capable of computerised re-scheduling	77
			Dispatchers sometimes have poor information and make the wrong decisions as a result	The system shall be capable of providing high quality information to dispatchers	78
		F	Large numbers of computer tools are costly to maintain		
			Compatibility between computer tools is poor	The system shall be capable of integrating existing tools	79
		I	Compatibility between computer tools is poor	The system shall be capable of integrating existing tools	80
			Available performance data is poor	The system shall be capable of providing high quality performance data	81
		GB	Data integration is poor	The system shall be capable of integrating existing tools	82

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
			Data for train running time calculation is poor	The system shall be capable of providing robust data for train running time calculation	83
			Conflict detection is poor	The system shall be capable of detecting train conflicts	84
		D	Many tools and databases		
			Manual data input for things like speed restrictions	The system shall be capable of integrating existing tools and databases	85
1.5.3	Development and Innovations	NL	None		
		S	None		
		F	None		
		I	None		
		GB		The system shall be capable of conflict detection	86

Questionnaire Reference		Country	Problems that Impact ON-TIME	ON-TIME Capability Requirements	Requirement ID Number
Section Number	Description				
				The system shall be capable of integrating the IM/RU timetable planning interface	87
				The system shall be capable of integrating the IM/RU operations interface	88
		D	None		

5.3 Requirements Analysis

Table 13 shows the results of an analysis of the requirements in Table 12. The analysis is designed to show which requirements are the most important, where importance of a requirement is measured in terms of the number of IMs having that requirement.

The analysis is based on the requirements identified by WP1 and published in Deliverable D1.1; the two columns on the far left-hand side of Table 13 show the requirement categories (Timetable Development Strategy, Operations Planning, Network Control and Train Control), requirement descriptions and requirement numbers used in that document. The six columns on the right-hand side of Table 13 show where the requirements identified in Table 12 correspond to those from D1.1: for example, in the case of requirement 1.1 below, the Italian IM identified a similar requirement (requirement 25 from Table 1).

Some of the requirements from Table 12 did not correspond to those from D1.1. In those cases, additional requirements have been added to the list in Table 13: these are shown shaded grey.

Table 13: A table showing a consolidated list of capability requirements and the correspondence of each to ON-TIME's IM partners

Number	Requirements	Infrastructure Managers					
		D	I	S	NL	F	GB
1	**Timetable Development Strategy**						
1.1	Timetable sub-systems shall be capable of transferring data between one another		25				
1.2	The system shall be capable of objective allocation of capacity in accordance with the relevant standards	3	27	16	1		2
1.3	The system shall be capable of validating timetable requirements in accordance with the relevant standards						
1.4	The system shall be capable of verifying timetable design				4	22	

Number	Requirements	Infrastructure Managers					
		D	I	S	NL	F	GB
1.5	The system shall be capable of identifying timetable conflicts		39			68	84, 86
1.6	The system shall be capable of integrating the timetable planning and traffic control sub-systems	64, 85	40, 80	13, 15, 21, 32, 34, 54, 57, 72, 76,	28, 48,	17, 35, 59, 73, 76	82, 87
1.7	The system shall be capable of reconfiguration in response to network changes					70	
2	**Operations Planning**						
2.1	The system shall be capable of checking ad hoc timetable changes for conflicts						
2.2	The system shall be capable of checking ad hoc timetable changes for compliance against relevant standards						
2.3	The system shall be capable of generating probability-based values for timetable margins						
2.4	The system shall be capable of automatically including timetabling rules into timetable development						
2.5	The system shall be capable of identifying operating margin erosion						

Number	Requirements	Infrastructure Managers					
		D	I	S	NL	F	GB
2.6	The system shall be capable of generating ad hoc, scenario specific, point-to-point running times.						
2.7	The system shall be capable of providing accurate information on planned engineering access						
2.8	The system shall be capable of integrating the different operating assumptions of planners, controllers and signallers						
2.9	The system shall be capable of providing a systematic approach for dealing with scheduling conflicts that is in accordance with the relevant standards.						
2.10	The system shall be capable of creating timetables to meet specified performance levels		9, 26, 38	20			83
2.11	The system shall be capable of simulating timetable operation		10	14	19		
2.12	The system shall be capable of optimising use of timetable margins					36	
2.13	The system shall be capable of rapid production of timetables and associated rolling stock and crew rosters		24, 37		30, 66		
3	**Network Control**						
3.1	The system shall be capable of optimising train recovery plans in accordance with the relevant standards		46, 63	56	5, 41, 52		

Number	Requirements	Infrastructure Managers					
		D	I	S	NL	F	GB
3.2	The system shall be capable of providing early warning of incipient infrastructure failures						
3.3	The system shall be capable of optimising platforming of trains during perturbed operation		18				
3.4	The system shall be capable of optimising the design of train service contingency plans in accordance with the relevant standards						
3.5	The system shall be capable of integrating all communications relating to train service disruption		61,62	33,55	43,49	44,45, 58	
3.6	The system shall be capable of predicting the network impact of local service disruption						
3.7	The system shall be capable of supporting integration of IM and RU controller actions	11			50		88
3.8	The system shall be capable of providing early warning of resource constraints						
3.9	The system shall be capable of supporting integration of IM and RU station staff actions						
3.10	The system shall be capable of learning from previous disruption						

Number	Requirements	Infrastructure Managers					
		D	I	S	NL	F	GB
3.11	The system shall be capable of supporting real-time decision-making		47		42, 65, 75	23	
3.12	The system shall be capable of supporting engineering access planning and management						
4	**Train Control Requirements**						
4.1	The system shall be capable of integrating rolling stock and train-crew rostering during service disruption				6, 29, 31, 53		
4.2	The system shall be capable of providing advanced warning of delays elsewhere on the network likely to impact on the local service						
4.3	The system shall be capable of providing advanced warning of emerging train diagram problems						
4.4	The system shall be capable of monitoring the location of rolling stock and train crew relevant to service operation						
4.5	The system shall be capable of monitoring the operational status of train crew and rolling stock						
4.6	The system shall be capable of communicating safely with drivers while they are on duty	12			51	71	
4.7	The system shall be capable of optimised rescue of failed trains						

Number	**Requirements**	**Infrastructure Managers**					
		D	**I**	**S**	**NL**	**F**	**GB**
4.8	The system shall be capable of optimised recovery of train service						
4.9	The system shall be capable of advanced warning of train diagram/crew roster problems						
4.10	The system shall be capable of real-time management of traffic		60, 81	77, 78	7, 67	69	

5.4 Prioritised Requirements

Table 14 shows a prioritised list of requirements to guide the work of WPs 3, 4, 5, 6 and 7. The Table was created by firstly removing from Table 13 those requirements showing no correspondence with IMs, and then re-ordering the remaining requirements in descending order of the number of IM correspondences each has.

Table 14: Prioritised list of requirements

Table 13 Requirement Number	Requirement Priority Number	Requirements
1.6	1	The system shall be capable of integrating its sub-systems
1.2	2	The system shall be capable of objective allocation of capacity in accordance with the relevant standards
3.5	3	The system shall be capable of integrating all communications relating to train service disruption
4.10	4	The system shall be capable of real-time management of traffic
1.5	5	The system shall be capable of identifying and managing timetable conflicts
2.10	6	The system shall be capable of creating timetables to meet specified performance levels
2.11	7	The system shall be capable of simulating timetable operation
3.1	8	The system shall be capable of optimising train recovery plans in accordance with the relevant standards
3.7	9	The system shall be capable of supporting integration of NR and RU controller actions
3.11	10	The system shall be capable of supporting real-time decision-making
4.6	11	The system shall be capable of communicating safely with drivers while they are on duty
1.4	12	The system shall be capable of verifying timetable design

Table 13 Requirement Number	Requirement Priority Number	Requirements
2.13	13	The system shall be capable of rapid production of timetables and associated rolling stock and crew rosters
1.1	14	Timetable sub-systems shall be capable of transferring data between one another
1.7	15	The system shall be capable of reconfiguration in response to network changes
2.12	16	The system shall be capable of optimising use of timetable margins
3.3	17	The system shall be capable of optimising platforming of trains during perturbed operation
4.1	18	The system shall be capable of integrating rolling stock and train-crew rostering during service disruption

6 SYNTHESIS OF PRIORITISED CAPABILITY REQUIREMENTS, WORK PACKAGES AND INNOVATION TOPICS

Work Packages 3, 4, 5, 6 and 7 cover the following areas of research:

- WP3: development of robust and resilient timetables;
- WP4: Methods for real-time traffic management (perturbations);
- WP5: Operation management of large scale disruptions;
- WP6: Driver advisory systems, and;
- WP7: Process and information architecture.

The **ON-TIME** innovation topics are shown in Table 11 of this document. Synthesising these and the work packages above, with the prioritised capability requirements of Table 14 produces Table 15: a prioritised list of capability requirements, with each requirement related to work package and innovation topic.

Table 15: A prioritised list of capability requirements related to work package and innovation topic

Table 13 Requirement Number	Requirement Priority Number	Requirements	Work Package	Innovation Topic
1.6	1	The system shall be capable of integrating its sub-systems	7	5
1.2	2	The system shall be capable of objective allocation of capacity in accordance with the relevant standards	3	3,4
3.5	3	The system shall be capable of integrating all communications relating to train service disruption	4,5,6,7	5
4.10	4	The system shall be capable of real-time management of traffic	4,6	3,4
1.5	5	The system shall be capable of identifying timetable conflicts	3,4,5	2
2.10	6	The system shall be capable of creating timetables to meet specified performance levels	3	2
2.11	7	The system shall be capable of simulating timetable operation	3	2
3.1	8	The system shall be capable of optimising train recovery plans in accordance with the relevant standards	4,5,6	4
3.7	9	The system shall be capable of supporting integration of NR and RU controller actions	4,5,7	5,6
3.11	10	The system shall be capable of supporting real-time decision-making	4,5,7	3,4
4.6	11	The system shall be capable of communicating safely with drivers	6	5

Table 13 Requirement Number	Requirement Priority Number	Requirements	Work Package	Innovation Topic
		while they are on duty		
1.4	12	The system shall be capable of verifying timetable design	3	2
2.13	13	The system shall be capable of rapid production of timetables and associated rolling stock and crew rosters	3,5	1,2
1.1	14	Timetable sub-systems shall be capable of transferring data between one another	7	6
1.7	15	The system shall be capable of reconfiguration in response to network changes	7	1
2.12	16	The system shall be capable of optimising use of timetable margins	3	2
3.3	17	The system shall be capable of optimising platforming of trains during perturbed operation	4,5,6	3,4
4.1	18	The system shall be capable of integrating rolling stock and train-crew rostering during service disruption	4,5,6	3,4

“In addition to the requirements stated here, a separate document will outline human factors guidance and requirements for effective technology deployment within the ON-TIME project”

7 CONCLUSIONS

A set of prioritised capability requirements has been created to guide the work of WPs 3, 4, 5, 6 and 7. The requirements are shown in Table 15, related to the work packages that will carry out the work, and the innovation topics involved.

IDEF0 diagrams have been developed to show in a formal way the functional flow of the timetable planning and traffic control processes. These are shown in Figures 4 to 31 inclusive. High level system diagrams have also been produced to show the interfaces between infrastructure managers and railway undertakings throughout the timetable and traffic control processes. These are shown in Figures 1 to 3 inclusive.

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