Optimal Networks for Train Integration Management across Europe

Executive Summary:
The overall aim of the ON-TIME project was to improve railway customer satisfaction through increased capacity and decreased delays for passenger and freight trains. The ON-TIME project developed new methods, processes and algorithms that will enable railway undertakings to significantly increase the available capacity.

ON-TIME has been delivered by a multi-disciplinary team of 19 partners consisting of Railway Infrastructure Managers, Industry / Supply Chain Companies, SMEs and Academia.

The ON-TIME project has developed new methods and processes to help maximise the available capacity on the European railway network and to decrease overall delays in order to both increase customer satisfaction and ensure that the railway network can continue to provide a dependable, resilient and green alternative to other modes of transport. In the project, specific emphasis was placed on approaches for alleviating congestion at bottlenecks. Case studies considered included passenger and freight services along European corridors and on long distance main-line networks and urban commuter railways. Current best practices were identified and developed by examining national projects previously carried out by railway undertakings.

A key emphasis throughout this project was that the innovations developed should be implementable to solve real-life problems. The key outputs of the project are six innovations in the area of railway planning and operations management. These are:

Innovation 1: The development of standardised definitions and methods that can be used to create interoperable processes and tools that facilitate consistent, standardised and cross-border planning and real-time traffic management.

Innovation 2: The development of improved methods for timetable construction that are robust to perturbations and resilient to statistical variations in operations.

Innovation 3: The development of algorithms to either automatically provide control or provide decision support to controllers, to mitigate minor disturbances in railway operations.
Innovation 4: The development of methods, processes and algorithms that provide decision support when events occur that require changes to the disposition of assets and resources, potentially across multiple networks, undertakings, operators and/or countries.

Innovation 5: The development of standardised, interoperable approaches for the communication and presentation of information to drivers and controllers in order to present the right information at the right time in a clear and consistent form.

Innovation 6: The development of an information architecture to support the communication of standardised and contextualised train control data in order that information can be exchanged between actors (operators, undertakings, networks, countries).

Project Context and Objectives:
The overall aim of the ON-TIME project was to improve railway customer satisfaction through increased capacity and decreased delays for passenger and freight trains. The ON-TIME project developed new methods, processes and algorithms that will enable railway undertakings to significantly increase the available capacity. The ON-TIME was delivered by a multi-disciplinary team of 19 partners consisting of Railway Infrastructure Managers, Industry / Supply Chain Companies, SMEs and Academia.

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The objectives of the ON-TIME project have been:
1. To improve management of the flow of traffic through bottlenecks to minimise track occupancy times. This will be addressed through improved timetabling techniques and realtime traffic management.
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.
3. To reduce overall delays and thus service dependability through improved traffic management techniques that can recover operations following minor perturbations as well as major disturbances.
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.
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.
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.
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.
8. To provide a means of updating and notifying actors of changes to the timetable in a manner and to timescales which allow them to use the information in effective way.
9. To increase overall transport capacity by demonstrating the benefits of integrating planning and real-time operations, as detailed in Objectives 1-8.

The take up of the ON-TIME innovations would result in a step-change in railway capacity by reducing delays and improving traffic fluidity. These improvements will be delivered through innovations in principles, processes and tools in the following areas:

• Integrated Traffic Management, Optimised Timetables with Decision Support Tools and Automation: The ON-TIME project has developed improved methods of timetable construction that can be used for long term planning, for real time operating, and for replanning during disruptions (Innovations 2, 3 &4). This is done using the same processes and algorithms but applying different constraints (e.g. cost functions, operational constraints).
• Centrally Guided Train Operation (CGTO), Advanced DAS: CGTO uses closed-loop control to communicate control centre decisions which consider the operational situation to the train, and is the next step in driver advisory systems.
• Extended RailML standards, CAD based signalling plans electronically imported into railway operations simulator and Open source data architecture: The extended RailML standards developed by the ON-TIME project have been proposed to the UIC. The event-based architecture has been designed with open interfaces for use with the HERMES railway operations simulator and the traffic control systems from Ansaldo STS.
The ON-TIME innovations have been evaluated and demonstrated using a variety of complex problems present across the European rail network:

- Sweden, Iron Ore Line
- United Kingdom, East Coast Main Line
- The Netherlands, corridors through s’Hertogenbosch
- Italy, Bologna Node

Project Results:
The key outputs of the project are six innovations in the area of railway planning and operations management. These are:

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INNOVATION 1: STANDARDISED DEFINITIONS AND METHODS TO CREATE INTEROPERABLE PROCESSES

State of the art
Before the start of the ON-TIME project, there was a lack of knowledge and documentation about underlying railway operations management processes for strategic planning, tactical planning, operational traffic control and train driving. There was also a lack of methods to connect the timetable planning and operational traffic control processes. In the project plan this was divided into WP3: timetable planning, WP4: methods for minor perturbations, WP5: major disruptions and RU asset management and WP6: train driver advisory systems (DAS) (see Figure 1).

To estimate available capacity, the number of possible train paths and robustness of the system, IMs have common methods. The UIC 406 method outlines how track occupancy can be calculated. For traffic simulation, some commercial tools are available, which are used by the infrastructure managers. Traffic simulation is used to analyse and help the planners to provide quality in the timetable.

There is also a need to simulate the operational process. In the ON-TIME project a simulator system, HERMES, has been used and a demonstrator system has been developed by Ansaldo. Another future need is to have common procedures for IMs, RUs and Industry to share and exchange data.

In ON-TIME, data has been transferred from traffic simulation systems operated by IMs to the simulator HERMES and the demonstrator developed by Ansaldo and NTT Data. RailML is a standard system for transferring data.

Research aims and objectives
The main objective was to give a process framework for timetable planning and operation, to demonstrate how innovations could be implemented into practice and how we can measure the benefits of innovations. The improved methods in timetable planning and decision support in traffic control and train driving will:

- decrease track occupancy in bottlenecks
- improve punctuality
- improve energy efficiency

A second objective was to outline a framework for future research in timetable planning, methods for handling minor perturbations, major disruptions and train driver advisory systems.
Research outputs

The key outputs related to Innovation 1 have been:

1. Functional process descriptions for United Kingdom, Sweden, Germany, Italy, Netherlands and France.
2. State of the art studies and review of present technology readiness level (TRL) for traffic planning and timetabling (WP3), traffic control under minor perturbations (WP4), operational management in the event of large disruptions (WP5), and driving advisor systems (WP6).
3. Capability requirements of ON-TIME innovations. 1: Standardised definitions and methods to create interoperable processes, 2: Improved methods for timetable construction, 3: Decision support for traffic controllers to handle minor perturbations, 4: Development of methods and algorithms to handle major perturbations, 5: Standardised communication between traffic controllers and train drivers, and 6: IT architecture and standards for train control data.
4. Specifications for ON-TIME workpackage integration and interaction, see Figure 2. Traffic control handling large events needs RU decisions.
5. Specification of locations and scenarios for ON-TIME simulator system and demonstrator system.
   b. United Kingdom, East Coast Main Line, double and multiple track line.
   c. Italy, Bologna station, node with many merging lines.
   d. Netherlands, Corridors through s’ Hertengenboersch, network, complex node.
2. The Netherlands network was imported to HERMES from network data in RailML. The Iron ore line was imported to HERMES from a RailSys model.
6. Simulations have been performed, and the developed systems for solving perturbations and disruptions in the different scenarios have been evaluated.
7. Using the demonstrator system, the different scenarios have been further studied and the results visualized using graphical interfaces.
8. Specification of a strategy for putting methods into practice, including guidelines for a deployment process.

Future tasks

The ON-TIME project has connected timetable planning and decision support for the operational process:

• Infrastructure managers and system suppliers need to develop methods to export and import data with de facto standards as RailML.
• There is a need for continuing algorithm development and integration to provide decision support tools for Railway Operations.
• There is a need for further development of interactive solutions, i.e. systems where human traffic controllers can interact with the decision support tools developed in ON-TIME.
• There is a need of further research in timetable planning, methods for handling minor perturbations, major disruptions and train driver advisory systems. Further research will be done in EU projects, i.e. Capacity4Rail 201310 – 201709.

Deliverables and results

D2.1 - Review of capacity restrictions, railway planning and operations, problem description and existing approaches (including state-of-the-art).
D2.2 - Approach and specification of system integration and demonstration.
D2.3 - Evaluation of innovations and demonstrators and a strategy for putting methods into practice.

INNOVATION 2: IMPROVED METHODS FOR TIMETABLE CONSTRUCTION

State of the art

The scientific literature on railway timetabling mainly considers macroscopic optimisation models without concern for how to get accurate input parameters to set up the macroscopic model. On the other hand, the railway operations literature considers microscopic methods for calculating running times and blocking times given any infrastructure and signalling configuration, as well as microscopic methods for conflict detection and computing capacity consumption using timetable compression. The timetabling practice shows a similar separation, with either macroscopic models to compute network timetables using normative input, or microscopic blocking-time based tools for detailed planning on corridors and at stations, but without support for network optimisation. Timetable evaluation on feasibility, stability or robustness is typically applied – if at all – after the timetable construction using simulation tools with unclear procedures as to how the results are used to improve the timetable design.
Research aims and objectives
The key objectives of the ON-TIME project in this area of robust and resilient timetables were to develop methods to reduce overall delays through the use of improved planning techniques that are able to provide better timetables capable of coping with normal statistical variations in operations, as well as minor perturbations. The research has specifically focused on the development of robust and resilient timetables, i.e. timetables that are able to cope with variations that occur every day and are designed to be easily recoverable in the event of incidents or disturbances.

Research outputs
The key outputs related to Innovation 2 have been:
1. The development of common railway timetabling and capacity estimation methods appropriate for use by all EU member states that reflect customers’ satisfaction and enable interoperability, more efficient use of capacity, higher punctuality and less energy consumption;
2. Further development of methods for robust cross-border timetables and integration of timetables between different regional and national networks improving interoperability and efficient corridor management including standardised approaches for exchanging timetable information between stakeholders;
3. Improved timetable quality, stability, robustness, reliability and effectiveness;
4. Validated development methods, through benchmarking, using a number of standard, real-world case studies.

Implementation tasks
ON-TIME developed a classification of Timetabling Design Levels depending on the explicit incorporation of performance measures in the timetable design process with increasing performance with respect to dealing with delays and disturbances.

The Timetabling Design Levels (TDL) are as follows:
• TDL 0 (Low quality). No conflict detection nor stability analysis is incorporated in the design process leading to poor timetables unless traffic is very low;
• TDL 1 (Stable). Stability analysis is an integrated part in the timetabling process so that the time allowances are proven to have good delay absorption behaviour for minor perturbations;
• TDL 2 (Feasible). Both conflict detection and stability analysis are incorporated in the design process resulting in proven conflict free and stable timetables so that trains will run undisturbed in normal traffic;
• TDL 3 (Robust). Robustness analysis is incorporated in the design process on top of conflict detection and stability analysis, resulting in proved robust timetables that can cope with normal statistical variations in operations;
• TDL 4 (Resilient). Rescheduling measures are taken into account in the timetabling design process resulting in flexible timetables that enable efficient rescheduling in a late (ad-hoc) stage of the timetabling process or in real-time traffic management to deal with larger perturbations.

An innovative three-level timetabling design approach has been developed as a prototype path to the highest Timetabling Design Levels 3 or 4 (see Figure 3). This performance-based timetabling process approach takes timetabling KPIs explicitly into account, including feasibility, infrastructure occupation, stability, robustness, resilience, travel times and energy efficiency. The approach contains three levels:
1. Microscopic for highly detailed local computations;
2. Macroscopic for aggregated network optimisation; and
3. Fine-tuning for corridors.

Feasibility and stability are guaranteed by microscopic blocking time models, which feed a macroscopic model that optimises the timetable at the network level incorporating a Monte Carlo stochastic simulation model for robustness evaluation. These two levels iteratively compute a robust conflict-free and stable timetable. The fine tuning level computes energy-efficient speed profiles and optimises the timetable of the local trains on the corridors between main stations using stochastic optimisation with respect to dwell time distributions and energy consumption. This represents a sustainability dimension on top of the performance with respect to delays and disruptions.

This timetabling framework can be used to find optimal cyclic and non-cyclic timetables. Resilience is taken into account with respect to scheduling ad-hoc freight paths. The timetabling algorithms allow inserting additional (freight) train paths whilst sufficient residual
capacity must be reserved to guarantee that a stable conflict-free timetable can be found. The freight paths are specified in a multilayer freight path catalogue with various maximum speed paths (e.g. 80/100/120 km/h) on specified corridors. Depending on the maximum speed of a requested freight path, the passenger timetable might have to be adjusted slightly to maintain a conflict-free timetable. This procedure allows a multilayer timetable with a basic passenger timetable and additional freight paths of different speeds to be selected from a catalogue on a first-come-first-served basis.

The key academic work that has been undertaken is:
- Development of micro-macro network transformations;
- Microscopic conflict detection and capacity consumption;
- Macroscopic network timetable optimization including stochastic robustness evaluation;
- Computation of energy-efficient speed profiles;
- Stochastic optimization of optimal energy-efficient timetables on corridors between main nodes.

Moreover, the various timetabling processes have been implemented and integrated into an overall architecture, including microscopic running time calculations and conflict detection, macroscopic timetable optimisation, energy-efficient speed profile computations and timetable performance evaluation. The algorithms work for standard RailML input and deliver a RailML timetable at microscopic level, including energy-efficient speed profiles.

Case Study
The methods have been applied to a high-capacity mixed-traffic network around the railway node at Hertogenbosch in the Netherlands, including the synchronized corridors Utrecht – Eindhoven and Tilburg - Nijmegen. The network includes intercity and local trains (Sprinters) and freight trains. The high infrastructure occupation on the Utrecht – Eindhoven corridor is particularly challenging for designing conflict-free and robust timetables. Moreover, the frequencies will be increased even more in the Programme High-frequent Rail. It will be a challenge to maintain stability at these high frequencies for mixed-traffic (requiring good timetables and real-time traffic management) and deal with large disturbances. This network has been used in order to demonstrate the ability of innovative timetabling processes to construct conflict-free robust and energy efficient timetables. The Dutch demonstration also integrates real-time traffic management systems to deal with delays and operations management of big disruptions, integrating rescheduling of train paths, rolling stock and crews.

The ON-TIME timetabling approach was applied to the Dutch case study and the resulting timetable was tested and evaluated using the HERMES simulation tool, showing improvements on all performance indicators (see Figure 4 and 5).

Deliverables and Results
D3.1 - Methods and algorithms for the development of robust and resilient timetables
D3.2 - Benchmark analysis, test and integration of selected timetable tools.

INNOVATION 3: REAL-TIME TRAFFIC CONTROL ALGORITHMS

State of the art
For many years, algorithms for real-time conflict detection and resolution have been described in the scientific literature. Only recently have these algorithms been able to solve problems of practical relevance in real-time. They are, however, still not applied in daily operation in large railway networks for two main reasons:
1. The benefit of the algorithms is difficult to predict.
2. Operational traffic control systems (TCSs) currently in operation by nationally-acting railway infrastructure managers are not easy to extend.

In order to change this, the project defined and tested a flexible system design for railway traffic management based on extensible interfaces. This will lead to a situation where hardware equipment installed on the track-side remains usable for long periods of time, but software optimisation components and hardware used for non-safety-critical calculations, such as traffic management, can easily be exchanged and extended depending on the current and future state of the art.

Research aims and objectives
The objective of this part of the project was to develop a framework for a modular traffic management system (Perturbation Management Module), where independent modules collaborate.
Therefore, methods and tools for real-time traffic state monitoring and prediction, conflict detection and resolution, including train speed optimization, had to be developed or expanded to fulfill the requirements of this modular architecture (see Figure 6).

Research Outputs
The Perturbation Management Module (PMM) can be divided into four main sub-modules that allow traffic to be effectively managed in real-time when perturbations are observed in the network (see Figure 7).

The first sub-module is the so-called Traffic State Monitoring (TSM) module, which is responsible for monitoring current traffic conditions by collecting, via track-side and train-side sensors, all the information relating to both the traffic and the infrastructure.

The second sub-module is called Conflict Detection and Resolution (CDR) and represents the most important part of the PMM. It is triggered cyclically in normal operating conditions and firstly involves a call to the Traffic State Prediction function, which forecasts the state evolution of traffic (positions, speeds of trains) within a certain time period ahead called the “prediction horizon”. If conflicts exist, the Track Conflict Resolution function is executed, which computes a new Real-Time Traffic Plan (RTTP). This RTTP is used to derive route setting commands (Automatic Execution of the Real-Time Traffic Plan).

The third sub-module is the Train Path Envelope Computation (TPEC) that aims to identify the time allowances available in real operation that can be exploited by a train to adopt an energy-saving driving strategy without running late with respect to the timetable.

A fourth sub-module is the Human-Machine Interface (HMI), which is focused on giving real-time information to the operators (dispatchers, traffic controllers) by a screen visualization of the current traffic state, e.g. through a schematic infrastructure view, as well as the predicted traffic state from the RTTP, e.g. through the so-called train graph (time-distance diagram).

Implementation tasks
The separation of tasks into different modules has proven to be feasible. The obtained solution has been designed to work on general cases. However, it turned out during experiments that the update processes, in particular of the real-time traffic plan as core object of real-time traffic management, need to be defined more specifically in order to become more robust. To allow better predictions of traffic and more information about train behaviour, interlocking and ATP rules need to be available; this would require further extensions in the data modelling. For continuing development, simulation engines need to be developed with an open architecture similar to the one proposed in the project, in order to enable testing of smaller modules. The most critical success factor of the algorithms in WP4 is a correct supply of static and dynamic data.

For a real-world implementation, comprehensive processes for data management first need to be established by the railway infrastructure managers (e.g. concerning data changes, construction work, timetable changes). These update processes must then be considered for real-time traffic management.

Case study
The East Coast Main Line (ECML) in the UK is a complex and busy corridor linking London with the North East (see Figure 8). There is mixed traffic, consisting of commuter routes, two long distance intercity routes and key freight paths. The ECML has been the test location for GB Rail investigations into the application of Traffic Management (TM) and ERTMS. This route has been used as one of four test cases for the management of small perturbations.

One algorithm applied for real time traffic management on the ECML is the Differential Evolution Junction Rescheduling Model (DEJRM) developed by The University of Birmingham. It optimally reschedules train timings at junctions in the event of minor perturbations.

The capability of the DEJRM is demonstrated by its application to ECML delay scenario 4, described below.

- Time period: From 7am to 10am on a weekday
- Description: Signal SIG2764 fails at 7:16:00 until 7:23:00, causing a passenger train (light blue line in Figure 9) to be delayed, which results in a conflict with a freight train (yellow line in Figure 9) at approximately 7:25:00am at the junction to the ECML. A number of trains are also affected at Finsbury Park station.

Deliverables and results
D1.2 - A framework for developing an objective function for evaluating work package solutions (Cost function)
D1.3 - Best practice, recommendations and standardisation
D2.1 - Review of capacity restrictions, railway planning, problem description and existing approaches
D2.2 - Approach and specification of system integration and demonstration
D2.3 - A strategy for putting methods into practice and a formal evaluation of demonstrators
D4.1 - Functional and technical specification of perturbation management module
D4.2 - Tools for real-time perturbation management including human machine interface
D4.3 - Benchmark analysis for algorithms, methods, human machine interfaces using simulator tests
D7.3 - Service-oriented architecture with integrated software artefacts

Additionally, the following software modules have been developed or extended in the project:
- Traffic State Monitoring by TU Dresden
- Traffic State Prediction: modules by TU Dresden and Transrail
- Conflict Detection and Resolution: DEJRM (University of Birmingham), RECIFE (IFSTTAR), ROMA (TU Delft), University of Bologna
- Automatic Execution of real-time traffic plan: TU Dresden
- HMI: Ansaldo

INNOVATION 4: IMPROVED DECISION SUPPORT - HANDLING MAJOR PERTURBATIONS

State of the art
Recovering from a disrupted situation to a feasible state in the network requires railway operators to perform changes in the timetable such as cancelling, rerouting or re-timing trains, changing the order of departure at stations, maintaining or dropping connections between trains, and also to perform reallocation of rolling stock and changes in crew schedules (see Figure 10).

Various forms of objective functions are considered, which focus mainly on minimizing customer dissatisfaction by minimizing deviations from the intended timetable or minimizing expected delays.

Further objectives include minimizing deviations from the original rolling stock allocation plan, as well as costs related to the rescheduling and cancellation of crew tasks. This recovery problem is very complex and needs to be solved in real-time; it is therefore often heuristically solved manually by the railway operators or by using fast combinatorial optimization algorithms. Furthermore, the problem is usually split up into three main phases that may be defined as timetable rescheduling, rolling stock rescheduling and crew rescheduling.

The timetable rescheduling problem is solved with a list of emergency scenarios. However, there is no emergency scenario available when several disruptions occur at the same time. A combination of contingency plans has to be used in such cases. This is often done in a non-automatic way, by using the experience of the practitioners, especially when large disruptions occur, such as the unpredictable unavailability of some tracks or train failure or line fault leading to a complete closure of the line.

Most current solutions deal with a single rescheduling phase. There are just a few approaches that integrate two phases, namely either timetable and rolling stock rescheduling, or timetable and crew rescheduling. One research goal of ON-TIME was to work on further integration of the three main rescheduling phases (timetable, rolling stock and crew rescheduling).

Research aims and objectives
The main objective of Innovation 4 was to focus on traffic changes and resource management strategies to deal with large scale disruptions (see Figure 11). These objectives were:
1. To design and validate effective intelligent decision support strategies and tools for the optimal human supervisory control of the recovery processes in case of a large disruption.
2. To evaluate the state-of-the-art in optimisation algorithms strategies and stakeholder processes and information flow for managing large scale disruptions;
3. To specify the integration of the real-time traffic and asset management procedures, optimisation models and tools;
4. To develop algorithms for resource management in the case of a large disruption;
5. To design and validate effective intelligent decision support strategies and tools for the optimal human supervisory control of the recovery processes in case of a large disruption.
Research outputs
The key outputs related to Innovation 4 have been:
1. State-of-the-art of recovery algorithms for real-time railway optimization.
2. Questionnaire on best practices for modes of human-automation co-operation and monitoring state of resources put in use in case of railway disruptions, from the point of view of the infrastructure managers involved in ON-TIME.
3. A human factors study with structured interview method to determine a set of representative incidents and to analyze the processes associated with the incidents, and the decisions and strategies required to mitigate their impact.
4. Elicitation of a generic workflow of the recovery process with SysML activity diagrams (see Figure 10).
5. Design of a tool with a framework that consists of a closed loop in which each rescheduling phase (i.e. timetable, rolling stock and crew rescheduling) is solved by an efficient algorithm to find a good feasible solution and gets feedback from the other phases in order to obtain a good feasible solution for the whole system (see Figure 12).
6. Benchmarking of the tool developed within a distributed architecture in the case of a disruption scenario in the Dutch network.

Case study
The case study area is an important part of the Dutch railway network (see Figure 4). The network is bounded by Utrecht Centraal in the northwest, Tilburg in the southwest, Eindhoven in the southeast and Arnhem in the east. On this network, about 90% of the trains are domestic passenger trains operated by Nederlandse Spoorwegen (NS). The case study only considered the timetable, rolling stock and crew schedule of these trains.

Disruption scenarios considered were:
1. Accident with a person near Rosmalen in the morning peak. As a consequence no train traffic is possible for 3 hours between Den Bosch and Oss. Passengers from s’Hertogenbosch to Nijmegen can use the bus or travel via Utrecht and Arnhem.
2. Signalling problems near Culemborg. As a consequence no train traffic is possible for 2 hours between Utrecht and Geldermalsen. Passengers and/or trains moving from north to south (Utrecht–s’Hertogenbosch–Eindhoven) can travel through Arnhem.

Since these disruptions have an impact on the whole Dutch railway network, the algorithms for timetabling (at a macro level), rolling stock and crew rescheduling also need data for the rest of the schedule of domestic trains. The main assumption is that in the remainder of the country, all trains run on time. Our experimental results show that the disruption management module computes feasible resource schedules in a couple of minutes. Such solution times are acceptable in practice. This shows that our iterative algorithm can be applied in a practical setting for the disruption management process.

Deliverables and results
D5.1 - Functional and technical requirements specification for large scale perturbation management
D5.2 - Decision support tools for the optimal human supervisory control of the recovery processes
D5.3 - Analysis of the benchmarking

INNOVATION 5: CENTRALLY GUIDED TRAIN OPERATION (CGTO)

State of the art
Prior to the start of the ON-TIME project some Infrastructure Managers and Train Operators had already performed significant research activities and tests on communication of control centre decisions to train drivers. However, only one control-centre-connected system in an operationally specific area had been applied to real operations.

On the other hand the use of driving advisory systems (DAS) disregarding current operational conditions has increased in recent years. Notwithstanding the great progress in DAS, the consideration of current operational conditions has remained an open issue.

The high interest of Infrastructure Managers, Train Operators and the Railway Industry in developing driving advisory systems with control centre connection went together with the need to agree on common standards of communication to ensure interoperability and prevent different developments leading to a wide range of incompatible systems within the European railway network.

Research aims and objectives
The main objective is to prove the concept of communicating driving advice in a DAS based on control centre decisions, leading to smoother traffic flow in order to:

- decrease track occupancy in bottlenecks;
- increase energy efficiency.

To allow the interoperable use of DAS throughout Europe the second objective is to propose a standardised data format for communication of operational decisions (e.g. speed advice) between control centres and trains.

Research outputs
The key outputs related to Innovation 5 have been:

1. State of the art analysis of 22 DAS (most of them not operational), of which only 8 are control-centre-connected, leading to the identification of key functions (see Figure 13). Based on existing experiences, three design alternatives distributing these functions differently between control centre and on-board components have been analysed and described as system architectures:
   - DAS-C: mainly central intelligence
   - DAS-I: distributed intelligence
   - DAS-O: mainly on-board intelligence
2. Specification and implementation of an XML-interface data format supporting all three system architectures mentioned above and enabling bidirectional communication between central and on-board components.
3. Enhancement of existing algorithms for optimising train speed profiles (trajectory computation) to match the time constraints set by control centre decisions.
4. Evaluation of different methods to present advice to drivers (e.g. speed vs. time targets) based on simulator studies and expert interviews, examination of useful contextual advice (e.g. icons displaying the reason for advice) and experimental implementation of the proposed HMI design (see Figure 14).
5. Implementation of a demonstrator for all components, calculating and displaying driving advice based on control centre decisions.

Implementation tasks
In order to apply Centrally Guided Train Operation in real operations these steps should be followed after the end of the ON-TIME project:

- Infrastructure managers have to upgrade their Traffic Management Systems to support driving advice (e.g. to collect the operational data required and generate target points) and set up a communication server with the specified interface.
- Train operators and industry have to include the specified interface in existing or newly developed DAS and enhance internal algorithms to consider targets set by control centre decisions in their calculation. Optionally, enabling the communication of current train data back to the control centre could further increase the quality of control centre decisions.
- Standardisation of the specified interface should be taken forward.

Deliverables and results
D6.1 – Specification of a driving advisory systems (DAS) data format. A Java-library for integration of XML-IF in existing Java software
D6.2 – Sample Human Machine Interface (HMI)

INNOVATION 6: STANDARDISED ICT ARCHITECTURE SUPPORTING INTEROPERABILITY OF OPERATIONAL DATA BETWEEN INDUSTRY STAKEHOLDERS

State of the art
The increasing availability of distributed system architecture paradigms and messaging protocols has given information system designers the freedom to develop feature-rich software systems. The management of railway operations is an ideal candidate application domain for the use of these architectures, because of the geographical distribution and multi-stakeholder nature of most railway networks.

The ON-TIME Project proposes a distributed architecture to integrate different algorithms to solve typical problems in railway operations, such as timetable planning, dynamic re-planning of services at macroscopic and microscopic levels following disturbance, resource management and rostering. Since it would be unfeasible to create a system capable of substituting current Train Management Systems, the purpose of the ON-TIME architecture is to complement Train Control Systems extending their functionalities with a new layer of algorithms and real-time solutions to cope with the usually static planning of Train Control Systems.
They key-purpose of the architecture definition is to define a distributed, configurable and flexible infrastructure to exchange data and messages between different modules. The advantage of using a distributed architecture in this context is the ability to collect and exchange data on systems that are by their own nature loosely coupled and create a coherent, dynamic communication context in which these information can be exchanged.

Data and technical standards must be implemented in order to easily integrate a collection of systems and to represent data in a way such that regional differences between neighbouring systems will have a small impact on the communication semantic. Since most European countries have different processes and data standards, a common data representation is needed. In line with EU open data policy, common standards must be used to encourage the adoption of the platform and to implement a uniform data representation that will supersede specific regional requirements.

Another key aspect is to treat modules as services that can be queried and interacted by other systems and users. This is a very important aspect of distributed systems: each functional module should be black-boxed and self-sufficient, to be easily replaced by another implementation using the same modular framework.

As it is paramount for real-time operational systems to have data consistency and to avoid synchronization issues, seeing systems as services opens the possibility to abstract their data as services as well.

Research aims and objectives
From an ICT perspective, the ON-TIME project aimed to deliver a modular, service-based, distributed processing architecture for use in the rail domain. The architecture would facilitate the integration of diverse ICT systems from around the industry by exposing a range of data integration algorithms via a standard communications interface.

The basic architectural principles defined by the ON-TIME team were:
• Modularity – Every element of the ON-TIME system should be a black box encapsulating a single function. Module abstraction would allow easy substitution of differing implementations of each functional unit, encouraging competition between module providers and facilitating user choice.
• Extensibility – Open and extensible software paradigms would be adopted, freeing developers from dependencies on particular programming languages and allowing the ON-TIME architecture to evolve alongside the railway in future years.
• Distributed functionality – State-of-the-art protocols would be employed to allow the system to operate in distributed physical environments; a vital feature in the multi-stakeholder setting of the rail industry.
• Responsivity – Communication between different modules would be facilitated by the passing of event messages via the architecture, removing dependencies and allowing individual processing units to react to the changing environment of the operational railway.

Research outputs
The key outputs related to Innovation 5 have been:
1. The ON-TIME data dictionary was developed to help the project team identify the types and content of messages that may be required in the context of railway operations. It contains over 300 concepts relevant to the domain, along with definitions and mappings to the RailML data model as appropriate. In order to facilitate easy multi-site access to the resource, the dictionary was implemented as a wiki; this had the added benefit of enabling cross-references between entries to be embedded as hyperlinks, helping users to easily navigate between related entries.
2. The ON-TIME architecture can be seen in Figure 15. It consists of a collection of loosely coupled data providers and data processing modules that communicate via the passing of event messages. The architecture utilises a publish-subscribe communication pattern, allowing modules to join or leave the system at any time without interfering with the communications to other elements of the framework. The well-known open source RabbitMQ messaging platform has been used to provide this functionality. RabbitMQ runs on all major operation systems and clients can be written using a wide range of programming languages, including Java, .NET, Ruby, Python, Erlang, PHP and C/C++. This flexibility is vital to the wide-scale adoption of the ON-TIME architecture.

Real-time data is passed as events in near-real-time from the live rail network / rail network simulator to the traffic management modules; when disruptions occur re-planning takes place and new events informing stakeholders of updated traffic management plans / crew rostas etc. are raised within the system.
Non-real-time data used by ON-TIME (for example infrastructure data and the current timetable) are cached by the platform and provided via an on-demand, read-only public interface allowing it to be accessed as required by any system. By providing a single-source-of-truth for these key, largely static data resources, the ON-TIME architecture reduces the risk of inconsistencies arising between stakeholder systems.

ON-TIME module integration specification allows generic processing modules to be added to the ON-TIME framework through the implementation of a standard set of interfaces. In particular, the specification covers subscription to event queues, the production / consumption of event messages and access to static data resources.

For the representation of messages to be exchanged within the system, the ON-TIME team needed to make use of an open, extensible set of data models that aligned well with the terminology set identified in the data dictionary. A mapping was created between the dictionary terms and the RailML format which is rapidly gaining traction within the industry, and the degree of overlap between the two established. The coverage of the ON-TIME data dictionary by the RailML model was good, with only a few gaps found. These included information on Interlockings, ETCS-type train control concepts, disruption information, crew duty assignments, and resource conflicts. Where gaps existed, project-specific data model extensions were created, and this work has included contributions back to the RailML community in the form of the candidate RailML interlocking model.

Deliverables and results
D7.1 - Library of data and communication models
D7.2 - Architecture specification & integration requirements

DEMONSTRATIONS
Benchmarking of simulations have been done for East Coast Main Line, Iron Ore line and Utrecht/Arnhem/Eindhoven network in the Netherlands.

Potential Impact:
POTENTIAL IMPACTS
The Infrastructure Managers involved have a key role to bring about the socio-economic benefit of the project. For example, in the UK, the project will aid NR in achieving the 4Cs targets (Capacity increase, Customer-satisfaction increase, Cost-decrease and Carbon-emission decrease). Discussions are ongoing with the timetabling section on how the results of the ON-TIME project can be implemented to create the new timetable to make better use of the Capacity. Customer satisfaction at RFI will be enhanced for example, with enhanced ability to provide Freight Operators with suitable information on freight routes when requested. These actions will take time but will bring about substantial and sustained improvements to the Railway.

On the other hand, the SMEs have provided job creation and new products. Below are listed in more detail the various impacts and which partner(s) will be involved.

Activity: HERMES further development
Partners: Graffica
Details: Development of demonstrators of the HERMES simulation tool for the UK, Italy, Netherlands and Sweden

Activity: Analysis services
Partners: Graffica
Details: New UK projects to support ETCS studies, GSM-R simulations and traffic management decision support

Activity: Job creation
Partners: Graffica
Details: Team increase in size by 6 people

Activity: Future collaborative European research
Partners: Network Rail, Trafikverket, Ansaldo, University of Birmingham
Technical University of Dresden
IFSTTAR
Details: Collaboration as part of the CAPACITY4RAIL FP7 project which will take forward some of the results of ON-TIME

Activity: Future collaborative European research proposal
Partners: Network Rail
Trafikverket
RFI
Ansaldo
University of Birmingham
Details: Collaboration as part of the IN2RAIL FP7 project proposal which will take forward some of the results of ON-TIME, if successful

Activity: Further development and standardisation of CTGO
Partners: Deutsche Bahn
Details: Move towards standardisation of driver advisory data exchange and human machine interfaces

Activity: Education and training material
Partners: University of Birmingham
Technical University of Delft
Details: Material incorporated into masters level teaching material. Demonstrators and case studies used for laboratories and student projects

Activity: Future national traffic management projects
Partners: Network Rail
Details: The results of the ON-TIME project will directly feed into the East Coast Main Line traffic management, and the subsequent national roll-out of traffic management throughout Britain. The results will also feed into the ‘Digital Railway’ initiative that have been launched by Network Rail.

Activity: Uptake of RailML extensions
Partners: Network Rail
RFI
NTT Data
University of Birmingham
Details: Early use, and in-service verification of RailML extensions

Activity: Automation of signalling diagrams
Partners: RFI
Details: Using the RailML simulation definitions to automatically create site layouts, including signalling design

Activity: Improved timetabling methods:
Partners: Trafikverket
Details: Updating of timetable development processes to incorporate the state-of-the-art practices developed in the ON-TIME project.

Activity: Future integrated research demonstrators
Partners: Network Rail
Trafikverket
Ansaldo
Details: Demonstration of research outputs from ON-TIME integrated with other project outputs as part of SHIFT2RAIL

MAIN DISSEMINATION ACTIVITIES
During the project dissemination activities have included:
• Development and maintenance of a public website to disseminate results of the project to those outside the project;
• Presentations to industry representatives and government agencies;
• Trade magazine articles and academic journal papers;
• Presentation at conferences, including the organisation of special sessions at conferences and specific workshops;
• The preparation of a series of fliers and project leaflets that have been distributed at various events and also uploaded to the public website;
• The participation in trade show events;
• Project specific events held to present the project’s progress and results at a European level.

EXPLOITATION OF RESULTS
The exploitation of the results of the project will be based around the six innovations developed during the project, namely:
• Innovation 1: The development of standardised definitions and methods that can be used to create interoperable processes and tools that facilitate consistent, standardised and cross-border planning and real-time traffic management (WP1 and WP2).
• Innovation 2: The development of improved methods for timetable construction that are robust to perturbations and resilient to statistical variations in operations (WP3).
• Innovation 3: The development of algorithms to either automatically provide control or provide decision support to controllers, to mitigate minor disturbances in railway operations (WP4).
• Innovation 4: The development of methods, processes and algorithms that provide decision support when events occur that require changes to the disposition of assets and resources, potentially across multiple networks, undertakings, operators and/or countries (WP5).
• Innovation 5: The development of standardised, interoperable approaches for the communication and presentation of information to drivers and controllers in order to present the right information at the right time in a clear and consistent form (WP6).
• Innovation 6: The development of an information architecture to support the communication of standardised and contextualised train control data in order that information can be exchanged between actors (operators, undertakings, networks, countries) (WP7).

Figure 16 shows how the innovations are being taken forward to be exploited following the project.

The parties involved in the exploitation, and potential impact of the innovations are as follows:

Innovation 1 – Standardised definitions and methods
Main technology developers – Birmingham, Uppsala, Trafikverket, Network Rail, RFI, SNCF
Exploitation partners – Network Rail
External commercial exploitation – N/A
Target market – Railway infrastructure managers

Innovation 2 – Improved methods for timetable construction
Main technology developers – Delft, EPFL, Dresden, Bologna
Exploitation partners – Network Rail, RFI, Trafikverket
External commercial exploitation – Delft, Ansaldo
Target market – Railway infrastructure managers
Impact – Reduction in overall network delays through improved planning techniques that provide robust and resilient timetables capable of coping with normal statistical variations in operations and minor perturbations.

Innovation 3 – Algorithms for controllers
Main technology developers – Dresden, Delft, Bologna, IFSTTAR, Birmingham
Exploitation partners – SNCF, Network Rail, Trafikverket, RFI, Graffica, Transrail
External commercial exploitation – Ansaldo
Target market – Traffic management suppliers and infrastructure managers
Impact – Reduction in overall delays and thus service dependability through improved traffic management techniques that can recover operations following minor perturbations. Improved management of the flow of traffic through bottlenecks to minimise track occupancy times.
Significant increase in competitiveness of traffic management suppliers.
Innovation 4 – Decision support for disposition of assets and resources
Main technology developers – IFSTTAR, Delft, Bologna, Nottingham, Uppsala, ERASMUS
Exploitation partners – Trafikverket, Network Rail, Ansaldo
External commercial exploitation – Ansaldo
Target market – Traffic management suppliers and infrastructure managers
Impact – Reduction in overall delays and thus service dependability through improved traffic management techniques that can recover operations following major perturbations. Significant increase in competitiveness of traffic management suppliers

Innovation 5 – Approaches for presenting information
Main technology developers – DB, EPFL, Nottingham, Delft
Exploitation partners – Network Rail, DB
External commercial exploitation – DB
Target market – Rolling stock manufacturers and railway infrastructure managers
Impact – Improvement 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.

Innovation 6 – Information architecture
Main technology developers – ValueTeam, Birmingham
Exploitation partners – ValueTeam, RFI
External commercial exploitation – ValueTeam
Target market – Rolling stock manufacturers and railway infrastructure managers
Impact – Providing an underlying enabling capability that is able to support future traffic management and operational decision making innovations

List of Websites:
One of the key dissemination mechanisms for the project has been the project website. The ON-TIME website can be found at: http://www.ontime-project.eu; a screenshot of the front page is shown in Figure 17.

The project website details information about the project and its partners. All public deliverables are freely available to download from the website, and users from outside the project can register with the website to receive e-mailed notifications of events and updates. From 1st November 2011 to 31st October 2014 (the period of the project) the website received 606,613 genuine hits with 26,851 visitors. As can be seen from Figure 18, the number of visitors has increased during the length of the project, peaking at the time the project’s final dissemination activities.

The website received a large number of visitors from around the world. The number of visits from the 10 most popular countries is shown in Figure 19.

192 individuals outside of the project consortium formally registered with the website from 26 different countries and 131 different companies. The location of the companies is shown in Figure 20.

The website will be made available for public users for at least a further 5 years. During this time further updates will be made to the website, as appropriate.