Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Analysis of European best practices and levels of automation for traffic management under large disruptions

Submission date: 14/11/2016

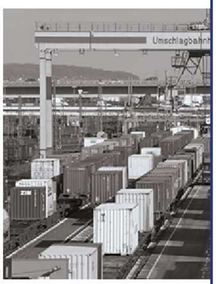
Deliverable 33.1

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605650







Collaborative project SCP3-GA-2013-60560
Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations
FP7-SST-2013-RTD-1

Lead contractor for this deliverable:

- IFSTTAR

Project coordinator

- International Union of Railways, UIC

Executive Summary

The work presented in this document analyses European best practices currently used in several member countries for managing railway traffic in case of incidents causing large service disruptions. Incidents might be due to sudden failures of the infrastructure (e.g. rail cracks, point failure, signals breakdown) or to external events such as extreme weather (e.g. floods, heavy snow). Current disruption management processes have been reviewed for United Kingdom, Spain, Czech Republic, Slovakia, Sweden, and France, providing a complete overview of how large incidents are tackled in different geographical locations of the continent. Each of these practices for disruption management has been then represented by means of formal models (SysML in particular) with the main objective of braking down the entire process in unitary activities so to identify those activities which are on the critical path and might improve the entire process if supported by automation. The use of formal models has also allowed a detailed comparison among practices of different countries so to spot similarities and differences with the intent of identifying a shared European practice for disruption management.

The use of different levels of automation within current practices has also been reported for several member countries, including possibilities for further development of technologies to increase levels of automation and make disruption management more effective.

As one of the main outcomes of this work, reliability and continuity of information exchange between traffic controllers and the incident location has resulted to be a common critical issue for all the countries involved in the study. This means that infrastructure managers across Europe envisage the use of technology to improve the communication between dispatchers and on-site staff to exchange reliable real-time information on current traffic conditions, state of the incident, progress of repairing/maintenance operations. Increasing levels of automation for an improved continuity and reliability of information is expected to consequently enhance the entire process of railway disruption management. The capability of predicting delay propagation to assess impacts of an incident and/or to evaluate different strategies of traffic recovery is also considered as relevant. Hence, increasing levels of automation in this case could be beneficial for the effectiveness of the entire disruption management process.

After a general introduction on traffic management processes currently in place across Europe, best practices are reviewed and represented in terms of formal scheme diagrams. These diagrams are defined following SysML guidelines. SysML is a standardized and open-source modelling language for system engineering, which allows specifying abstract system requirements, main system structures, activity flows and data exchanges. SysML also offers a visual representation which can be easily interpreted by readers with different backgrounds.

In this work SysML are used to enable the identification and description of high level requirements, structures and procedures which best capture the main features of disruption management processes currently in use across different European countries. Process formalisation paves the way

for a coherence analysis of disruption management processes by translating defined SysML diagrams into state graphs. A validation process is then implemented to validate the SysML diagrams versus the disruption management processes in place in UK, France, Sweden, Spain and Czech Republic.

A review is also provided on existing data formats which could be used in real operations to communicate real-time information about traffic conditions, railway infrastructure and incident status. Such data formats are in line with the study delivered on ubiquitous data in work package 3.4. A state-of-the art on levels of automation defined in IT systems in general and in railways in particular, has finally allowed the definition of current and envisaged levels of automation that will support critical traffic management activities in order to improve the entire process of disruption handling.

After providing a background of the project Capacity for Rail in Section 1, a description of current disruption management process is reported in Section 2. A distinction between small and large disruption management is initially proposed, following the distinction reported in the EU FP7-founded project ON-TIME. Then, two original contributions are provided. On one hand, a deep analysis of disruptions due to extreme weather is carried out referring to existing literature, best practices and case studies. On the other hand, observations of disruption management processes in use across different European countries are described.

Section 3 introduces a SysML formalisation of traffic management process under large disruptions. As mentioned, the basis for this formalisation is provided by the work previously delivered in work package 5 of the EU FP7 funded project ON-TIME. In this document, the disruption management process is considered in more detail, with a deeper investigation of several activities and a more careful analysis of human-machine interactions. Attention is also devoted to disruptions due to extreme weather events. Making use of results deriving from SP2 ("New concepts for efficient freight"), a section is dedicated to analysing how improvements envisaged for rail freight transport system may impact on the disruption management process. A discussion is then reported on how the capability matrix developed in work package 3.1 can be used to support disruption management process. This section then concludes with a validation of SysML disruption management processes by comparison versus actual processes used by several Infrastructure Managers across Europe.

Section 4 reviews literature on existing levels of automation for guided system, as a propaedeutic step for analysing automation used or envisaged for critical activities of the disruption management process. A detailed analysis on current and future levels of automation used for managing disruptions across Europe is performed in Section 5, including a review on capabilities of existing data structure identified by work package 3.4 that can help with improving reliability and continuity of information exchange during real-time disruption management.

Table of contents

Index of figures

Index of tables

Abbreviations and acronyms

Abbreviation / Acronym	Description
ATP	Automatic Train Protection
ARS	Automatic Route Setting
CRH	Conductor Rail Heating
CTA	Capability Trade-Offs Assessment
CTL	Computational Tree Logic
DMM	Disruption Management Module
EASA	European Aviation Safety Agency
EWAT	Extreme Weather Action Team
FOC	Freight Operating Company
GIS	Geographic Information System
HMI	Human-Machine Interface
IAc	Information Acquisition
IAn	Information Analysis
IM	Infrastructure Manager
IS	Information System
KPI	Key Performance Indicator
KRS	Key Route Strategy
NCI	National Control Instructions
NOC	National Operating Control
NOL	National Operative Leaders
NROCC	National Railway Operations Control Centre
OLE	Overhead Line Equipment
PMM	Perturbation Management Module
RIA	Railway Infrastructure Administration
RIO	Rail Incident Officer
ROC	Regional Operating Control
ROL	Regional Operative Leaders
RU	Railway Undertaker
RTTP	Real Time Traffic Plan
SA	Situation Awareness
SITT	Snow Ice Treatment Trains
TOC	Train Operating Company
TOCC	Train Operating Control Centre
TRS	Temporary Speed Restriction
TT	Timetable
VSTP	Very Short Term Planning
WERM	Washout and Earthflow Risk Mapping
WRCCA	Weather Resilience and Climate Change Adaption

1. Background

The CAPACITY4RAIL project is an EU funded industry lead initiative which tries to answer the question

"How to obtain an affordable, adaptable, automated, resilient and high-capacity railway; for 2020, 2030 and 2050?"

The aim of CAPACITY4RAIL is to provide an overall increase in railway capacity by developing a holistic view on the railway as a system of interacting technical components driven by customer demand. In order to best address this goal the project has been broken down into six sub-projects (SP) with several work packages and tasks (Figure 1-1):

- SP1 Infrastructure;
- SP2 New Concepts for Efficient Freight systems;
- SP3 Operations for enhanced capacity;
- SP4 Advanced monitoring;
- SP5 System assessment and migration to 2030/2050;
- SP6 Management, dissemination, training & exploitation.

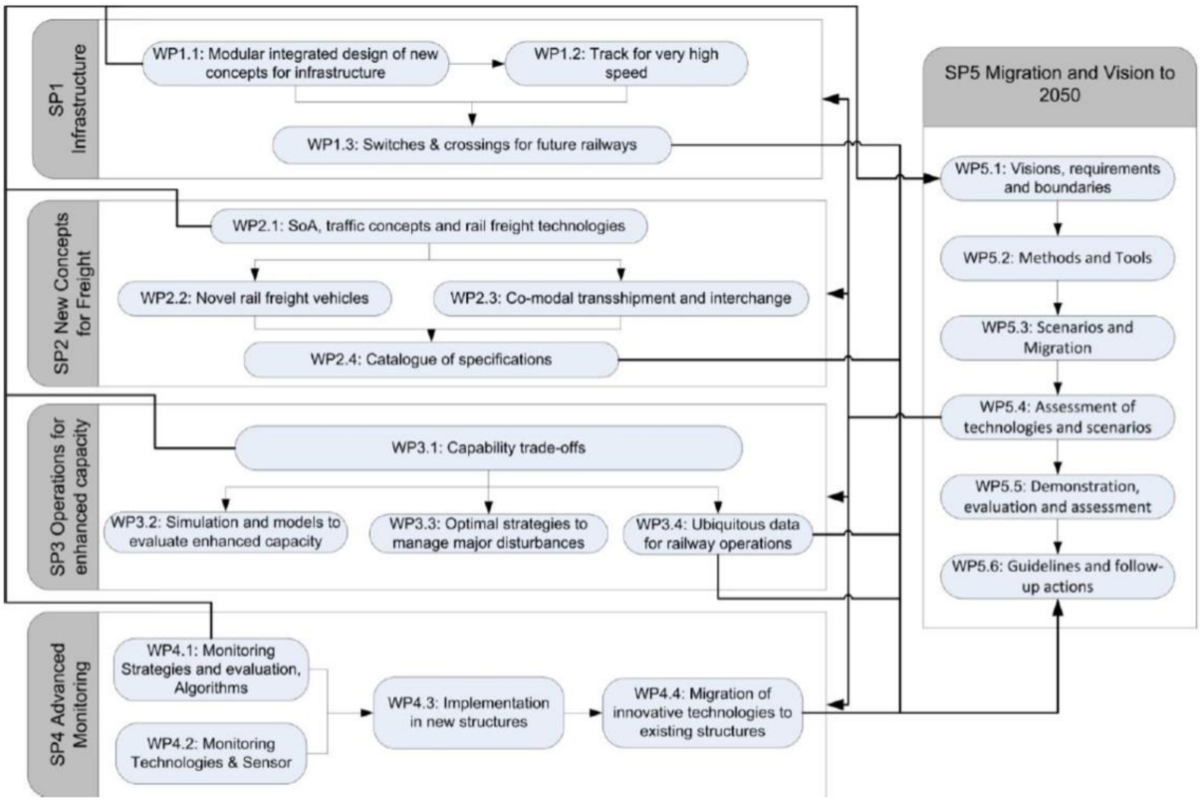


FIGURE 1-1 CAPACITY4RAIL STRUCTURE BREAKDOWN AND INTERACTIONS

SP3 "Operation for enhanced capacity" focuses on railway operations strategies that will increasingly use automation for optimised performance and enhanced capacity (Figure 1-2).

It highly refers to the previous FP7-project ON-TIME (Optimal Networks for Train Integration Management across Europe; 2011-2014; http://www.ontime-project.eu/) and reunites parts of the former core team with Infrastructure Manager of the UK (NR) and Sweden (TRV) as well as Research Institutes from France (IFSTTAR), Germany (TUD) and UK (UoB).

It will develop road maps for technology that will transform decision support systems into automated systems that enable the rail industry to meet the challenges of the future, such as high-speed freight and greater levels of transhipment between rail and other modes.

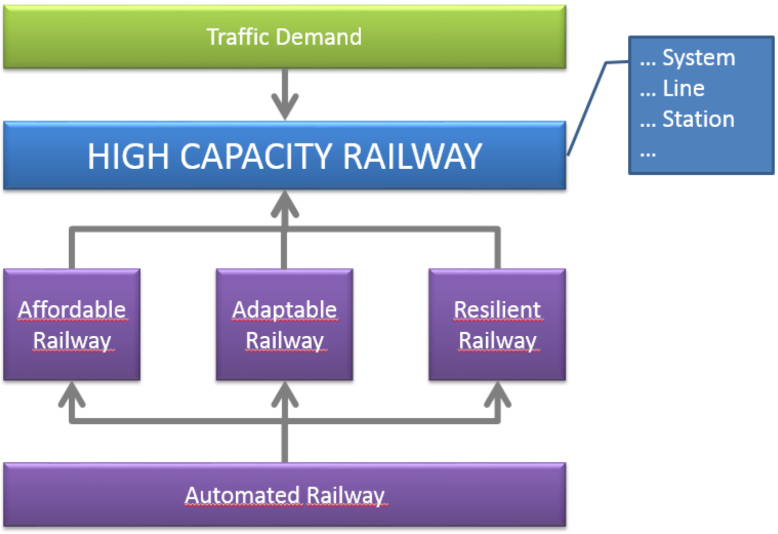


FIGURE 1-2 CAPACITY4RAIL STRUCTURE BREAKDOWN AND INTERACTIONS

The sub-project will deliver approaches that help planners to understand and prioritise system capabilities and decide on optimal strategies to: increase overall system capability; respond dynamically to planned and unplanned changes; and support real-time punctuality management. SP3 will deliver guidance documents for incident and contingency management including recommendations for the management of extreme weather situations. Furthermore, it will provide a roadmap for automation of traffic management systems. (CAPACITY4RAIL, 2013)

SP3 is divided into four work packages (WP):

- WP3.1 Capability trade-offs;
- WP3.2 Simulation and models to evaluate enhanced capacity (infrastructure and operation);
- WP3.3 Optimal strategies to manage major disturbances;
- WP3.4 Ubiquitous data for railway operation.

This deliverable is the first contribution of WP3.3. The main objective of WP3.3 is to derive joint guidelines for a standard European Traffic management system to handle large disruptions, e.g., in extreme weather and other hazardous conditions.

2. Current disruption management process

Disruption management in railway operation describes the (re-)actions that are performed to return the system back in its initial operational state, after an unexpected event affected the system lastingly. G. Yu and X. Qi describe disruption management as "*a real-time dynamic revision of an operational plan when disruptions occur*". They characterize several sources for internal and external factors that cause disruptions in general (Yu & Qi, 2004):

- *Changes in system environment*: The environment in which the system is operating has changed unexpectedly (e.g., weather conditions). Such a change will affect the system's performance.
- *Unpredictable events*: Spontaneous events unanticipated in the planning stage may severely impact the system. Examples include terrorist attacks, union strikes, power outages, etc.
- *Changes in system parameters*: The parameters characterizing the system may have an unexpected change.
- *Changes in availability of resources*: The resources used in the system may become unavailable due to failure, quality reasons, and sicknesses. Examples include machine failures, resign of key personnel, etc.
- *New restrictions*: New restrictions added to the system may make the original plan inferior or even infeasible. Examples include new government laws, new union contracts, new industry regulations, etc.
- *Uncertainties in system performance*: Very often due to limited understanding of the system, its realized performance may fall below of our expectations.
- *New considerations*: New considerations that were not present in the planning phase must be handled properly and in a timely manner, or the system will bear costs and penalties.

The challenge of disruption management in railway operation is to get back to regular operation after an unexpected event occurs and to minimize loss and negative impacts on the whole railway system.

The railway system itself is characterized by high complexity, dependencies and responsibilities. Thus, disruption management for railway operations includes:

- Consideration of constrains (e.g., connection information, resource dependencies);
- Determination of optimization parameters (e.g., increasing capacity);
- Optimization of the process: Coordination of individual measures.

The following sections describe approaches on disruption management in railway operation for small and large disruption management as they were principally dealt in ON-TIME WP4 and WP5 (see 2.1 and 2.2). Furthermore, management strategies for big disruptions due to extreme weather events are introduced in Section 2.3.

Thereon based, the described processes are validated for different European Countries in Section 2.4).

2.1 Small disruption management

This section considers small disruption as perturbations with only local effects, i.e., they can be solved by the responsible Infrastructure Manager (IM) itself and without intervention of Railway Undertakers (RUs) or neighboured IMs.

In general, small disruptions occur due to resource conflicts, i.e., local infrastructure failure or delay in time schedule. Two main decisions are needed to be made during the minor perturbations, the first is to decide on the estimated delay time and the second is to adopt optimum regulating strategies to keep the disruption to the service to minimum.

The D4.1 "Functional and technical requirements specification for perturbation management" (ON-TIME, 2013) of the ON-TIME project already dealt with small disruption management, especially to solve track occupation conflicts in order to increase railway capacity. Within ON-TIME, small disruption management is defined as a process of railway operation that handles an unplanned event which implies a change to the way in which train sequences over the infrastructure were originally planned (ON-TIME, 2013).

The result is defined as an optimisation module called "Perturbation Management Module (PMM)" which is described in the following sub clauses:

Constraints for small disruption management

The decisions and processes of small disruption management are limited by restrictions imposed by the complexity of the railway system. Some constraints should be considered that ensure the conflict-free railway operations, e.g., (ON-TIME, 2013):

- Train separation by fixed block distances;
- National interlocking, signalling and operational rules;
- Characteristics of automatic train protection systems;
- Planned running movements (train runs for passenger and freight trains);
- Temporary unavailability of track elements / routes, e.g., in case of track blockade, switch fault etc.

The infrastructure shall be regarded in a microscopic way for the interaction with the traffic control system although a macroscopic network model might be sufficient for some functions. The control area is limited, e.g., covering a major node, one or multiple lines or a combination of these. All perturbation management actions can take place inside the regarded control area only. It must be possible to consider trains entering and leaving the control area. It shall be assumed, that the PMM gets detailed predictions on train delays from neighbouring control centres before they enter the control area.

Furthermore, a microscopic timetable should be available. Joining and splitting of trains are considered as well as shunting movements in the sense of ordinary train movement with the respect of prevailing shunting speed constraints, restrictions by ATP, etc. In general, shunting movements shall be considered (i) if rolling-stock is added to or removed from a train before a train can continue its ride or (ii) if the order of rolling-stock within a train is changed.

Control decisions shall be implemented through the existing signalling system technology whenever possible. Decisions taken by perturbation management (re-routing of trains, change of meeting points or departure times, changing order of trains, etc.) shall be implemented in the field automatically, i.e., without human intervention. Nevertheless, the human control must always be aware of control decisions and their consequences.

Within ON-TIME WP4, the role of human controller is defined as being responsible for the real-time re-planning of the real-time traffic plan (RTTP). The human traffic controller will normally not be involved in the signalling activities, since the RTTP is proposed to be executed automatically. Decisions shall be avoided which put unnecessary restrictions to the PMM. At the same time the human controller must continuously have efficient possibilities to be in control of relevant decisions that the PMM cannot handle.

This results in several demands to specify the work environment and role of human controller (ON-TIME, 2013):

- *High situation awareness*: The work organization and HMI must be designed for high and continuous high situation awareness. This means that the human controller must be kept “in-the-loop” even when re-planning is performed automatically by the PMM.
- *Design the system according to “control by awareness”*: Actions of the PMM must always be visualized by the human-machine interface (HMI) in such a way that the human controller can understand when and why a specific solution to a perturbation problem was generated.
- *Avoid automation surprises and the “turn-it-off syndrome”*: No separate automatic route setting (ARS) system can be allowed in the execution of the RTTP. The actions of the PMM must be clearly visualized for the human controller. The execution of the RTTP must be made without any changes in the plan.
- *Support the human controller’s decision making*: Decision relevant information for the controllers’ interpretation of the traffic situation and consequences of alternative decisions must be visualized.
- *Design for high usability for skilled professional users*: Efficiency for the skilled controller must be provided. This is more important than designing for novice users or for making it easy to learn. The information environment must be integrated.
- *Separate decision from execution*: Re-planning actions, both the manual ones and those performed by the PMM, must always be possible until the plan is locked for execution. The order and time for human decisions must not be restricted.

Perturbation Management Module

The PMM developed in ON-TIME WP04 (ON-TIME, 2013) uses different functions with partially different models of railway operation. Therefore the PMM does not use a single objective function considering all aspects at once: the optimisation problem is decomposed and different functions deal with different optimisation parameters. The outcome of the PMM is the evolution of the microscopic real-time traffic plan over operation time.

2.2 Large disruption management

This section considers large disruption management in the sense of unplanned events that require to change the way in which resources were originally planned and managed by IM and RU controllers. In contrast to small disruptions that can be solved by one IM on its own, the management of large disruptions involves also RUs and in some cases several IMs. Thus, the role of human operators and organisations and the communication in between them are more complex than when dealing with small perturbations (ON-TIME, 2013).

In general, the scope of large scale disruption covers:

- Crew delay or unavailability;
- Train failure in station;
- Train failure during journey (interrupting a line section);
- Infrastructure degradation, e.g., track closure on multi-track section or section line closure;
- Other cases, e.g., strikes, external factors, etc.

Within ON-TIME WP5 a “Disruption Management Module” (DMM) was developed, including a decision support tool for stakeholders involved in the disruption management process. The module is composed by sub modules which are the core deliverables developed by WP5 (ON-TIME, 2013).

Constraints for Large Disruption Management

The organisation of large disruption management varies across Europe, and sometimes even within a country, depending on locations and physical layouts. Large disruption management relies on several actors who ensure railway operations. Most of them are already involved in normal railway operation procedures. The variety of involved actors and related requirements illustrates that a successful disruption management depends on unambiguous incident communication between all parties.

Incident communication is still paper and audio based, although the volume of communication is a major area for workload during incidents. Signallers, controllers and resource planners all highlight that the volume of phone based communication can be unworkable during incidents. The ability to view a shared plan, or to distribute information electronically rather than verbally, would benefit disruption operations. At the same time, the communication of new plans is critical across all stakeholders as plans may need confirmation and negotiation between the stakeholders themselves.

Large disruption management is a highly interconnected process, and any one aspect of decision-making is linked to other aspects of decision-making and progress within the own organisation and cross-organisation. Location, timing, type of incident and severity of incident will all influence the capacity to deliver an alternative timetable, and therefore influence alternative solutions.

Furthermore, different solutions come along with different benefits and require different considerations and constraints: Table 2-1 shows some alternative routing strategies, e.g., in case of a partial blockage of the line, and highlights their benefits and further considerations:

Table 2-1 Selected alternative routing strategies in case of partial blockage of a line (ON-TIME, 2013)

Alternative	Benefits	Considerations
Divert trains	Keeps basic service operational	All drivers need to be certified to drive alternative routes. Dependent on alternative infrastructure – diversion may add significant time to journey. May not be suitable for all traction
Cancel trains	Reduces traffic in and around an affected area	Passengers need to be notified. Passengers need alternatives either with extra services or alternative ones. May be easier for freight than passengers.
Cancel stops	Keeps service operational but closer to timetable than running all trains	Passengers need to be notified. Alternatives arranged for passengers waiting at stations or expecting to alight at cancelled stations
Additional stops	Allows service to be thinned while providing a service to all stations	Requires effective communication to signallers and train crew that this strategy is in place
Transport alternatives (allow passengers to travel on other routes, buses or metro systems)	Keeps passengers moving	Potential congestion on alternative services; coordination with other transport providers
Running on reduced infrastructure	Allows routes and services to remain approximately as planned	Difficult to arrange access if rectification work is taking place in the vicinity. Potentially high workload for signaller operating in degraded conditions; slower service leading to congestion

So far, there is only little technical support especially designed for disruption management. Contingency plans (if available) only cover strategies within the scope of one organisation. This is rather the case for the infrastructure part. Resilient contingency plans for crew and rolling-stock contingency are often non-existent.

The processes in disruption management and the workload due to cross-organisational communication would benefit from automated decision support that helps to manage large disruptions in a robust, reliable and simple way. There is no question that human operators cannot be substituted, but they need to be supported in disruption management decisions.

Disruption Management Module and decision support Module of ON-TIME WP5

Within ON-TIME a "Disruption Management Module" (DMM) was developed, including a decision support tool for stakeholders involved in the disruption management process. The process itself is mapped as SysML activity diagram with a particular focus on the so-called support rescheduling activity.

The basic structure of the support rescheduling module is outlined in Figure 2-1. It is broken down in four modules that consider timetable, rolling stock and crew rescheduling (ON-TIME, 2013):

- Change timetable Macro;
- Change timetable Micro;
- Rolling Stock Rescheduling;
- Crew Rescheduling.

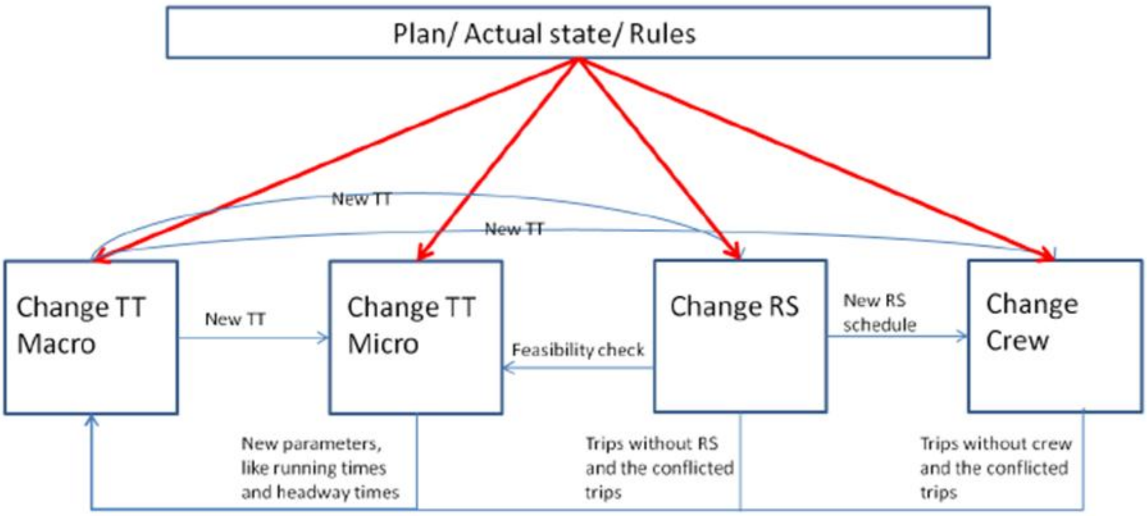


FIGURE 2-1 FRAME WORK OF SUPPORT RESCHEDULING MODULE (ON-TIME, 2013)

It starts with changing the timetable (TT) on a macroscopic level. Based on these decisions, the timetable on a microscopic level is also changed. In addition, the rolling stock (RS) and crew schedules are modified accordingly. However, if one of these steps is found to be infeasible then the TT can be re-adjusted on a macroscopic level.

The Disruption Management Module of ON-TIME WP05 is the basis for the SysML formalization for large disruption management process as it will be developed in Section 3.

2.3 Management of big disruptions due to extreme weather

Beside those disruptions that reveal inherent to the railway system, incidents originally outside the system also influence the performances of railway operations. One global cause is extreme weather that may affect the railway system in various facets. Several research projects already concentrates on weather effects on transport systems. The following projects were examined in detail in order to collect current disruption management strategies for railways due to extreme weather events:

WEATHER - Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions

The WEATHER project within the 7th framework program of the European Commission analyses the economic costs of the climate change that manifests in the more frequent and more extreme weather events on transport systems in Europe and explored ways for reducing them in the context of sustainable policy design. Therefore the Deliverable 2 "The vulnerability of transport systems" describes research results on impacts of the various types of weather extremes on the different modes of transport. (WEATHER, 2012)

EWENT - Extreme Weather Impacts on European Networks of Transport

In parallel, the EWENT project has the objective of assessing extreme weather impacts on the European transport system. The project also monetises the assessed impacts and draft mitigation and adaptation strategies to make the transport system more resilient against extreme weather phenomena. (EWENT, 2012)

FUTURENET- Future Resilience Transport Networks

The FUTURENET project within the ARCC "Adaptation and Resilience to Climate Change" program in UK examines possible transport scenario in the UK transport system in 2050 in terms of physical characteristics and usage as well as its resilience to the climate change. (FUTURENET, 2013)

MOWE-IT - Management Of Weather Events In the Transport system

Based on the result of the just presented projects WEATHER and EWENT, the MOWE-IT project deals with the Management of Weather Events, as indicated by its title. This project provides guidebooks and general recommendations for each transport system, reviewed by transport sector experts. For the rail transport sector the focus is on heavy rain, wind and snow/winter conditions. Nevertheless, resulting consequences of these categories are also considered (e.g., flood as consequence of heavy rain) and some general recommendations that are applicable to most weather-related events are given. (MOWE-IT, 2014)

2.3.1 Extreme weather events affecting the railway System

As a result of the previous projects, extreme weather events are categorised in five main groups, namely:

- Temperature;
- Precipitation;

- Wind;
- Atmosphere;
- Consequences.

These categories are further characterised and matched with affected European regions and relevant transport segments as shown in Table 2-2. Events without influence on the rail transport performance are grey shaded: this affects mainly weather events which are only relevant for the road traffic. For instance, it is assumed, that due to the rail guidance, hail and fog do not significantly influence the traffic performance. However, for less automated trains it is reasonable to reduce the speed in approach to signals and station platforms due to visibility conditions.

TABLE 2-2 OVERVIEW - CATEGORIES OF WEATHER EVENTS FROM WEATHER PROJECT

Categories of events		Explanation	Affected region and / or season	Relevant for transport segments
Temperature	Heat	Several consecutive days exceeding 35°C with single days exceeding 38°C	Northern countries not accommodated to high temperatures	Rail tracks and services Public transport Roads and road users
	Frost	Several consecutive weeks remaining below -5°C daily maximum	Middle and southern European states not accommodated	Inland navigation Roads and railways, Airports
Precipitation	Rainfalls	Strong single event or consecutive day exceeding 200 mm	All Europe, particularly severe in mountain areas	Roads and road users Rail tracks and services
	Snow	Longer period with snow level exceeding a given minimum.	Southern and middle Europe with varying thresholds	Road users Rail services Airports
	Hail	Hail with bigger hailstones		Road users
	Drought	Several consecutive dry weeks	Southern and partly middle Europe	Inland navigation
Wind	Storms	Events with wind speeds exceeding a certain level	British Islands, middle Europe	Road users, rail services Aviation
	Storm surges	Wind speeds and water levels exceeding certain levels	North-western Europe along coast lines.	Roads and road users Rail tracks and services Ports and shipping Airports and aviation
Atmos-phere	Fog	Longer periods with frequent sight below a certain distance	Mountain and northern coast line	Road users
	Ash cloud	Volcano ash or similar concentration in the atmosphere	All Europe	Aviation
Consequences	Wild fires	Uncontrolled fires covering bigger areas	Southern Europe	Roads and road users Rail tracks and services Aviation
	Floods/ flash floods	Water levels exceeding a given threshold	All Europe around river systems	Rail tracks and services Roads and road users Inland navigation, Airports
	Flash floods	Flooding in less than 6 hours	Geomorphic low lying	Rail tracks and services

			areas	Roads and road users Inland navigation, Airports
	Mass movement (dry)	Slipping ground (landslides) or avalanches	Mountain areas	Rail tracks and services Roads and road users Inland navigation, Airports
Key: no relevance for CAPACITY4RAIL indirect relevance for CAPACITY4RAIL, redistribution of cargo and/or passenger				

Impacts on railway operation can appear due to the following reasons caused by extreme weather events (WEATHER, 2012):

- *Closure of rail tracks due to damaged infrastructure*: All weather events that may possibly destroy infrastructure can cause such service interruption due to track damage. This includes failure of power supply/Overhead line equipment.
- *Closure of rail tracks due to safety reasons*: In case of storms and avalanches parts of the railway network can be closed in case of high risks in order to avoid accidents. Some railway companies have clear guidelines under which conditions (specific wind speeds in connection with specific vegetation along the line or a certain avalanche risk level of known avalanches threaten parts of the rail track). In the Alpine region (Suisse, Austria), natural risk assets are already installed to detect avalanches and landslides (Hübl, Pichler, Jocham, & Koschuch, 2014). Some installations are directly integrated in the infrastructural safety equipment and close the affected track autonomously (Nietlispach, 2012).
- *Temporary Speed Restrictions (TSR).* This is often the first measure to enhance safety, as long as the dimension of impact is not known.

2.3.2 Selected extreme weather events affecting railway Operation

Within the following paragraphs, selected extreme weather events are presented in order to demonstrate the possible consequences of weather disturbances on railway operation:

- Eruption of the volcano Eyjafjojujökull (Iceland) and its resulting ash cloud over Europe in 2010;
- Widespread flooding over UK in summer 2007;
- Winter storm Kyrill over Western Europe in January 2007;
- Exceptionally hard winter conditions across Europe in 2009-2010, especially in Sweden.

Eruption of the volcano Eyjafjojujökull

Volcanic eruption can lead to large-scale closure of airspace over long periods because of ash clouds. In this case, air passengers and air cargo need alternative transport routes. Especially air passengers who need an alternative transport mode will mainly choose to travel by train if possible. This refers in particular to high-speed rail connections to replace so-called short-distance connections in aviation up to 750km. For air cargo instead, rail is not an alternative to aviation, as the average kilometre speed of rail transport in Europe is very low and would delay freight shipments (high value goods) considerably (MOWE-IT, 2014).

The eruption of the volcano Eyjafjojujökull in 2010 in Iceland had high influence of the Northern and Middle Europe's airspace. At that time, a unique combination of three factors coming together resulted in an almost complete lock-down of European airspace (European Commission, 2011):

- Severe and prolonged volcanic eruption;
- Weather conditions that meant the ash cloud remained over Europe;
- Volcanic Ash risk management guidance for Europe based on a strict precautionary principle.

The impact of the six-day closure was enormous: more than 100,000 flights were cancelled and about ten million passengers were unable to travel. In many cases, passengers were stranded in another country without any immediate possibility of going home. Air cargo was re-routed to South Europe (Madrid, Rome, Istanbul) and transported by rail (or road) to Middle & Northern Europe.

Meanwhile, the risk management guidance was reworked. The new European approach provides a graduated response to ash clouds, and results in less disturbances of air traffic. Depending on the degree of contamination, three zones are defined (Alemanno, 2010):

- The first zone is located in the central nucleus of the emissions, where a full restriction of operations is maintained;
- The second zone consists of an intermediary zone, where Member States can allow flights in a coordinated manner but with additional restrictions and safety controls. This zone has since then split into two enhanced zones: a red zone in which some volcanic ash may be encountered, but where flights can still take place according to the European Aviation Safety Agency (EASA); and a grey zone in which EASA recommends two approaches that allow flights under certain conditions;
- The third zone (also known as blue zone), not affected by the ash, has no restrictions.

In consequence, the disruptions in air traffic are minimized, but of course, not completely eliminated. For the European railway sector, disruptions in air traffic results in temporarily increased demand of capacity, especially along TEN-T lines.

UK summer flooding

The extreme June/ July 2007 UK floods combined fluvial, pluvial and groundwater flooding with sustained high intensity rainfall occurring over a wide area. England was affected by the June and July floods, with the North badly hit in June, the West badly hit in July, and many areas hit in both. It was England's wettest July on record (Environment Agency, 2007). The heavy rainfalls represented over twice the 200-years-average July rainfall over large areas of England and Wales, over three times in most of the south Midlands and south-east Wales and over four times the July average locally in the south Midlands. This resulted in the flooding of thousands of homes and businesses and severe road and rail transport disruption across a wide area of the south Midlands (MetOffice, 2012). Embankments and cuttings that had been washed away had to be rebuilt, damaged bridges repaired and track and signalling systems replaced. Due to these massive damages on the infrastructure, train services were suspended on several lines. In some cases no replacement bus service along the route was possible due to the local road conditions. Instead, bus shuttles to reach stations on other lines were offered (Network Rail, 2007). The economic costs are estimated to have been around £36 million (MOWE-IT, 2014).

Winter storm Kyrill

The Winter storm Kyrill hit the UK, the Netherlands, Belgium, France, Germany, Poland and in minor intensity Austria, the Czech Republic, Denmark, Switzerland and Slovenia over the 18th and 19th of January 2007. Because of the heavy wind velocities up to 212 km/h in Poland large sections of forests were heavily affected and hundreds of thousands of households suffered power cuts.

For the German railway network for instance, the effects of Kyrill were immense: Velocity of gusts and fallen trees on tracks led in last consequences to the suspension of all services (apart from one region in the north that was not affected) for the first time in the history of the Deutsche Bahn national railway company (MOWE-IT, 2014). Reasons for that were, e.g., (pro Bahn, 2007):

- Poor preparation: underestimation of the force of the Winter storm and lack of contingency plan;
- Insufficient cut back of vegetation along the track;
- Centralised management of the railway infrastructure which does not permit regional decisions to close or open the track for operations.

The consequences of this over-all stop of operations were:

- Effects on passenger:
  - Lack of information: Information systems were overloaded, no actual information were provided;
  - Due to the suspension of services no passengers were injured. In summary, 35 locomotives and trains of DB were damaged.
  - Passengers did not strand concentrated in a limited set of long distance train stations. This turned out to be a fortunate coincidence, preventing further problems in providing passenger supply;
- Effects on operation:
  - Improvisation in operations;
  - Disturbances in RS rostering on long distance lines: several days were needed until all trains were back in an ordered circulation including the correct wagon order;
  - Backlog in freight traffic: 800 freight trains could not even start their journey. Three days later (with weekend days) 600 starts of trains were still delayed. End of January, effects of Kyrill were still remarkable in freight train operations.

Exceptionally hard winter conditions across Europe

The winter in 2009-2010 across Europe was extraordinarily strong with heavy snowfalls and very cold temperatures. The first incidents began in mid-December, but impacts occurred until April in some locations. The average temperature in southern Sweden was six degrees lower than the average of the previous 30–40 years. The average snowfall in Sweden was not exceptionally high but due to the coldness the snow did not melt away. Although the Swedish railway organisation raised their level of preparedness due to the received meteorological information, there were not enough maintenance personnel, machines and equipment for snow and ice removal. The cooperation between the different operational actors and gathering and sharing information between operators, to passengers and to the general population did not work very well.

Actions were put in place too late and the snow removal took too long. It was also identified that the subcontractors' resources for snow removal were inadequate. Replacement services for passengers were provided by buses.

In Sweden it was recognised that the variation of technical systems for controlling railway traffic in the traffic control centre requires efforts and improvements to guarantee the cooperation between traffic control centres. It was also emphasised that practical training should be organised so that every actor knows how to carry out the work in extreme situations (MOWE-IT, 2014).

Beside the common results as unprepared infrastructure, lack of maintenance, or rolling stock problems, the subsequent examinations of the incident management in Sweden revealed also some interesting aspects concerning operations (Kloow, 2001):

- There is a lack of experiences and knowledge of high-speed operation (far above 200 km/h) in winter climate.
- The operational problems often increase with the duration of the winter period (i.e., the length of a period with temperatures below 0 °C).
- Many problems are more or less independent of the train speeds; others are expected to increase when the speeds of the trains are increased.
- The co-operation between all the involved parties in the rail operation is improvable.

2.3.3 Disruption Management due to extreme weather

Divers extreme weather events across Europe in the recent years have developed the awareness of the negative influence of those incidents on the railway operation performances. Weather incident management is mainly led by infrastructural measures. In case of damaged infrastructure, the reconstructions consider mostly new findings on resistant materials and construction layouts that improve the reliability of the infrastructure. In case of track unavailability, re-routing strategies as used for large disruptions (see Section 2.2) are used. Extreme weather incidents require rapid intervention into actual operations. The aim is to develop generic as well as adaptable support for extreme weather incident management.

Management Plans for Closure of air space due to ash clouds

This section deals with the effect of ash clouds, namely the closure of air space, on railway operations. Contrary to other extreme weather events, the railway infrastructure is not affected by this type of extreme weather events. Directly exposed railway lines to volcanic eruption, accompanied by earthquakes and lava flows are out of the scope.

The event is characterized by short warning times and a high uncertainty on how long and how extensive the closure will be. Thus, the cooperation with meteorological institutes is mandatory.

The consequence of ash clouds for the rail sector is an increased demand on passenger transport on long-distance lines, especially within one country. This leads to higher occupancy rates. In a first step the RUs may implement additional waggons on dedicated lines to manage the demand. The rolling stock rostering has to be adapted.

Second, the use of special train seems appropriate. The re-routing of cargo planes and transatlantic flights to not affected European region increases the demand of railway capacity especially within the TEN-T corridors across Europe. This includes adaption on the real-time traffic plan and cooperation of IMs along the route. The nature of air cargo (e.g., fruits, other perishable food) requires a preferential treatment in the RTTP. However, it is likely that those goods will rather switch to road.

Management Plans for flooding events

For exposed regions it is expected that flooding events will increase in frequency and intensity. Flood prediction models incorporating weather forecasts and detailed information on topography, infrastructure, geology and hydrology supports the prediction of effects on the railway networks. This influences the level of necessary preparedness and availability of flood response plan. Due to the nature of extreme flood events (i.e., large-scale failure of network infrastructure) effective measures are needed in the long-term preparation of the infrastructure, e.g., the enhancement of flood resilience of infrastructure where necessary or the provision of movable flooding walls. The cooperation with local authorities to have general local flood defence plan is recommended.

When travellers' journeys are disrupted due to closure of railway lines during flood events, alternative transport has to be found for passengers, be it replacement bus services or taxis. Of course, where there is also disruption on the road network then it is not possible to arrange alternative transport and passengers may be stranded as a result (MOWE-IT, 2014).

Operational measures during a flood event can be:

- Reduce speed limits or stop trains in flooded areas where appropriate;
- Have extra personnel on standby to help with additional duties during a flood event or to replace crews displaced by delayed/cancelled trains;

- Clear track from debris to enable trains to run once flood water across the track has subsided.

Weather Resilience and Climate Change Adaption (WRCCA) Plans – Network Rail

Network Rail initiated across the UK the Weather Resilience and Climate Change Adaption (WRCCA) Plans, supported by an evaluation of the resilience of rail infrastructure to historical weather events and an awareness of potential impacts from regional climate change projections. The resilience of rolling stock operating is not specifically assessed. Eight main routes were examined with considerations of their specific regional weather vulnerability. The costs and delays caused per extreme weather phenomena during the period 2006/07 to 2013/14 were evaluated and measures to increase resilience against extreme weather incidents were put in place.

Network Rail uses the Met Office National Severe Weather Warning Service (http://www.metoffice.gov.uk). This service is recognised outside the railway industry and is widely used by public and emergency responders, providing a warning of severe or hazardous weather which has the potential to cause danger to life or widespread disruption. Further weather information is provided by Network Rail's contracted weather forecasters, Meteo Group (http://www.meteogroup.com), to assist with assessment of the weather patterns (Network Rail, 2014).

For each route, the influence of different extreme weather phenomena was analysed. The consideration of topography can significantly influence the weather conditions experienced. The topography is linked to the geology of the areas, and this plays an important role in determining the way in which the weather ultimately impacts the railway assets.

Of course, the most effective measures are on the infrastructure side, e.g., infrastructure maintenance and improvements during reconstruction works. Nevertheless, Network Rail developed operational response strategies to weather vulnerability (Network Rail, 2014):

"…

Network Rail manages risks from weather-related impacts through a range of asset management tools, operational response standards and alert systems. Higher risk assets are prioritised for investment within asset policies and proactively managed through risk-based maintenance.

Defining "normal", "adverse" and "extreme" weather conditions is fundamental to ensuring effective coordination across the rail industry. Network Rail and the National Task Force (a senior rail cross-industry representative group) are currently reviewing weather thresholds and definitions to improve the Extreme Weather Action Team (EWAT) process which manages train services during extreme weather alerts.

Control rooms monitor and respond to real-time weather alerts through a range of action plans. Operational response to the risks posed by weather events includes: temporary speed restrictions (TSRs), deployment of staff to monitor the asset at risk, proactive management of the asset including the use of *ice maiden trains to remove ice from OLE or inflatable dams to protect electronic assets from floodwater, and in some cases where the risk dictates, full closure of the line. Increasing the resilience of the infrastructure reduces the need for operational response; however, the range of weather events experienced today, potential changes in the future, and the prohibitive scale of investments required to mitigate all weather risks, means that operational response will always be a critical process for Routes to manage safety risks.*

Network Rail seeks continuous improvement of weather-based decision support tools, including flood, temperature, wind speed and rainfall alerts. A trial aiming to significantly improve real-time weather forecasting has installed approximately 100 weather stations on the Scotland rail network. In Western Route, there is wide coverage from Met Office weather stations and radar which is used to provide real-time weather information.

For the management of operational flooding risk, Network Rail receives alerts through our Flood Warning Database based on warnings issued by the Environment Agency and the risk is translated to rail assets. In locations where no national flood warnings are available, Network Rail can arrange to receive alerts from bespoke river level monitoring equipment.

Longer-term flood risk management of rail assets is provided through geographic information system (GIS) decision support tools including flood datasets, such as Network Rail's Washout and Earthflow Risk Mapping tool (WERM). Transformative asset information programmes are currently aiming to improve weather-related hazard mapping in decision support tools.

…"

The catalogue of measures includes, e.g., (Network Rail, 2014):

- predict the impacts of weather and use weather forecasting and asset monitoring to manage locations vulnerable to adverse weather;
    - install Remote Condition Monitoring on selected assets;
    - combine this monitoring with Met Office and Environment Agency "broader" data and intelligence;
    - use triggers and action levels to apply operational restrictions based on asset condition and local weather observations;
- engage with key regional stakeholders to communicate the Route strategy, planned programmes of work and identified weather resilience and climate change adaptation actions.

Irrespective of the kind of extreme weather event and as far as the lines are not totally closed, weather incidents often results in Temporary Speed Restrictions (TSR). This ensures at least a continuous railway operation although the capacity is minimized. The better the weather incident is monitored, the smoother the contingency timetables can be implemented.

The following paragraphs present identified measures to minimize disturbances due to specific weather events.

WRCCA Plans for Storm events

Climate modelling cannot provide strong projections for future changes to wind speeds, though increased storms are generally projected and may increase the risk of wind-related incidents on the Route. Wind affects the operation performance directly by imposing blanket speed restrictions when thresholds are reached. Wind also affects the operation performance indirectly primarily as a result of damaging lineside trees which then fall, or drop branches on or near the line or overhead line equipment (OLE). Wind also moves other debris on to the line from the lineside environment. High winds can also lead to significant waves to form even in waters protected from the open sea, these can cause damage to the infrastructure (Network Rail, 2014).

The Network Rail company standard NR/L3/OCS/043 – National Control Instruction, mandates that blanket speed restrictions are imposed when specific wind gust speeds are triggered. The imposition of the blanket speed restriction is to reduce the likelihood and/or consequence of a train striking obstructions blown on to the line (Network Rail, 2014).

Wind speed data were transmitted from weather stations to a website that can be accessed by Control via the mobile phone network. Beside this, the operative measures are rare. Preventive measures as maintain the vegetation along the lines are more effective.

The primary operational risk mitigation to strong wind is to impose speed restrictions on the parts of the route forecast to be impacted, or in extreme conditions to suspend operations completely. Due to the complex nature of train planning this cannot be applied on too local a scale, the route needs to be operated in wind speed zones to allow train paths to be planned. High wind forecasts in small areas reduce the flexibility of large route sections. Thus, contingency timetables with more flexibility must be developed to allow restrictions to be imposed on smaller areas of route when required (Network Rail, 2014).

WRCCA Plans for Winter events

Cold weather poses perhaps the biggest risk to track; ice formation on the third rail prevents trains from accessing the power supply via the shoe gear and often results in arcing and sparking which damages the train and the track, points can become frozen which prevents paths from being set by signallers, and a build-up of snow on the track simply means that trains cannot run until cleared by the Snow Ice Treatment Train (SITT), much as roads need to be cleared by a snowplough before cars can drive through them. While the climate change projections would suggest an improving situation for frequency of cold days, the fact is that even the shortest periods of cold and/or snow have a serious impact on the network.

Measures taken to mitigate the effects of snow and cold at these locations include:

- Installing more conductor rail heating (CRH): While CRH holds many benefits, there is the drawback that it increases the power consumption required by the line. This means there is an increasing draw on the power supply during cold weather, as it is required not only to run the trains and power them, but also for points heaters and conductor rail heating, and this is a risk within itself;

- No splitting of trains in cold conditions: This may affect the rolling stock rostering;
- Providing staff on the ground to react to incidents.

Although these measures are not sufficient to completely mitigate the risk, there is a positive effect on delays. Furthermore, the removal of lineside trees to prevent line blockage improves the resilience. Adequate de-icing arrangements and material supplies in conjunction with train operating companies spread the responsibility to all affected parties (Network Rail, 2014).

Summary on Strategies for operative disruption management due to extreme weather events

The previous review of extreme weather events, their impacts and strategies to avoid severe impacts in the future shows only a few promising measures:

- Preventive maintenance of infrastructure: This is the most effective measure but refers to the infrastructure sector;
- Cooperation with local authorities and weather forecast institutes;
- Cooperation with regional stakeholders and neighboured IMs;
- Temporary speed restrictions (TSRs), on affected routes: The complexity of train path planning must be considered. Local changes in speed restrictions have large-scale effects on operations;
- Preparation of contingency plans and emergency timetables for routes at high risks;
- Automated transmission of weather alerts from weather stations to Control Centres and to Train drivers;
- Adaptation of rolling stock rostering: avoidance of train splitting in heavy winter conditions.

The aim of Disruption Management is to keep the train operation ongoing. Nevertheless, in case of infrastructure failure and line closure, replacement services by bus and large-scale re-routings of trains need to be installed.

2.4 Observations for different European countries

In the following, we report some observations on the general traffic management process implemented by different European IMs. As it can be observed, the processes are coherent with the discussion proposed earlier in this section.

2.4.1 Spain

Train Traffic in Spain, for both high-speed and conventional network, is controlled from different control points (Regulation and Control Centres) distributed throughout the country. Additionally there is an “Incident Control Centre” for the entire network (by the name of H24) that is responsible for the coordination with the corresponding "Centre for Regulation and Control" during incidents that may cause great affection to traffic (accident, extreme weather events or incidents affecting the infrastructure).

In the case of the conventional network, each "Regulation and Control Centre" controls a geographical area (northwest, north, northeast, central, east and south). In the case of high-speed network, each "Regulation and Control Centre" usually controls a high-speed line.

Typically, each "Regulation and Control Centre", always according to the laws and regulations in force, knows what to do in case of an incident that may cause a great traffic disturbance, taking ultimate responsibility in decision-making. In case that any alternative plan of transport or any external resource must be mobilized, H24 would be the coordination centre. The H24 centre is also responsible for communicating with the media that ultimately informs citizens of existing problems.

On a monthly basis, a meeting takes place at the centre H24 with those responsible for each geographical area and the head of the high-speed network. At that meeting the indicators are reviewed and plans on important actions are set to be developed:

- Anticipating works on the network that will involve cuts in the lines.
- Winter Contingency Plan (concerning the possible interruption of service by frost, snow…).
- Summer Contingency Plan (concerning the interruption of service for possible fires).
- ...

Notably respect to meteorological phenomena that may affect the operation of the railway network, all "Regulation and Control Centres" receive on a regular basis (hours) forecasts of wind, snow and rain. The high-speed network has its own network of weather stations that predict the wind on the line. This information is communicated by an internal telecommunications network.

2.4.2 Sweden

In Sweden, train traffic control is basically divided in three operational levels: local, regional, and national.

On the local level, train traffic controllers manage the train traffic directly. Train traffic control is done centralised from eight different traffic control centres. The traffic controllers deal with smaller deviations from the timetable directly. If larger disruptions occur, e.g., a track section has to be closed or can only provide very limited capacity, this is reported to the higher operational levels via telephone or support systems. The main task on this level is to maintain traffic flow, monitor planned maintenance work, and to maintain safety. The traffic controllers also implement plans to deal with disturbances, which have been decided on higher levels.

The regional level is called ROL (Regional Operative Leaders). Sweden is divided into four geographical regions, each having a dedicated regional control centre. ROL has a more preventive focus. Their tasks include monitoring quality of traffic operation and communication with external actors, e.g., train operating companies and maintenance. ROL ensures that the planning data that is used during traffic control is of sufficient quality. ROL also ensures that the needed resources are available when disruptions are foreseen (e.g., increased passenger traffic in combination with certain events). ROL makes sure that the regional perspective is kept during local train traffic control, e.g., by prioritising certain trains. Another main task is to support the national level in management of large disruptions; they implement national plans on the regional level and communicate with the actors in their region.

The national level is called NOL (National Operative Leaders). There are usually one or two persons on duty, responsible for Sweden as a whole. Therefore, in cases of large disruptions, close collaboration with ROL is inevitable. The goal of NOL is to anticipate and manage disruptions in order to minimise the impact on overall service. NOL continuously monitors traffic abnormalities that have the potential to cause larger disruptions (e.g., closed track sections) and overall conditions (weather conditions, specific events, etc.) and analyses them in terms of risks. In urgent situations, they call in national leader meetings. On these virtual meetings, the involved actors, as train operation companies, ROL, and representatives from other authorities, discuss the current situation and possible actions. In case of disturbances, emergent as well as expected, e.g., due to extreme weather conditions, NOL adapts and delegates defined action plans to handle the disruption. In extreme cases, NOL decides on capacity delegation. NOL usually acts on disruptions that have a time horizon of at most 48 hours, i.e., when a disruption is expected to take longer to resolve, it will be handed over to other departments, e.g., planning and maintenance.

All levels have the task to document disturbances for later analyses with the main goal of continuously developing and improving the process of disruption handling.

Particular for the two higher operative levels, ROL and NOL, is that they both deal with road traffic as well. The reason for the integration of rail and road traffic is to make decisions with a holistic perspective. In this way, it is easier to deal with events that effect both rail and road, e.g., extreme weather conditions in a region or a fire or a flood that affects both means of transport, which may happen where rails and roads are next to each other. The integration also improves the possibilities to organise replacement busses for cancelled train connections and helps to avoid planning of maintenance simultaneously on both rails and highways connecting the same cities/regions.

2.4.3 France

In France, infrastructure manager organisation for train traffic control is basically divided in three operational levels: local, regional, and national (Figure 2-2).

On the local level, signallers manage the train traffic directly. Depending on the signal box technology, complexity of track layout and the volume of traffic, the control area of each signaller is from a couple of kilometres to several decades of kilometres. The traffic controllers deal with small deviations from the timetable directly: route used in case of trains conflict or conflict with a possession, platform used in stations, train order in very specific conditions. If larger disruptions occur, e.g., a track section has to be closed or can only provide very limited capacity, this is reported to the higher operational levels via telephone. The main task on this level is to maintain traffic flow, monitor planned maintenance work, and to maintain safety. The traffic controllers also implement plans to deal with disturbances, which have been decided on higher levels.

The regional level is called Train Operating Control Centre (TOCC [COGC for French acronym]). France is divided into 21 geographical regions, each having a dedicated regional control centre. TOCC main activities include:

- To monitor quality of traffic operations: supervision of trains, preventive actions on train running in contact with others TOCCs, train drivers and signaller, allowance to use work possessions, etc.;
- To avoid conflicts giving priority on certain trains to local train traffic control, etc.;
- To take in charge any exchange (communication or negotiation) with external actors, e.g., train operating companies, station managers and infrastructure manager maintenance people, others IM, etc.;
- To ensure data that is used during traffic control is of sufficient quality and trigger the analysis of any disruption on its control area;
- To take in charge large disruptions occurring on its area: apply or control any immediate contingency measures, inform all actors including third party actors (e.g., first aid, police, etc.), define the remaining capacity possible, define and implement the recovery plan negotiated with RUs; participate to define and implement the strategic plan to restore infrastructure capacity;
- Support the national level in management of large disruptions; they implement national plans on the regional level and communicate with the actors in their region.

The national level is called National Railway Operations Control Centre (NROCC [CNOF for French acronym]). There are usually 4 persons on duty, responsible for France as a whole. Therefore, in cases of large disruptions over several TOCC or for specific disruptions (e.g., trains delays over a threshold), close collaboration with TOCCs is inevitable. The goal of NROCC is similar to TOCC and continuously monitors traffic abnormalities that have the potential to cause larger disruptions (e.g., closed track sections) and overall conditions (weather conditions, specific events, etc.) and analyses them in terms of risks.

It exists a specific organisation for the high speed lines on the French network. Because of the little number of connections with the conventional network, traffic control organisation is different and those lines are supervised by the national level. The local level, signaller, is in charge of dispatching functions on the area it controls (couple of hundred kilometres).

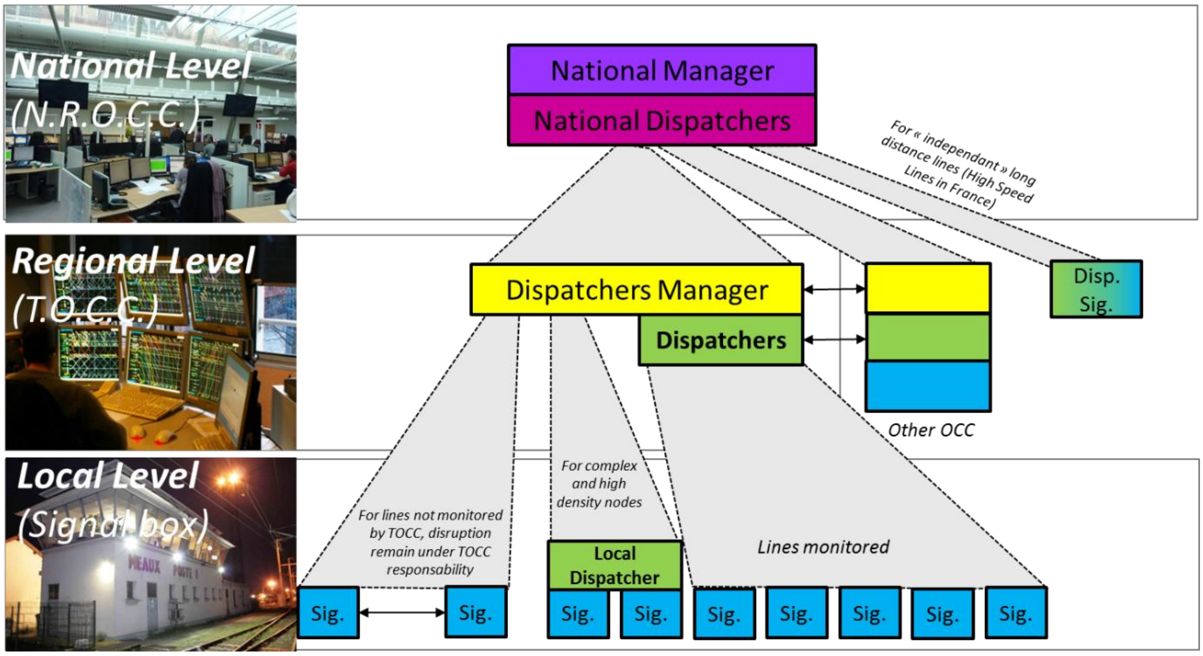


FIGURE 2-2 CURRENT ORGANIZATION OF TRAFFIC MANAGEMENT IN FRANCE

In the two decades coming, train traffic control on main lines (it concerns about 14 000 km of line on the total 30 000 km) should be done from sixteen Operational Control Centres (Figure 2-3). Those OCCs should replace the current TOCCs and permit to relocate first level and second level in the same place in order to improve train traffic control.

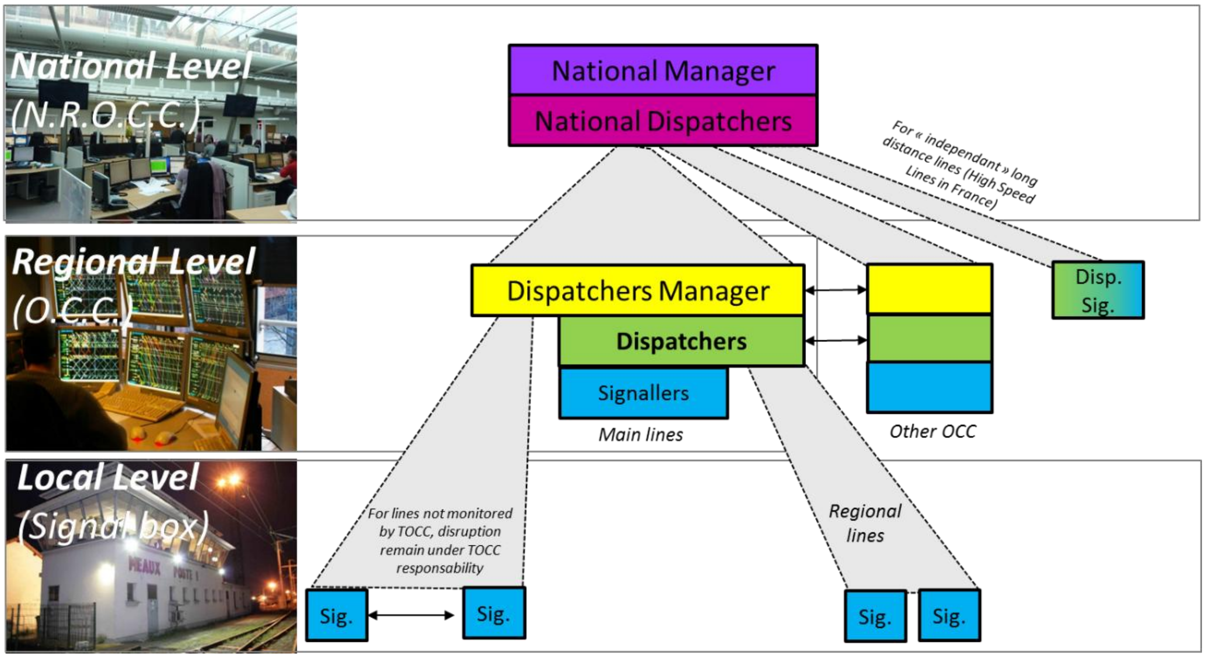


FIGURE 2-3 FUTURE ORGANIZATION OF TRAFFIC MANAGEMENT IN FRANCE

Currently, various projects are under development to provide tools for operators of level 1 and 2 in order to reduce workload (mainly data grab and operation in nominal situation), give access to IM data, shared the same data during nominal and disrupted situations and offer advanced support function for aiding the decision process. Results are expected for next decade.

Operational actors of the RUs in charge to manage resources (rolling stock, driver and other train crew, services (e.g., catering, cleaning, etc.)) are for passengers trains located physically with infrastructure manager operators, at regional and national level. For freight trains, the situation is different. At regional level, RU operators are located in different offices. At national level, few RUs decided to locate their operators in the NROCC building.

Concerning Station Manager (mainly broadcast of information for passenger), this function is handled during the operational phase by passengers trains RU (SNCF Mobilités).

The process presented for small disruption management in Section 2.1 is applicable for the French network[1]. It's handled by first and second level of traffic control as presented above.

- Nevertheless, today there isn't any automation to support operators of the second level to take their decision. Operators of the first level may have support from computer-controlled interlocking providing simple algorithm for certain small disruptions. Note that those algorithms are turned-off for large or big disruptions not being designed for that.
- Nevertheless, traffic control decisions for small disruptions are not only based on the key indicators defined in this document which use "only" train delay. Rules used for French network are presented in the French network statement and available on the current priority rules presented on the Rail Net Europe website http://www.rne.eu/priority-rules-in-operations.html. By the way, this document gives an excellent view of variety of rules in application in Europe.

The elements presented for large disruption management in Section 2.2 are globally valid for the French network. Nevertheless, the understanding of this type of disruption for the French network involves the definition of sub-categories:

- The disruption concerns few trains, and only one RU is concerned by the negotiation. For this situation for crew and rolling stock, there may exist updated plans, pre-agreed between the IM and RUs that the IM can apply. If no plan exists, the negotiation is quick: RU resources manager is physically present in the TOCC or a single phone call is made;
- The disruption concerns several trains, several RU are concerned by the negotiation but there is no need to arbitrate the services proposed by the RUs. In that case, the IM applies the decision made by the RU. There is no automation of the negotiation. A daybook is used to log the negotiation. Pre-agreed plans exist for certain area and for certain situations but

[1] Based on ON-TIME project results, In2Rail EU funding project introduce the three types of large disruption and big disruption in deliverable D7.2 "I2M Consolidated functional and non-functional requirements." indicated below.

they are not always applicable due to differences between the plan and the current state of the resources (number of trains, compositions of trains, rolling stock maintenance on-going, ability of drivers, etc.). For information, an evolution is expected to digitalise (not automated) the exchanges between RUs and IM during negotiation phase. Today, the exchanges are done orally, by phone, by fax or email;

- The disruption concerns several trains, several RUs are concerned by the negotiation but it exists incompatibility of the solutions negotiated with each RU. The process is similar to the one above but in the end, the IM is the arbitrator of the solution applied.

Concerning the process presented for extreme weather disruption management in Section 2.3: this notion for the French network concerns any disruption requiring the application of a contingency plan decided by the IM. This contingency plan, prepared long before, can include any preventive actions and a specific organisation settled to prevent or at least minimize the consequences of the disruption using or not data from specific equipment's. It's hardly possible to validate each organisation, actions and equipment's identified in this document to face an event, because of the variety of the railway environments. But it's possible to say that this is coherent with the current situation for French network.

2.4.4 United Kingdom

In the UK, railway traffic is regionally controlled by Regional Operating Control (ROC) centres whose decisions are coordinated and advised at national level by the National Operating Control (NOC).

There are currently more than 800 operating local traffic management sites made up of various operating models from Victorian type lever frames, to more modern power signal boxes and modern ROC locations. They are gradually being migrated into ROC's. A ROC contains the people and process required to carry out rail operations across their areas of control. Currently some locations have command and control in one place, from a business continuity this is seen as having 'all your eggs in one basket' so thinking is developing to a future state of having the ROC's as places where only people are based with the technology being elsewhere.

The final ROC's as they are planned are shown in column 2 of Table 2-3. Additional ROC locations that will be installed in the future are reported in column 1. The third column shows instead the parts of the railway network that are covered by each one of the ROC's.

TABLE 2-3 REGIONAL OPERATING CONTROL CENTRES IN THE UK

Approximate ROC DR Location	ROCs covered	Routes covered	
Motherwell (A)	Edinburgh (2), Glasgow (1)	Scotland	
Leeds (B)	Manchester (3), York (4)	LNE/EM, LNW	
Newport (D)	Cardiff (7)	Wales	
Leicester (C)	Derby (5), Rugby (6)	LNE/EM, LNW	
Reading (E)	Basingstoke (9), Didcot (8)	Wessex, Western	
Sevenoaks (F)	Romford (11), Three Bridges (10)	Anglia, South East	

The way the NOC collaborates with ROC's to handle large disruptions due to extreme weather events, is reported as follows:

1) The NOC (currently located in Milton Keynes) liaises with the long range weather forecast supplier which notifies whenever extreme weather events are predicted.
2) In this case, the NOC advises regional controls (some currently in the ROC's, some in other locations) as well as national level Train operating companies (TOC's) and Freight Operating Companies (FOC's) of the predicted event, likely severity and timeframe.
3) Controls then arrange for Emergency Weather Actions Team meeting (EWAT) with the affected stakeholders (internal & external), agree a plan and response arrangements for the duration of the event, and cascade that to: industry teams; route and national controls; TOC/FOC controls. Any advice required by support and front line operations is cascaded to them.
4) In case of disruptions and/or other events occur during operations, the flow of communication is effectively reversed. This means that drivers report the event to the signaller and control, the signaller reports it to route control, route control advises national control if required, emergency response arrangements are put in place as required.

The process reported above clearly highlights the involvement of passengers and freight train operators in managing the disruption so to take real-time decisions which mitigate as much as possible the impact on scheduled service. Taking effective decisions in real-time requires an efficient communication process between TOC's/FOC's and the infrastructure manager which allows a quick collaborative evaluation of different management strategies from all stakeholders' standpoints. To facilitate the communication between infrastructure managers and train operators during real-time traffic management, some controls of the TOC and the infrastructure manager are co-located with the signallers, and will together formulate an agreed plan, then communicate that verbally and perhaps with written instructions communicate that to signallers and train crew (verbal & paged).

Others not co-located will discuss and agree the plan via conference then cascade the plan via phone calls, emails, paged messages etc.

Sitting above this, during large scale disruption, Routes have pre-defined contingency plans known as Key Route Strategy (KRS), which define how lines of route shall be managed during disruptions, so following an incident they will already be aware what the KRS advises, and they will act in accordance with that cascading the decision. Other locations have other pre-defined contingency plans that also may be adopted during disruptions. Guidance and instructions as to how controls go about their business under differing circumstance are detailed in guidance such as The National Control Instructions (NCI).

In extreme weather events, often the need for evacuating passengers and/or facilitating their intermodal transfer (e.g., to buses) can be a critical factor in the decisional process. There is a rule book guidance and instruction as to how operators shall act on advice or becoming aware of weather effecting events. The NCI has a section dedicated to weather (section 7.1), that describes different weather events and how they should be dealt with. Other sections of the NCI also deal with weather, e.g., management of the infrastructure during high temperatures.

Train operators have call off contracts with other transportation providers that can be enacted, e.g., call off contract for a replacement bus service. Other organisations also have to be considered in terms of what/who is being carried; e.g., perishable goods, ships waiting in dock to be loaded/unloaded, power stations waiting on coal, dangerous goods such as nuclear, etc.

Once the management plan has been commonly agreed, TOC’s and FOC’s will reschedule their resources (rolling stock and train crew) by means of their own “Rolling stock & Crew” management system which are currently not connected to any up-stream traffic management system of the infrastructure manager. The KRS and agreed route contingency plans describe however how resources may react to a given incident. The nature of large scale disruptions and always differencing circumstances require that discussion and dialogue still take place to agree how to best resolve it.

A large disruption decision support system which can automatically integrate traffic rescheduling with the rescheduling of TOC’s and FOC’s resources would in this case constitute a big innovation to facilitate more effective management plans.

2.4.5 Czech Republic

The train traffic control in Czech Republic (from the guideway operating point of view) is carried out by the Railway Infrastructure Administration (RIA, in the Czech language = SŽDC – National Infrastructure Manager)). From the disruption management point of view there is The Rail Safety Inspection, which is responsible for disruption management due to incidents. This establishment is divided into four geographical regions – Prag, Pilsen, Brno and Ostrava. According to the location of the railway line the operational control and the solution of incidents belongs to the relevant subdivision of this establishment.

In some cases such as operational disturbances, unpredictable possessions or traffic problems, which are caused by the infrastructure manager or by railway owner, some trains must go through the diversion path. All conditions and requirements for train composition as in ordinary situations are valid also for these trains. There are no special regulations for the train composition of trains on diversion path. The diversion path must be negotiated flexibly with the relevant carrier. In case the diverted train consists of wagons with higher axle load, it is necessary to have the agreement of RIA for the diversion path.

The system of railway traffic control in the Czech Republic is shown in Figure 2-4.

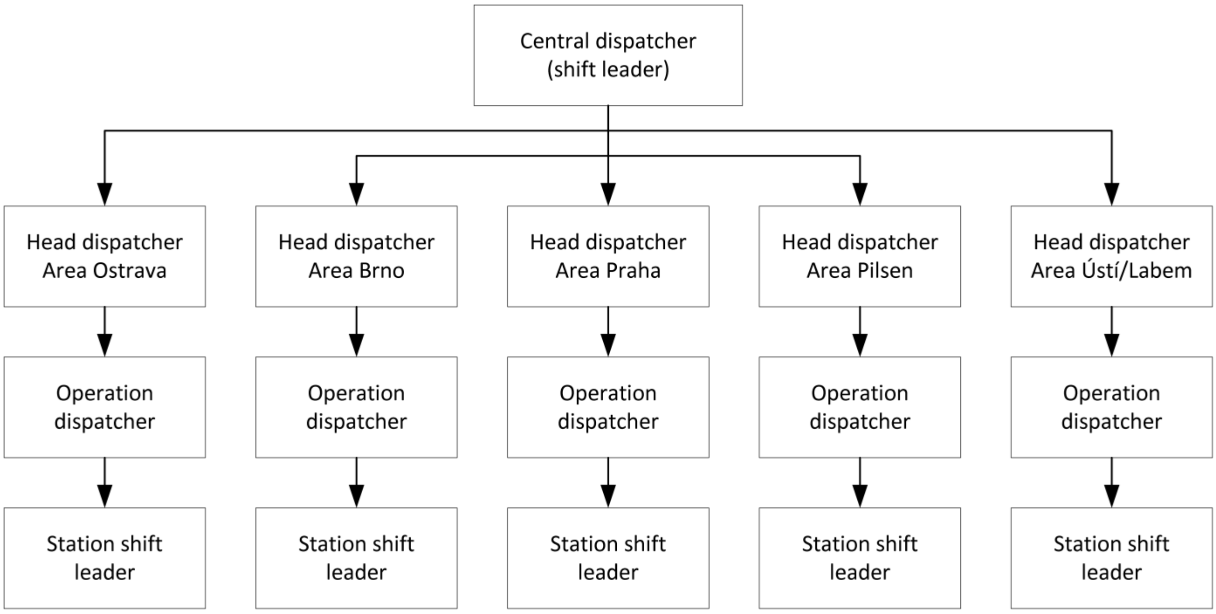


FIGURE 2-4 RAILWAY TRAFFIC CONTROL STAFF IN CZECH REPUBLIC (SOURCE: RIA)

As shown in Figure 2-4, there are geographic areas of control. Each area has its own head dispatcher. The superior dispatcher (central dispatcher) is responsible for all area head dispatchers. The traffic within one station is controlled by one employee, e.g., a train dispatcher. The hierarchy of control is given in regulation SŽDC (ČD) D7. There are (in June 2016) two departments for centralised traffic control, one in Prag and one in Přerov.

The level of traffic planning is represented by a train traffic diagram which is valid usually for one year and which is created in advance.

Operational traffic control (in general) is the set of procedures which has direct influence on moving of train in station, in track section, etc. The operation of signalling and control system is the tool for the traffic route controlling. The management of signalling and control system must be strictly distinguished from the management of train traffic, which corresponds to the application of decision processes and activities related to the train movement on the railway infrastructure.

On the regional railways, where the frequency of trains is low, the simplified train operation control is established according to regulation SŽDC D3. This regulation gives a definition of train dispatcher for a controlled line. All operations for transport operating are performed by directions, which are transferred among all participating staffs. Directions are transmitted personally, through the telecommunication device, through the signalling, etc. The responsibility for correctness of the instruction is on the staff who published the instruction. The staffs who receive the instruction are responsible for its correct execution.

3. Formalization of the big disruption management process

3.1 SysML formalization

Within this section, the formalisation of the big disruption management process is described. The process is modelled in SysML, a standardised and open source modelling language for system engineering. It is based on the work done in ON-TIME, in particular in ON-TIME D5.1 "Functional and requirements specification for large scale perturbation management" (ON-TIME, 2013). The ON-TIME process is enhanced and expanded to integrate also extreme weather management process and to capture additional details of the big disruption management one.

The consideration of extreme weather events follows the general process of the disruption management process. Information about upcoming or actual local extreme weather events, e.g., from weather forecast institutes, can be treated as local disruptions of infrastructure. Contingency plans for routes at high risk can be developed in advance by what-if scenarios. Moreover, weather forecasts may be used to build specific contingency plans to be applied if the forecasts are correct, or adapted if slightly different meteorological conditions occur.

3.1.1 Requirements of the disruption management process

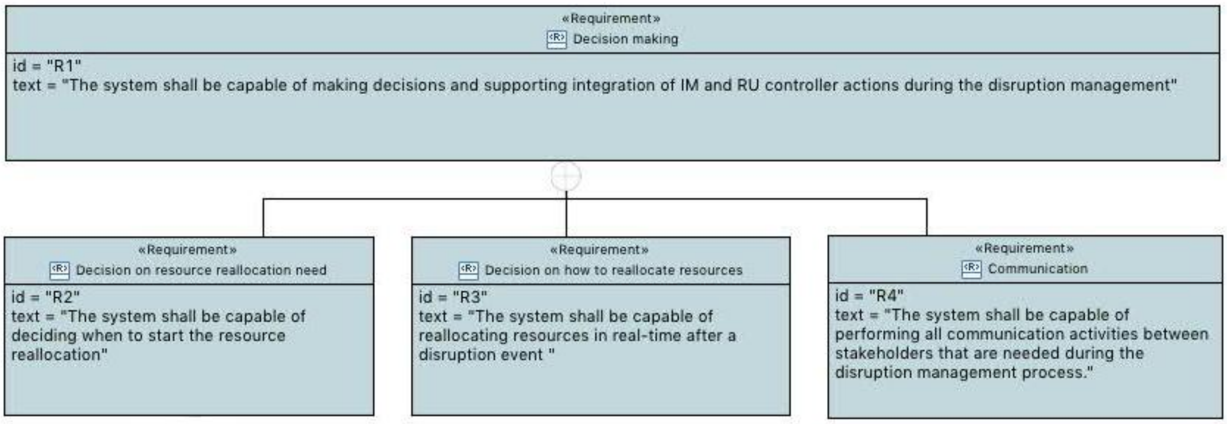


FIGURE 3-1 TOP-LEVEL REQUIREMENTS OF THE DISRUPTION MANAGEMENT PROCESS

Figure 3-1 shows the text-based requirements of the disruption management process. They are organized into the top-level requirement *Decision making*. The technical system (and its interfaces) for disruption management is considered at this requirement level.

Decision Making requirement

The top-level requirement contains detailed requirements based on the prioritised list of capability requirements that has been produced in ON-TIME WP2 "Examination of existing approaches and specification of innovations" (ON-TIME, 2012).

The *Decision making* requirement indicates the need for the system to be able to make decisions during disruption management. Moreover, it shall be able to support both IM's and RU's controller actions in this framework. As specifications to this requirement, we remark that the system needs to be able to make decisions on the need for resource reallocation, and in case the need is detected, to make decisions on the actual reschedule. Furthermore, Communication activities between stakeholders that are needed during the disruption management process are to be assured (Figure 3-1).

Decision on resource reallocate need Requirement

The *Decision on resource reallocation need* requirement indicates the feasibility of the system to decide when the start of reallocation is needed during disruption management. It is supported by *Monitoring* and *Prediction* of the infrastructure and traffic state (Figure 3-2).

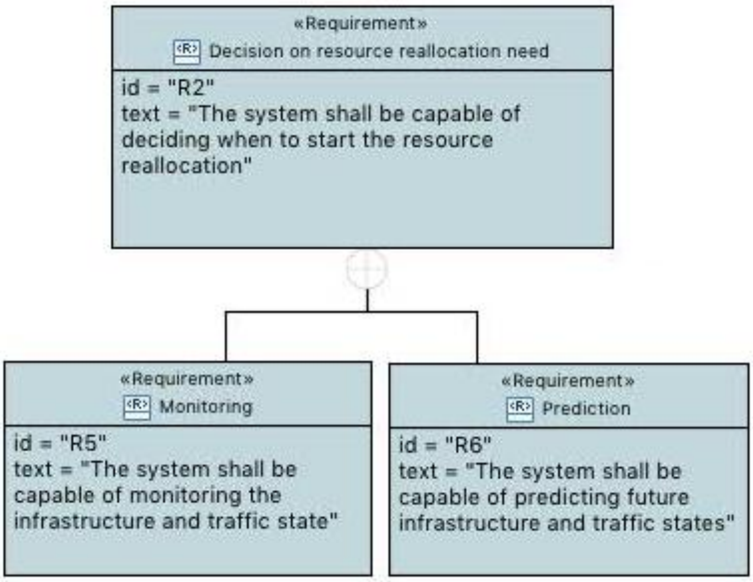


Figure 3-2 Decision on resource allocation need

The *Monitoring* and *Prediction* requirements are needed to decide when to start the resource reallocation process. The former concerns the constant observation of the infrastructure and the traffic state. The latter concerns the analysis of the result of this observation for the production of a prediction on the infrastructure and traffic future state. This includes also natural risks assets. The *Monitoring* and *Prediction* must be assured to allow the timely trigger of necessary processes.

Beside the system immanent monitoring equipment, also external data, e.g., from weather forecast institutes, can be considered for *Monitoring* and *Prediction*. While the current state mainly will be based on own monitoring results, the future state of infrastructure and traffic state can be predicted by integrating external data, e.g., precipitation quantity or wind speeds that can lead to temporary speed restrictions. All these data are to be analysed in terms of their impact on the railway infrastructure and traffic state.

DECISION ON HOW TO REALLOCATE RESOURCES REQUIREMENT

The last requirement, named *Decision on how to reallocate resources*, is elaborated in Figure 3-3, where it is shown that the system shall be able to

- Rapidly produce a feasible schedule;
- Optimize train recovery plans;
- Optimise platforming;
- Integrate rolling-stock and crew schedule rostering in case of disruption.

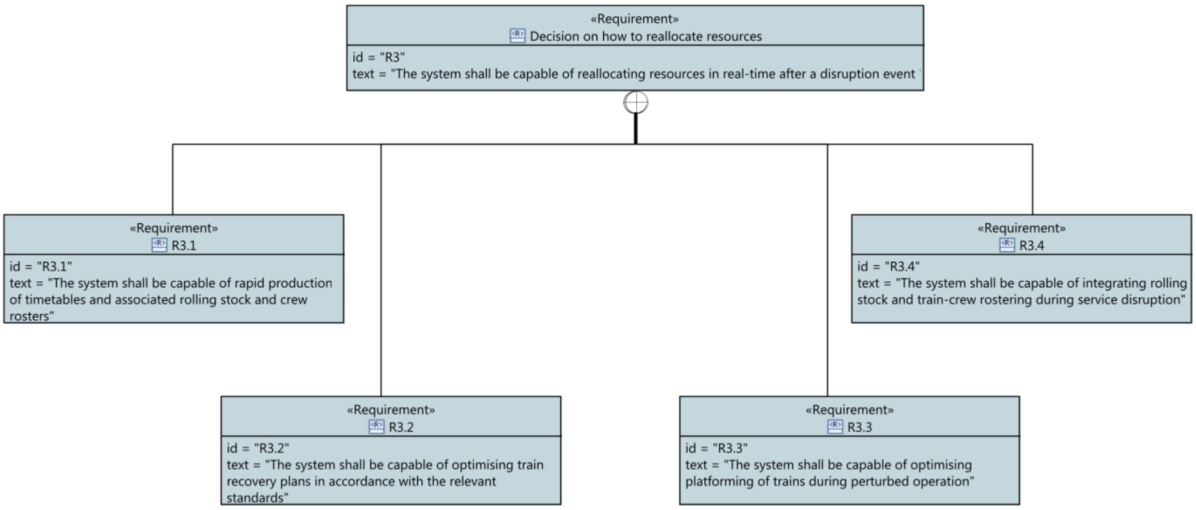


FIGURE 3-3 RESOURCE REALLOCATION REQUIREMENT

The *Decision on how to reallocate resources* requirements cover also resource reallocations due to extreme weather events, e.g., the avoidance of train splitting in heavy winter conditions.

COMMUNICATION REQUIREMENT

The *Communication* requirement supports the integration of IM and RU decisions. *Communication* consists in the ability of the system to perform all the necessary communication activities during a disruption (Figure 3-4):

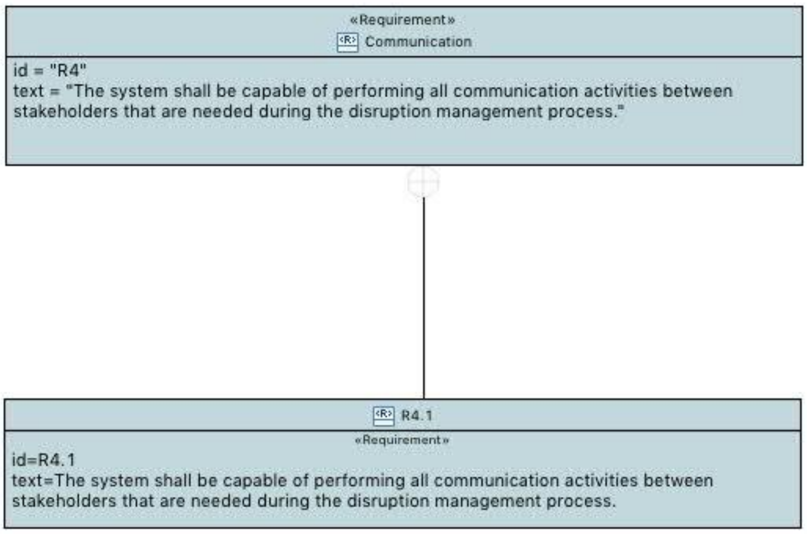


FIGURE 3-4 COMMUNICATION REQUIREMENTS

3.1.2 BLOCK DEFINITIONS

The blocks used for modelling the disruption management process define the relevant properties of the Infrastructure, the train definition, the overall schedule, etc.

RESOURCE SCHEDULE

The most critical block definition is the one describing the Resource schedules (Figure 3-5).

It defines relevant properties, constraints, and values that must characterize a whole schedule:

- *Timetable*;
- *Rolling-stock schedule*;
- *Crew schedule*.

Starting from the left hand side of Figure 3-5, the *Resource Schedules* block is related to a *Timetable* block by a composite association with cardinality 1 to 1. This means that a *Resource Schedules* block contains exactly 1 *Timetable*, and a *Timetable* belongs to exactly 1 *Resource Schedules* block. Moreover, the *Resource Schedules* block is related to a *Rolling Stock Schedule* and to a *Crew Schedule* block by a composite association with cardinality 1 to many: a *Resource Schedules* block contains at least 1 of these types of block.

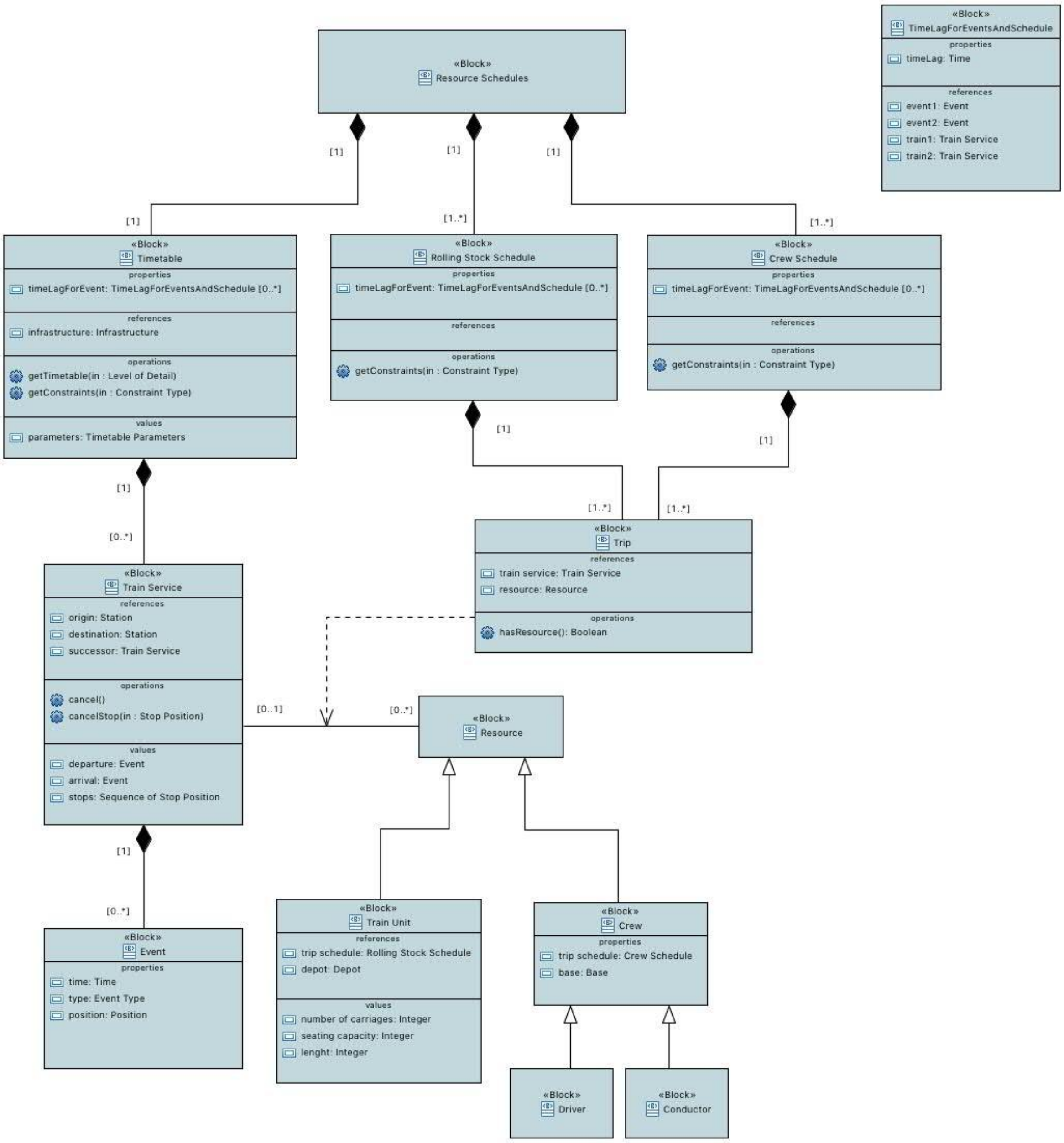


FIGURE 3-5 RESOURCE SCHEDULES – BLOCK DEFINITION

TIMETABLE BLOCK

A *Timetable* is composed by a set of tasks (*Train Services*) that use the *Infrastructure*. The *Infrastructure* block, shown in Figure 3-6, has several properties which are necessary for its representation at either the macroscopic or the microscopic level. Moreover, the *Timetable* block (Figure 3-5) has an attribute *parameters* typed by *Timetable Parameters*. In Figure 3-6, the structured value type *Timetable Parameters* is defined: it includes data of *running times*, *headway times* and *capacity* of the stations and open lines (subtypes of Area). The inclusion of the *Timetable parameters* as attribute of the *Timetable* block allows the number of output pins in the disruption management process activity diagram (see 3.1.4) to be reduced.

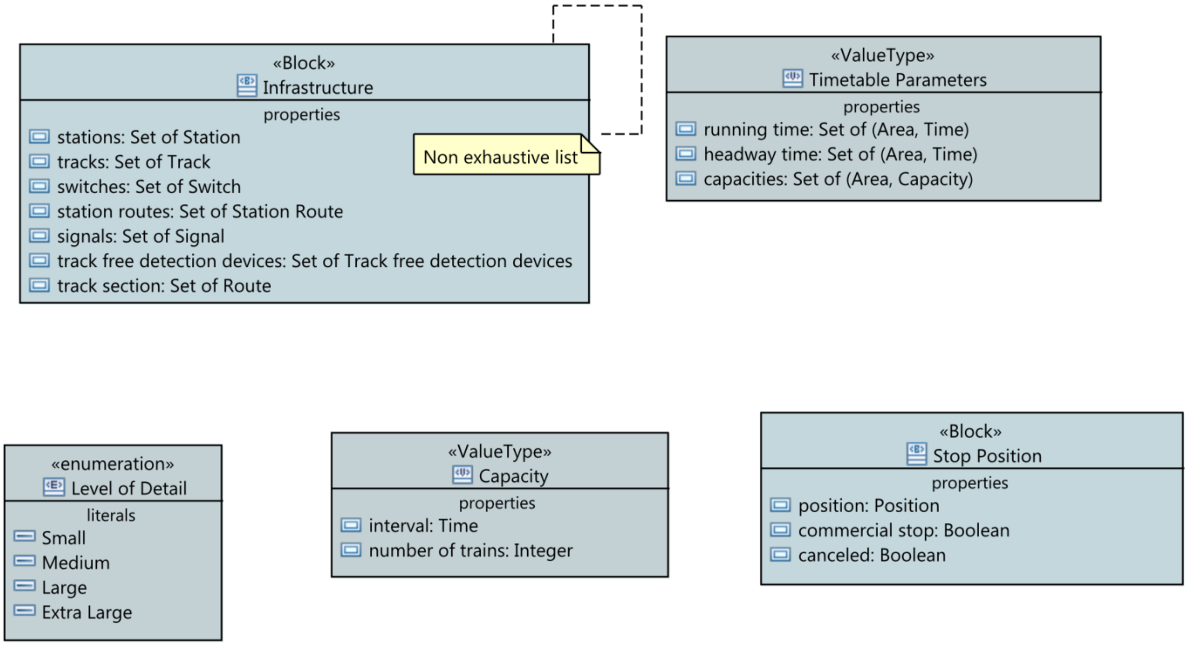


FIGURE 3-6 TIMETABLE REFERENCE AND VALUE TYPES

Several levels of detail of the *Timetable* must be accessed depending on the context of usage. In this model, all levels of detail are put together in the *Timetable* block. They are independently accessible through the operation *getTimetable*, where an enumeration value type, named *Level of Details*, has been defined with the different literal levels (Figure 3-6).

The operation *getConstraints* allows the guarantee of the respect of time constraints due to the coordination of several *Train Services* in a *Timetable*. The events for which a constraint must be imposed are reported in the *TimeLagForEventAndSchedule* block. Here, the *event1* of *train1* and the *event2* of *train2* are said to require a time separation of *timeLag* time units. Through the constraints which are explained in detail in 3.1.3, the elapse of a minimum time interval between events as rolling stock reutilization and train connections can be ensured.

TRAIN SERVICE BLOCK

In Figure 3-5, to detail the tasks composing a *Timetable,* a composite association links the *Timetable* block to the *Train Service* block. To represent the fact that a Timetable may contain several trains and it surely contains at least one, the multiplicity of the terminal part of this association is "1..*". A *Train Service* block represents a train mission that starts from a station and arrives at a destination station referenced respectively by *origin* and *destination* reference properties. The turning connections are specified by the *successor* reference property.

The *Event* structured value type captures event features of a *Train Service*, as the arrival at a station or the passing of a signal. The *type* property gives information of the category of events which is to occur and *position* locates where the event occurs (see also Figure 3-7).

Another important property is the sequence of stops, which is modelled by the *Stop Position* block (in Figure 3-6. The *Stop Position* block is defined to manage the state (Boolean parameter *cancelled*) of the commercial and non-commercial stops.

During the disruption management process it may be necessary to cancel train services or some of their stops. The implementation of these decisions are realised respectively by the operations *cancel()* and *cancelStop()* of the *Train Service* block (Figure 3-5).

Rolling Stock Schedule Block

In addition to the composite association between the *Resource Schedules* and the *Timetable* block, another composite association links the *Resource Schedules* and the *Rolling-Stock Schedule* block (Figure 3-5). As mentioned, this association has a multiplicity 1..*, to model the fact that a *Resource Schedules* block may contain several rolling-stock schedules. This may be necessary if the schedules must be distinguished between each RUs or depots.

As for the *Timetable*, the *Rolling-Stock Schedule* block implements an operation *getConstraints()* that gives temporal constraints on the elements of *timeLagForEvents*. A rolling-stock constraint links events of two successive *Train Services* that use the same *Train Unit*. The details of all tasks between successive Trips of the rolling-stock schedule are not considered in this report. A key data is the minimal duration between the end of a trip and the start of the successor trip.

Crew Schedule Block

Similarly to the *Timetable* and the *Rolling-Stock Schedule*, in the SysML block definition diagram of Resource schedules in Figure 3-5, the *Crew Schedule* block has a composition relationship with the *Resource Schedules* block. Even if not explicitly shown in the diagram, the *Crew Schedule* is organised as sequences of *trips* per day, called duties. Some breaks and other activities are added in between. The duties start and end at bases. The duties are put together and rest periods are added to form a roster. The assignment and schedule of *crew* have to conform to technical and social rules. These rules impose the respect of some constraints realized by an operation *getConstraints()* that gives temporal constraints on the elements of *timeLagForEvents*. As it contains *Trips*, the *Crew Schedule* block has a composition relationship with the *Trip* block.

Trip Block

In this framework, the *Trip* block constitutes the link of the Timetable (via the *Train Services*), the *Rolling-Stock Schedule* and the *Crew Schedule* blocks (Figure 3-5). The *Trip* block is an association block. An association block describes the structural properties of an association. A *Trip* is the association between a *Train Service* and a resource to achieve the *Train Service* itself. The assignment of resources is internally managed within the *Trip* block. The operation *hasResource()* returns false if all the required resources for the *Train Service* are not assigned. Otherwise it returns true.

RESOURCE BLOCK, TRAIN UNIT BLOCK, CREW BLOCK

These blocks correspond to the *Resource* (*Train Units* and *Crew*) affected to the *Train Service* (Figure 3-5). Hence, the *Train Unit* and the *Crew* blocks are subclasses of *Resource* block. The subclass relation facilitates the block to reuse the features of the superclass blocks and to add its own features.

A *Train Unit* is a self-propelled railway vehicle with one source of energy (electrical, diesel, etc.). It is the basic rolling-stock element to operate trains; the case of operating with carriages and a locomotive will not be considered here for the sake of simplicity, but the modelling constructs used can also incorporate these rolling-stock elements. *Train Units* can be coupled and uncoupled to form trains of different length, called train composition. With respect to the *Rolling-Stock Schedule*, *Train Units* are assigned to a sequence of *Trips*. Along this sequence, the departure station of a *Trip* must be the same station as the arrival station of the predecessor *Trip*. Each day, the first and last *Trip* of the sequence must respectively start and end at a depot. The number of *Train Units* available at a depot is called the rolling-stock inventory. A *Trip* sequence is "balanced" if the inventory of the depots at the end of the day is sufficient to cover the required rolling-stock inventory for the beginning of the next day. An important goal during operations is to avoid off-balance at the end of the day. In a *Rolling-Stock Schedule*, each *Train Unit* follows a coherent *Trip Schedule*, starting from a depot. Moreover, its definition includes information as the number of carriages, the seating capacity and the length of the *Train Units*.

The *Crew* block has two subclasses: the *Driver* block and the *Conductor* block.

3.1.3 RESOURCE CONSTRAINT

SysML introduces constraint blocks to capture the constraints between properties of blocks, i.e., to represent the rules that constrain the properties of a system. In the resource management, the temporal constraints related to the use of resources can be captured with this kind of block. Constraint blocks are used in parametric models to support different engineering analyses, such as performance analysis or reliability. Here, constraint blocks are used to validate *Resource scheduling* solutions.

Constraint blocks are defined on block definition diagrams and used on parametric diagrams. The block definition diagram shown in Figure 3-7 gives the definition of the resource constraints, which can cover almost all temporal requirements of train service events managed in the *Disruption management process* activity. A constraint block is defined similarly to a block.

A constraint block has two features:

- A set of parameters;
- An expression that constraints the parameters themselves.

In the graphical representation, the compartment name contains the keyword "constraint" above the name, the constraint expressions are defined in the *constraints* compartment and the parameters are in the *parameters* compartment (Figure 3-7). Here, the *parameters* are named *type*: the *Constraint Type* enumeration value type collects all literals of constraint types.

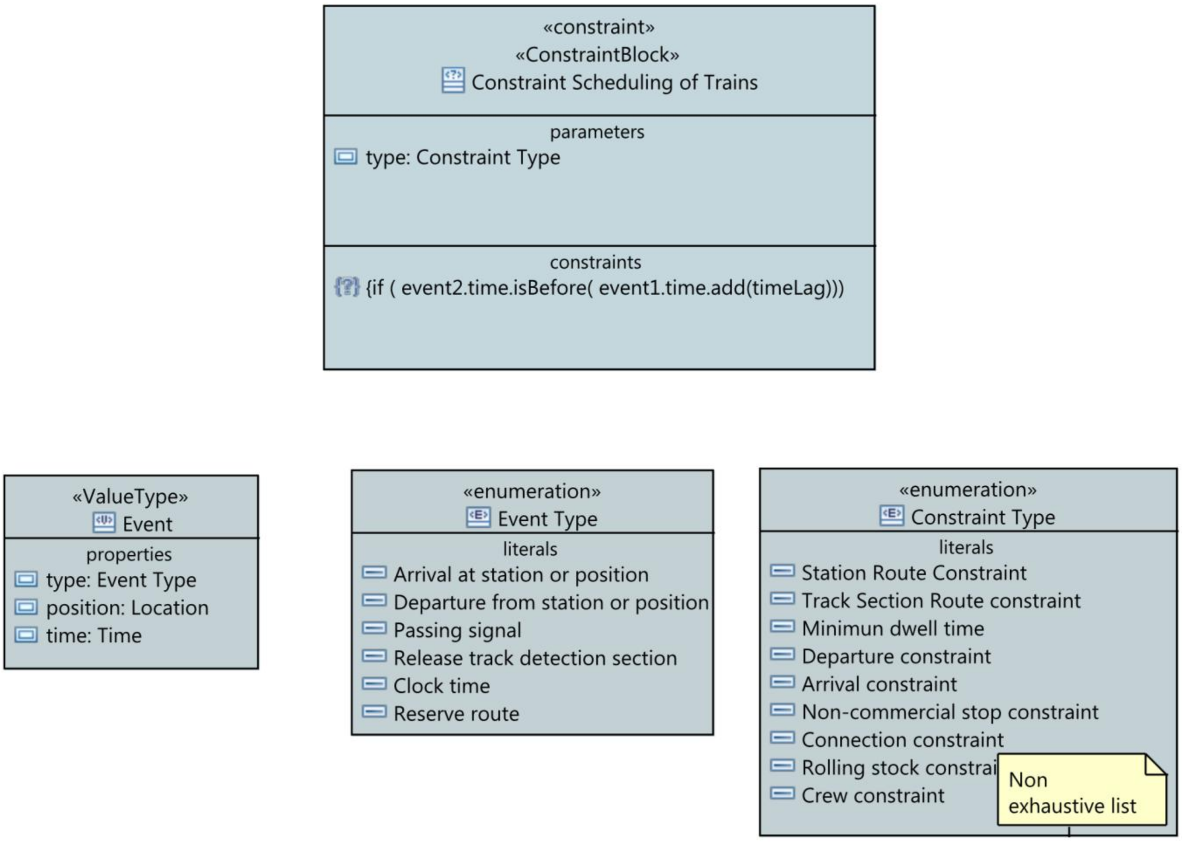


FIGURE 3-7 RESOURCE CONSTRAINTS DEFINITIONS

Figure 3-8 shows a parametric diagram of the use of constraint blocks. In this block definition diagram, the constraint block is connected to the block whose values are constrained by a composite association. The block *Constraint Scheduling of Trains* specifies the constraint parameters within the context of each block containing the constraint. The value and references of the *TimeLagForEventsandSchedule* block identified in the *Timetable*, *Rolling Stock Schedule* or *Crew Schedule* are linked. In particular, *event1* of the constraint is linked to an event of a first train service, while *event2* is linked to an event of a second one. The constraint allows ensuring the respect of a minimum time to separate the two events. As an example, it may be the arrival and the departure of two trains in connection at a station. Thanks to the combination of *Event Types* and *Constraint Type*, all the necessary constrains can be defined to check the feasibility of a *Resource schedule* (Figure 3-8).

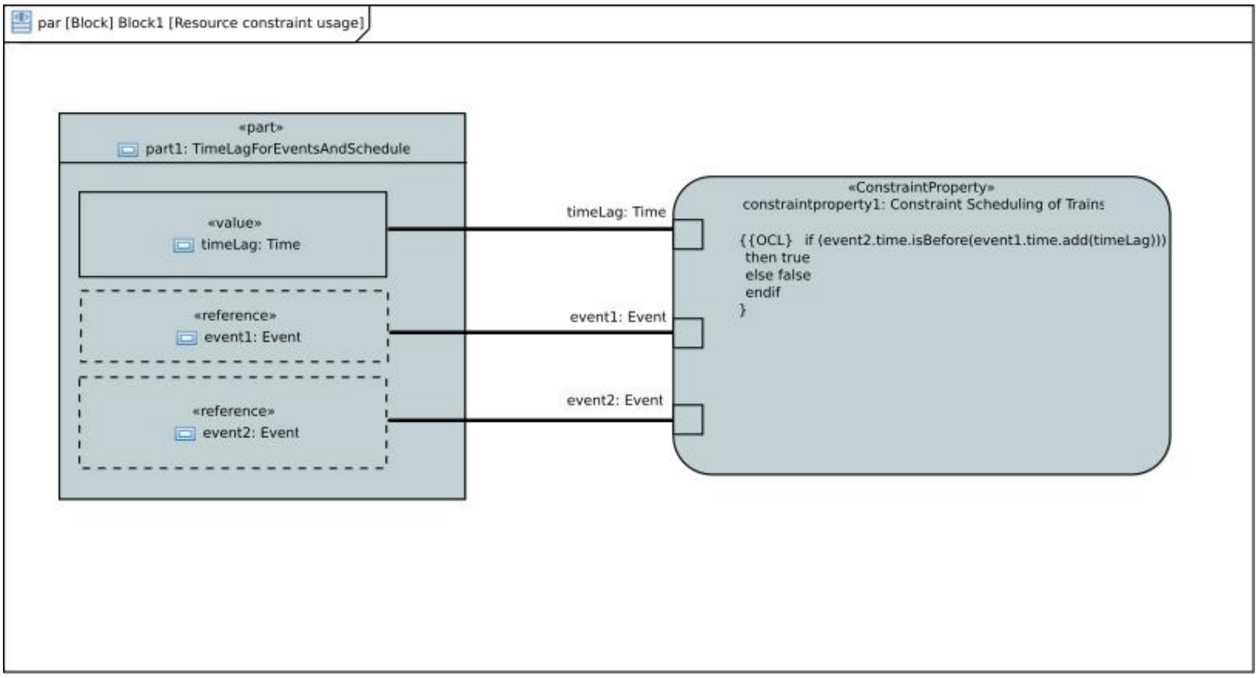


Figure 3-8 Resource constraints Usage

3.1.4 Activity diagrams of disruption management process

This section describes an activity diagram of the whole process of disruption management considered in WP3.3.

The process is described as sequences of actions that transform input tokens to output tokens. The input/output pins of actions are connected to enable the flow of inputs/outputs. In addition, the execution of the actions is enabled by control tokens.

The activity diagram of the Disruption Management Process shows the connection of the actions and the activities composing the disruption management process (Figure 3-9).

In a SysML activity diagram, the activity starts at the initial node shown as a solid black circle. A token is placed on that node and triggers the execution of one or more actions via the outgoing control tokens.

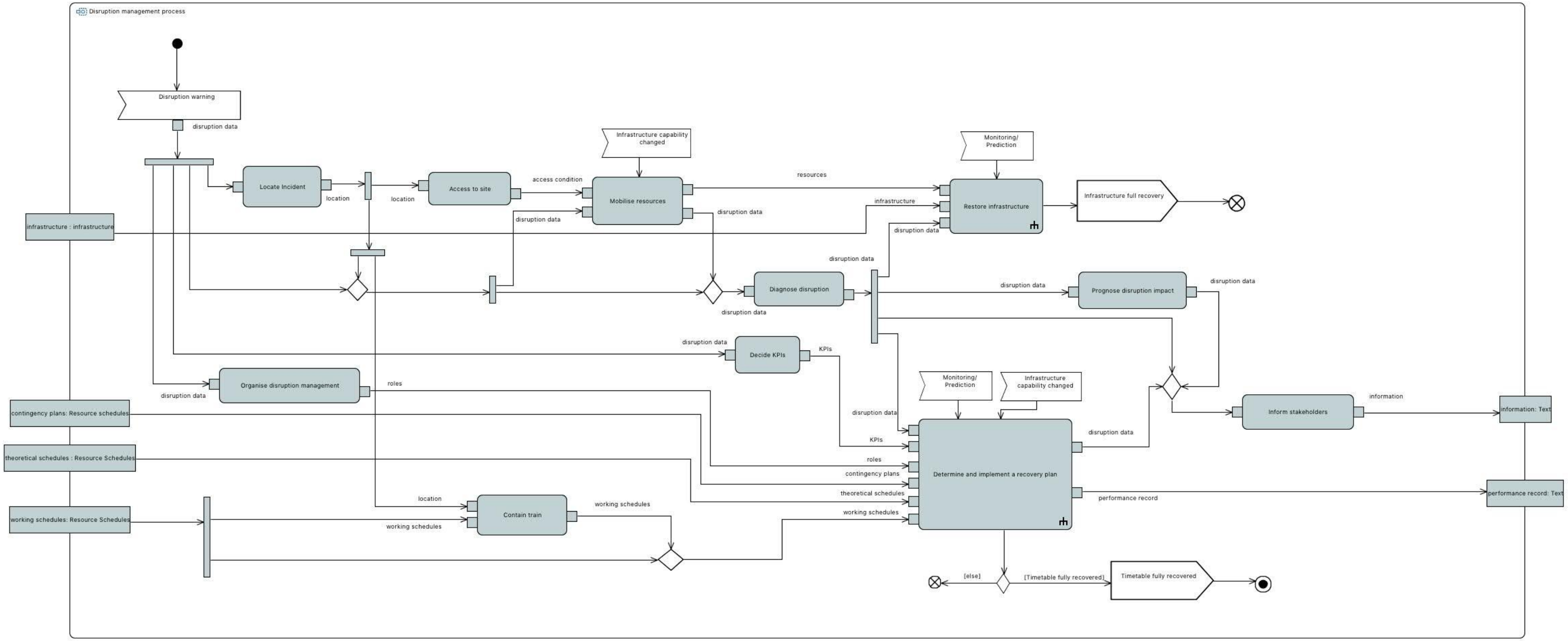


FIGURE 3-9 DISRUPTION MANAGEMENT PROCESS – ACTIVITY DIAGRAM

DISRUPTION WARNING

In Figure 3-9 the process starts as soon as a *Disruption warning* signal is received.

This is represented through an accept signal action. It is drawn by a rectangle with a triangular section missing from the left hand side. In a traffic monitoring process (not modelled here) an activity, whose goal is to monitor the traffic, detects a disruption and communicates a signal event of a *Disruption Warning* with a send signal action. Furthermore, preventive suspension of railway operation, e.g., due to warnings from weather forecast institutes, can also be handled as disruption warnings. At this level of description of the process, there is no specification of the SysML block which owns the activity that will send the *Disruption warning* signal. More specifically, this means that the signal can be sent by an activity performed either by a technical system or by a human operator through any communication support.

A signal defines a message with a set of attributes. The definition of the signal *Disruption warning* is in Figure 3-10 and includes *Disruption Data* block that in turn contains system immanent *causes* (e.g., *Crew delay*, *Section line closure*) as well as external *causes* (e.g., *Weather events*). An *accept signal* action outputs the received signal on an output pin to flow the properties of the signal, in this case the *Disruption data*.

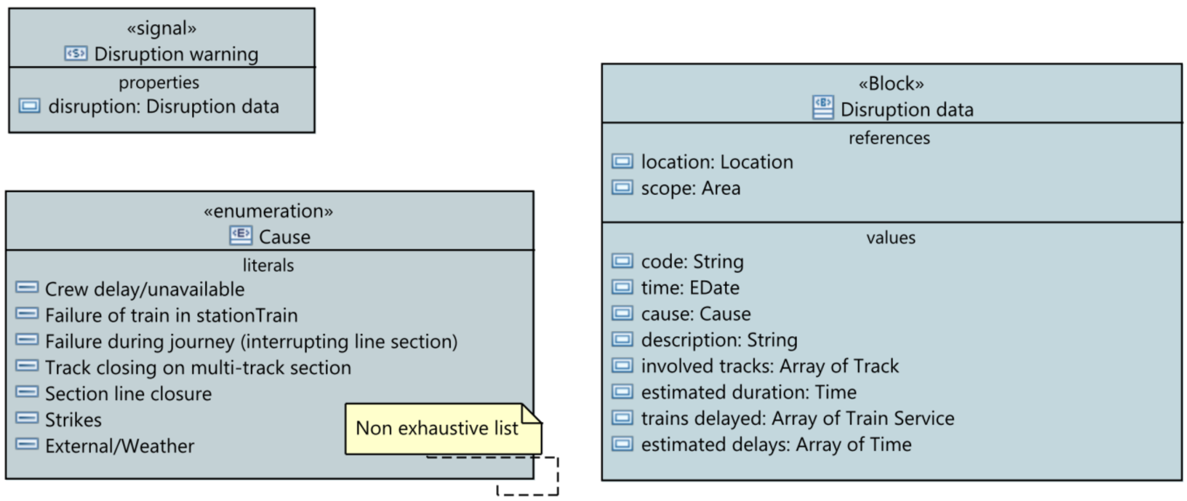


FIGURE 3-10 DISRUPTION MANAGEMENT PROCESS – BLOCKS AND DATA TYPES

Let us remark here that the *accept signal* actions and the *send signal* actions allow asynchronous communications between activities: the sender activity does not wait for a response from the receiver to proceed to the next action.

As shown in Figure 3-9, following the acceptance of the *Disruption warning* signal, a fork node duplicates the token object *disruption data* and enables the execution of the four following actions to be triggered:

- Locate incident;

- Organise disruption management;
- Diagnose disruption;
- Decide Key Performance Indicators (KPIs).

These four actions will invoke activities, not detailed here, that will refine *location*, *scope*, *causes* of the disruption, roles within the organisation and KPIs to be used to estimate the evolution of the process. In particular, *Locate incident* is the activity in charge of determine the location of the incident and the scope of the affected area based on the currently available information. *Organise disruption management* consists in assigning people to specific roles for the duration of the incident (e.g., specifying the name and contact details of the temporary RIO (Rail Incident Officer)). In the activity *Diagnose disruption*, after receiving a signal of a *disruption warning* and *disruption data*, the aim is to determine the cause of an incident (e.g., receiving an emergency message from a stopped train, receiving a call from a driver saying that the overhead line has come down or receiving extreme weather warnings from external stakeholder). Finally, *Decide KPI's* involves the definition of the key performance indicators which will be used to assess the evolution of the situation and the quality of the proposed *Resource Reschedules*.

Location, *scope* and *causes* are attributes of the *disruption data* token put in the input/output pins of the actions (Figure 3-10): these data will be filled as soon as the information becomes available within one of the mentioned activities.

LOCATE INCIDENT

After invoking *Locate incident*, the process can proceed with the action *Contain trains* as the location is known and trains to hold can be determined to prevent escalation. The holding of trains is recorded in the timetable of the input parameter *working schedules*. The changed *working schedules* is placed on the output flow to be input to *Determine and implement a recovery plan*, to make a decision on the hold trains.

The action *Access to site* is invoked simultaneously. It requires the plan, execution or handback of track or electrical isolation to allow access to site of incident (e.g., setting signals to red so that track-workers can access the failed point). Once the access conditions are met, the action *Mobilise resources* is invoked to move resources (people or plant) on the site of the incident. To do so, the *disruption data* are also required, which explains the further transmission of this token from the initial fork. When the activity *Mobilise resources* is completed, the resources on site can provide new information about the incident. This information updates the *disruption data* and invokes the activity *Diagnose disruption*, the output of which is the cause of the disruption.

Depending on the nature of the incident (e.g., for some kind of weather events as strong winds), the activities *Access to site*, *Mobilise resources* and the subsequent *Restore Infrastructure* may not actually imply any actual action.

DIAGNOSE DISRUPTION

The cause identified is stored on the corresponding attribute of the output token *disruption data*. The token of the identified cause of the disruption is then replicated to enable execution of four actions:

- Restore Infrastructure;
- Inform stakeholders;
- Prognose disruption impact;
- Determine and implement recovery plan.

RESTORE INFRASTRUCTURE

Restore infrastructure is a complex action, as shown in Figure 3-11. The rake symbol at the bottom right of the box *Restore infrastructure* (Figure 3-9) indicates the invoked activity is described in a separate diagram. It consists in performing all the activities necessary to restore the infrastructure capability (Figure 3-11). Examples are: repair overhead line, get trapped train and passengers out of the immediate vicinity of an incident, etc. In this framework, the execution starts with the activity *Design a restore plan*, which depends on the actually mobilized *resources*, the *Infrastructure* characteristics, the latest version of the *disruption data* and of *Monitoring/Prediction*.

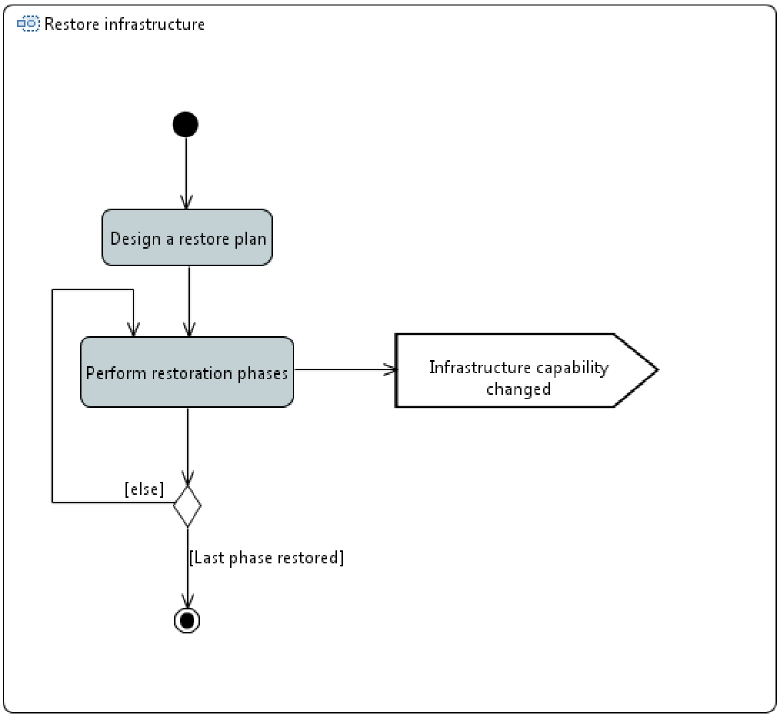


FIGURE 3-11 RESTORE INFRASTRUCTURE – ACTIVITY DIAGRAM

The restore plan may be composed of different phases. Each phase is dealt with sequentially, through the activity *Perform restoration phase*s. The output of this activity is an *Infrastructure capability changed* signal, which communicates the current phase achieved. This signal is received by the *Mobilise resources* activity, in which the current resource mobilisation may be changed depending on the new capabilities. If necessary, the *Restore Infrastructure* activity is re-started based on the new *resources*. Concurrently to the re-assessment of the mobilized resources, the next phase of the restore plan is performed, until the last phase is completed and the *Infrastructure full recovery* signal is sent. When the capability is fully recovered the flow stops.

INFORM STAKEHOLDERS

Simultaneously to the invocation of *Restore Infrastructure*, the action *Inform stakeholders* is executed. It consists in the communication to the stakeholders of the cause and the estimations of major delays (e.g., putting information on screens at all affected station platforms). This action provides the output parameter *Information* of the overall activity.

PROGNOSE DISRUPTION IMPACT

Concurrently, also *Prognose disruption impact* is executed: it estimates the delay caused by the disruption and updates coherently the *disruption data*. The updated disruption data are then transmitted again to the *Inform stakeholders* action.

DETERMINE AND IMPLEMENT A RECOVERY PLAN

The last token sent by the *Diagnose disruption* activity triggers one of the most important activities of the process: *Determine and implement a recovery plan*. This complex activity is detailed in a dedicated diagram, in Figure 3-12. This activity takes as input all the known information on traffic (*theoretical schedules, working schedules, Monitoring signal* (see *disruption data*) which keeps constant track of traffic conditions), on existing *contingency plans (*e.g., the implementation of special trains to deal with the demand mode-transfer due to ash clouds, or the TSR due to strong winds), on current *infrastructure* capabilities (signal *Infrastructure capability changed*), and on the *KPI's* and *roles* defined for dealing with the disruption. The action performed here is the iterative performance of *Evaluate working schedules and emergency schedules quality*, comparing the current *working timetable* and the *emergency schedules* proposed by the activity *Support rescheduling*.

If the quality of one of the available schedules is satisfactory, the activity *Choose the best schedules, implement and update working schedules with them* is executed, the results are recorded in the outputs *disruption data* and *performance record*, and the activity is terminated. Otherwise, the *Support rescheduling* action is executed again and new *emergency schedules* are obtained and compared.

After the termination of the activity *Determine and implement a recovery plan*, first of all the *Inform stakeholders* activity (Figure 3-12) is repeated with the newest information on *disruption data*. Concurrently, if the timetable is fully recovered the corresponding *Timetable fully recovered* signal is sent and the flow finishes. The same signal may be sent also if the timetable is not fully recovered, but the magnitude of the disruption has become small enough to be treated as a small perturbation (Section 2.1). Otherwise, no action is performed and the process continues its execution. Remark that, as the *Mobilise resources* one, the *Determine and implement a recovery plan* activity will re-start as soon as it receives one of its accepted signals (*Infrastructure capability changed* and *Monitoring/Prediction*).

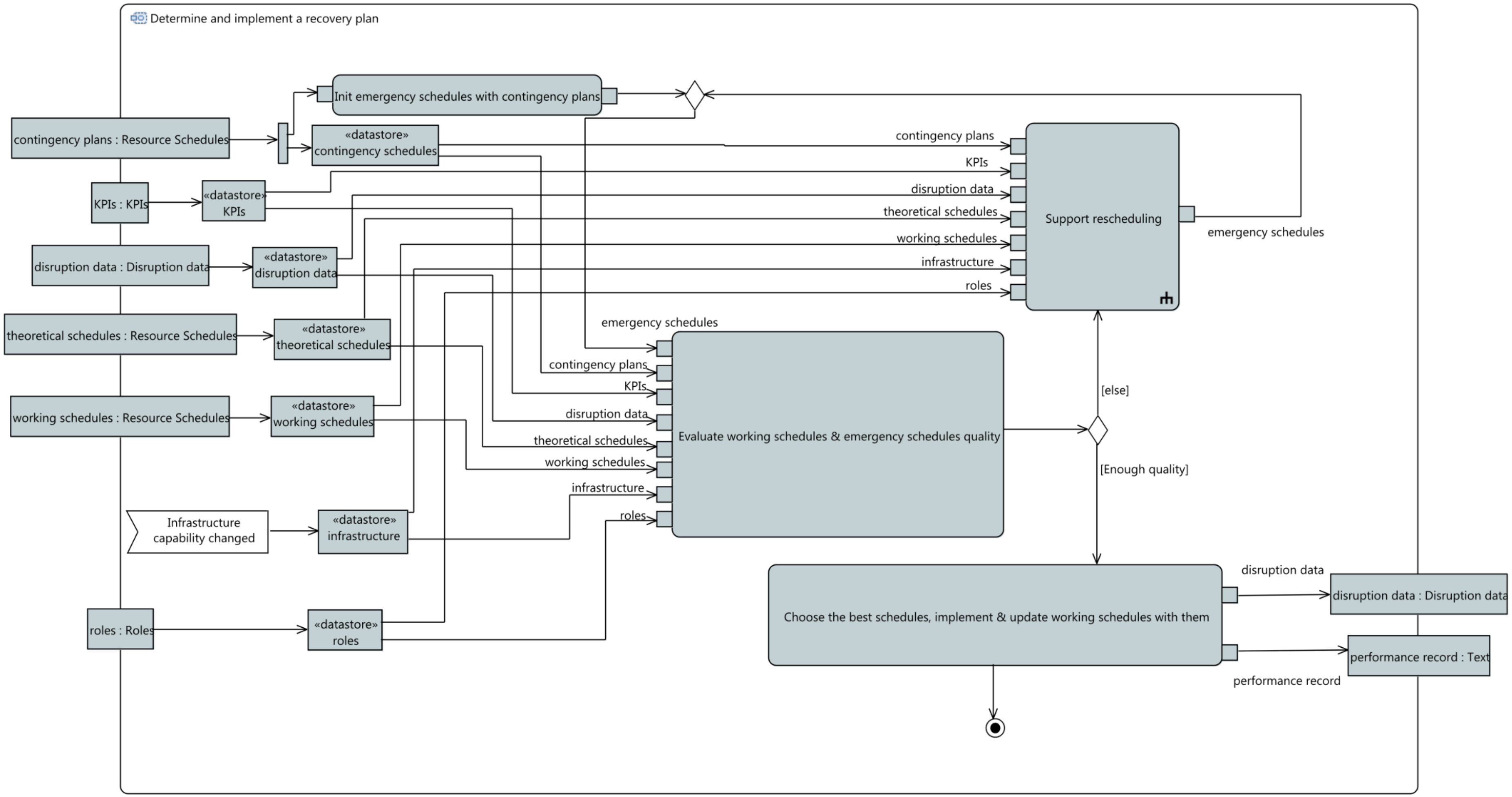


Figure 3-12 Determine and implement a recovery plan – activity Diagram

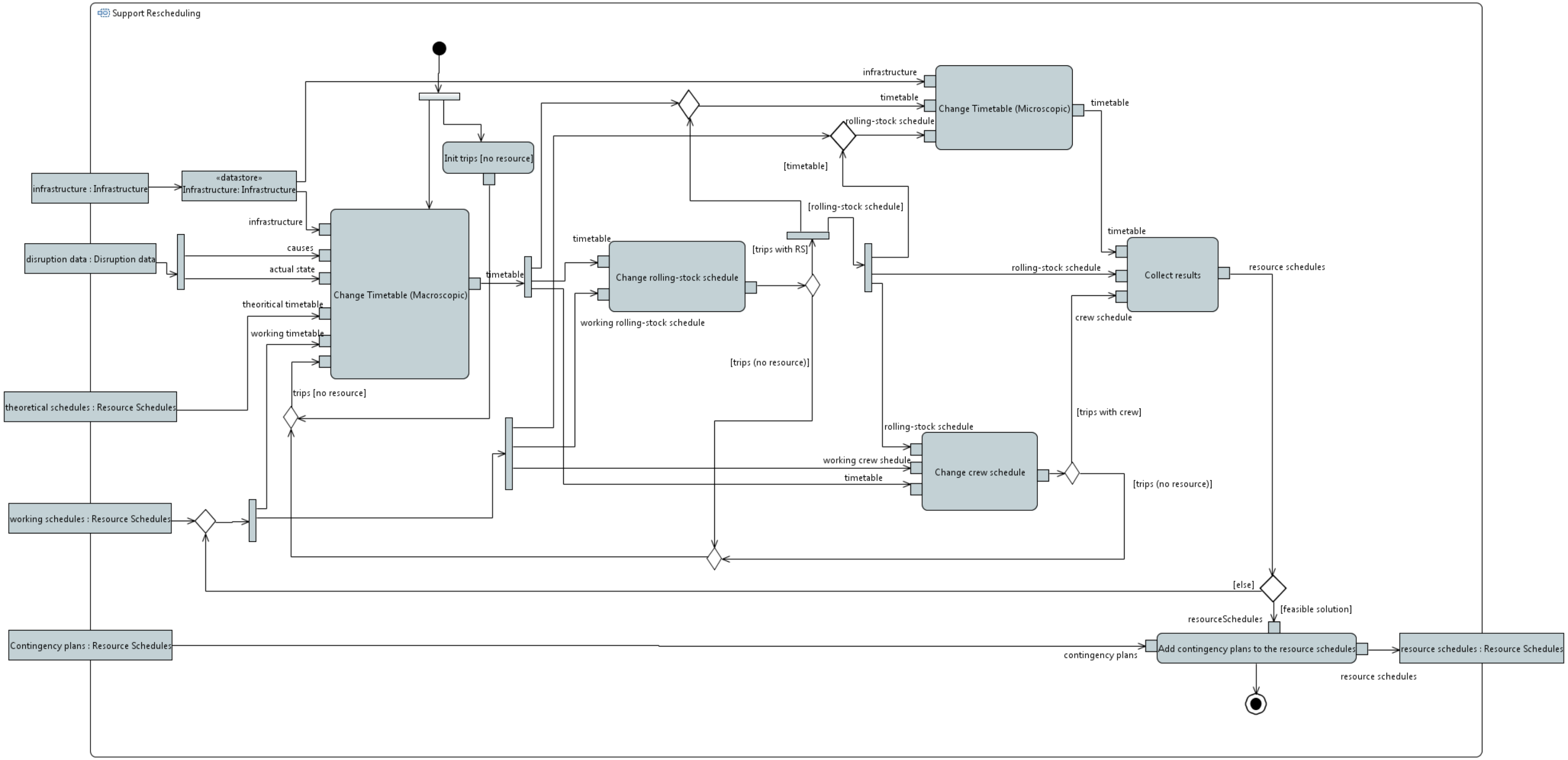


FIGURE 3-13 SUPPORT RESCHEDULING – ACTIVITY DIAGRAM

Support Rescheduling

The complex activity *Support Rescheduling* is represented in Figure 3-13. It consists of an iterative loop executing five actions:

- Change timetable (Macroscopic);
- Change timetable (Microscopic);
- Change rolling-stock schedule;
- Change crew schedule;
- Collect results.

The initial action executed is *Change timetable (Macroscopic)*. Once it has finished, the new timetable is available through a token *timetable* placed on the output pin connected to a fork node. The token is replicated three times and each token is placed onto each output flow of the fork node.

The two actions *Change timetable (Microscopic)* and *Change rolling-stock schedule* immediately start execution as all their input pins have a token available. If the action *Change rolling-stock schedule* changes the characteristics of the rolling-stock used, the action *Change timetable (Microscopic)* must be executed again with the new rolling-stock characteristics.

The execution of *Change crew schedule* can start only when the *Change rolling-stock schedule* has finished. The process of these actions will change the state of the *Trips* of the *Rolling-Stock Schedule* and the state of the *Trips* of the *Crew schedule*. In SysML, a state constraint can be specified on object tokens that flow from one action to another. This is equivalent to specifying pre-conditions and post-conditions on the flow of actions. A state constraint on an object node is shown by the name of the constraint in square brackets. As shown in Figure 3-13, a state constraint on the *Trips* output of *Change rolling-stock schedule* specifies that it is a collection of trips with *[no resource]* state. This means that no rolling-stock composition has been appointed to each *Trip* of the collection. Similarly, the *[no resource]* state of the *Trips* output of the *Change crew schedule* means that no crew could be found for each *Trip*. Here, it is assumed that there is no partial resource assignment, i.e., there are only two possible states for each *Trip*: either all the required resources are assigned, or no resource is assigned. When one of these tokens is available, the Change timetable (Macroscopic) activity is re-started to produce a new timetable compatible with the unavailability of part of the necessary resources. Thereafter, the *Timetable* must be adapted. To implement these pre- and post-conditions, the operation *HasResource()* has been defined in the block definition of *Trips* in Figure 3-5.

If *Change timetable (Macroscopic)* indicates that the changes to *Timetable*, *Rolling-Stock* and *Crew Schedule* can be accepted by stakeholders, then the variable *feasible solution* is set to true. This variable is tested on the guard of a decision node; if false, a new loop for changes is performed from *Change timetable (Macroscopic)*. If true the activity terminates. Formerly the action *Collect results* has put together all schedules and details of the timetable into a *resource schedules* object. To this object the contingency plans are added in the *Add contingency plans to the resource schedules*. This is done so that the people in charge of making a decision on the suitability of the implementation of the proposed schedule receive as a concurrent input the *contingency plan*. In fact, in the *Evaluate working schedule & emergency schedule quality activity* (Figure 3-12), based on identified *KPI's*, on their expertise and on their knowledge of the system, they may decide to implement a known and possibly tested *contingency plan* rather than a new *resource schedule*. Even if the *Support rescheduling* activity returns a *Resource schedule* which appears to be satisfactory according to the criteria defined, the operator always has the last word on its implementation. The chosen *Resource schedules* is available on the output parameter of the activity and therefore on the output pin of the action *Support Rescheduling*.

The actions involved in the *Support rescheduling* activity are not detailed here, since they have been object of extensive study during the ON-TIME project. However, we shortly report here their main features, as well as the inputs required and the outputs produced for completeness.

Change timetable (Macroscopic)

As for the *Change Timetable (Macroscopic)*, the decisions that can be taken in the algorithm to change the timetable are the following:

- cancelling trains;
- reordering and retiming trains (i.e., determining a new schedule with different departure and arrival times at stations);
- rerouting trains (i.e., determining a new schedule with a different set of visited stations: this can be done for freight trains or for passenger trains between scheduled stops.

In particular, starting from the planned timetable and the information on the actual state, trains are rescheduled, by applying cancelling, reordering, retiming and rerouting, with the goal of applying as few changes as possible. Indeed, the objective function consists of minimizing the deviation from the original plan. The inputs considered are:

1. The description of the railway *Infrastructure*: it consists of the list of stations (or relevant points where trains can overtake each other or stop) in the railway network considered, with the indication of their capacity (i.e., number of trains that can be present at the station) and the list of tracks connecting the stations, with the indication if they are bidirectional or monodirectional.
2. The *theoretical* and *working schedules*: this consists of the resource schedule that was defined in the planning phase which is no longer feasible due to the disruption that has occurred, as well as the one which was possibly defined in an earlier stage, and which is currently being implemented.
3. The *Disruption data*: The *actual state* as well as the *causes* for disruption are transmitted.

The output of the action is the new computed timetable.

CHANGE TIMETABLE (MICROSCOPIC)

The *Change Timetable (Microscopic)* considers the railway network at a high level of detail and it performs a microscopic check of the feasibility of the new timetable computed macroscopically. If the timetable is proved to be feasible, this action produces a conflict-free microscopic working timetable detailed at the local route level.

The data required as input to the microscopic timetable module are as follows:

- *Macroscopic Timetable*:
  - Train services with arrival/departure times at stations;
  - Dwell times at stations;
  - Routes at the level of corridors between stations (global routes);
  - Non-commercial stops;
  - Train connections.
- *Infrastructure data:*
  - Track lengths;
  - Track gradients;
  - Curvature radii;
  - Speed limits;
  - Signalling system data and ATP characteristics:
    - Track layout with positions of signals, balises and track-free detection devices;
    - Block section lengths;
    - Time delays to release block sections;
    - Time delays to update signal aspects and cab-signalling information;
    - Characteristics of the track-side/cab signalling system;
    - ATP braking behaviour;
    - ATP/ATO speed codes.
  - Interlocking system data:
    - Locations of switches;
    - Interdependencies between signal aspects and switch directions;
    - Interdependencies between positions of adjacent switch directions;
    - Speed limits on switches in diverging direction;
    - Time delay to move/lock/unlock switches in a given direction;
    - Time delay to set routes (local routes).
- *Rolling*-stock data:
  - Train composition in terms of number and type of traction units and wagons;
  - Train length;
  - Train mass;
  - Tractive effort-speed curve;

- Braking rates;
- Coefficients of the resistance equations.
- Unavailable tracks;
- List of feasible train routes (local routes).

The output data returned by the microscopic timetable module is the microscopic working timetable detailed at the local route level.

CHANGE ROLLING-STOCK SCHEDULE

After the macroscopic timetabling, the *Change rolling-stock schedule* activity is executed: rolling-stock has to be rescheduled to cope with the new timetable. The aim of rescheduling is to assign rolling-stock to as many scheduled trips as possible.

The input required for the rolling-stock rescheduling algorithm is as follows:

- The macroscopic timetable:
  - Departure and arrival times;
  - Departure and arrival locations;
  - The successor or predecessor of each train;
  - The length of the trip.
- Working rolling-stock schedule (rolling-stock schedule currently being operated) which gives
  - The list of trips;
  - The appointed composition to every trip;
  - The planned shunting operations;
  - The allowed shunting operations at every station;
  - The different rolling-stock units;
  - The number of available units;
  - The allowed compositions;
  - The desired number of rolling-stock units at each station at the end of the day.

The output of the action is an assignment of rolling-stock compositions to the trips, or a *[no resource]* indication for the Trips to which it was not possible to find an assignment.

CHANGE CREW-STOCK SCHEDULE

When the timetable is changed, the original crew schedule may become infeasible. The *Change crew schedule* activity assesses this feasibility and reschedule the crews so that as many train services as possible have enough crew assigned to operate them. If, for a certain train service, not enough crew can be assigned to the service, the train cannot be operated and the *[no resource]* state will be assigned to the trip.

The input required for the crew rescheduling is the following:

- The working crew schedule, which is the currently implemented list of tasks. A task is a part of a train service between two stations where crew is allowed to switch trains. Each task must have the following information:
    - Departure and arrival time;
    - Departure and arrival location;
    - Used rolling-stock composition;
    - Number and location of available reserve crew (including start and end time of each duty).
- The macroscopic timetable;
- The changed rolling-stock schedule.

The output of this action consists of two items:

- A crew schedule (i.e., a list of duties which is feasible);
- A list of trips for which no crew could be found.

3.2 Impact of the improvement of Freight Traffic on the process

The disruption management process described above impacts both freight and passenger traffic.

Rail Freight background

Although total demand for freight in Europe has increased over the past couple of decades, rail freight as a whole continues to lose market share, predominantly to the road sector. A small increase in rail market share or stabilising of the market was recorded in some countries following deregulation particularly in countries which had previously had one incumbent operator. At the same time, an increase in truck fees occurred in some countries, but in most countries railway market share remains very low.

To tackle this, the EC White Paper (European Commission, 2011) set goals of "30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050".

Rail freight demand forecasting carried out in 2012 during the D-Rail project (D-RAIL, 2012) was based on three scenarios: the Reference scenario with no change from the current rail system in infrastructure, policies and other trends, and two White Paper scenarios (High and Low), which describe how rail demand will develop through implementation of the White Paper guidelines assuming both a full and partial modal shift to rail. Results indicated that in terms of tonnes, total freight demand is expected to grow on average by 1.53% annually according to the Reference scenario. This average growth rate increases significantly in the High White Paper scenario strongly affecting the modal split and doubling rail demand. In the Low scenario, total demand is increased by almost 20% over the present position (Reference Scenario in 2050) while in the High scenario, the total demand is expected to almost double favouring long-distance transport.

To accommodate the increase in rail freight demand will have implications for the rail freight sector both in terms of wagon fleet capability and capacity and infrastructure availability.

To sustain this demand it will be necessary to increase the quality of service, together with lowering the cost of rail freight. The customers must be able to trust the delivery time to meet the requirements of their logistic chain and the cost must be competitive with road freight.

Requirements for the freight system of 2030/2050

To meet these challenges, SP2 "New Concepts for Efficient Freight systems" (C4R, 2014) is investigating the requirements for the freight system of the future. Vision 2050- The railway- a new transport mode for future needs has been produced wherein improvements for freight have been identified as;

- A trans-European High capacity freight rail network. Achieved through rail freight corridors and freeing up capacity on conventional lines by building a cohesive high speed network for passenger traffic.
- The heavy traffic network permits 30 tonnes axle load and a maximum speed of 120 km/h. Some lines with only freight traffic have 35 tonnes axle load but lower speeds. TEN-T guidance suggests 22.5 tonnes axle load to be achieved by 2030 for all core network corridors, while acknowledging that 30 tonnes axle load may be achieved before 2030 on some routes especially in Northern Europe (EC, 2014).
- The load gauge is larger than today meaning that the railway is competitive from 200 kilometres if volumes are large.
- The wagons have quiet, track-friendly bogies and automatic couplers. The automatic coupler is an "intelligent coupler", i.e., it can both couple and uncouple automatically by means of remote control from the locomotive or somewhere else, e.g., a marshalling tower.
- The freight wagons also have antilock protection and also other electronic monitoring systems such as weight and load displacement indicators, "the intelligent freight wagon".
- For small consignments of finished products and semi-manufactures and for customers without a local freight siding, intermodal traffic exists that consists of two systems: heavy intermodal and AutoCombi.
    - Heavy intermodal is conventional intermodal traffic of heavy containers and trailers over long distances. It offers overnight transportation within three nights in the whole of Europe at an average speed of 70 km/h and is competitive from about 500 kilometres. Heavy intermodal trains operate between ports and "Freight Services Centres" with logistics functions and local deliveries by truck. Heavy intermodal can handle containers up to 53' weighing 40 tonnes (the trucks limit their weight) or 25-metre trucks weighing 60 tonnes on low-built wagons. This is made possible by heavy intermodal using the heavy traffic network.
    - A completely new type of intermodal traffic has also been introduced: AutoCombi. In this system loading and unloading are done automatically by means of horizontal

transfer using a loading robot. This is done at terminals located on sidings or, on lines with little traffic, in the main train path. The load is transferred to a storage area where it is held while waiting to be fetched by a local delivery truck or local freight train. AutoCombi can handle swap-bodies up to 15 metres and containers up to 53' and that are 2.5-3.6 metres wide. Careful, systematic load planning and follow-up are accomplished with the help of a computerised booking system that the "train manager" also has access to.

- AutoCombi interacts with heavy intermodal and also calls at Freight Services Centres, which have automated warehouses where the load units are briefly stored to await transshipment between different transport modes, and where there are industrial and distribution warehouses close by. The transport companies can then also provide storage and carry out deliveries for industry.
- In the metropolitan areas the railway is used for some distribution traffic with the help of automated unloading at a number of small terminals in the region instead of one large concentrated terminal. By using horizontal transfer technology at certain nodes metros and tramways can also be used for distribution in the cities.
- The same system is also used for loading in the heavy intermodal system and for unloading large containers at ports and in warehouses and industry. Automated unloading systems for unit trains where an entire train can be unloaded at once also give completely new possibilities.
- In wagonload traffic, the system is used partly to marshal the load carriers instead of the wagons and for wide containers that go directly to industry and are not transported on by truck.
- The high -speed freight trains transport perishable finished goods, spare parts, parcels and mail at an average speed of up to 225 km/h. They can transport goods overnight in central Europe and go directly to the central parts of towns and cities and special mail and parcel terminals for further distribution by road. The high-speed freight trains also interact with air transport and call at several airports.

To realise this vision, SP2 have identified prerequisites for sustainability and intermodality, including the advancements of the rail sector in line with environmentally friendly measures, along with developments for passenger, infrastructure and operations. For further details refer to D21.1 Intermediate Report- Requirements toward the freight system of 2030/2050 (C4R, 2014).

Disruption management and freight traffic

In the freight railway context just delineated, it is clear that some aspects of the disruption management process described in Section 3.1 are particularly critical for freight services.

First of all, the definition of Contingency Plans is to be considered. In some EU countries for example the UK, contingency plans for big disruption management, are pre agreed, wherein passenger services have the highest priority for rerouting as public safety is paramount. More consideration for freight services within contingency plans could mean that for certain situations, instead of freight services being deferred until the timetable is fully recovered, freight services could travel to a certain point closer to the disruption then be held, so that by the time the disruption is cleared they wouldn't be as far behind schedule. To implement this, the nodal yard concept may be used wherein, freight services are held at locations where there is a large siding with driver facilities. (Rail Freight Group, 2016)

Second, in the Determine & implement a recovery plan and Support rescheduling activities, special attention shall be devoted to the rerouting of freight services. Indeed, freight services can be easier to reroute than passenger services as there are not as many intermediate stops and it is less of an inconvenience for freight goods to take a different route as long as they get to the destination on time. The critical issue with rerouting for freight services is infrastructure, in particular in relation to clearance. High cube containers and specific wagon types may only be able to travel on certain routes. This is an issue when rerouting a service, as a route with suitable clearance may not be available and this may lead to the cancellation of these freight services.

An aspect to be taken into account in the resource rescheduling decisions and which is specific to freight services is the goods monitoring. IN fact, freight goods may be temperature controlled or perishable, meaning that the time between diagnosing the disruption and determining and implementing a recovery plan is the most crucial.

Other freight specific constraints for large disruption management are due to:

- the variation between operators. Disruption management plans in place by freight operators are dependent on a number of factors: the scale of the operator in terms of the volume of cargo handled; the number of yards that they own; the number of trains run and geographical coverage;
- the commodity carried and the location and number of yards along their routes;
- the commodity type, which has the highest impact on disruption management particularly in cases where time sensitive goods, postal goods, supermarket goods and perishables are being transported.

Table 3-1 reports an analysis on the expectable impact of the main elements described above on the vision 2050 for the freight railway system on the disruption management process.

TABLE 3-1 FREIGHT SYSTEM OF 2030/2050 & THE BIG DISRUPTION MANAGEMENT PROCESS

Vision 2050	**Relation to disruption management process**	**How will it modify the process or ease the achievement of automation for big disruption management?**
Loading gauge larger than 2016 meaning that the railway is competitive from 200km if volumes are large.	Currently the loading gauge can impact on the rerouting of freight services during big disruption.	A larger loading gauge throughout the EU will mean that loading gauge may be less of a consideration when

		rerouting freight services.
Freight wagons will have antilock protection and other electronic monitoring systems.	Electronic monitoring systems for both wagons and containers are not widely deployed at the moment. In relation to big disruption management these could assist in the location of the incident so that the train and other trains in the vicinity can be held.	Tracking & tracing of freight wagons will ensure incidents with freight services can be located more easily. Electronic monitoring of wagons and containers will also ensure more visible information to all parties of the content of the wagons meaning that if the wagons contain perishable, time dependent goods this could be considered within the determination & implementation of a recovery plan. Freight wagons which have electronic monitoring systems will improve the information available to inform stakeholders (in this case the operator or the customer) of the delay & the new estimated time of arrival, so that the operator can ensure there are personnel available to service the train on its arrival into the terminal.
High -speed freight trains transport perishable finished goods, spare parts, parcels and mail at an average speed of up to 225 km/h. They can transport goods overnight in central Europe and go directly to the central parts of towns and cities and special mail and parcel terminals for further distribution by road. The high-speed freight trains also	Current passenger developments, including high speed services, can mean more and faster passenger services, with pressure on train paths for freight. This can also cause implications in terms of train sequencing, response to big disruption and alternative routes able to accommodate the diverted freight services.	Higher speed freight services as part of an EU high capacity freight rail network, will ease the achievement of big disruption management automation, as freight will be more able to comply with the prevailing line speeds and demonstrate an ability to accelerate and brake at levels closer to passenger services. Re-routing and disruption

interact with air transport and call at several airports.		response could be less difficult as a result.

3.3 Analysis of the process through the capability matrix

WP3.1 is developing a capability matrix tool that can be used by railway operators and managers, at a strategic level, to investigate the impacts on the overall capabilities of a route (or network) after the introduction of innovations. The tool itself will be called the Capability Trade-Offs Assessment (CTA) tool and will enable the examination of the interactions of capabilities within the railway system.

The aim of the CTA Tool is to effectively evaluate the impact on performance of changes to different aspects of railway capabilities. It can be used to assess the changes to selected sections of railway, based on its current state and a future state following the implementation of one or more innovations. While it would be possible to use the CTA tool to compare different sections of railway, this is not the intended use. Rather, it is for the assessment and comparison of the performance of sections of railway in terms of the C4R goals with regard to current and post-innovation statuses. As such, one of the uses of the tool is to support railway infrastructure managers to take a whole systems approach to evaluating the potential of different investment options to meet their strategic goals with regard to high(er) capacity, affordability, resilience, adaptability and automation. Figure 3-14, gives an overview of the component parts of the CTA tool.

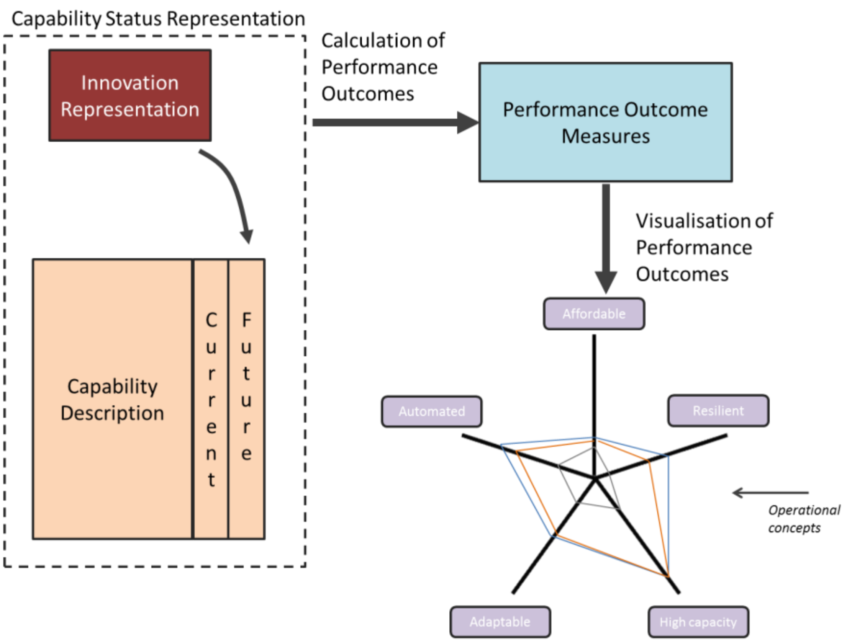


Figure 3-14 Overview of the Capability trade Off Analysis Tool

Within the tool, the functions/sub-functions delivered by a railway will be represented and the user guided to select the status of each function, arriving at a complete description of the selected section's capability status. The performance outcome is reported in terms of C4R's high level goals of adaptability, affordability, automation, capacity and resilience.

The measurement is made via a combination of a series of mappings between capability status and performance outcome. In some cases the mapping is performed automatically, for example, using look-up tables included in the tool, and in others the user is guided to directly enter information or select appropriate statements or options with a score attached to each.

The tool will contain several options for the visualisation and reporting of the performance outcomes. A headline view of the performance in terms of the C4R high level goals will be summarised, while the components of the scores for individual capabilities will be broken down and visualised or reported at a more detailed level to provide a greater level of detail.

Undoubtedly, trade-offs between capabilities will be required in terms of the C4R high level goals. The overall performance aims of different sections of railway vary; for example, the focus of one may be "high capacity for passenger throughput" while for another it could be "a passenger friendly railway". The visualisation part of the tool will allow the representation of pre-defined outcome concepts in terms of the C4R high level goals alongside the results of the calculations made for the section under consideration. Thus, the visualisation module of the CTA tool will be able to provide an overview of the extent to which an innovation facilitates the move from current performance towards a desired level of future performance.

One element where this relates strongly to the big disruption management process is in the reporting of the resilience of a railway network. The CTA will allow users to investigate the addition of an innovation and then report on how that innovation affects the resilience of the network. For example, an innovation that delivers high resilience may not score well on affordability, i.e., the innovation delivering increased resilience is very costly. The CTA tool will allow an improved analytic ability in planning for change, and a better understanding of how the changes can be linked with a resilient network, and therefore dealing with disruption. By targeting innovations that improve the resilience of the network the result will naturally be a railway that can respond more efficiently to big disruption events.

3.4 Model Checking on an activity graph

The given activity models can be used to check further properties of the system behaviour. To do so, we translated the SysML activity diagrams into a state graph (see a simplified variant in Figure 3-15 State graph corresponding to the activity diagramsFigure 3-15). Please refer to (ON-TIME, 2012) for a detailed explanation of model checking on SysML diagrams by conversion into a state graph. During the translation process, some SysML elements need special handling as they can't be modelled as a single node or edge like join and fork nodes. The given activities can be shown in a single state graph as they are connected, but they contain concurrent actions which are summed up not using join nodes but with actions showing the same behaviour. To avoid the introduction of hyperedges (Eshuis, 2006) the system state is modelled referring to the interweaving processes having already finished at each node. This results in a few states depicting the termination order of the concurrent actions which are named after the latest terminated action or an action where it is waited for (noted by a "!" in from of the action's name). In the resulting graph (Figure 3-15) the upper part (above evalWS) represents the activity given in Figure 3-9. The state graph makes clear that there are some concurrently working threads which sum up in evalWS. The lower part of the state graph representing the activities of Figure 3-12,Figure 3-12 instead, contains some recursions.

The absence of deadlocks and the system's termination after a working schedule has been chosen either sending the fully recovered timetable event or just existing could be verified. For brevity the execution of these terminating actions is depicted in Figure 3-15 by the final state choose best. It has to be shown that every run eventually ends there (apart from other processes running concurrently). For this model checking the usage of CTL (Computational Tree Logic) based on event graphs (see (Baier & Katoen, 2008) for an introduction) is quite common. It is required that in all paths (A) through the graph eventually (F) $\mathrm{chooseBest}$ is reached:

$$\mathrm{AF}(\mathrm{chooseBest})$$

As the lower part of the state graph contains recursions without any explicit break condition, it holds:

$$\mathrm{EG}(\neg\mathrm{chooseBest}),$$

so there exists (E) a path, where in all nodes (G) *chooseBest* is not true, which is in opposition to the upper.

To ensure the termination of the activity, the quantity of recursive runs has to be restricted. This can be done by number or by time. As the number of possible timetables is finite after a finite number of recursion steps all possible working schedules have been checked and the best is found and the recursion process can be stopped. Apart from this theoretical view, in many cases a new feasible schedule will be found before or a timeout will be set to prevent full enumeration.

Except the accepting node, each node has at least one following node unequal to itself, so the system is deadlock free as long as all processes finish in finite time. Having in mind that these processes often involve human interaction, it is needed to set time outs, as well as standard values for their output objects to proceed (or abort) the system run.

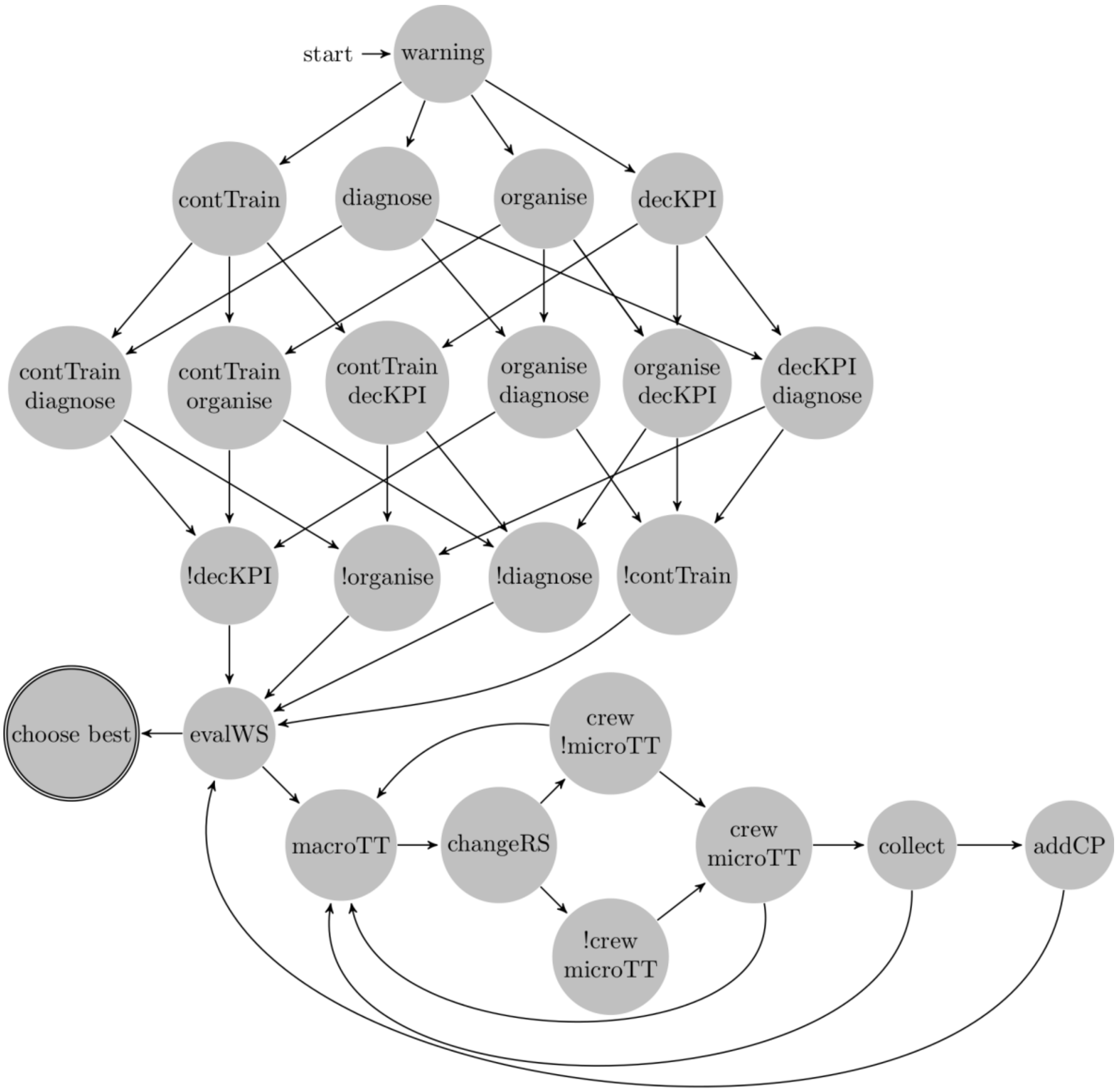


FIGURE 3-15 STATE GRAPH CORRESPONDING TO THE ACTIVITY DIAGRAMS

3.5 VALIDATION FOR DIFFERENT EUROPEAN COUNTRIES

The disruption management process formalized through the above presented SysML diagrams has been validated by different European IMs. In particular, it well represents the currently implemented processes in the UK, France, Spain, Sweden and Czech Republic. In the following, we report a more detailed validation analysis concerning France and the UK.

3.5.1 FRANCE

As for any system, the process applied on the French network is tightly linked to the organisation/resources and systems in place. This triptych involves some differences with the process proposed here.

To clarify the following comments, remarks will mainly make reference to Figure 3-9 presenting the activity diagram for the disruption management process. Otherwise, the reference will be indicated.

Starting from the beginning, detection is one of the main issue on the network and it would make no sense to consider it will cover the entire activity of railway operations if you compare costs (system and personnel to set) and benefits (frequency of disruption). Indeed disruptive events might be detected indirectly and fare after it starts (e.g., the absence of a driver is detected X minutes later because the shunting movement of the engine is not arrived on due time). Plus it has to be indicated that disruption data might have different sources, system or operators, for which the reliability is not equivalent.

Once received the disruption data, the first actions concerns the application of any required safety measure. Today these measures are applied mainly at the local level and sometimes at the regional one. It’s important to reconsider the disruptive events once applied the safety measure, because these measures might broaden the restrictions.

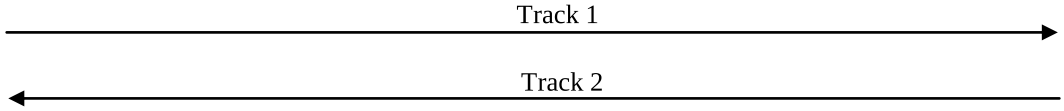
Then, the objective is to confirm the disruptive event, to understand the source of the event and to clearly identify the area concerned. These activities are done at the same time. The idea is to avoid sending non relevant alerts and mobilising unnecessary resources. Once triggered, it’s difficult to modify or stop the process (number of actors involved, multiple information channels, etc.).

Some comments concerning the sequence “Locate incident / access to site / mobilise resources”. The procedure required to access to a site is generally triggered only when the personnel is mobilised and physically present on site. Two reasons for this, once the measures are applied you might broaden the restrictions: close other routes, tracks or lines (e.g., electrical isolation, route locked, etc.), reduce speeds, etc. Indeed, IMs prefer to let trains run even under restrictions rather than stop all trains and wait for personnel. The other reason is that the measure can be temporary (e.g., time for the operator to cross a specific area) and the IM prefers to reduce this temporary phase.

Concerning the processes “prognosis disruption impact” and “determine and implement a recovery plan”. The process applied on the French network establishes a direct link between those two processes and the “Restore infrastructure” process.

The main reason is that the duration and the nature of the disruption tightly depend on the global strategy defined to restore the infrastructure. There could be intermediate steps in which restrictions and milestones are evolutionary. These elements have to be considered to define the recovery plan and the prognosis of the impact of the disruption.

<u>Example: overhead is broken on track 1.</u>



- T0 - step 0: overhead broken is detected by train passing on track 2. Safety measure is applied, track 1 is blocked;
- T0+5min - step 1: next train on track 2 indicates overhead is entering in track 2 gauge. Safety measure is applied, track 2 is blocked;
- T0+20min - step 2: maintenance personnel is on site and removes all obstacle from track 1 and 2. All tracks remain blocked in both direction for 1h;
- T0+1h20 - step 3: track 2 is clear and track 1 is blocked. It's decided to keep clear track 2 for 2h to let trains run and avoid over incident due to passengers discomfort.
- T0+3h20 - step 4: track 1 is blocked and track 2 has speed restriction to fix the overhead.
- T0+5h20 - step 5: track 1 has speed restriction for 5 trains to test the catenary and track 2 is clear;
- T0+6h00 - Step 6: all tracks are clear.

The process presented to determine the recovery plan (Figure 3-12) does not indicate how the recovery plan is defined, coordinated and optimised when various RUs are concerned. This point is one of the main issues to get efficient process and result. On the French network, this process is done by operator orally as follow: a first step is done by each RU to set its own plan, then the many plans are coordinated and negotiated directly between RUs, and the final result is propose to the IM which has to arbitrate the possibly remaining conflicts between RUs.

Last comment, for each disruptive event, all the processes discussed are applied for the French network on a delimited geographical area, which will have to be configurable in any future system envisioned.

3.5.2 United Kingdom

In the UK, the process adopted for managing disruptions and implementing a recovery plan is largely similar to those represented in Figure 3-9 and Figure 3-12. However, some differences exist. Regarding the process for disruption management, the main difference is that decisions of the management strategies are not currently based on any optimised decision support system that considers all variables at the same time to identify the best plan which minimises the impacts. The management plan is indeed just based on the prediction that the Train Running Controller will make of the impact that the disruption will have on the service. Based on such a prediction the Key Route Strategy (i.e., the contingency plan) is adapted to the specific circumstances and the agreements between TOC's/FOC's and the infrastructure manager. This will constitute the management plan to adopt during the disruption.

Another difference stays in the fact that the impact of the disruption on resources (rolling stock and crew) is not predicted, since there is no operating tool which is currently able to do so. This means that resource rescheduling is performed by "Rolling Stock and Crew" management system owned by TOC's/FOC's, after that a decision on the management plan has been taken. However these resource management systems are not integrated in any stream Traffic management system of the infrastructure manager.

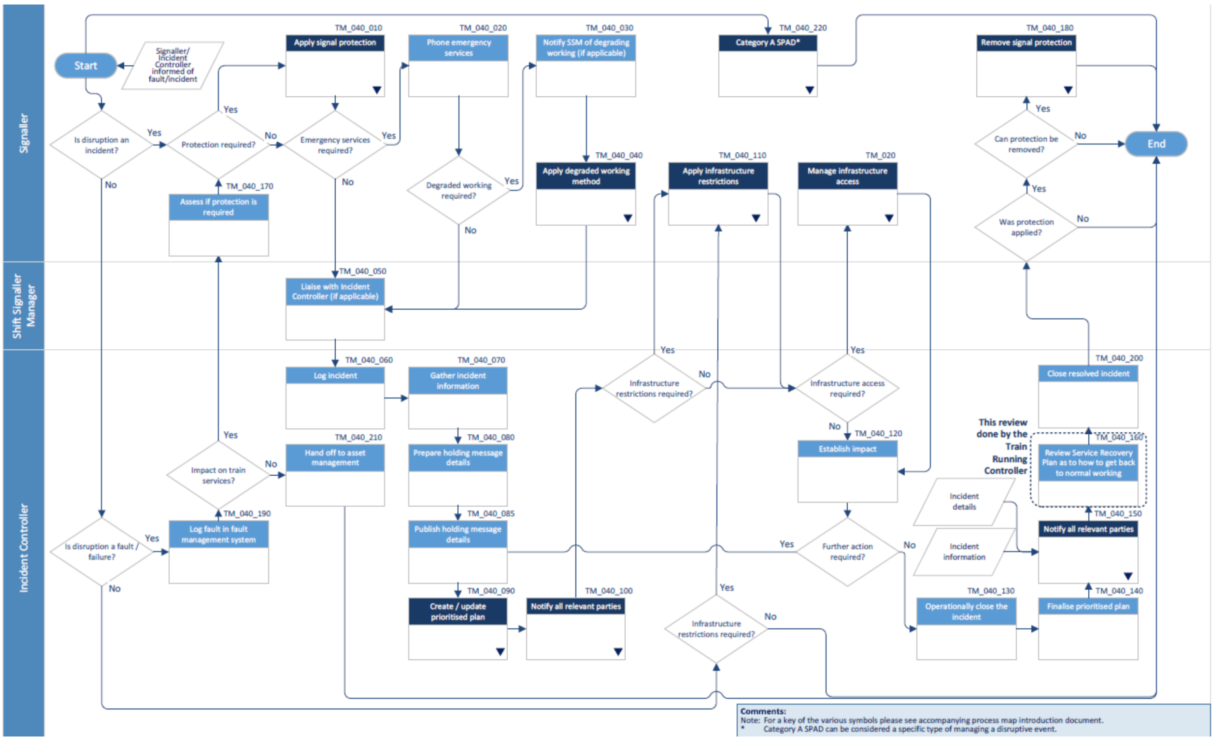


FIGURE 3-16 PROCESS MAP FOR DISRUPTION MANAGEMENT IN THE UK

Figure 3-16 depicts the process map for managing disruptions in the UK, reporting the actions competing to the incident controller and the signaller. When an incident, fault or failure occurs either the signaller or the incident controller is informed. The signaller will provide any necessary protection (e.g., putting signals at danger) and notify different response teams if required. The event is logged, a plan of action is created and the appropriate measures are put in place. Once the management plan is put in place, the infrastructure manager will regulate the access of the maintenance to the infrastructure so to repair the damage, fault or failure. All relevant parties are informed and regularly updated about how the event is progressing. When the disruption has ended, applied protections will be removed and information about the resuming service will be communicated.

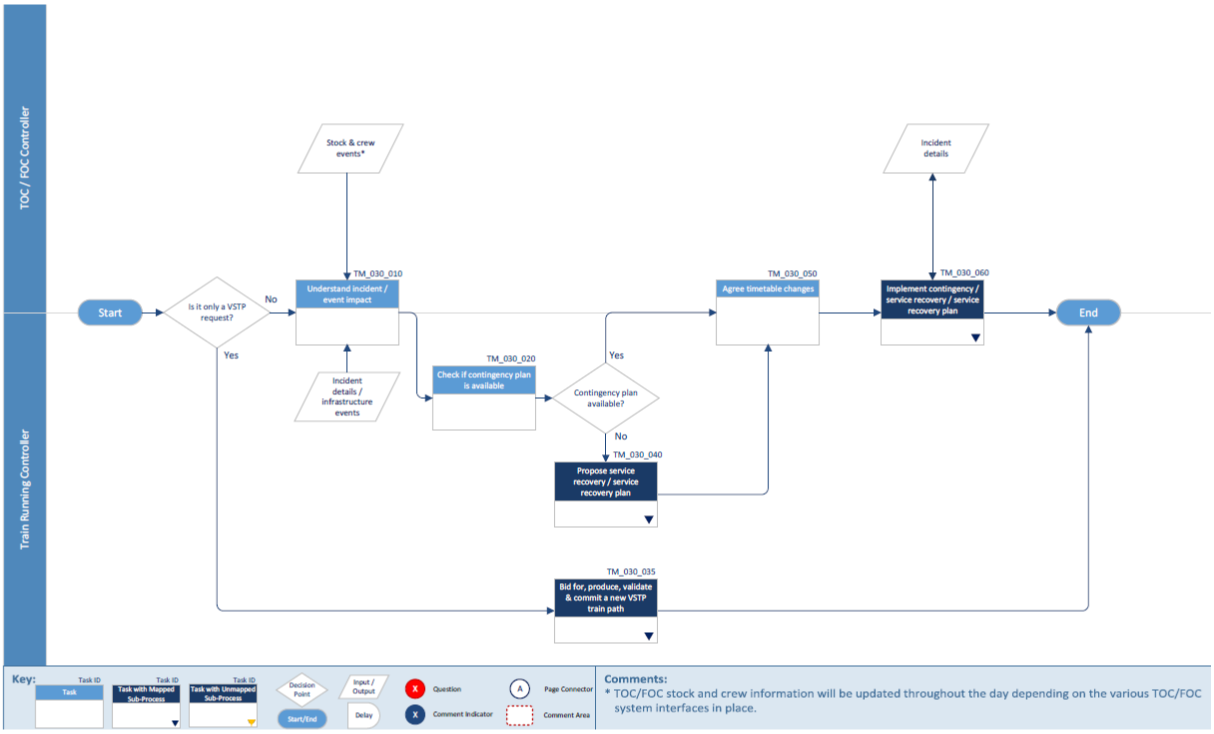


FIGURE 3-17 PROCESS MAP TO REPLAN AND RECOVER SERVICE DURING A DISRUPTION IN THE UK

Figure 3-17 illustrates in detail the process map adopted in the UK to re-plan and recover train service during disruptions, showing the responsibilities of the Train Running Controller and the TOC's/FOC's controller. The objective of this process is indeed to manage services during times of disruption and to create service recovery plans which mitigate the impact of the disruption on network performances, as well as to provide additional train paths in response to requests of TOC's/FOC's. On receipt of details about an incident, the Train Running Controller will assess the impact of the incident or event. If a contingency plan is in place then it is implemented, otherwise a service recovery plan is created by the Train Running Controller in cooperation with the TOC's/FOC's controller. Very short term planning (VSTP) requests will also be assessed and approved/rejected depending on the other services being managed on the route. Observing this process it is clear that the main difference with respect to the process illustrated in Figure 3-12 is the absence of a system that evaluates the quality of different management plans taking into consideration all the variables and constraints of the re-planning problem.

4. Review of existing scales of automation for guided systems

According to a widely shared definition, automation is a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator (Parasuraman, Sheridan, & Wickens, A model for types and levels of human interaction with automations, 2000). The automation can differ in type and complexity, from simply organizing the information sources, to integrating them in some summary fashion, to suggesting decision options that best match the incoming information, or even to carry out the necessary action.

Indeed, men are good at performing tasks which machines are not good at, and machines are good performing other tasks which men are not good at. Jordan (Jordan, 1963) correctly states that men and machines are not comparable; they are complementary levels of automation. Following the author, machines serve man in two ways: as tools and as production machines. A tool extends a man's ability. A production machine replaces a man in doing a job. The principle underlying the complementarity of tools is as follows: man functions best under conditions of optimum difficulty. If the job is too easy he gets bored, if it is too hard he gets fatigued.

In the last decades, several taxonomies have been proposed to formalize the concept of automation, with the definition of scales identifying the main characteristics of the possible levels of automation of a system. Moreover, an important body of literature has focused on the presentation of the relevant aspects to be considered when assessing an automated system, or when designing a new one. These aspects are mostly considered for their impact on the human-machine interaction.

In this section, we first describe the main scales of automation which have been proposed. Then, we describe the aspects to be considered for the automation assessment and design. Finally, we report a brief analysis centred on the railway system. This analysis tries to identify the different contexts in which automation may play a relevant role.

4.1 Level of Automation

The first work toward the formalization of a scale describing reference levels of automation is proposed by Sheridan and Verplank (Sheridan & Verplank, Human and Computer Control of Undersea Teleoperators, 1978). The authors first introduce the following list as a sequence of six "decision sub-elements" which is assumed to apply to most man-computer decisions.

- Request: ask from other party.
- Get: fetch what is requested or necessary.
- Select: choose from among options for intended action.
- Approve: agree or disagree with a particular decision.
- Start: initiate implementation.
- Tell: inform what was done.

There is a variety of ways in which man and computer can cooperate by assigning the decision sub-elements to either of them. The list of Sheridan and Verplank (Sheridan & Verplank, Human and Computer Control of Undersea Teleoperators, 1978) orders these ways of cooperation as levels of automation. The list goes from a level where the human operator does everything to a level where the computer does everything. It is reported in Table 4-1.

TABLE 4-1 FORMALIZATION OF THE LEVELS OF AUTOMATION ACCORDING TO SHERIDAN AND VERPLANK (SHERIDAN & VERPLANK, HUMAN AND COMPUTER CONTROL OF UNDERSEA TELEOPERATORS, 1978)

Description of interaction	Human operator and computer functions
1. human does the whole job up to the point of turning it over to the computer to implementation	human gets options from outside, selects action and starts action
2. computer helps by determining the options	human requests options, computer gets options, human selects action and starts action
3. computer helps determine options and suggests one, which human need not follow	human requests options, computer gets options, human requests select action, computer selects action, human selects actions – can be different – and starts action
4. computer selects action and human may or may not do it	human requests options, computer gets options, human requests select action, computer selects action, human approves selected actions and starts action if approved)
5. computer selects action and implements it if human approves	human requests options, computer gets options, human requests select action, computer selects action, human approves selected actions, computer starts action if approved
6. computer selects action, informs human in plenty of time – T – to stop it	human requests options, computer gets options, human requests select action, computer selects action, human approves start actions, computer starts action if approved or if t>T and human has not disapproved
7. computer does whole job and necessarily tells human what it did	human requests select action, computer gets options, selects action, starts action and tells action
8. computer does whole job and tells human what it did only if human explicitly asks	human requests select action, computer gets options, selects action, starts action and tells action if human requests tell action
9. computer does whole job and tells human what it did and it, the computer, decides he should be told	human requests select action, computer gets options, selects action, starts action and tells action if computer approves
10. computer does whole job if it decides it should be done, and if so tells human, if it decides he should be told	human requests select action, computer gets options, selects action, starts action if computer approves and tells action if computer approves

The list is refined by Sheridan (Sheridan, Telerobotics, Automation, and Human Supervisory Control, 1992), who introduces a slightly different 10-point scale which has been used since then as a main reference on the topic. This scale defines the level of automation, with higher levels representing increased automation, intended as the autonomy of computer over human action. It is reported in Table 4-2.

Table 4-2 Levels of automation according to Sheridan (Sheridan, Telerobotics, Automation, and Human Supervisory Control, 1992)

High	
	10. The computer decides everything, acts autonomously, ignoring the human
	9. The computer decides everything, acts autonomously and informs the human only if it, the computer decides to
	8. The computer decides everything, acts autonomously and informs the human only if asked
	7. The computer decides everything, executes automatically, then necessarily informs the human
	6. The computer decides everything and allows the human a restricted time to veto before automatic execution
	5. The computer suggests one decision/action alternative and executes that suggestion if the human approves
	4. The computer suggests one decision/action alternative
	3. The computer narrows the selection of decision/action alternatives down to a few
	2. The computer offers a complete set of decision/action alternatives
	1. The computer offers no assistance: human must take all decisions and actions
Low	

Later on, Wickens et al. (Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation, 1998) start from the scale of Table 2 and state that the automation of information acquisition shall be differentiated from the automation of decision and action selection and from the automation of action implementation.

Moreover, they further decompose the information acquisition into six relatively independent features involving operations performed on raw data:

- Filtering: Filtering involves selecting certain items of information for recommended operator viewing. Filtering may be accomplished by guiding the operator to view that information (e.g., highlighting relevant items while greying out less relevant or irrelevant items (Wickens & Yeh, Attentional filtering and decluttering techniques in battlefield map interpretation, 1996); total filtering may be accomplished by suppressing the display of irrelevant items. Automation devices may vary extensively in terms of how broadly or narrowly they are tuned.

- Information Distribution: Higher levels of automation may flexibly provide more relevant information to specific users, filtering or suppressing the delivery of that same information for whom it is judged to be irrelevant.
- Transformations: Transformations involve operations in which the automation functionality either integrates data or otherwise performs a mathematical or logical operation on the data. Higher levels of automation transform and integrate raw data into a format that is more compatible with user needs (Vicente & Rasmussen, 1992) (Wickens & Carswell, The proximity compatibility principle: Its psychological foundation and relevance to display design, 1995).
- Confidence Estimates: Confidence estimates may be applied at higher levels of automation, when the automated system can express graded levels of certainty or uncertainty regarding the quality of the information it provides.
- Integrity Checks: Ensuring the reliability of sensors by connecting and comparing various sensor sources.
- User Request Enabling: User request enabling involves the automation's understanding specific user requests for information to be displayed. If such requests can be understood only if they are expressed in restricted syntax (e.g., a precisely ordered string of specific words or keystrokes), it is a lower level of automation. If requests can be understood in less restricted syntax (e.g., natural language), it is a higher level of automation.

The level of automation may be different for these different features.

As far as the level of automation of decision and action selection and implementation, the authors observe that higher levels of automation define progressively fewer degrees of freedom for humans to select from a wide variety of actions. At levels 2 to 4 on the scale, systems can be developed that allow the operator to execute the advised or recommended action manually or via automation. The manual option is not available at the higher levels for automation of decision and action selection. Hence, the dichotomous action implementation scale applies only to the lower levels of automation of decision and action selection.

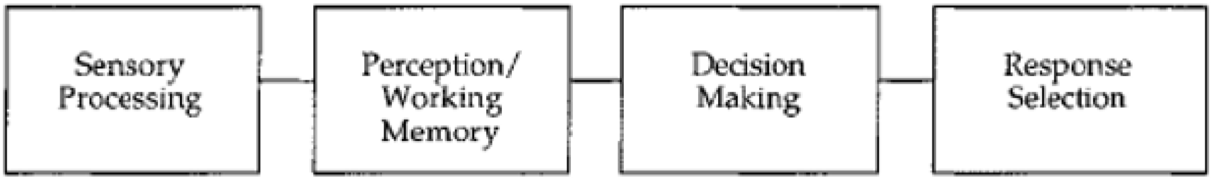


FIGURE 4-4-1 FOUR-STAGE MODEL OF HUMAN INFORMATION PROCESSING (PARASURAMAN, SHERIDAN, & WICKENS, A MODEL FOR TYPES AND LEVELS OF HUMAN INTERACTION WITH AUTOMATIONS, 2000).

With a similar aim of decomposing the processes to separately assess automation, Parasuraman et al. (Parasuraman, Sheridan, & Wickens, A model for types and levels of human interaction with automations, 2000) propose a four-stage model of human-automation interaction, along with the consideration of several evaluative criteria (Figure 4-4-1). The stages proposed are:

- Sensory processing: acquisition and registration of multiple sources of information (function: information acquisition);
- Perception/Working memory: involves conscious perception and manipulation of processed and retrieved information in working memory (function: information analysis);
- Decision making: decisions are reached based on the cognitive processing of stage 2 (function: decision and action selection);
- Response Selection: implementation of a response or action consistent with the decision choice (function: action implementation).

For the authors, automation may apply to any stage of a four-stage model of human information processing, possibly at different levels.

This model is refined by Sharples et al. (Sharples, Millen, Golightly, & Balfe, 2011), with the distinction of automation levels for each stage:

1. Information acquisition
    a) None: human gathers all information without assistance from computer or technology, using senses for dynamic information and paper-based sources for static information
    b) Low: human gathers all information but with assistance from IT (telephone/fax/email/CCF/TRUST)
    c) Medium: information acquisition is shared between the automation and the human
    d) High: computer and technology provide the majority of the information to the human
    e) Full: computer gathers all information without any assistance from human
2. Information analysis
    a) None: human analyses all information
    b) Low: computer analyses information as it is received and detects conflicts only as they occur
    c) Medium: computer gives a future prediction based on basic information for the short term (e.g., current trains on the workstation)
    d) High: computer gives a future prediction based on fuller information (e.g., trains arriving in future, infrastructure state, and current situation on other workstations), and highlights potential problems/conflicts over a longer period of time
    e) Full: computer gives a long-term future prediction using all relevant data (e.g., up-to-date information on train speeds, infrastructure state, etc.)
3. Decision and action selection
    a) None: human makes all decisions, without any support
    b) Low: computer provides decision support to the human to help ensure decision is not unsafe
    c) Medium: computer performs basic decision making (e.g., first come first serve and run trains to timetable) and leaves perturbed modes to the human
    d) High: computer performs mid-level decision making (e.g., apply set rules to delayed trains) and has basic plans for implementation during perturbed operations

e) Full: computer makes all decisions under all circumstances using complex algorithms to determine the optimal decision (e.g., based on a high-level prediction of the future state and optimal conflict resolution) and provides flexible plans for disrupted operations

4. Action implementation
   a) None: human implements all actions and communications
   b) Low: computer augments human's physical labour (e.g., hydraulic assistance on lever)
   c) Medium: computer implements physical actions, but human is required to perform communications (possibly with assistance from information and communication technologies)
   d) High: computer implements physical actions and basic communications but human is required to perform complex or unusual communications
   e) Full: computer implements all actions and communications

Following these decomposition of processes into different stages, according to Onnasch et al. (Onnasch, Wickens, Li, & Manzey, 2014), the identification of the level of automation of the overall process is not trivial. For the authors, all other factors held equivalent,

- a higher level of automation constitutes "more automation"
- a later stage of automation constitutes "more automation" and
- as a consequence, a combination of higher levels and a greater number of stages at which automation is implemented constitutes "more automation."

This quite intuitive relative scale, however, may bring to the impossibility of identifying the level of automation in a given process.

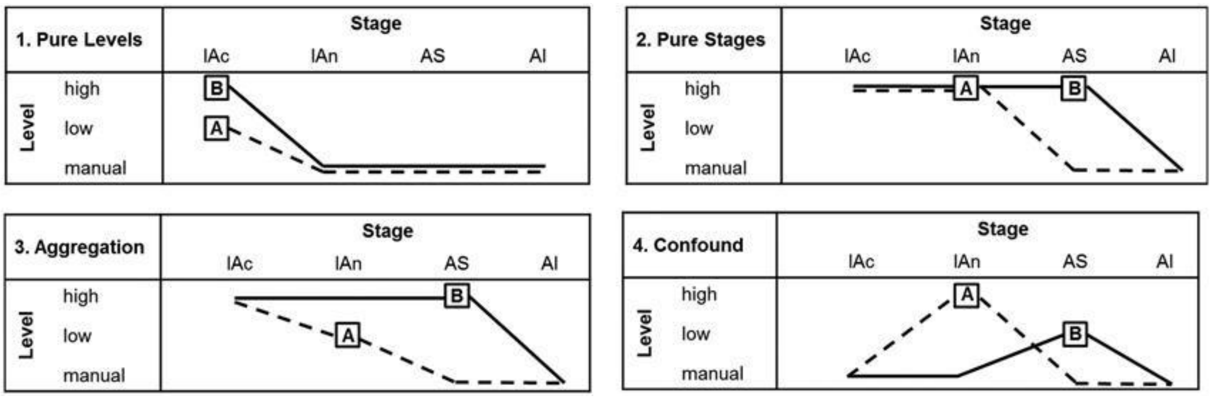


FIGURE 4-2 FOUR CASES COMPARING DEGREE OF AUTOMATION (DOA) ACROSS STAGES, THAT IS, INFORMATION ACQUISITION (IAC), INFORMATION ANALYSIS (IAN), ACTION SELECTION (AS), AND ACTION IMPLEMENTATION (AI), AND LEVELS, THAT IS, HIGH, LOW, AND MANUAL. SOURCE: ONNASCH ET AL. (2014)

To show this, the authors propose the example shown in Figure 4-2, in which a process is decomposed into the four-stage model of Parasuraman et al. (Parasuraman, Sheridan, & Wickens, A model for types and levels of human interaction with automations, 2000). For sake of simplicity, only three possible levels of automation per stage are considered. Each of the four stages contains two automation options, A and B, which are compared to determine which one corresponds to the more automated one. The automation characteristic of each of these options is characterized by a profile of levels across the stages. The figure is divided in four rectangles representing four possible cases. Case 1 ("Pure Levels") represents different levels within the first stage (information acquisition, IAc). After this stage, the two options A and B are equal. Case 2 ("Pure Stages") represents different stages at the same level (information acquisition, IAc, and information analysis, IAn). Case 3 ("Aggregation") represents an earlier stage and lower level versus a later stage and higher level. Case 4 ("Confound") represents an earlier stage and higher level versus a later stage and lower level (i.e., a "trade-off" between stages and levels). Onnasch et al. (Onnasch, Wickens, Li, & Manzey, 2014) argue that, to the extent that the three postulates given earlier are agreed on, comparisons 1 to 3 clearly represent contrasts between options with more (option B) versus less (option A) automation, as defined on an ordinal scale. Case 4 is shown as an important exception. Here, there is a trade-off between later stages and higher levels. It is impossible to assess a relative level of automation, unless both stages and levels are expressed on an interval or ratio scale, and the authors say to have no confidence that this has or even can be done.

4.2 Design and assessment of automation

Several studies have shown that well-designed automation can enhance human operator and overall system performance. At the same time, many observations of the performance of automation in real systems have identified a series of problems with human interaction with automation, with potentially serious consequences for system safety. These observations have been supported by a remarkable body of research which includes laboratory experiments, simulator studies, field studies and conceptual analyses (Bainbridge, 1983) (Billings, Aviation Automation: The Search for a Human-Centered Approach, 1996) (Parasuraman & Mouloua, Automation and Human Performance: Theory and Applications, 1996) (Parasuraman & Riley, Humans and automation: Use, misuse, disuse, abuse, 1997) (Sarter & Woods, Strong, Silent, and Out-of-the-Loop: Properties of Advanced (Cockpit) Automation and Their Impact on Human-Automation Interaction, 1995) (Wickens C. , Designing for situation awareness and trust in automation, 1994) (Wiener E. , 1988) (Wiener & Curry, 1980). Many of these, although not all, relate to human response when automation fails, either through failure of the system itself or failure to cope with conditions and inputs.

The design of the automation of a system shall consider the human-machine interaction for assessing the behaviour of the overall system in which the automation itself is introduced. This assessment is possible a priori, to build expectations in the context of the system design, or a posteriori, to judge the current automation and possibly modify it.

4.2.1 Operators' Performance

Starting with Woods (Woods D. , 1996), many researchers have focused on the impact of automation on operators' performance and considered specific categories of performance limitations that surface when humans interact with automation.

An essential formalization is proposed by Parasuraman et al. (Parasuraman, Sheridan, & Wickens, A model for types and levels of human interaction with automations, 2000). Here, the automation impacts on the operators' performance under four points of view:

- Mental workload: a well-designed information automation can change human operator mental workload to a level that is appropriate for the system tasks to be performed. However, automation can be "clumsy", that is, they may increase the workload, for example in case of systems in which the automation is difficult to initiate and engage, or in which intensive data entry is required.
- Situation awareness: the automation of decision making functions may reduce the operator's awareness of the system and of certain dynamic features of the work environment.
- Complacency: if automation is highly but not perfectly reliable in executing decision choices, then the operator may not monitor the automation and its information sources and hence fail to detect the occasional times when the automation fails. Automation in information can also lead to complacently is the algorithms underlying filtering, prediction or integration operations are reliable but not perfectly so.
- Skill degradation: if the decision-making function is consistently performed by automation, there will come a time when the human operator will not be as skilled in performing that function.

The analysis of the performance considering these four points of view has often brought to the discrete trade-off according to which automation supports better performance in routine situations but is problematic when automation breaks down.

For Onnasch et al. (Onnasch, Wickens, Li, & Manzey, 2014), this trade-off shall be expressed as a more continuous trade-off, as illustrated in Figure 3. The two primary performance functions in this figure (heavy lines) indicate that, as the level of automation (named degree of automation in the paper) increases, routine performance will improve but performance under failure will decline. This relationship is expressed intuitively by the lumberjack analogy: the higher the trees, the harder they fall. With a higher level of automation, the workload imposed by the automated task is progressively reduced, almost by definition, since if the automation is doing more cognitive/physical work, the human is doing less. Indeed, the loss of situation awareness (SA) may be due to both an increase in automation reliability and an increased level of automation. The hypothetical trade-off between workload and loss of SA is depicted in Figure 4-4-3. As mentioned, with a higher level of automation, the workload decreases and the operator can allocate more attention to other concurrent tasks. However, if this happens, the resulting reduction of attention to the tasks served by automation could have consequences expressed in the loss of SA. The appropriate level of automation of a system is to be identified by finding the point "a" indicated in the figure. This level is the one which allows the best routine performance and the minimum workload, without sacrificing the failure performance (which depends on the loss of SA).

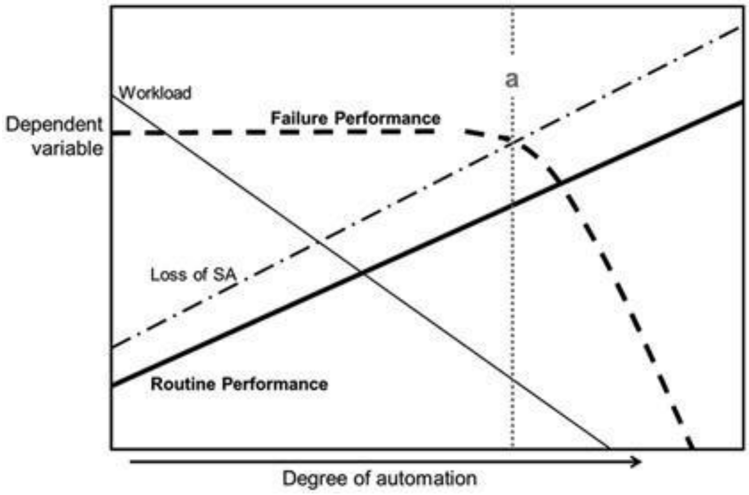


Figure 4-4-3 Trade-off of variables, with level of automation. Source: Onnasch et al. (Onnasch, Wickens, Li, & Manzey, 2014).

With a different approach, Wickens and the US National Research Council Panel on Human Factors in Air Traffic Control Automation (Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation, 1998) propose a general framework to examine the human performance issues by illustrating relationships between three major elements of human interaction with dynamic systems—trust, situation awareness, and mental models—as well as factors that can affect these elements. This framework is reported in Figure 4-4-4.

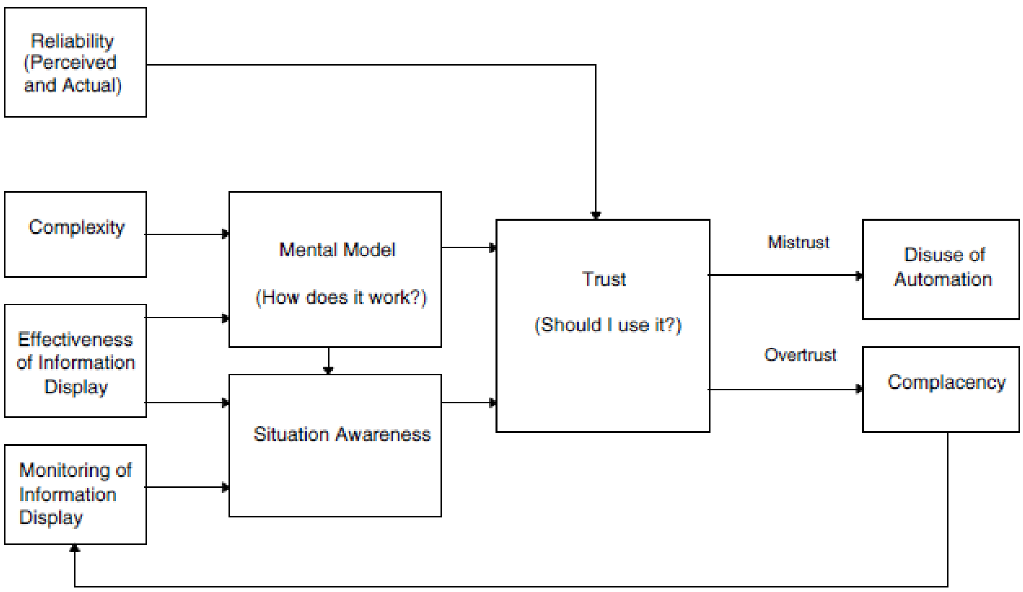


Figure 4-4-4 Framework for examining human performance issues. Source: Wickens and the US National Research Council Panel on Human Factors in Air Traffic Control Automation (Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation, 1998)

The authors observe that a key driver of the human operator’s trust of the automation, to answer the question “Should I use it?”, is the reliability of the system being monitored. The authors underline that the operator’s perception of reliability may differ from the actual reliability of the system. The degree of correspondence between actual and perceived reliability may change over time; the software in new systems is often complex, not completely tested, and, therefore, may fail or degrade in ways that may surprise the operator. In addition to the perceived reliability, other factors impact the operator's trust, such as his expectations based on the operator's mental model, and his situation awareness. More in detail, the authors propose a list of the most relevant determining factors for trust:

- Reliability: the repeated, consistent functioning of automation.
- Robustness: the demonstrated or promised ability to perform under a variety of circumstances.
- Familiarity: the employ by the system of procedures, terms, and cultural norms that are familiar, friendly, and natural to the operator.
- Understandability: the ability of the operator to form a mental model and predict future system behaviour.
- Explication of intention: the explicit communication by the system explicitly of a particular action it will perform.
- Usefulness: the utility of the system to the operator in a formal theoretical sense.
- Dependence: the relation of the operator to the automation.
- A similar list is proposed by Balfe et al. (Balfe, Wilson, Sharples, & Clarke, 2012), who perform a benchmarking exercise to understand the impact of current levels of automation and to provide input to the design and implementation of new automated systems. This benchmarking is based on interviews with the operators who have to work with an automated system. Namely, the operators interviewed are railway traffic controllers and the system analysed is the automated rail traffic control system. One of the results of the interviews is the identification of 10 key principles of automation:
- Reliability: The automation should function consistently.
- Competence: The automation should perform tasks correctly given the information that is input.
- Visibility: All decision relevant information for a given situation should be available to the operator.
- Observability: Automation should provide effective and immediate feedback to the operator allowing him/her to maintain awareness of system state.
- Understandability: Decisions made by the automation should be understandable to the operator given the current state of the system and environment.
- Directability: The operator should be able to direct the automation easily and efficiently.
- Robustness: The automation should be able to perform under a variety of conditions, not just normal operating conditions.

- Accountability: The operator should be responsible for overall performance and therefore in charge of the automation.
- Proactive Control: The system should support the operator in predicting and controlling ahead rather than controlling reactively.
- Skill Degradation: The automation should incorporate a method to guard against operator skill degradation.

In addition to supporting these principles through the interviews, the authors corroborate them by explicitly referring to the literature. In particular, reliability is intended as the repeated consistent functioning of an automated device (Sheridan, Human supervisory control, 1999). Muir and Moray (Muir & Moray, 1996) identify competence as a key dimension in development of trust in automation and suggested that designers of automated systems should consider whether automation will be able to carry out a function effectively as any weaknesses will reduce the likelihood that operators will use the automation. Visibility may be taken as supporting the first stage of situation awareness (Endsley, 1996). It refers to the provision of information regarding the system being controlled. Sarter and Woods (Sarter & Woods, Team Play with a powerful and independent agent: Operational experiences and automation surprises on the airbus A-320, 1997, p. 554) define observability as the ability of available feedback to actively support operators in monitoring and staying ahead of system activities and transitions. Parasuraman and Riley (Parasuraman & Riley, Humans and automation: Use, misuse, disuse, abuse, 1997, p. 248) argue that better operator knowledge of how the automation works results in more appropriate use of automation. Woods (Woods D. D., 1997) recommends that users shall be given the ability to direct the automation as a tool in achieving goals, and Dekker (Dekker, 2004) that the human operator shall be allowed to assume a strategic role in directing the automation. Sheridan (Sheridan, Human supervisory control, 1999) terms the ability of automation to cope with a variety of conditions' robustness. Miller and Parasuraman (Miller & Parasuraman, 2007, p. 58) recommend that the control of the delegation of tasks between humans and automation shall be firmly in the human operator’s hands. Endsley (Endsley, 1996) states that supporting system automation by allowing operators to keep up with changing system parameters and understanding the effect of these allows operators to proactively optimise system performance and prevent future problems. Proactive control can be enabled by ensuring that the automation is predictable. Bainbridge (Bainbridge, 1983) suggests that skill degradation is a likely but undesirable trait of automation, an irony of automation.

Also considering the impact of automation of the operators' performance, Wickens and the National Research Council Panel on Human Factors in Air Traffic Control Automation (Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation, 1998) observe that the appropriate level of automation in the different contexts depend on the uncertainty and risk associated to them. In particular, the authors make the distinction between lower-level decision actions (in the case of low uncertainty) and higher-level decision actions (in the case of high uncertainty and risk). Tasks with higher levels of uncertainty should be constrained to lower levels of automation of decision and action selection.

To cope with similar considerations, Sheridan (Sheridan, Human centered automation: oxymoron or common sense? Systems, Man and Cybernetics, 1995) suggests a two-dimensional characterization of where the authority might reside (human vs. computer) in automation depending on the state of the process. This characterization is shown in Figure 4-4-5.

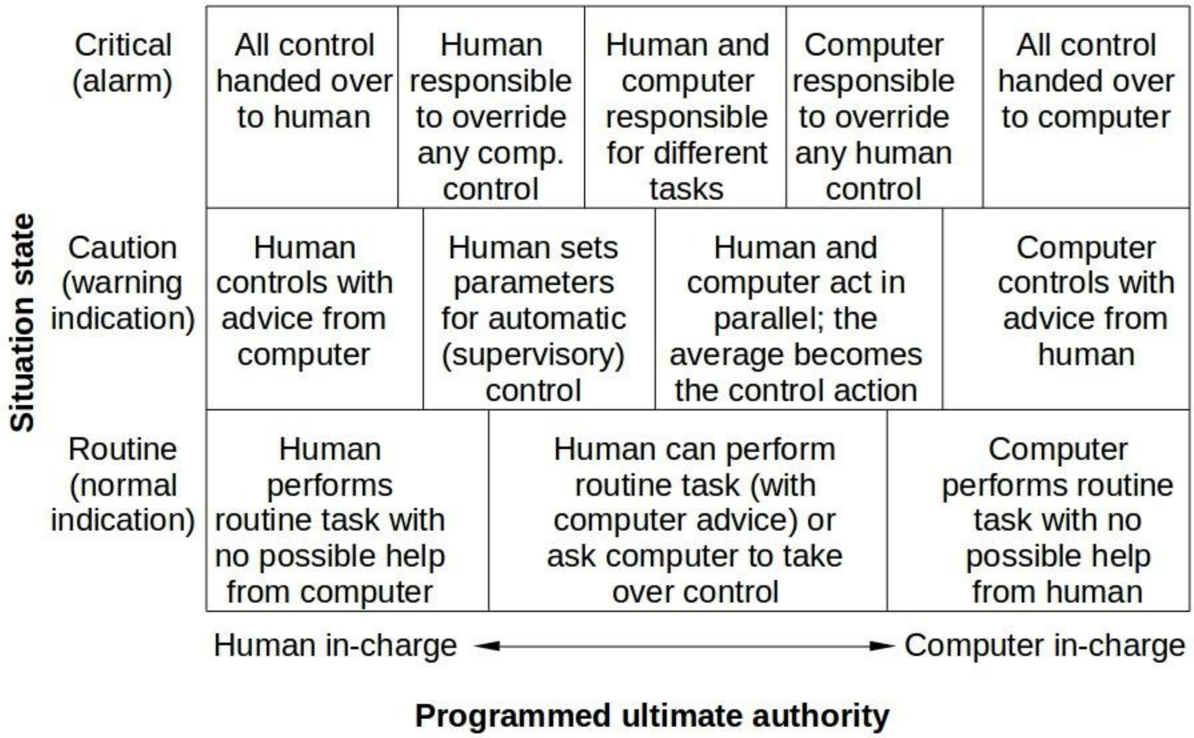


FIGURE 4-4-5 ALTERNATIVES FOR ULTIMATE AUTHORITY AS RELATED TO DEGREE OF CRISIS. SOURCE: SHERIDAN (SHERIDAN, HUMAN CENTERED AUTOMATION: OXYMORON OR COMMON SENSE? SYSTEMS, MAN AND CYBERNETICS, 1995).

4.2.2 USE OF AUTOMATION

According to Wickens and the US National Research Council Panel on Human Factors in Air Traffic Control Automation (Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation, 1998), inappropriate levels of trust may imply inappropriate uses of the automation. These uses are deeply investigated by Parasuraman and Riley (Parasuraman & Riley, Humans and automation: Use, misuse, disuse, abuse, 1997). The authors define misuse as overreliance on automation (e.g., using it when it should not be used, failing to monitor it effectively), disuse as underutilization of automation (e.g., ignoring or turning off automated alarms or safety systems), and abuse as inappropriate application of automation by designers or managers (e.g., automation that fails to consider the consequences for human performance in the resulting system).

Through the paper, the authors suggest many strategies for designing, training for, and managing automation by considering its use. They summarize these strategies as follows:

1. Automation use

   a) Better operator knowledge of how the automation works results in more appropriate use of automation. Knowledge of the automation design philosophy may also encourage more appropriate use

   b) Although the influences of many factors affecting automation use are known, large individual differences make systematic prediction of automation use by specific operators difficult. For this reason, policies and procedures should highlight the importance of taking specific considerations into account when deciding whether or not to use automation, rather than leaving that decision vulnerable to biases and other factors that may result in suboptimal strategies.

   c) Operators should be taught to make rational automation use decisions.

   d) Automation should not be difficult or time consuming to turn on or off. Requiring a high level of cognitive overhead in managing automation defeats its potential workload benefits, makes its use less attractive to the operator, and makes it a more likely source of operator error.

2. Automation misuse

   a) System designers, regulators, and operators should recognize that overreliance happens and should understand its antecedent conditions and consequences. Factors that may lead to overreliance should be countered. For example, workload should not be such that the operator fails to monitor automation effectively, individual operators who demonstrate a bias toward overreliance because of specific factors should be taught to recognize these biases and compensate for them. Overreliance on automation may also signal a low level of self-confidence is the operator's own manual control skills, suggesting that further training or evaluation of the operator's suitability for the job is needed.

   b) Operators use automation cues as heuristics for making decisions. Although the use of heuristics is usually effective, occasionally it may lead to error because of decision biases. Training is required to recognize and counter decision biases that may lead to overreliance on automation.

   c) Although it is often pointed out that human monitoring is subject to errors, in many instances operational monitoring can be efficient. Human monitoring tends to be poor in work environments that do not conform to well-established ergonomics design principles, in high-workload situations, and in systems in which the automation is highly autonomous and there is little opportunity for manual experience with the automated tasks.

   d) Feedback about the automation's states, action and intentions must be provided and it must be salient enough to draw operator attention when he or she is complacent and informative enough to enable the operator to intervene effectively.

3. Automation disuse

   a) The impact of automation failures, such as false alarm rates, on subsequent operator reliance on the automation should be considered as part of the process of setting automation performance requirements. Otherwise, operators may grow to mistrust the automation and stop using it. When the operator makes an error, system designers and managers may grow to mistrust the operator and look to automation as the ultimate authority in the system.

b) Designers of automated alerting systems must take into account not only the decision threshold at which these systems are set but also the base rate of the hazardous condition to be detects.

c) Designers of automated alerting systems should consider using alarms that indicate when a dangerous situation is possible ("likelihood" alarms), rather than encouraging the operator to rely on the alarm as the final authority on the existence of a dangerous condition.

4. Automation abuse

a) The operator's role should be defined based on the operator's responsibilities and capabilities, rather than as a by-product of how the automation is implements.

b) The decision to apply automation to a function should take into account the need for active operator involvement in the process, even if such involvement reduces system performance from what might be achieved with a fully automated solution keeping the operator involved provides substantial safety benefits by keeping the operator informed and able to intervene.

c) Automation simply replaces the operator with the designer. To the extent that a system is made less vulnerable to operator error through the application of automation, it is made more vulnerable to designer error. The potential for and costs of designer error must be considered when making this trade-off.

d) Automation can also act as a surrogate for the manager. If the designer applied a specific automation philosophy to the design of the system, that philosophy should be provided to the manager so that operational practices are not imposed that are incompatible with the design. In addition, just a system designers must be made aware of automation-relates issued, so must those who dictated how it will be used.

4.2.3 Human centred automation

After the discussion proposed in the previous sections, it is evident that humans must continue to manage and direct the automated processes: automation should be designed to assist and augment the capabilities of the operators. It is important, then, to develop the so called human-centred automation to maximize the overall human-system performance. However, though human centred automation is a fashionable idea in many contexts, its precise meaning is not well or commonly understood.

In an attempt of formalization, Sheridan (Sheridan, Human centered automation: oxymoron or common sense? Systems, Man and Cybernetics, 1995) proposes a list of faces to be considered. Here, at various times and in various contexts human-centred automation is supposed to mean:

- Allocating to the human the tasks best suited to the human, allocating to the automation the tasks best suited to it.
- Keeping the human operator in the decision and control loop.
- Maintaining the human operator as the final authority over the automation.

- Making the human operator's job easier, more enjoyable, or more satisfying through friendly automation.
- Empowering or enhancing the human operator to the greatest extent possible through automation.
- Generating trust in the automation by the human operator.
- Giving the operator computer-based advice about everything he or she might want to know.
- Engineering the automation to reduce human error and keep response variability to a minimum.
- Casting the operator in the role of supervisor of subordinate automatic control system(s).
- Achieving the best combination of human and automatic control, where best is defined by explicit system objectives.

Unfortunately, these seemingly reasonable objectives are often in conflict with one another. According to the Sheridan (Sheridan, Human centered automation: oxymoron or common sense? Systems, Man and Cybernetics, 1995), the problem is that neither automation nor human-centred automation are singular ideas. Both involve multiple problems and considerations, mostly not quantifiable by any method that we can agree to. Hence, we are far from having an algorithmic approach to engineering human-centred automation in any given context.

4.2.4 Adaptive automation

A different option which has been proposed to keep high overall system performance is the use of adaptive automation.

Under adaptive automation, the division of labour between human operators and computer systems is flexible rather than fixed. Sometimes a given function may be executed by the human, at other times by automation, and at even other times by both of them. Adaptive automation may involve either task allocation, in which case a given task is performed either by the human or the automation in its entirety, or partitioning, in which case the task is divided into sub-tasks, some of which are performed by the human and others by the automation. Task allocation or partitioning may be carried out by an intelligent system on the basis of a model of the operator and of the tasks that must be performed (Rouse, 1988). This defines adaptive automation or adaptive aiding. For example, a workload inference algorithm could be used to allocate tasks to the human or to automation so as to keep operator workload within a narrow range (Hancock & Chignell, 1989) (Wickens C. , Engineering Psychology and Human Performance (2nd ed.), 1992).

Figure 4-4-6 depicts a schema of how adaptive automation could be achieved within a closed loop system (Wickens C., Engineering Psychology and Human Performance (2nd ed.), 1992).

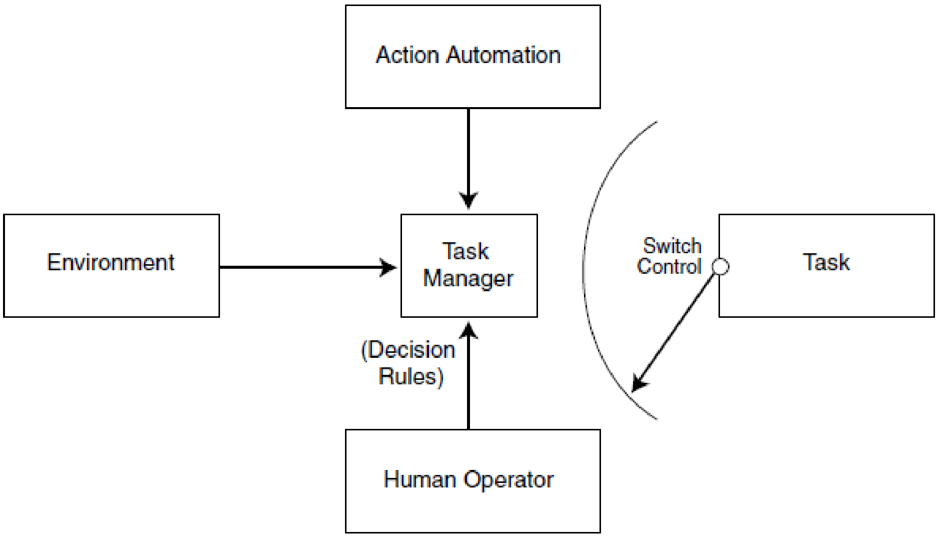


Figure 4-4-6 Closed-loop adaptive system. Source: Wickens (Wickens C. , Engineering Psychology and Human Performance (2nd ed.), 1992)

Indeed, not all tasks can be reasonably dealt with through adaptive automation. For example, long-term fixed (or non-adaptive) automation will generally not be problematic for data-gathering and data integration functions because they support but do not replace the operator's decision-making activities (Hopkin, 1995). Also, fixed automation is necessary, by definition, for functions that cannot be carried out efficiently or in a timely manner by the human operator (Sheridan, Telerobotics, Automation, and Human Supervisory Control, 1992).

An alternative to having an intelligent system invoke changes in task allocation or partitioning is to leave this responsibility to the human operator. This approach defines adaptable automation (Billings & Woods, Concerns about adaptive automation in aviation systems, 1994) (Hilburn, 1996).

4.3 Automation in railways

The described scales and assessment and design principles for automation may be applied to virtually any process and system.

Specifically for the railway system, the literature focuses mostly on the assessment of different automated systems, mostly concerning automatic driving and automatic traffic management.

To the best of our knowledge, the analysis of automation in railway has been mostly focused on the automation of guided systems. Mostly in this direction, the IRSE International Technical Committee (IRSE International Technical Committee , 2009) proposes a taxonomy of the different contexts in which automation in railway shall maximize the operational performance of the existing or planned transportation infrastructure. More in particular, the taxonomy is initially studied for metro systems, but it is said to be extendable to the general railways:

- Train driving: The automation of the train driving functions can provide for more regular and predictable run times between stations, eliminating the variations inherent with manual driving, and providing for a more uniform ride quality and reduced wear-and-tear on train propulsion and braking systems; moreover, the automatic, real-time control and coordination of train acceleration, train coasting, and train braking can also be utilized to implement energy optimization algorithms for example though coasting controls or by synchronizing the acceleration of one train with the braking of another train to maximize use of brake energy recovery;

- Train operation: Driverless/unattended train operation, with automatic passenger door opening and closing and automatic train departure from station platforms, can further reduce the variations in line operation. Unattended train operation also frees the operator of the constraints imposed by the need to provide for the rostering of train crews and provides the flexibility to operate shorter trains more frequently. Furthermore, automation of turnbacks at terminal stations can reduce turnover times, reducing the number of train sets needed for operation;
- Maintenance yards and stabling tracks: Unattended train operation, when combined with fully automated maintenance yards and stabling tracks, also provides the flexibility to respond to unexpected increases in passenger demands by adding additional trains to the service, all without requiring additional train drivers or manual intervention;
- Train regulation: Automation of train regulation, train dispatching and train routing functions can more effectively regulate the performance of trains in relation to timetable (schedule) and/or headway adherence. Regulation can be achieved by automatically adjusting dwell times and/or by automatically controlling run times between stations (e.g., through adjustments to train acceleration and service brake rates, and speeds).

Although this taxonomy is undoubtedly relevant for the railway system, several aspects are neglected. Namely, most of the activities discussed in the previous section of this deliverable have not been considered. In the next section, we make a step forward the fill of this gap.

5. Large disruption management process: current and envisaged level of automation

The goal of the first part of this chapter is the analysis of data formats which are frequently used for the description of the railway infrastructure in various countries and at different level of operation. On the basis of the analysis, their usability in disruption management will be discussed. At the end of the first section, there will be the comparison of data formats in the optic of an increase of automation of the disruption management process.

5.1 Mapping of standard data formats with the main tasks identified in the disruption management process formalization

Historically, each infrastructure manager uses its own data format for description of the railroad infrastructure. In CZ, for example, it is called *line characteristics table*. With the implementation of the computer technology the formats as the paper line characteristics tables have been replaced by electronic ones. The electronic version is better for update, share and usability in modern software products for timetable construction or simulation. In addition to these independent improvements in the different countries, the EU imposes further steps towards interoperability and standardisation of infrastructure description. The target is the mutual sharing of the data between infrastructure managers and railway operators from different countries. This section reports an analysis of the main data formats which are used for description of the railroad infrastructure or the vehicles and the timetable.

5.1.1 RailML

RailML is open data format based on XML (Extensible Markup Language). It is developed by the railML.org organisation. The RailML schema uses the XML for the description of rail-specific data. In April 2016 the latest available version of RailML is version 2.3 (SVN revision 668, released 9. 3. 2016). The RailML schema is available for download after free registration from the webpage https://www.railml.org/en/developers/download.html .

The RailML schema is divided into four main parts: infrastructure, timetable, rolling stock and interlocking. Each sub-schema is supervised by the coordinator. It is possible to use only the relevant sub-schema for its implementation into the different applications or the complete schema can be used. Apart from these four main sub-schemas the development of sub-schemas for crew rostering, asset management or real-time data is planned.

The RailML timetable sub-schema, https://www.railml.org/en/user/subschemes/timetable.html , is focused on the description of the railway timetable including all its various facets that are needed by the data exchange applications. In particular, the RailML timetable schema contains the following information:

- Operating Periods: The operating days for train services or rostering.
- Train Parts: The basic parts of a train as a sequence of operation or control points with the same characteristics such as formation and operating period. The train part includes the actual information regarding the path of the train as well as the corresponding schedule information.
- Trains: One or more train parts make up a train and represent either the operational or the commercial view of the train run.
- Rostering: Train parts can be linked to form the circulations necessary for rostering (rolling stock schedules).

The RailML rolling stock sub-schema, https://www.railml.org/en/user/subschemes/rollingstock.html, is focused on the description of the railways rolling stock including all its various facets that are deemed to be needed by the data exchange applications. In particular, the RailML rolling stock schema contains the following information:

- Vehicles: The characteristics of individual railway vehicles or vehicle families are described in this part of the schema. The description of vehicles considers some general data used for organising assets like naming, classification or vehicle numbers as given by its operator. The schema provides the structure to store the various technical aspects of railway vehicles with regard to their propulsion system, car body features, brakes or services installed within the vehicle.
- Formations: The features of train sets or parts of it formed of several different or similar vehicles are described in this part. This combination of vehicles is used to describe train features as needed, e.g., in timetables. However, the logical consistency between the formation and the vehicles it is made of is not enforced by the schema. It must be ensured by the application producing the data.

The RailML infrastructure sub-schema, https://www.railml.org/en/user/subschemes/infrastructure.html, is focused on the description of the railway network infrastructure including all its various facets that are needed by the data exchange applications. In particular, the RailML infrastructure schema contains the following information:

- Topology: The track network is described as a topological node edge model.
- Coordinates: All railway infrastructure elements can be located in an arbitrary 2- or 3-dimensional coordinate system, e.g., the WRG84 that is widely used by today's navigation software.
- Geometry: The track geometry can be described in terms of radius and gradient.
- Railway infrastructure elements enclose a variety of railway relevant assets that can be found on, under, over or next to the railway track, e.g., balises, platform edges and level crossings.

- Further encompassed elements that are closely linked with the railway infrastructure, e.g., speed profiles and track conditions.

The RailML interlocking schema, https://www.railml.org/en/user/subschemes/interlocking.html, focuses on information that infrastructure managers typically maintain in signal plans and route locking tables. The main users of this schema are interlocking suppliers and simulators. Data preparation is the process of adapting a railway interlocking and signalling system to a specific yard. Errors in the data affect safety; it is all too obvious that a wrong signal aspect can cause terrifying accidents. This is why railway people invest much time and effort in testing. A standard data exchange format will allow the automation of data transfer and reduce the number of errors by taking the human factor out of the loop. This will create higher levels of safety at substantially lower cost. Simulation programs compute the impact of interlocking and signal configuration on capacity. Things like shifting a signal, using a faster point drive or shortening blocks can have significant impact. Simulation tools grow ever more powerful and reach a level of accuracy where seconds matter. At present, the real-time behaviour of interlocking and signalling often is unknown. The RailML interlocking schema allows modellers to quickly absorb information about the interlocking systems such as timing behaviour and routes and analyse the impact on railway capacity.

An example of RailML code for timetable is shown on Figure 5-1.

```
<?xml version="1.0" encoding="UTF-8"?>
<railml xmlns:xsi=http://www.w3.org/2000/10/XMLSchema-instance xsi:noNamespaceSchemaLocation="timetable.xsd">
 <timetable version="1.1">
     <train trainID="RX 100.2" type="planned"  source="opentrack">
         <timetableentries>
             <entry posID="ZU" departure="06:08:00" type="begin"/>
             <entry posID="ZWI" departure="06:10:30" type="pass"/>
             <entry posID="ZOER" arrival="06:16:00" departure="06:17:00"
                         minStopTime="9" type="stop"/>
             <entry posID="WS" departure="06:21:00" type="pass"/>
             <entry posID="DUE" departure="06:23:00" type="pass"/>
             <entry posID="SCW" departure="06:27:00" type="pass"/>
             <entry posID="NAE" departure="06:29:00" type="pass"/>
             <entry posID="UST" arrival="06:34:30" type="stop"/>
         </timetableentries>
     </train>
 </timetable>
</railml>
```

FIGURE 5-1 EXAMPLE OF RAILML CODE. SOURCE: HTTPS://EN.WIKIPEDIA.ORG/WIKI/RAILML

Today RailML is used by some companies for the data exchange among software applications, which are focused on passenger timetable, timetable simulation and rostering. RailML is used in software tools as Viriato, OpenTrack, FSB. An overview of the software tools which use the RailML schema can be found in https://www.railml.org/en/introduction/software.html . More than 30 different software tools are mentioned. For each tool, the country in which it is used is mentioned. In many cases, the countries of use are Germany or German speaking countries. Besides these software tools RailML is used also in RailTopoModel, which is developed under supervision of UIC. Other examples of RailML usage can be found on the webpage http://www.railml.org/en/user/use-cases.html.

As an example of use of RrailML, let us consider RailTopoModel. It is a generic railway data model that has been designed to support current and future business usages and needs. For example, railway infrastructure managers may set up their asset database following the basic structure of the RailTopoModel. Moreover, RailML 3.0 is a common XML-based railway data exchange format. It can be seen as a direct use case of the RailTopoModel as it implements the concepts of the RailTopoModel for data exchange purposes. Together, the RailTopoModel and RailML 3.0 form the standardized data exchange format proposal. (http://www.railtopomodel.org/en/)

Based on the above description, it is clear that RailML can be used for sharing and transferring data for the disruption management without problems. In fact, the schema enables the transfer of messages of all types, which may originate from disruption management. RailML in its current version 2.3 is not accepted by ERA as a standard. However, the tool for the conversion from RailML to RINF-XML format is available (even if only for the infrastructure part). The objective, in the future development of RailML 3, is to get ERA to accept RailML 3 files as an alternative to the specific ERA RINF-XML. (http://wiki.railml.org/index.php?title=IS:UC:RINFReporting)

5.1.2 RINF

The data format of RINF is based on XML likewise RailML. The main difference is that the RINF schema is specified only for infrastructure description, while RailML can be used in other cases (see section 5.1.1). The RINF schema is developed by ERA according to decision of the European Commission. This data format is obligatory for EU members. ERA has the responsibility for the RINF schema development, and it is also responsible for the implementation of the regulations of European Commission. The RINF format is developed according to the European regulations and decisions (EU, 2008) (EU, 2011) (EU, 2014).

The RINF schema is divided into two groups: Section of line and Operational points. This division constitutes the macroscopic level. The detailed division (microscopic level) is following:

- Section of lines
    - Track
        - Infrastructure subsystem
        - Energy subsystem
        - Control-, command and signalling subsystem
- Operational points
    - Track
        - Infrastructure subsystem
    - Siding
        - Infrastructure subsystem

Complete specification can be found in the ERA documentation (ERA, 2011). The above mentioned division can be found in chapter 3 in specification. Detailed description of particular parameters can be found in RINF Application Guide (ERA, 2011).

The possible application of the RINF format in the disruption management is limited, because this format can be used only for the description of the infrastructure. However, the advantage of this format is that its use is obligatory for all ERA members. The administrators of the national registers of infrastructure have systems designed for the import/export of infrastructure data in the RINF format. Currently, the RINF system contains only some of the main infrastructure, mostly those which are part of TEN-T. Few other infrastructures are present. The RINF system is not designed for an on-line use. The infrastructure managers have a responsibility for the data update but data have to be updated only once every three months. Since this format is used for the description of infrastructure only, it is not possible to expect its implementation into RUs' systems. Transfer of the messages (e.g., about track closure) to the RUs is not straightforward in this format. Similarly, this format cannot be used for the transfer of messages about reallocation of resources or about an actual reschedule. More specifications can be found at the web address http://www.era.europa.eu/Document-Register/Pages/Recommendation-on-specification-of-RINF.aspx. All documents related to the RINF can be found on the webpage http://www.era.europa.eu/Core-Activities/Interoperability/Pages/RINF.aspx.

5.1.3 TAF/TAP TSI

For the TAP TSI is obligatory at the European level (EU, 2011). This regulation describes the content of TAP TSI. In addition, this regulation contains information on which data must be published. It includes the provision of information on the following aspects:

- systems providing passengers with information before and during the journey;
- reservation and payment systems;
- luggage management;
- issuing of tickets via ticket offices or ticket selling machines or telephone or Internet, or any other widely available information technology, and on board trains;
- management of connections between trains and with other modes of transport.

The detailed description of data structure for transferring of information from the mentioned fields can be found in the technical documents TAP, which are labelled B.X where the X means number of documents. The complete list of these documents can be found on the webpage http://www.era.europa.eu/Document-Register/pages/TAP-TSI.aspx. Some messages are transferred in the format of open text with a given structure, some use the XML schema and some are transferred in the native format of the relevant software application. There exists the list of possible values for some selected entries. For the transfer of the messages in any format the Common Interface must be used in the interoperability. Common Interface use XML (ERA, 2013). This specification is common for TAP and TAF TSI.

For the TAF TSI is divided into subsystems:

- Interfaces with the TSI Infrastructure
- Interfaces with the TSI Control/Command and Signalling
- Interfaces with the rolling stock subsystem
- Interfaces with the TSI operation and traffic management.

The schema for the data and the model of messages are specified in different documents and webpages (ERA, 2013) (http://www.era.europa.eu/Document-Register/Pages/TAF-TSI.aspx) (http://www.era.europa.eu/tools/TAFTSI/Pages/Common-Interface-Function.aspx).

From the disruption management point of view, the TAP/TAF TSI doesn't provide complex data format of messages which can cover all areas of disruption management (e.g., timetable, crew rostering). Each RU and IM can use its own data format. In most cases, TSI determines which information must be provided to the others. This information must be transferred through the common interface.

5.1.4 OpenStreetMap

For the transfer of map data based on the OpenStreetMap (OSM) between different systems it is possible to use several formats. The most common used formats are PBF (Protocolbuffer Binary Format) and compressed format OSM XML (http://wiki.openstreetmap.org/wiki/OSM_XML). The advantage of PBF is the highest speed of read/write processes and smaller size in comparison to OSM XML format (http://wiki.openstreetmap.org/wiki/PBF_Format). For data description the three basic elements are used:

- node
- way
- relation (http://wiki.openstreetmap.org/wiki/Elements)

A node represents a specific point on the earth's surface defined by its latitude and longitude. Each node comprises at least an id number and a pair of coordinates. A way is an ordered list of between 2 and 2,000 nodes that define a polyline. A relation is a multi-purpose data structure that documents a relationship between two or more data elements (nodes, ways, and/or other relations).

All types of data element (nodes, ways and relations) can have tags. Tags describe the meaning of the particular element to which they are attached. A tag consists of two free format text fields; a 'key' and a 'value'. Each of these is a Unicode string of up to 255 characters. For some map objects, the content of the 'key' and the 'value' fields are standardized. For elements related to the railway infrastructure, tags for tracks, stations, stops and other selected objects can be used.

This format can be used for purpose of disruption management without problems. However, its usage is limited to the elements with geographical position (mostly the parts of infrastructure). It can be used, for example, for transferring information about the borders of the area where the disruption is located. For the other types of messages, e.g., need of resource reallocation, this is not the appropriate format.

5.1.5 Comparison of data format usability

The following tables show which data format is suitable for input/outputs in the disruption management process formalized in Section 3. In particular, we refer here to the Support Rescheduling activity diagram shown in Figure 3-13. Support Rescheduling – Activity DiagramIn case of TAP/TAF TSI format only the transfer through the Common Interface is ensured, but the specific format of transferred data is not set. He data format depends on the software application which will send/received the data. The second side of communication is supposed to have information about the data format in this case. The main difference between the usability of RailML and the TAP/TAF TSI format is that the former has specific data structure for all messages. If all the applications have the support for the RailML, the data can be imported or exported without limitations.

Change Timetable (Macroscopic)	RailML	RINF	TAP/TAF TSI	OSM
Inputs				
Description of the railway Infrastructure	Yes	Yes	Yes*)	Yes
Theoretical and working schedules	Yes	No	Yes*)	No
Disruption data	Yes	Partly	Yes*)	Partly
Outputs				
New computed Timetable	Yes	No	Yes*)	No

*) Data can be in various formats

Change Timetable (Microscopic)	RailML	RINF	TAP/TAF TSI	OSM
Inputs				
Macroscopic Timetable	Yes	No	Yes*)	No
Infrastructure data	Yes	Yes	Yes*)	Partly
Rolling-stock data	Yes	No	Yes*)	No
Unavailable tracks	Yes	Yes	Yes*)	Yes
List of feasible train routes (local routes)	Yes	Partly	Yes*)	Yes
Outputs				
New Microscopic Timetable with local routes	Yes	No	Yes*)	No

*) Data can be in various formats

Change Rolling-stock Schedule	RailML	RINF	TAP/TAF TSI	OSM
Inputs				
Macroscopic Timetable	Yes	No	Yes*)	No
Working rolling-stock schedule	Yes	No	Yes*)	No
Outputs				
Assignment of RS compositions to the trips	Yes	No	Yes*)	No
Trips without assignment	Yes	No	Yes*)	No

*) Data can be in various formats

Change Crew-stock Schedule	RailML	RINF	TAP/TAF TSI	OSM
Inputs				
The working crew schedule	Yes	No	Yes*)	No
The macroscopic timetable	Yes	No	Yes*)	No
The changed rolling-stock schedule	Yes	No	Yes*)	No
Outputs				
A crew schedule	Yes	No	Yes*)	No
A list of trips for which no crew was found	Yes	No	Yes*)	No

*) Data can be in various formats

5.2 Analysis of the automation of the processes

As case studies, in this section we analyse the level of automation currently implemented and envisaged for the disruption management process in different European countries. To do so, we consider the levels of automation presented in Table 4-2 Levels of automation according to Sheridan Table 4-2.

5.2.1 Level of automation – The Czech Republic

All trains, which ride on the railway network under the management of the RIA must be approved in IS (information system) KADR or IS KANGO. The IS KADR (IS for capacity requests) is the IS for submission of routes by carriers, creation of timetables for these routes by RIA, approval of the proposal by the carrier and then allocating railway capacity. The IS KADR performs automatic calculation of charges for capacity allocation to individual carriers. The IS KANGO (Infrastructure database) is the IS for drawing up the annual and periodic changes in timetables. The trains are inserted into the IS KANGO eight months in advance and aren't essential for disruption management (processes). The importance of these trains starts when they are activated by carriers and when they enter into ISOŘ. ISOŘ (Information system for operational management) is the IS of the operational management, which ensures the "operational management" of the trains. It takes the necessary information from previous IS and passes it in the form of a plan to shift IS, providing support for departmental or local operational management operation. The current state of infrastructure is maintained in the IS KADR. If the carrier puts its request for a train path into this system, it can see the actual availability of the infrastructure. All limitations of the infrastructure are automatically transferred into the IS KADR from the IS DOMIN. The IS DOMIN (Information system of incidents) is the IS centrally recording the full infrastructure constraints. This system meets the requirements IRN database according to the TAF TSI; it contains the database of all known constraints of infrastructure that the RIA operates. The IS DOMIN is connected to the "electronic transport dairy", GTN and ISOŘ. The setting of restrictions of the infrastructure is automatically transferred from these systems into the IS DOMIN. Furthermore, the information is automatically sent to carriers who have their own IS according to the requirements of TAF.

The affected routes and trains are shown in the IS KADR and an ISOŘ (Figure 5-2). In the case of the affected routes (in KADR) the process according to TAF / TAP – "Path not available" is activated. In the case of the affected train, the process according to the TAF / TAP – "Service Disruption" is activated. It seems that there is the automation of these processes. In fact, there is only the information sharing and code for automation is evaluated as level 1 as presented in Table 4-1.

Here is stated the example for the Czech Republic divided between the current situation and future outlook.

Situation	Current Status	Possible outlook
The carrier requests the allocation of railway capacity after the constraints were entered into the IS DOMIN.	When applying for a capacity, the carrier can see all restrictions in the IS DOMIN and can adapt to them. After the submitting of the application, timetable drafts and capacity allocation there is a link between IS DOMIN and IS of the carrier. In the case of restrictions in the infrastructure ("path not available") and the emergence of the affected routes, the carrier is informed. Further steps depend already on the carrier. **Level of automation: 1**	IS KADR automatically provides the appropriate solution on reduced infrastructure and the carrier can choose an optimal variant or prepare its own solutions. L**evel of automation: 3**
The carrier requesting the allocation of railway capacity before the commencement of limitations.	The carrier submits an application as usually and the capacity is assigned to him. The carrier receives information about the origin of restrictions on his train journey through the communication between his IS and the IS DOMIN (path not available). It is the responsibility of the carrier to choose remedial measures. **Level of automation: 1**	IS KADR automatically provides the appropriate solution on reduced infrastructure and the carrier can choose an optimal variant or prepare its own solutions. **Level of automation: 3**
A capacity limitation produces less than 12 hours before the train's departure from the starting station.	In this time period, the train is already in ISOŘ and is under the responsibility of operational management (of the RIA). Railway operator communicates with the carrier about the impact of the restrictions (Service Disruption) on his trains and prepares the remedies - change of route, traction, the position of the train. Any such amendment then goes back through the IS KADR. At the same time, the IS of the carrier communicates with the IS DOMIN about restrictions on infrastructure. **Level of automation: 1**	KADR IS automatically offers to the carrier and to the dispatcher SŽDC's suitable solution on reduced infrastructure. The carrier together with the operator selects the optimal option for them or prepares another solution. **Level of automation: 3**

This table can be coupled with the scheme of the capacity request with different types of disruptions taken into account.

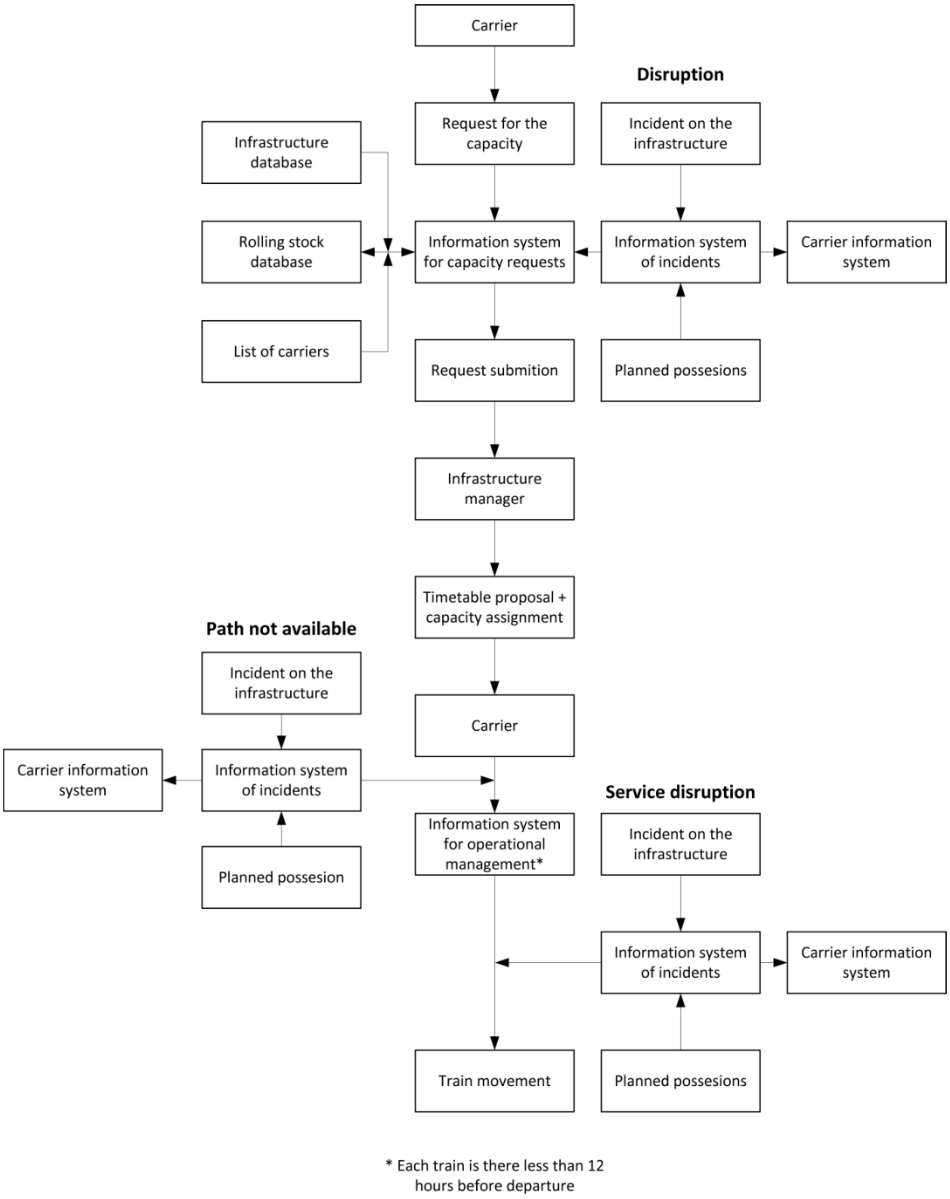


FIGURE 5-2 INFLUENCE OF DISRUPTION ON TRAIN MOVEMENT

5.2.2 LEVEL OF AUTOMATION – SLOVAKIA

For the evaluation of the automation process was addressed Mr. Šulko from ŽSR (Slovakian infrastructure manager). He compared the process in Slovakia with the Czech Republic. The situation is very different. ŽSR does not have any IS for disruption management. All disruptions are just in the table version and the carrier can see them on the webpage of ŽSR. There is no IS for capacity requests for national trains. The request is applied in MS Excel and the infrastructure manager sets it into IS for timetable (IS ZONA). The carrier can only see his request, but he has no authority to change the time or path. Also, the specialist who constructs the timetable must observe all disruptions along the path himself. There is no system support. The same situation characterizes ad-hoc trains.

Nowadays ŽSR is implementing the system for capacity requests (KADR in CZ). At the beginning, this system will be used just for passenger trains.

Situation	Current Status	Possible outlook
The carrier requests the allocation of railway capacity after the constraints starts	When applying for a capacity, the carrier has no information about the constraints. **Level of automation: 0**	IS automatically provides the appropriate solution on reduced infrastructure and offers the best one to the carrier. The carrier can choose to approve or prepare his own solution. **Level of automation: 5**
The disruption happens after the allocation of railway capacity	The infrastructure manager communicates with the carrier and looks for a solution. **Level of automation: 1**	IS automatically provides the appropriate solution on reduced infrastructure and offers the best one to the carrier. The carrier can choose to approve or prepare his own solution. **Level of automation: 5**

6.2.3 Level of automation – Spain

The capacity of the Spanish rail network is quantified in paths that are allocated from the Planning and Network Management Department.

Trains are divided into two types: regular and occasional. The former are trains that run regularly, while the latter are usually isolated requests from operators (special charters for sports events, business travel, tourism, etc.). A train is considered occasional when it runs less than 30 or 40 days a year.

The management of path requests is done with the software SIPSOR (System for Occasional and Regular Path Requests). It is used by carriers to request their trains through two ways: SERVITREN, for regular trains, and TRENDÍA, for occasional trains.

There are two adjustments of the timetable per year that are complemented by other monthly adjustments which are more restricted.

Once awarded the capacity, carriers and Traffic Control Centers can consult the meshes (time-space graph), where they can get information about the general availability of paths for planning new trains or tests.

The capacity is regulated from the Traffic Control Centers. When an issue affecting the normal development of the traffic is detected, it is immediately communicated to CGRH24 (Network Management Center H24). It is in these centers that the necessary steps both to regulate the traffic through alternative routes or means of transport and to establish forecasts of resolution in the case of an incident affecting the infrastructure are taken.

Situation	Current Status	Possible outlook
The carrier requests the allocation of railway capacity after the constraints starts	Communication of incidents (traffic disruption, delay, etc.) occurred before the carrier (operator) send the path request is managed from the "information area CGRH24" through the website of ADIF. **Level of automation: 1**	The level of automation should be on level 3 in the year 2030 and on level 4 in the year 2050. **Level of automation: 3 – 4**
The disruption happens after the allocation of railway capacity	In this case, as in the above, the relevant information can be viewed in near real time on the website of ADIF. **Level of automation: 1**	The level of automation should be on level 3 in the year 2030 and on level 4 in the year 2050. **Level of automation: 3 – 4**

6. Conclusions

In this deliverable we aimed at reporting the work performed to formalize and study the disruption management process implemented in different European countries.

To do so, we started with an analysis of the literature and best practices of the general process concerning the management of small and large disruptions. The former are the disruptions which can be tackled by an IM on its own. The latter are those that require the collaboration, agreement and negotiation of RUs and possibly several IMs. Examples of these disruptions are those caused by extreme weather events as floods or intensive snow falls. Different European IMs participated to this analysis, validating the main guidelines identified.

The main contribution reported in this deliverable is the formalization of the large disruption management process, which was again validated by the different IMs. This formalization was carried out in the form of SysML diagrams, which have the double merit of allowing a precise description of requirements, modules and activity and information flows, and of providing an understandable representation for readers with different backgrounds.

The formalization proposed permitted the achievement of different objectives:

- The unified description of the processes implemented in different European countries;
- The analysis of the process in terms of its formal coherence;
- The identification of how some envisaged developments of the railway system, namely concerning freight transport, may impact the disruption management process;
- The understanding of the capability of the existing data formats for the railway system to support the automation of the process;
- The study of the current and envisaged level of automation of the process in European different countries.

The two last objectives made the object of a dedicated section of this deliverable. In this section, we considered specific cases of three European countries. This analysis allows the observation of the rather low level of automation of the process in general, and the diversity characterizing different countries.

The analysis of the automation constitutes the bridge that will bring to the second deliverable of WP3.3 “Requirements for incident management plans”, in which further investigations on automation will be presented.

7. References

Alemanno, A. (2010). *The European Volcanic Ash Crisis: Between International and European Law.* American Society of International Law.

Baier, C., & Katoen, J.-P. (2008). *Principles of Model Checking.* Cambridge, Massachusetts: MIT Press.

Bainbridge, L. (1983). Ironies of automation. *Automatica*, 19(6), 775-779.

Balfe, N., Wilson, J. R., Sharples, S., & Clarke, T. (2012). Development of Design Principles for Automated Systems in Transport Control. *Ergonomics*, 37-54.

Billings, C. E. (1996). *Aviation Automation: The Search for a Human-Centered Approach.* Mahwah, NJ: Erlbaum.

Billings, C. E., & Woods, D. D. (1994). Concerns about adaptive automation in aviation systems. In M. M. (eds.), *Human Performance in Automated Systems: Current Research and Trends* (pp. 264-269). Hillsdale, NJ: Erlbaum.

Billings, C. E., & Woods, D. D. (1994). Concerns about adaptive automation in aviation systems. In M. M. (eds.), *Human Performance in Automated Systems: Current Research and Trends* (pp. 264-269). Hillsdale, NJ: Erlbaum.

C4R. (2014). *Requirements toward the freight system of 2030/2050, Intermediate Report, C4R- 'New concepts for railway infrastructure and operation: adaptable, automated, resilient and high-capacity'.*

CAPACITY4RAIL. (2013). *Annex I - "Description of Work", Part B1 Concept and objectives, progress beyond state-of-the-art, S/T methodology and work plan.* Grant Agreement no: 605650.

Dekker, S. W. (2004). On the other side of promise: What should we automate today? In D. H. (Ed.), *Human Factors for Civil Flight Deck Design* (pp. 183-198). Aldershot, Hampshire: Ashgate Publishing.

D-RAIL. (2012). *Rail Freight Forecast to 2050, Deliverable 2.1, D-RAIL- 'Development of the Future Rail Freight System to Reduce the Occurrences & Impact of Derailment.*

Endsley, M. R. (1996). Automation and situation awareness. In R. P. (Eds.), *Automation and Human Performance: Theory and Applications* (pp. 163-181). Mahwah, NJ: Lawrence Erlbaum.

Environment Agency. (2007). *Review of 2007 summer flood.*

ERA. (2011). *Annex 1 to Recommendation ERA/REC/04-2011/INT - Specification for Register of Infrastructure.*

ERA. (2013). *ERA-TD-104 - TAF TSI - ANNEX D.2 : APPENDIX E - COMMON INTERFACE.*

ERA. (2013). *ERA-TD-105 - TAF TSI - ANNEX D.2 : APPENDIX F - TAF TSI DATA AND MESSAGE MODEL.*

Eshuis, R. (2006). Symbolic model checking of uml activity diagrams. *ACM Transactions on Software Engineering and Methodology*, 15(1):1-38.

EU. (2008). *DIRECTIVE 2008/57/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the interoperability of the rail system within the Community.*

EU. (2011). *2011/633/EU: Commission Implementing Decision of 15 September 2011 on the common specifications of the register of railway infrastructure .*

EU. (2011). *COMMISSION REGULATION (EU) No 454/2011 of 5 May 2011 on the technical specification for interoperability relating to the subsystem 'telematics applications for passenger services' of the trans-European rail system.*

EU. (2014). *2014/880/EU: Commission Implementing Decision of 26 November 2014 on the common specifications of the register of railway infrastructure and repealing Implementing Decision 2011/633/EU.*

European Commission. (2011). *MEMO/11/346: Volcano Grimsvötn: how is the European response different to the Eyjafjallajökull eruption last year? Frequently Asked Questions.* Brussels.

European Commission. (2011). *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, EC White Paper.*

European Commission. (2014). *Core Network Corridors Progress Report of the European Coordinators.*

EWENT. (2012). *Extreme Weather Impacts on European Networks of Transport, EU-project FP7.* Retrieved June 13, 2014, from http://ewent.vtt.fi/

Freight Group. (2016). Personal Communication, C Woroniuk with Maggie Simpson, 24.2.16.

FUTURENET. (2013). *Future Resilience Transport Networks , project.* Retrieved June 17, 2014, from http://arcc-futurenet.org.uk

Hancock, P. A., & Chignell, M. A. (1989). *Intelligent Interfaces: Theory, Research, and Design.* Amsterdam, The Netherlands: North Holland.

Hilburn, B. (1996). The Impact of Advanced Decision Aiding Automation on Mental Workload and Human/Machine System Performance. *PhD dissertation*. Washington, DC, Department of Psychology, Catholic University of America.

Hopkin, V. (1995). *Human Factors in Air Traffic Control.* London, UK: Taylor and Francis.

Hübl, J., Pichler, J., Jocham, P., & Koschuch, R. (2014). *Automatische Detektion alpiner Massenbewegungen mittels Hochfrequenzradartechnik - Naturgefahren-Radar .* final report, Universität für Bodenkultur, Department für Bautechnik und Naturgefahren, Institut für Alpine Naturgefahren, Wien.

IRSE International Technical Committee . (2009). Semi-automatic, driverless, and unattended operation of trains. *IRSE NEWS*, 150 8-10.

Jordan, N. (1963). Allocation of functions between man and machines in automated systems . *Journal of Applied Psychology* , 47 (3) 161-165.

Kloow, L. (2001). *High-speed train operation in winter climate.* Stockholm: KTH Railway Group and Transrail.

MetOffice. (2012, October 30). *Heavy rainfall/flooding - July 2007*. Retrieved from http://www.metoffice.gov.uk/climate/uk/interesting/july2007

Miller, C. A., & Parasuraman, R. (2007). Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control. *Human Factors*, 49 (1) 57-75.

MOWE-IT. (2014). *Management Of Weather Events In the Transport system, EU-project FP7.* Retrieved May 05, 2014, from http://www.mowe-it.eu

Muir, B. M., & Moray, N. (1996). Trust in automation. Part II. Experimental studies of trust and human intervention in a process control simulation. *Ergonomics*, 39 (3) 429-460.

Network Rail. (2007, July 23). *News Release : Flooding on the Cotswold Line - service update*. Retrieved from http://www.networkrailmediacentre.co.uk/news/flooding-on-the-cotswold-line-service-update

Network Rail. (2014). *Route Weather Resilience and Climate Change Adaption Plans: Western Route.*

Network Rail. (2014). *Weather Resilience and Climate Change Adaptation Plans: London North West Route.*

Network Rail. (2014). *Weather Resilience and Climate Change Adaptation Plans: South East Route.*

Network Rail. (2014). *Weather Resilience and Climate Change Adaptation Plans: Wessex.*

Nietlispach, U. (2012). Zugkontrolleinrichtung ZKE - Keine Kompromisse bei der Sicherheit. In G. A. Luzern (Ed.). Retrieved December 03, 2015, from http://www.gdi-adi.ch/fileadmin/content/ausschuesse/fachtagung/de/120403_Nietlispach_ZKE.pdf

Onnasch, L., Wickens, C. D., Li, H., & Manzey, D. (2014). Human Performance Consequences of Stages and Levels of Automation An Integrated Meta-Analysis. *Human Factors The Journal of the Human Factors and Ergonomics Society*, 56 (3) 476-488.

ON-TIME. (2012). *D2.1 Review of capacity restrictions, railway planning, problem description and existing approaches.* Deliverable.

ON-TIME. (2013). *D4.1 Functional and technical requirements specification for pertubation management.* Deliverable.

ON-TIME. (2013). *D5.1 Functional and technical requirements specification for large scale perturbation management.* Deliverable.

ON-TIME. (2014). *Optimal networks for train integration management across Europe, EU-project FP7.* Retrieved May 08, 2014, from http://www.ontime-project.eu/

Parasuraman, R., & Mouloua, M. (1996). *Automation and Human Performance: Theory and Applications.* Mahwah, NJ: Erlbaum.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39 (2) 230-253.

Parasuraman, R., Sheridan, T. B., & Wickens, C. (2000). A model for types and levels of human interaction with automations. *IEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans*, 30 (3) 286-297.

pro Bahn, F. (2007). "Kyrill"erheblich unterschätzt. *derFahrgast 2/2007*, 23-31.

Rouse, W. (1988). Adaptive aiding for human/computer control. *Human Factors* , 30 431-438.

Sarter, N. B., & Woods, D. D. (1995). Strong, Silent, and Out-of-the-Loop: Properties of Advanced (Cockpit) Automation and Their Impact on Human-Automation Interaction. *Technical Report CSEL 95-TR-01*. Columbus, Cognitive Systems Engineering Laboratory. Ohio State University.

Sarter, N. B., & Woods, D. D. (1997). Team Play with a powerful and independent agent: Operational experiences and automation surprises on the airbus A-320. *Human Factors*, 39 (4) 553-569.

Sharples, S., Millen, L., Golightly, D., & Balfe, N. (2011). The impact of automation in rail signalling operations. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, 225 (2) 179-191.

Sheridan, T. B. (1992). *Telerobotics, Automation, and Human Supervisory Control.* Cambridge, MA: MIT Press.

Sheridan, T. B. (1995). Human centered automation: oxymoron or common sense? Systems, Man and Cybernetics. In *Intelligent Systems for the 21st Century., IEEE International Conference on (Volume:1)* (pp. 823-828).

Sheridan, T. B. (1999). Human supervisory control. In A. P. (Eds.), *Handbook of Systems Engineering and Management* (pp. 645-690). New York: John Wiley & Sons.

Sheridan, T. B., & Verplank, W. L. (1978). *Human and Computer Control of Undersea Teleoperators.* MIT Man-Machine Systems Laboratory Report.

Vicente, K. J. (1999). *Cognitive work analysis / toward safe, productive and healthy computer-based work.* Lawrence Erlbaum Assoc.

Vicente, K., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics*, 22 589-606.

WEATHER. (2012). *Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions, EU-project FP7.* Retrieved May 16, 2014, from http://weather-project.eu

Wickens, C. (1992). *Engineering Psychology and Human Performance (2nd ed.).* New York: HarperCollins.

Wickens, C. (1994). Designing for situation awareness and trust in automation. In I. F. Control, *In Proceedings of the IFAC Conference on Integrated Systems Engineering* (pp. 77-82).

Wickens, C. D., & Carswell, C. M. (1995). The proximity compatibility principle: Its psychological foundation and relevance to display design. *Human Factors*, 37 (3) 473-494.

Wickens, C. D., & Yeh, M. (1996). Attentional filtering and decluttering techniques in battlefield map interpretation. In *Proceedings of Army Research Laboratory Advanced Displays and Interactive Displays Federated Laboratory First Annual Symposium* (pp. 2-55/2-42). Adelphi, MD: US Army Research Laboratory.

Wickens, C.D. & US National Research Council Panel on Human Factors in Air Traffic Control Automation. (1998). *future of air traffic control: human operators and automation (Chapter 1).* Washington, DC : National Academy Press.

Wiener, E. (1988). Cockpit automation. In E. W. (Eds.), *Human Factors in Aviation* (pp. 433-461). San Diego, CA: Academic Press.

Wiener, E. L., & Curry, R. E. (1980). Flight-deck automation: Promises and problems. *Ergonomics*, 23 995-1011.

Woods, D. (1996). Decomposing automation: Apparent simplicity, real complexity. In R. P. (Eds.), *Automation and Human Performance: Theory and Applications* (pp. 3-17). Mahwah, NJ: Erlbaum.

Woods, D. D. (1997). Human-centered software agents: Lessons from clumsy automation. In T. H. J. Flanagan, *Human Centered Systems: Information, Interactivity and Intelligence* (pp. 288-293). Washington, DC: National Science Foundation.

Yu, G., & Qi, X. (2004). *Disruption Management - Framework, Models and Application.* World Scientific Pub Co Inc.