D1.1 Principles, Definitions and Requirements

Grant Agreement N°: FP7 - SCP0 – GA – 2011 - 265647

Project Acronym: **ON-TIME**

Project Title: **O**ptimal **N**etworks for **T**rain Integration **M**anagement across **E**urope

Funding scheme: Collaborative Project

Project start: 1 November 2011

Project duration: 3 Years

Work package no.: WP1

Deliverable no.: ONT-WP01-DEL-001

Status/date of document: Final, 26/06/2012 (revised 27/06/2013)

Due date of document: 30/04/2012

Actual submission date: 26/06/2012 (revised 27/06/2013)

Lead contractor for this document: University of Birmingham

Project website: www.ontime-project.eu

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Revision control / involved partners

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

Revision	Date	Name / Company short name	Changes
1	11/04/12	UoB	Draft for discussion
2	29/04/12	UoB	Final draft
3	27/06/13	UoB	Amendments following EC review

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Executive Summary

This document describes research carried out to provide a better understanding of maximum theoretical capacity and the factors, both static (things like infrastructure that tend to be fixed in the short to medium term) and dynamic (things like timetables that tend to be more flexible in the short to medium term), that affect it. The type and influence of timetabling allowances on railway maximum theoretical capacity are discussed, and system aspects of the capacity problem are explored: in particular, a diagram is presented showing where the work of WPs 3, 4, 5 and 6 fits in the context of the overall timetable planning and train control system; current planning and control processes are described taking the British case as an example; an outline list of user requirements is developed to focus the innovation work of the other WPs, and; use of a formal notation to describe planning and control functions is proposed. The document concludes with a Glossary of terms assembled in the course of the research, and a set of conclusions.

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1 INTRODUCTION

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

ON-TIME is studying improvements to capacity management on a number of fronts: firstly, in Work Package (WP) 3, the development of methodologies for the production of resilient timetables (i.e. timetables able to accommodate minor disruptions); secondly, in WP4, the development of methodologies for improved real-time management of train service disruption, with the aim of returning rapidly to the timetable in the event of disruptions; thirdly, in WP5, improved methods of recovering train services from large-scale, major disruptions; and fourthly, in WP6, development of advanced driver advisory systems. WPs 7, 8 and 9 deal respectively with: development of an information architecture to support improved capacity management; execution of a project to demonstrate the capacity benefits of the new methodologies and processes; and dissemination of the project findings.

ON-TIME begins, however, with WPs 1 and 2, which provide the foundation on which the rest of the project is built. The principal aim of WP1 is to elicit the user and technical requirements that will drive development of improved methods and processes in the other work packages. This involves work to provide a better understanding of what capacity is, what the maximum capacity of a route might be, and how the cost, in capacity terms, of changes to operational rules can be calculated. WP1 also works closely with stakeholders in the project to identify the main causes of customer dissatisfaction with current arrangements, and their requirements for improvement. The aim of WP2 is to explore existing approaches to capacity management as a basis for specifying innovations that will drive future improvements.

This document is focused on the work of WP1. It describes research carried out to provide a better understanding of maximum theoretical capacity and the factors, both static (things like infrastructure that tend to be fixed in the short to medium term) and dynamic (things like timetables that tend to be more flexible in the short to medium term), that affect it. The type and influence of timetabling allowances on railway maximum theoretical capacity are discussed, and system aspects of the capacity problem are explored: in particular, a diagram is presented showing where the work of WPs 3, 4, 5 and 6 fits in the context of the overall timetable planning and train control system; current planning and control processes are described taking the British case as an example; an outline list of user requirements is developed to focus the innovation work of the other WPs; and use of a formal notation to describe planning and control functions is proposed. Deliverable D1.1 concludes with a Glossary of terms assembled in the course of the research, and a set of conclusions.

1.1 High level principles

The ON-TIME project will be guided by a set of principles that will govern all of the work packages. These set out the fundamental aims of the project and the approaches to the work of the Work Packages. The high level principles are:

- The processes of timetable planning and control will be integrated.
- The capacity of the railway can be increased by:
  - Constructing timetables that contain allowances, which are based on simulation, empirical data or rigorous theoretical calculation and which exist solely to make the timetable stable against minor perturbations and resilient when asset re-dispositions are needed to recover from major disturbance;
  - Managing railway traffic more efficiently – using the allowances built into the timetable.
- Therefore, allowances within the timetable will be those that can be managed by a traffic management system or by human traffic managers.
- It is better to prevent disruption than to manage it. Therefore traffic management will be predictive – seeking to identify potential causes of disruption and managing traffic to remove the cause.
- Algorithms within traffic management systems will be based on the timetabled allowances.
- Trains can operate with reduced headways if the effect of a single perturbed train can be mitigated so as to not cause a knock-on or ripple effect on other trains.
- Timetable planning can be evaluated and improved by software support using traffic simulation systems and optimisation systems.
- Traffic simulation systems and empirical data give the ability to analyse bottle necks and timetable stability.
- Contingency plans should include information about how to handle different kinds of disturbances, especially in bottle neck areas.
- A resilient timetable will allow railway assets (rolling stock, crew, paths) to be reallocated to allow services to be continued and capacity maintained at the optimal level.
- Timetables contain access for trains (paths); access for engineering; and whitespace to allow a margin for recovery.
- Timetable planning is done in different time perspectives, for example: 1 year, 2 weeks and 24 hours before operation.
- As planned maintenance is a timetabled event, unplanned maintenance is a perturbation.

- The network is highly automated and makes automatic decisions and provides decision support for operators. This allows control centre operators to take greater service management responsibilities and exercise supervisory control.
- Instructing drivers to vary train speeds will allow traffic managers to manage the separation between trains and so increase the used capacity of the infrastructure.
- A railway cost function will be used to support traffic management decisions; partly by allowing the trade off between capacity and delay to be understood.
- WP3 (Timetabling) will include the use of traffic scenarios for timetable planning/traffic simulation.
- ON-TIME will study the management of railway disruption in two major subsets:
  - Those that can be resolved through correction by an ICT system with no human intervention. IM/RU communication will be between systems.
    - These will be within WP4 (Traffic Management/Perturbations)
  - Those that can only be resolved with human intervention to make decisions about the redisposition of resources (paths, crew, rolling stock). These decisions will need RU/IM communication between both human and ICT system. The role of ICT systems will be only to provide decision support – including "what-if" modelling.
    - These will be within WP5 (Management of Disruption).
- Following human intervention and decision-making to resolve disruption, the traffic situation should be restored sufficiently to be manageable once again by the ICT system. This implies that:
  - there must be a mechanism for transferring perturbations from the domain of WP5 (Disruption) to the domain of WP4 (Perturbation).
    - There must be limits to the correction methods that can be applied by ICT systems without human intervention. It is not acceptable for a system to cancel station stops, for example.
- ATO is beyond the scope of the ON-TIME project. However, ON-TIME will research and propose automatic algorithms up to and including those appropriate for ATO.

2 UNDERSTANDING OF THE MAXIMUM THEORETICAL CAPACITY

Capacity and how to improve it are currently among the most significant concerns of many railways worldwide. However, whilst the term railway capacity is used frequently, it has neither a standard definition nor a standard method of measurement. Whether a line has reached its capacity and which are the attributes most critical to its capacity constraints are not obviously apparent.

The question of route capacity is a prominent issue for the modern railway network, especially since a railway is a fixed guidance system, requiring a combination of civil, electrical, mechanical and environmental engineering to construct and maintain and a widely spread, diverse control and management organisation to operate. All of these require substantial planning, building and operating resources. In addressing railway capacity, the combination of these wide-ranging factors must be considered in a way that ensures that the effects of all of them upon the system are drawn into the debate and realistically assessed. The consideration must also include the feasibility of proposals to provide increased capacity in terms of the cost, technical difficulty and efficiency of the proposed changes for the railway system as a whole.

2.1 Capacity as a concept

It is generally accepted that railway capacity is an elusive concept that is not easily defined or quantified (Kozan & Burdett, 2004; Kozan & Burdett, 2005; Krueger, 1999; UIC, 2004). Therefore, railway capacity is often understood and defined differently according to the context. An example of various views is shown in Table 1.

Market (customer needs)	Infrastructure planning	Timetable planning	Operations
Expected number of train paths (peak) Expected mix of traffic and speed (peak) Infrastructure quality need Journey times as short as possible Translation of all short- and long-term market-induced demands to reach optimised load	Expected number of train paths (average) Expected mix of traffic and speed (average) Expected conditions of infrastructure Time supplements for expected disruptions Maintenance strategies	Requested number of train paths Requested mix of traffic and speed Existing conditions of infrastructure Time supplements for expected disruptions Time supplements for maintenance Connecting services in stations Requests out of regular interval timetables (system times, train stops, etc.)	Actual number of trains Actual mix of traffic speed Actual conditions of infrastructure Delays caused by operational disruptions Delays caused by track works Delays caused by missed connections Additional capacity by time supplements not needed

Table 1: Different views of capacity (UIC, 2004)

Ultimately, the capacity of a railway can be considered to be the quantity of passengers and goods that the railway can transport over a given time period. It is often expressed in terms of the number of passenger kilometres per year and freight tonne kilometres per year or passengers per hour and freight tonnes per hour. This relates to the carrying capacity of the railway and reflects both infrastructure capacity and train capacity. However, while this concept is often used to express the scale of a railway in comparison with other railways or with other modes of transport, it is rarely used in day-to-day railway operations.

In practice, railway capacity is often associated more with the ability of infrastructure to accommodate train traffic. Below are examples of this type of definition.

According to Kozan & Burdett (2004, 2005), "the simplest approximation and the most prevalent encountered is that the capacity of a single line is the total number of standard train paths that can be accommodated across a critical section in a given time period, where a standard train is defined as the most prevalent type to traverse the corridor".

The International Union of Railways (UIC) has attempted to provide a definition of railway capacity which is supposed to work for as broad a spectrum of scenarios as possible (UIC, 2004):

> *"The capacity of any railway infrastructure is:*
>
> *- the total number of possible paths in a defined time window, considering the actual path mix or known developments respectively and the Infrastructure Manager's own assumptions;*
>
> *- in nodes, individual lines or part of the network;*
>
> *- with market-oriented quality."*

Krueger (1999) of the Canadian National Railway adopted the following general definition:

> *"Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan."*

He also provided various specific definitions and measures of capacity as follows:

> *"**Theoretical (Physical) Capacity**: This is the theoretical maximum upper boundary of capacity. It assumes all trains are the same, with the same train consist, equal priority, and are evenly spaced throughout the day with no disruptions. It ignores the effects of variations in traffic and operations that occur in reality."*
>
> *"**Practical Capacity**: The practical limit of "Representative" traffic volume that can be moved on a line while achieving a defined performance threshold. "Representative" traffic reflects actual train mix, priorities, consists, power to weight, and traffic bunching."*
>
> *"**Used Capacity**: The actual traffic volume occurring over the territory. Reflects actual variation in traffic and operations that occur on the line."*
>
> *"**Available Capacity**: The difference between Used and Practical Capacity. It is an indication of the additional traffic volume that could be handled while maintaining the predefined performance threshold."*

According to Krueger, practical capacity is the most significant measure of track capacity since it relates the ability of a specific combination of plant, traffic and operations to move the most volume within an expected service level.

The definitions of railway capacity provided in a report prepared for the Washington State Department of Transportation (HDR Engineering, 2001), are given in Table 2.

Capacity type	Definition
Theoretical	The number of trains per day that could run over a route in a strictly perfect, mathematically-generated environment. This number is useful because it is relatively easy to generate. For example, if the longest running time between two sidings were one hour, that implies that it would take at least two hours between trains to travel in each direction. This would imply a capacity of 12 trains travelling east and 12 trains travelling west each day (or 24 trains per day).
Practical	It's not possible to actually run the number of trains you work out mathematically. Things will happen – one train doesn't have enough locomotive power, the rail is slippery, there is wind or fog, or the engineer is a little slow on his train handling. A reasonable and slightly reduced figure for what the real world might produce is 75% of the theoretical capacity. Using this relationship for practical capacity makes it possible to produce a reasonable estimate fairly easily.
Commercial	Commercial capacity is simply the practical capacity available during the times when business needs would actually want shipments to move. Practical capacity is the number of trains you could reasonably expect to run in a day, but using all of it would require you to run trains when you don't need them. Suppose that the Seattle area could practically accept one train an hour and send out one train per hour. However, shippers want to receive their shipments before 6am, so they can be ready for the day's business, and they want to send shipments after a day of loading cars (say, after 6pm). In effect, the commercial capacity in this very simple example is six trains per day outbound from 6pm to midnight and six trains per day inbound from midnight to 6am. Shippers might want to increase their rail business to a level that would need ten trains, but since their businesses only accept or send out trains at certain times, the commercial capacity is much less than the practical capacity.

Table 2: Types of railroad capacity (HDR Engineering, 2001)

In the context of signalling, Woodland, in his PhD thesis (2004), has adopted the following definitions of railway capacity:

- **Train Following Capacity**: The maximum throughput at a particular point on the railway network, such as a signal position, if all trains were to follow each other at line speed and with a minimum of braking distance separation, no allowance being made for station stops.
- **Point Capacity**: The maximum throughput at a particular point on the railway network, such as a station platform, accounting for station stops and actual train speeds.
- **Theoretical Line Capacity**: Indicates the theoretical maximum throughput of a railway line when all trains complete more than one round trip.

- **Sustainable Line Capacity**: Indicates the sustainable throughput of a railway line when all trains complete more than one round trip, in accordance with the time tabled service pattern.
- **Optimum Line Capacity**: Indicates the sustainable throughput when passenger / goods travel times and comforts are optimised.

The US Transportation Research Board (2003) introduced definitions of capacity to balance between railway capacity supply and demand, as stated below:

- ***Design Capacity:*** The maximum number of passenger spaces past a single point in an hour, in one direction on a single track.
- ***Achievable Capacity:*** The maximum number of passengers that can be carried in an hour in one direction on a single track allowing for the diversity of demand.
- ***Line Capacity:*** The maximum number of trains that can be operated over a line in a peak hour.
- ***Train Capacity:*** The product of passengers per car and the number of cars, adjusted to achievable capacity case using a diversity factor to compensate for uneven car loadings over multiple-car trains."

The relationship between these definitions is expressed in Figure 1.

DESIGN CAPACITY	=	LINE CAPACITY Maximum throughput in TRAINS/HOUR	×	TRAIN CAPACITY Number of PASSENGER SPACES

Basic design capacity expression

ACHIEVABLE CAPACITY	=	DESIGN CAPACITY	×	PEAK HOUR DIVERSITY FACTOR

Basic achievable capacity expression

Figure 1: Expressions for Design and Achievable Capacity (Transportation Research Board, 2003)

For transit systems (e.g. light rail) Vuchic (2005) adopted two types of capacity:

(1) Static Capacity: Total number of spaces or persons a vehicle can accommodate.

(2) Dynamic Capacity: The maximum number of transit units, vehicles, spaces or persons that can be transported on a transit line past a fixed point in one direction per unit of time (usually one hour).

2.2 Introduction of existing capacity measures

As shown in Section 2.1, there are two types of capacity definition. The most common type reveals the highest volume capability of a railway network. It is addressed by the

UIC 405 method, which has already been superseded. The other type of definition concentrates on capacity consumption or utilisation. UIC 406 (the succeeding assessment to UIC 405) and many other methods all support this definition.

2.2.1 UIC 405 method

Before the current railway capacity code (UIC, 2004) was issued, another method had been provided by the International Union of Railways (UIC, 1983). Although this code is now superseded, it is still worth reviewing since it provides a direct assessment of capacity in terms of the number of trains per given time period (day or hour).

The UIC 405 basic formula is:

$$\boldsymbol{L} = \frac{\boldsymbol{T}}{\boldsymbol{t_{fm}} + \boldsymbol{t_r} + \boldsymbol{t_{zu}}}$$

where L is the capacity of a line section in number of trains in period T (the reference period in minutes), t_{fm} is the average duration of minimum train headway time (minutes), t_r is the extra time margin (minutes) and t_{zu} is an additional time (minutes).

- The average duration of minimum train headway time t_{fm} is calculated from the headway of all trains running on the line section. There are two different methods for determining t_{fm}: dependent and independent of the running schedule.
- The extra time margin t_r is a "breathing space" provided after each minimum train headway to reduce the risk of the occurrence of a build-up of delays.
- The additional time t_{zu} is another additional period of time allowed after each train headway to ensure more or less the desired quality of service over the whole line section and also when a number of sections of line are involved.

UIC 405 gives an explicit explanation of the relevant parameters based on a timetable. It is widely used in supporting railway network capacity evaluation.

The document has been applied by Swiss Federal Railways in developing CAPACITY, a computing tool used for quickly analysing different long-term scenarios and to determine bottlenecks for the whole of the Swiss railway network. UIC 405 was also used to construct CAP1 (for one direction flow) and CAP2 (for bi-directional flow) capacity models under the European project IMPROVERAIL (Viegas et al., 2003; Moreira et al., 2003; Moreira et al., 2004). These two models can be seen as further development of the UIC 405 formula and the CAPACITY model, and have been used for a capacity study of a 336 km section of the North Line in Portugal (Figure 2). Railway planning software such as VIRIATO also includes modules based on UIC 405 (Moreira, N. et al, 2004).

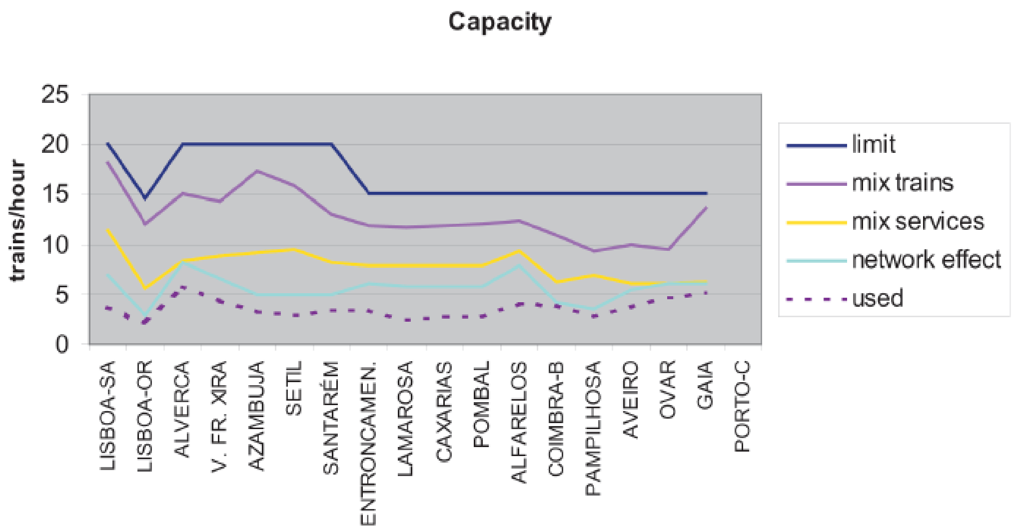


Figure 2: Calculated capacity on North Line, Portugal (Moreira *et al.*, 2003)

The capacity in Figure 2 was calculated for five scenarios:

- Capacity limit - The maximum capacity of a railway section, obtained with all trains running in the same direction (one section of double track), all equally spaced at the minimum headway;
- Capacity with a mix of trains - Capacity with a mix of trains with different running times between two stations and without the possibility of overtaking;
- Capacity with different train services – Taking operational patterns of passenger and freight trains into account. Typically, passenger trains are not passed in stations due to the additional stop time required, but for freight trains the additional stop time is not so relevant;
- Capacity with network effect – Taking into account the fact that not all trains have the same path or end in the same station, where shorter trains and also convergence or divergence of trains generate unusable capacity.;
- Used capacity - Actual capacity used.

2.2.2 UIC 406 method

With the rising volume of border-crossing traffic in Europe and increasing demands for quality and quantity, the UIC 406 (UIC, 2004) method was developed to evaluate railway infrastructure capacity. Railway capacity is assessed though the capacity consumption, as shown in Figure 3.

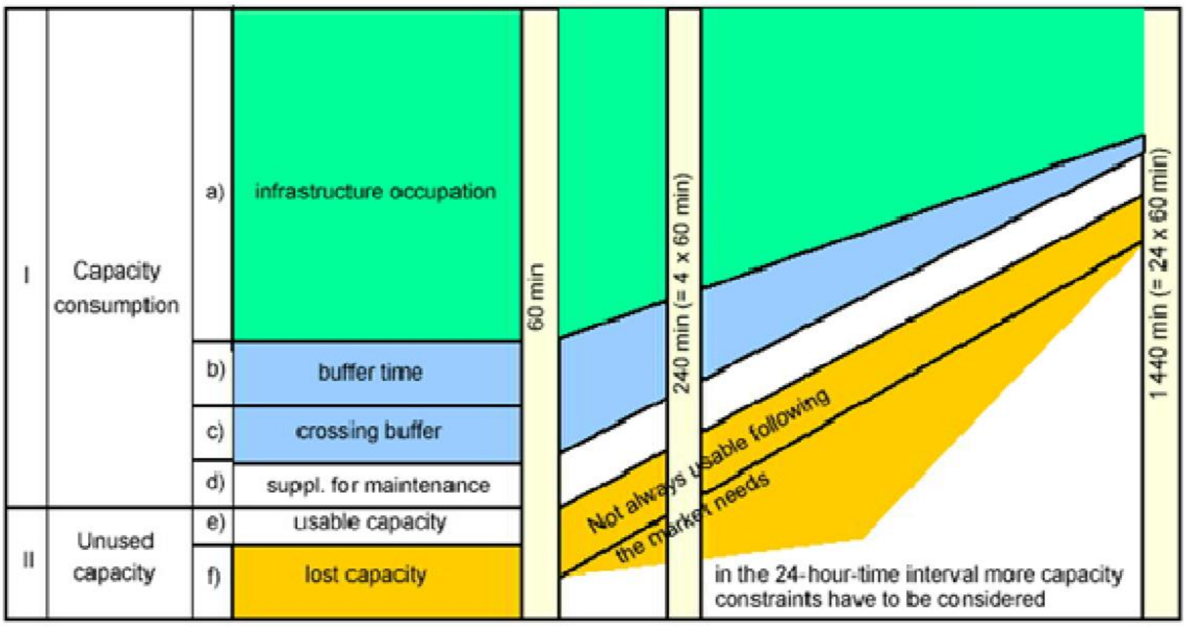


Figure 3: Determination of UIC 406 Capacity Consumption (UIC, 2004)

The formula for determining capacity consumption is as follows:

k = A+B+C+D

k: total consumption time [min]

A: infrastructure occupation [min] (includes running time supplements [allowance time])

B: buffer time [min]

C: supplement for single-track lines [min]

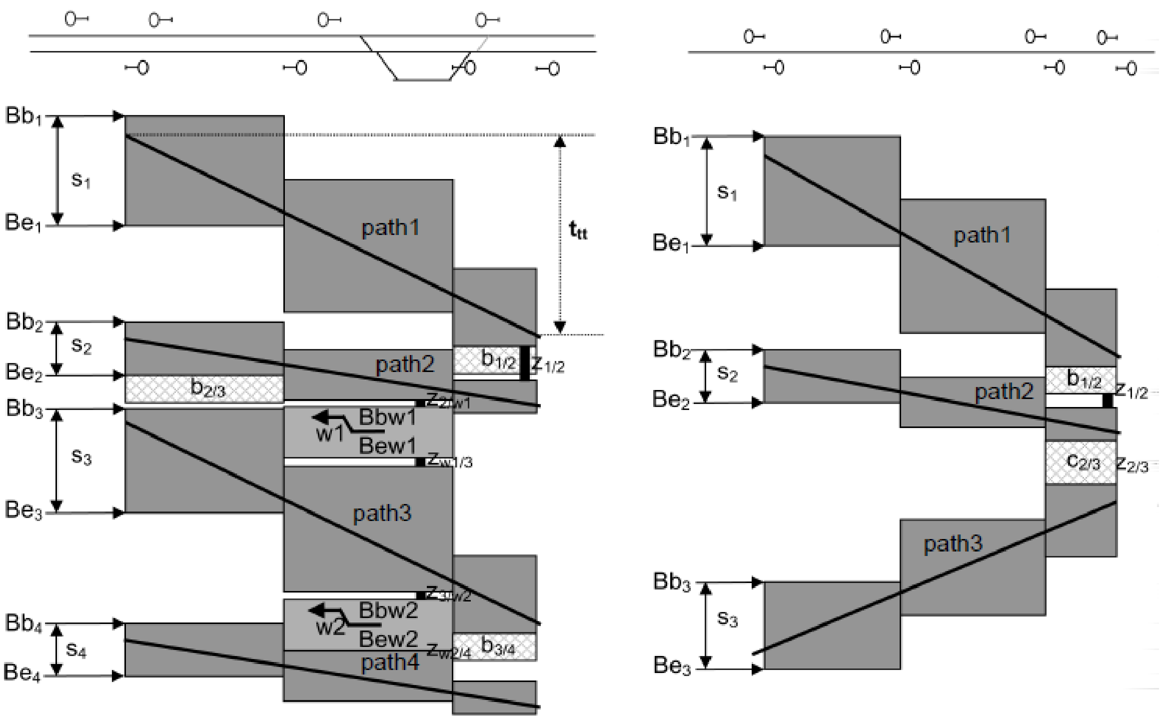
D: supplements for maintenance [min]

K=k*100/U

K: capacity consumption [%]

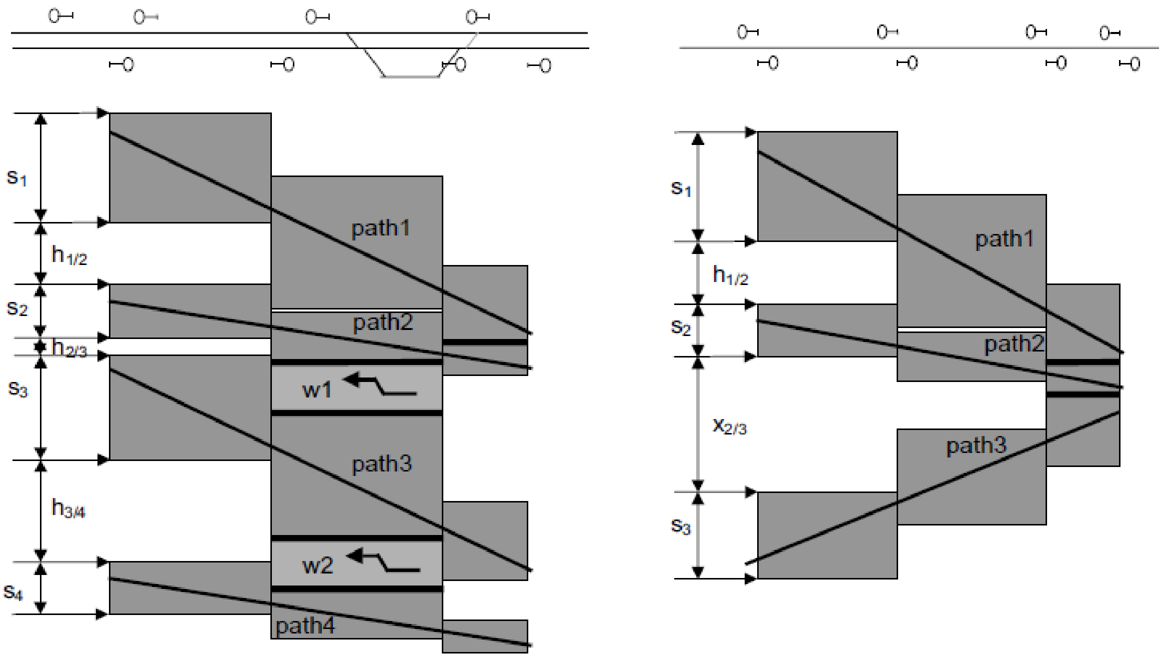
U: chosen time window [min]

The timetable compression method, which reveals the time shares of a non-compressed timetable and of a compressed timetable, can be used to determine the capacity consumption components in the above equation. For compression purposes, all single train paths are pushed together up to the minimum theoretical headway according to their timetable order, without recommending any buffer time. This compression can be done by constructing graphical analysis (see Figure 4), using suitable tools, or by analytical calculation.



w_1, w_2 are white blocks or indirect infrastructure occupation times

Timetable shares within a timetable



$h_{1/2}$, $h_{2/3}$, $h_{3/4}$ are heterogeneity times

Timetable shares after compression

Figure 4: UIC 406 timetable compression (UIC, 2004)

There is a relationship between infrastructure occupation time (% of time window) and the risk of congestion. Based on the assessment of about 3000 km of lines on several

European rail networks, UIC has proposed recommended values for a capacity consumption index (see Table 3). Capacity consumptions above these values may significantly increase the risk of congestion if delays occur.

Type of line	Peak hour (%)	Daily period (%)	Comment
Dedicated suburban passenger traffic	85	70	The possibility to cancel some services in case of delays allows for high levels of capacity utilisation
Dedicated high-speed line	75	60	
Mixed-traffic lines	75	60	Can be higher when number of trains is low (fewer than 5 per hour) with strong heterogeneity

Table 3: UIC recommended capacity consumption index (UIC, 2004)

The UIC 406 method has been used widely in many European countries (Wahlborg, 2004; Landex et al., 2006; UIC, 2004) to assess railway capacity. Figure 5 shows the results of a study undertaken in Sweden by Banverket.

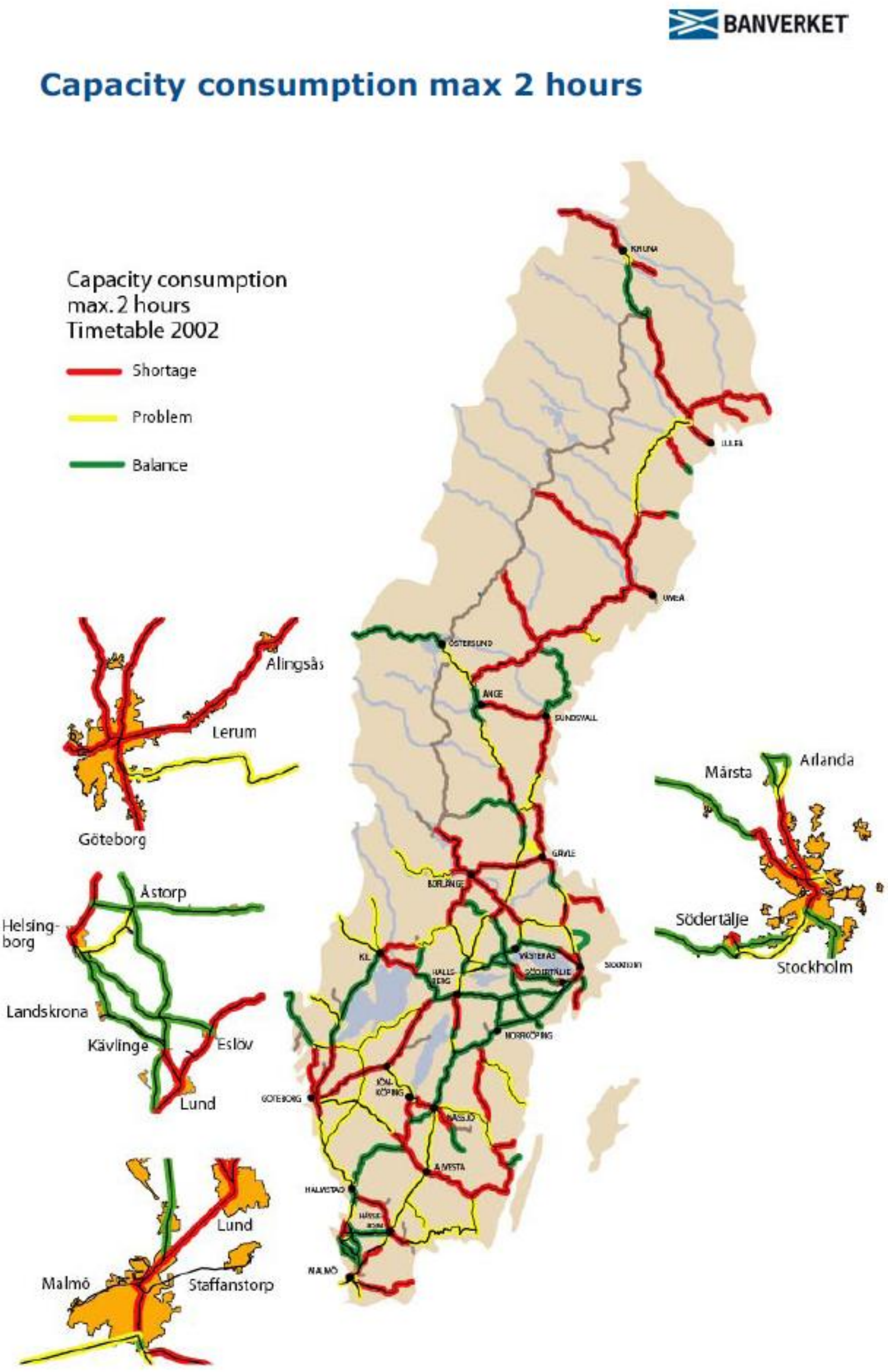


Figure 5: Capacity consumption on Swedish Banverket rail network (Wahlborg, 2005)

2.2.3 British method: Capacity Utilisation Index

In Great Britain the Capacity Utilisation Index (CUI) has been adopted as a measure of capacity utilisation. The CUI was established in the late 1990s and has only been used for assessing the utilisation of track sections, not of junctions. It is based on Minimum Headways.

Its concept, which is fairly similar to the UIC's capacity consumption, is illustrated in Figure 6.

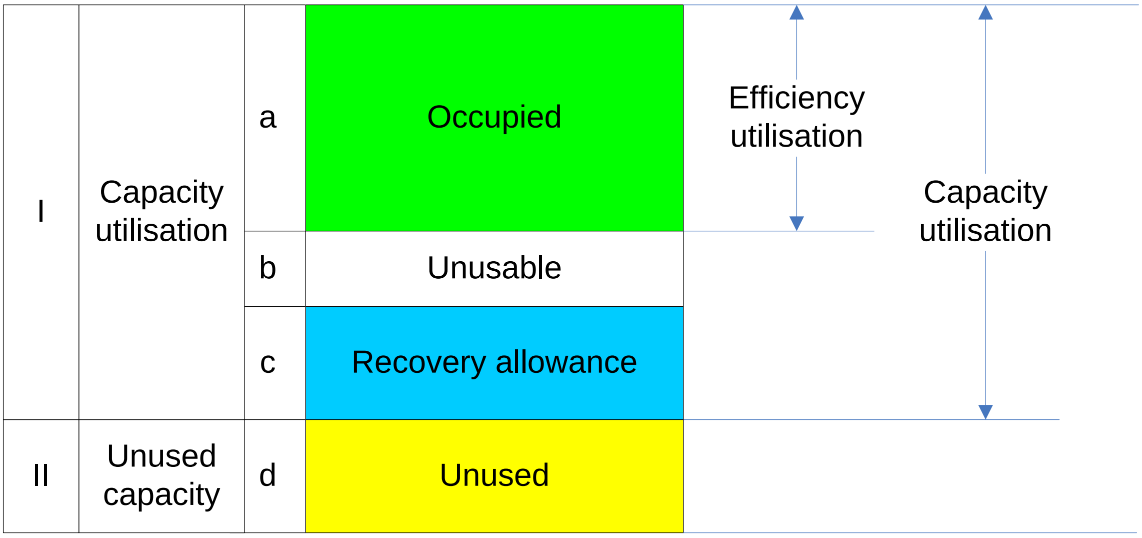


Figure 6: Graphical representation of the Capacity Utilisation Index

The CUI can therefore be determined as:

$$CUI = \frac{(a + b + c)}{(a + b + c + d)} \times 100\%$$

A detailed calculation based on compression is illustrated in Figure 7. The basic concept of CUI is to find "white space" on the train graph.

The calculation of CUI depends on the following inputs (AEA Technology, 2005):

- Route
- Time Period
- Timetable
- Headways
- Order and speed mix of trains in the timetable

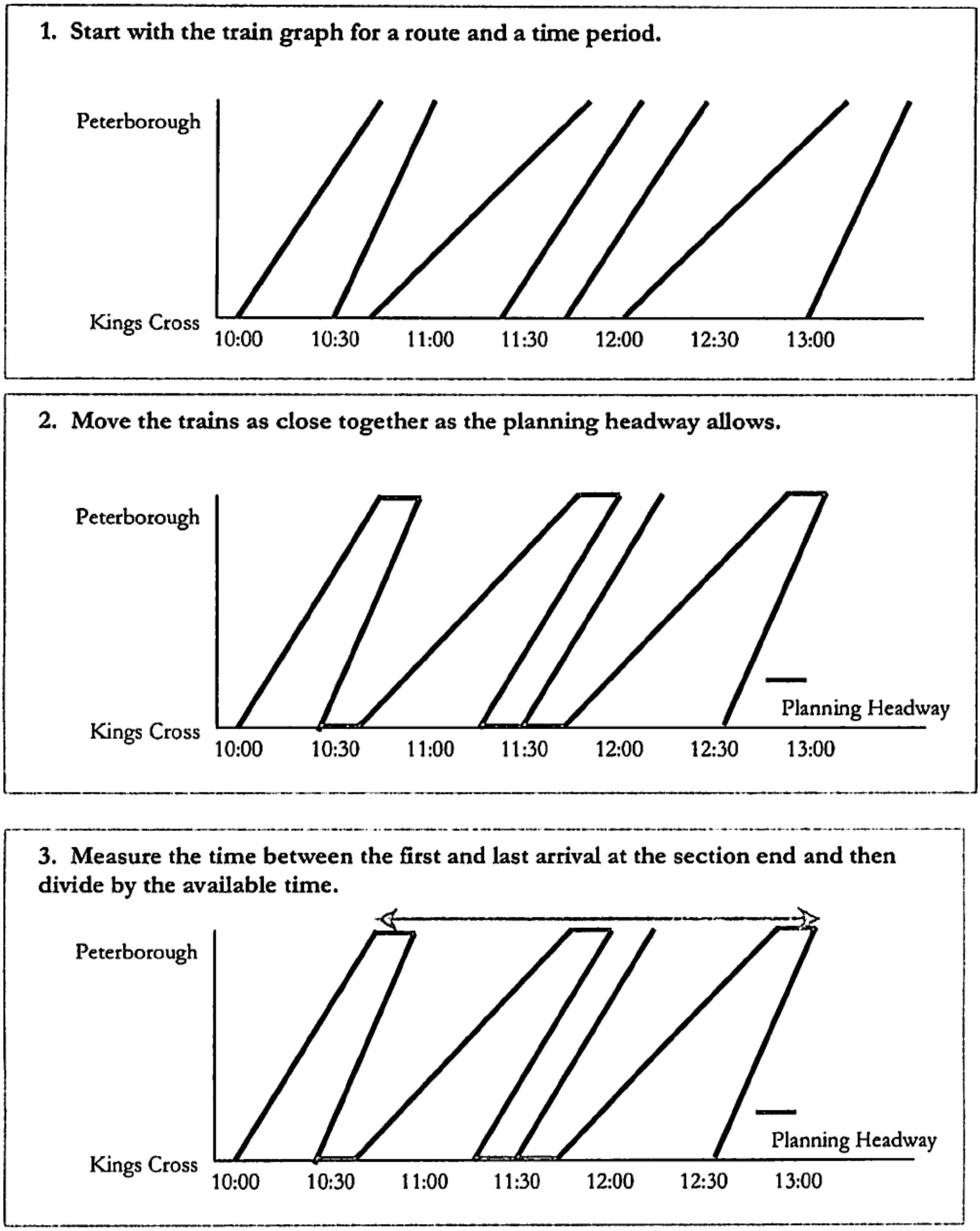


Figure 7: Expression of CUI method (AEA Technology, 2005)

The mathematical expression is:

$$CUI = \sum (max\ (Journey\ Time\ Differential_{i,i-1},\ 0) + Headway)\ /\ Timeband\ Length$$

$Journey\ Time\ Differential_{i,i-1}$ is the difference in journey times between each pair of scheduled trains (i and i-1).

Journey Time is defined as the sum of the following elements:

- a basic time without time supplements, which is calculated according to line and rolling stock characteristics;
- a time supplement which is assigned depending on the type of route (about 5% of journey time);
- time for market requirements;
- time resulted from the timetable construction process.

Based on this method, Network Rail has established a map of the peak CUI of the national (GB) rail network (see Figure 8). Analysis by the Strategic Rail Authority (SRA) (SRA, 2003) suggests that 75% is the maximum CUI beyond which benefits arising from the operation of further services on a route are likely to be outweighed by the effect of worsening performance.

It is worth noting that CUI does not reflect the number of trains (or train paths) per hour. For example, a timetable for trains with identical speeds and stopping patterns might allow 20 trains per hour at a CUI level of 67%, whereas a timetable over the same route accommodating trains with very diverse speeds and stopping patterns might reach the same CUI level with just eight trains per hour (SRA, 2003).

2.3 Analysis of existing capacity measures

UIC 405, UIC 406 and CUI are all widely used capacity measures. They are all timetable-related, yet there are many differences between them.

UIC 405 is measured in tph (trains per hour), while UIC 406 and CUI are expressed as percentages. This is mainly because of the different aims of each method. UIC 405 measures the number of trains that can be run on a network whereas UIC 406 and CUI are both for the determination of the extent of 'spare' capacity on a route.

Armstrong et al (2009) made clear the key difference between UIC 406 and CUI. They state that "the UIC 406 analysis is based on the occupation times of individual signal blocks, whereas the CUI approach is based on the minimum headways specified in Network Rail's 'Rules of the Plan' for entire route sections". Thus UIC 406 can be applied to links. The CUI is not for junctions or locations, and is only considered at nodes (Sameni et al, 2011). UIC 406 and CUI are general methods which gives the possibility to study the relation between number of train paths, infrastructure and capacity utilisation (a percentage value).

Table 4 gives an example when using the methods from a technical view. One parameter is changed each time, and the attempt is to gain a rough cognition of the influences of capacity improvement measures, rather than precise quantitative results. In practical railway operations, the change of one improvement measure will lead to the changes of other parameters of railway systems, e.g. "Increase deceleration rate" leads to shorter train braking distance, thus the length of blocks can be reduced. These parameter changes also need to be reflected during the process of the simulation analysis.

Passenger demands such as punctuality, connectivity, comfort and information needs are not taken into consideration. The RUs consideration about longer trains and trains with more seats are not taken into consideration either. For train length there are threshold values, for example when a single track technical station is shorter than the freight train or when a platform is shorter than a passenger train.

The dynamic influence factors are not considered either in these measurements. A modified version of capacity definition and measurement is required to meet both system requirements and passenger satisfaction. In the next chapter, a new generic definition of capacity and the static and dynamic solutions for improving railway capacity are discussed.

UIC 406 and CUI are general and they have possibilities to handle the relation between traffic demand and capacity utilisation.

2.4 Traffic demand

Traffic demand is described more generally in strategic planning compared to timetable planning. Traffic demand in national strategic planning is long distance passenger services, regional passenger services, commuter passenger services and freight transports. The output is passenger travels passenger km for each service and freight transports ton km for each product category.

Traffic demand in annual timetable planning and ad-hoc timetable planning handles both the socio-economic benefit for railway traffic but also the commercial aspects for RUs to run trains. Traffic demand in timetable planning is focused on train paths and RU need of departure time, arrival time, frequency and punctuality.

The comparison results of UIC 405, UIC 406 and CUI listed in Table 4 were acquired with simulation tools by only changing one parameter each time; the attempt is to gain a rough cognition of the influences of capacity improvement measures, rather than precise quantitative results. In practical railway operations, the change of one improvement measure will lead to the changes of other parameters of railway systems, e.g. "Increase deceleration rate" leads to shorter train braking distance, thus the length of blocks can be reduced. These parameter changes also need to be reflected during the process of the simulation analysis.

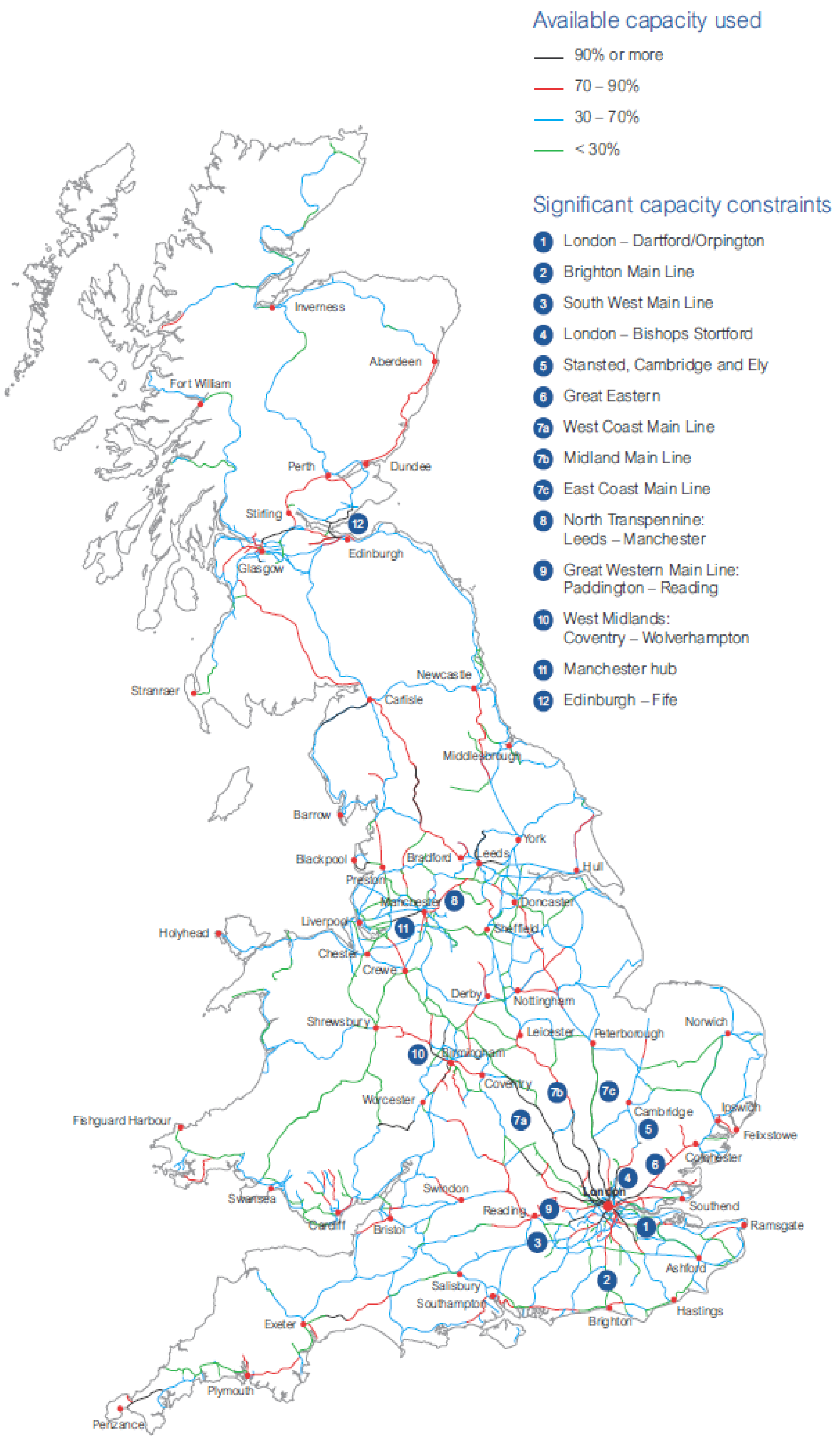


Figure 8: Network Rail peak CUI map (Network Rail, 2006)

	UIC 405 (L)	UIC 406 (K)	CUI
Lengthen trains	Block Section Release Time↑; t_{fm} (average minimum headway time)↑; L↓ (capacity decreased)	*Infrastructure occupation* ↑; K↑ (capacity decreased)	*Headway time*↑; CUI↑ (capacity decreased)
Increase deceleration rate	Approach time↓; t_{fm} ↓; L↑ (capacity increased)	Headway time↓; *Infrastructure occupation* ↓; K↓ (capacity increased)	*Headway time*↓; CUI↓ (capacity increased)
Increase buffer time	t_r(time to reduce build-up delays)↑; L↓ (capacity decreased)	*Buffer time*↑; K↑ (capacity decreased)	No change to *Headway time* or *Journey time differential;* CUI remains the same (same capacity)
Increase dwell time	t_{fm}(average minimum headway time)↑; L↓ (capacity decreased)	*Infrastructure occupation* ↑; K↑ (capacity decreased)	*Headway time*↑; CUI↑ (capacity decreased)
Increase signalling aspects	Shorter block section; t_{fm} ↓; L↑ (capacity increased)	Headway time↓; *Infrastructure occupation* ↓; K↓ (capacity increased)	*Headway time*↓; CUI↓ (capacity increased)
Increase train speed	L is changing as an upward parabolic curve which has a maximum value.	K is changing as a downward parabolic curve which has a minimum value.	CUI is changing as a downward parabolic curve which has a minimum value.
Add tracks	L↑ (capacity increased)	*Unused Capacity*↑ ; K↓ (capacity increased)	CUI↓ (capacity increased)
Add platforms at stations	t_{fm} ↓, t_{zu}↓; L↑ (capacity increased)	Headway time↓; *Supplements for maintenance* ↓; K↓ (capacity increased)	*Headway time*↓; CUI↓ (capacity increased)
Decrease train speed heterogeneity	t_{fm} ↓; L↑ (capacity increased)	Headway time↓; *Infrastructure occupation* ↓; K↓ (capacity increased)	*Headway time*↓; *Journey time differential*↓; CUI↓ (capacity increased)
Add commercial stops	t_{fm} ↑; L↓ (capacity decreased)	Headway time↑, *Infrastructure occupation* ↑; K↑ (capacity decreased)	*Headway time*↑; CUI↑ (capacity decreased)

Table 4: Comparison of Capacity Measures

Generally, all these measurements, including UIC 405, UIC 406 and CUI, are oriented from the engineering point of view. Passenger demands such as punctuality, connectivity, comfort and information needs are not taken into consideration. The dynamic influence factors are not considered either in these measurements. A modified version of capacity definition and measurement is required to meet both system requirements and passenger satisfaction. In the next chapter, a new generic definition of capacity and the static and dynamic solutions for improving railway capacity will be presented and analysed.

3 IDENTIFICATION OF STATIC AND DYNAMIC SOLUTIONS FOR IMPROVING RAILWAY SYSTEM CAPACITY

3.1 Common solutions for improving railway capacity

Railway capacity is highly dependent on the way it is used. It varies with changes in traffic characteristics, infrastructure and operations.

There are many factors which affect railway capacity. Abril, M. et al (2007) classified the parameters of capacity under three aspects, as follows:

- Infrastructure parameters:
  - Block and signalling system
  - Single/double tracks
  - Definition of lines, routes
  - Network effects
  - Track structure and speed limits
  - Length of the subdivision
- Traffic parameters
  - New or existing lines
  - Train mix
  - Regular timetables
  - Traffic peaking factor
  - Priority
- Operating parameters
  - Track interruptions
  - Train stop time
  - Maximum trip time threshold
  - Time window
  - Quality of service, reliability, or robustness

Theoretically, improving any parameter in the list would improve capacity utilisation. However, in practice, efforts are often focused on several areas that the railway industry believes to be most significant. With reference to the track, according to Patch (2004), the capacity of a railway line or a part of a network could be improved by:

- Modifying the timetable or the operating procedure,
- Removing slow speed sections,
- Modifying the signalling arrangement,
- Modifying the track layout.

In the UK, to accommodate demand for capacity whilst ensuring performance, the SRA (2003) provided several options:

- Increase load factors (where crowding is not an issue);
- Lengthen trains;
- Improve train path take up arrangements;
- Change pattern and mix of train services (timetables focussed on achieving higher throughput rather than highly diverse services);
- Reduce timetable 'fragility' (e.g. more robust plans for crew and stock movements);
- Better train regulation (revisit prioritisation rules, class regulation practices and use of passing facilities by passenger services).

These measures have been proven to improve capacity utilisation in the UK rail network (SRA, 2003).

The most common methods used to improve railway capacity are probably timetable and signalling solutions. For Network Rail, improving the use of existing capacity is a central element of its route utilisation strategies (Network Rail, 2006), and the first priority is to address lines with capacity constraints by timetable solutions (Hansen, 2003). In fact, improving timetabling is considered a very effective way of increasing capacity utilisation (UIC, 2004; Pachl, 2004; Hansen, 2003; Hansen, 2004). Network Rail's recent re-timetabling of the Settle and Carlisle line has been reported to have created significant additional capacity for freight traffic (Network Rail, 2006). However, there does not appear to be a straightforward method of optimising a timetable (or even assessing whether a timetable is optimised).

Station capacity is also an area that has attracted much attention. Several sophisticated algorithms and models (Yuan & Hansen, 2007; Carey & Carville, 2003; Carey & Crawford, 2007) have been developed to improve the capacity of stations or networks with busy, complex stations.

As signalling systems define the headway (time interval) between following trains, their improvement can significantly improve the railway capacity.

It is worth noting that within the UK rail industry, railway capacity allocation and charges are also a problem. Reviews and discussions of various methods can be found e.g. in Gibson (2003) and Watson *et al*. (2003).

There are many more components and attributes of railway systems that have an impact on railway capacity, however small. Nonetheless, in specific cases their improvement may have a significant impact e.g. improving passenger handling facilities (station gate, signs, stairs, elevators and escalators) in a big and busy station.

However, it is not straightforward to quantify the impact of improving these components on capacity.

When considering improvement to railway capacity through changes to railway system components or attributes, it is essential to consider the feasibility (both technical and financial) of the change. This is because only if an improvement option is feasible will its impact on capacity be meaningful.

Railway System Components and Attributes	Impact of Improving on Railway Capacity
Platform Length	Improving platform length may not directly increase capacity unless the existing platform is shorter than the requirement. However, platform length should be taken into consideration when examining the feasibility of adding more carriages to trains.
Passenger Handling Facilities	Improving passenger handling facilities (station gate, signs, ticketing, stairs, elevators and escalators) may reduce dwell time and thus increase capacity.
Junction Characteristics	Improving junction characteristics may ease speed limits and thus increase capacity (but only for speeds <55 mph). The signalling techniques used at junctions may also be worthy of further analysis.
Distance between Stations/Junctions	Increasing distance between stations/junctions may reduce headway time, recovery time, buffer time and waiting time thus increase capacity.
Power Supply	Power supply capability will limit capacity. Upgrading will therefore have an impact in situations where the power supply is limited.
Door Characteristics	Improving train door characteristics (number of doors, width or operating technology) may reduce dwell time and thus increase capacity.
Braking System (braking rate)	Improving the braking rate may reduce headway time, thus increasing capacity. This is, however, controlled very strictly.
Safety Rules	Improving safety requirements may increase headway time and thus reduce capacity.
Priority Rules	Changing the priorities of train services changes the order in which trains run and thus affects capacity either positively or negatively.
KPI Targets	Improving the Key Performance Indicator targets (e.g punctuality and reliability) may require increased recovery time and buffer time and thus reduce capacity.
Environment Protection Rules	Rules preventing freight trains from operating during night-time because of noise disturbance will put these trains on day-time timetables and potentially reduce capacity.
Station Stops	Station stops can influence capacity. Homogenising the stopping pattern, as is practised in metro operations tends to optimise the capacity.
Timetabling Techniques	Improving timetabling techniques may reduce headway time and waiting time and thus increase capacity.
Maintenance Strategy	Improving infrastructure maintenance strategy may reduce special delivery time and thus increase capacity.

Table 5: Potential Impact on Railway Capacity of Improving Other Components

3.2 Systems views of railway capacity

In recent years, attention has been drawn to the railway capacity problem on the system scale. By considering railway capacity in systems terms, a more comprehensive picture of the factors which may affect it can be established. London Underground produced a diagram showing the factors affecting Line Capacity, as shown in Figure 9: Drivers Affecting Line Capacity and Possible Technological Solutions - London Underground's Perception.

The diagram clearly displays the interaction of factors, but does not distinguish operational functions from railway components. Moreover, passenger satisfaction and human factors are hardly considered in this diagram.

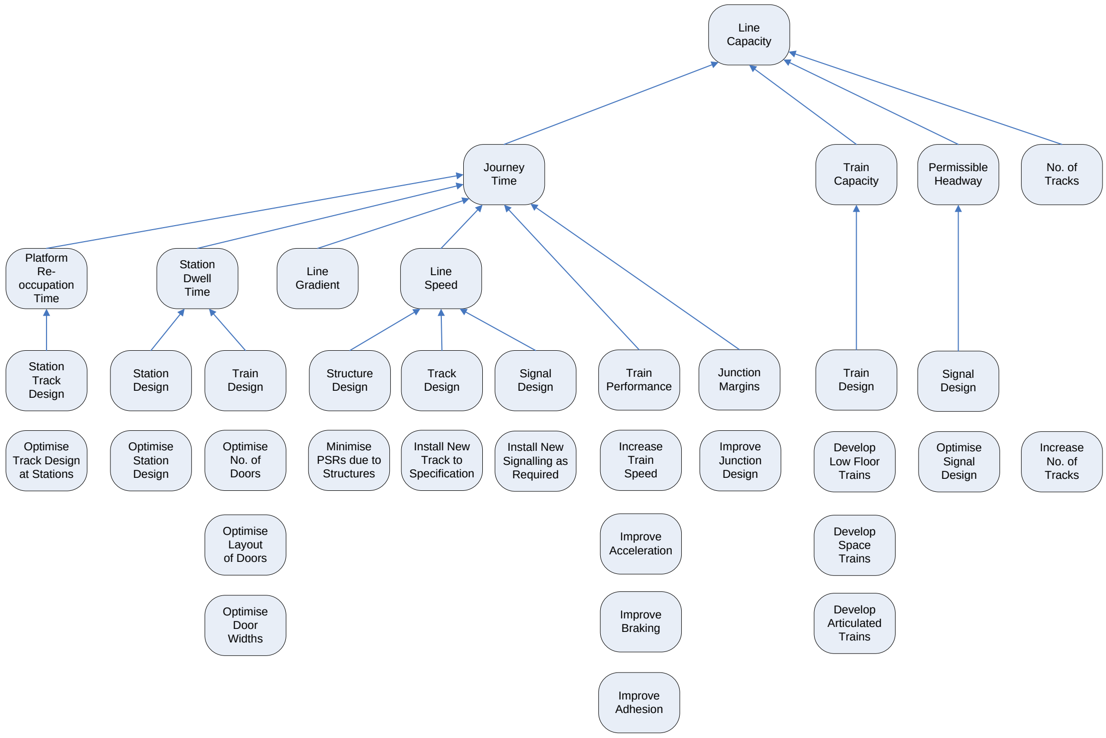


Figure 9: Drivers Affecting Line Capacity and Possible Technological Solutions - London Underground's Perception

Woodland, in his PhD thesis (2004), has suggested a system breakdown of the "Achieved Line Capacity" in the context of signalling control (Figure 10). This diagram is much more informative and logical than that of the London Underground (Figure 9) and clearly distinguishes the capacity functions (rounded corner shapes) from the railway components (rectangle shapes).

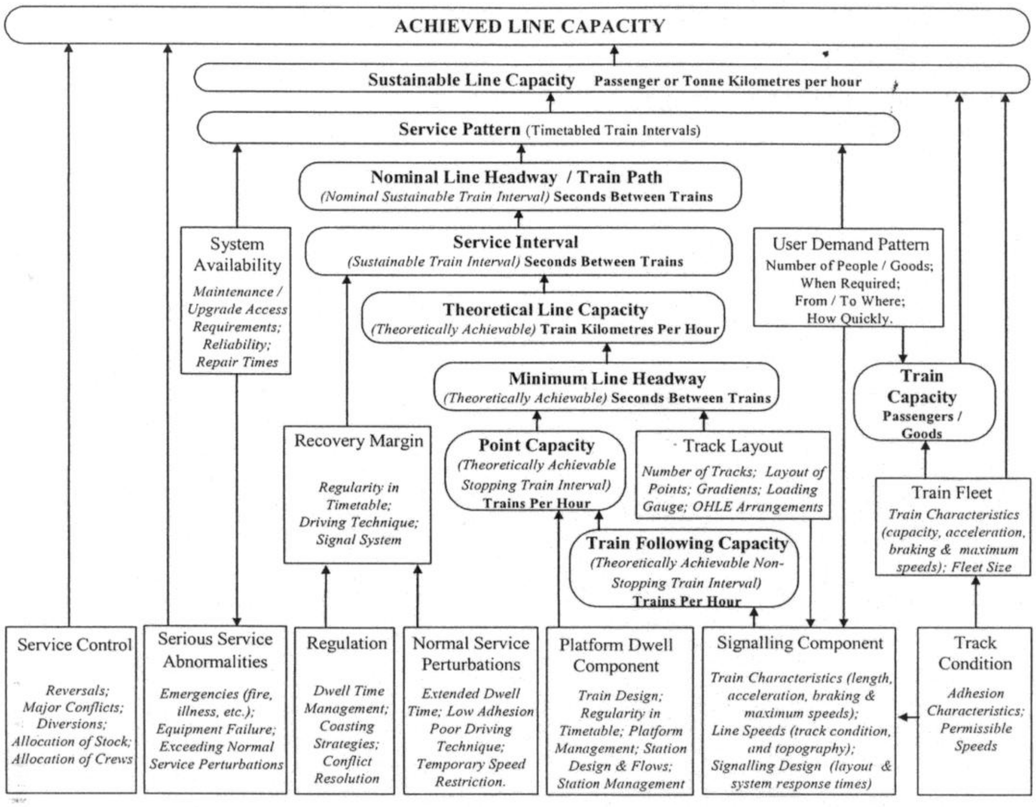


Figure 10: Factors Affecting Achieved Line Capacity (Woodland, D, 2004)

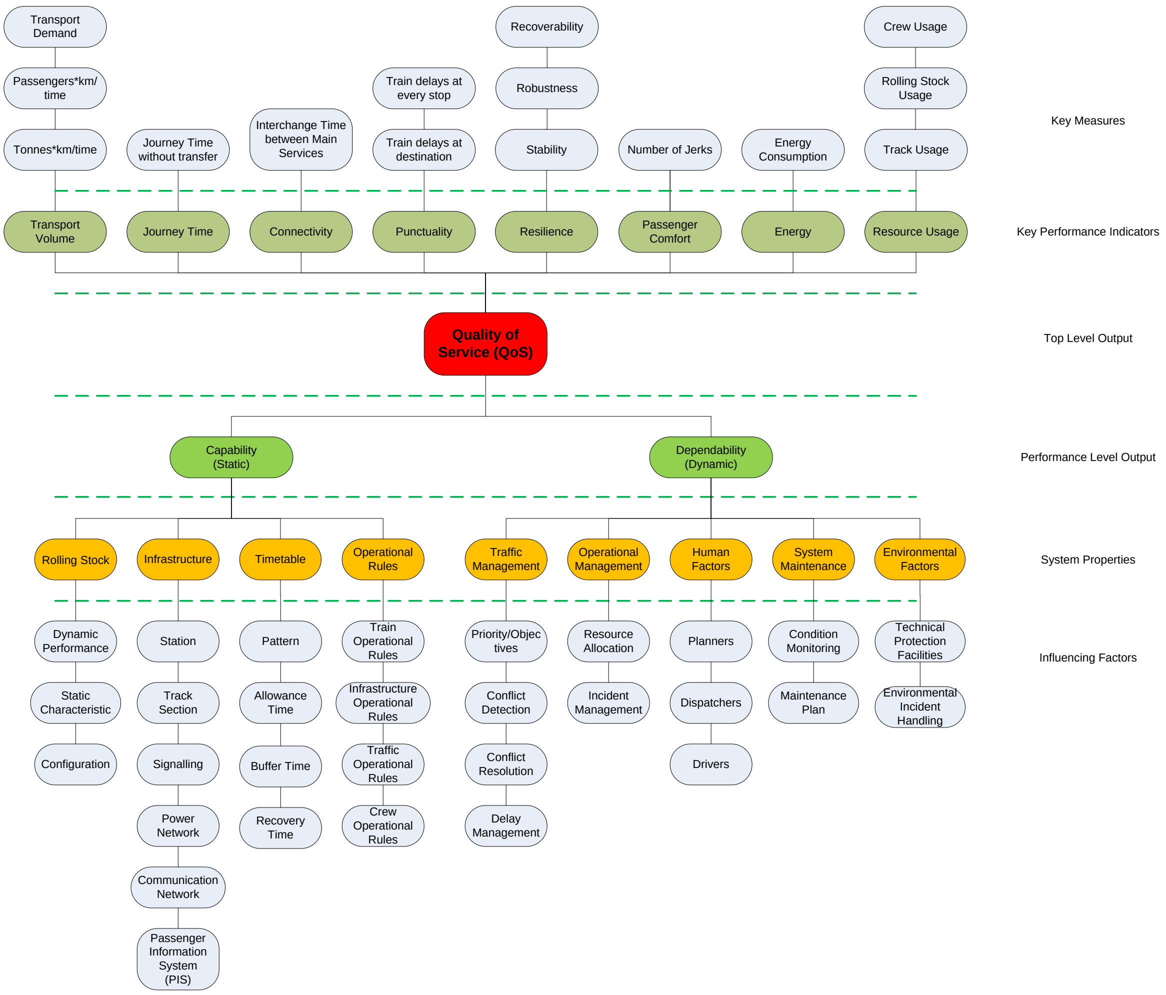


Figure 11 Factors for Quality of Service

3.3 Implemented view of railway system capacity

As shown in the previous sections, existing definitions and measures of capacity are often focused on traffic volume or infrastructure occupation. To cover the requirements of the market, infrastructure planning, timetabling and operations, as emphasised in UIC 406, Quality of Service (Figure 11) is proposed as an improved definition of railway system capacity.

Quality of service is an indication of the comprehensive performance of the railway system. It covers Transport Volume, Journey Time, Connectivity, Punctuality, Resilience, Passenger Comfort, Energy and Resource Usage. The railway systems are expected to be optimal in terms of all the indicators; however, trade-off needs to be made in practice due to the various constraints in real life railway operations.

On the engineering side, the factors affecting Quality of Service can be broken down into Capability and Dependability. Capability covers all the “static” elements which are relatively hard to change, such as Rolling Stocks, Infrastructure, Timetable and Operational Rules. Dependability includes all the dynamic components of the system, such as Traffic Management, Operational Management, Human Factors, System

Maintenance and Environmental Factors. These components can be modified in short term practice.

Capability: Rolling stock

Rolling stock comprises all the vehicles running on the railway network. The main features of rolling stocks that can affect Quality of Service are as follows:

- Dynamic Performance: braking, acceleration, resistance, traction force, etc.
- Static Performance: length, mass, adhesion, maximum speed, etc.
- Configuration: the way rolling stocks are formed is also very important. This may affect the length, mass, traction, etc. and thus affect the running dynamics.

Capability: Infrastructure

Infrastructure is a vital component of the railway system. It has great influence on the train run, energy utilisation and potentially passenger comfort. Infrastructure is mainly made up of the following elements:

- Station: The number, positions and architecture of stations on the network have great impact on the throughput. They may also influence the service pattern and the robustness of the timetable.
- Track section: The length, gradient, adhesion and curvature of track sections will affect the braking, acceleration and maximum speed of trains. Moreover, the number of available track sections is an influencing factor of throughput.
- Signalling: The signalling system determines the headway time and thus the throughput of the network.
- Power network: A good power network can ensure the safety and energy efficiency of the train run.
- Communication network: The communication network transfers the traffic information to and from trains. Faults of the communication network can lead to delays, conflicts or even accidents in the system.
- Passenger Information System (PIS): This system provides information to the passengers, helping them make travel decisions and reduce stress.

Capability: Timetable

A railway timetable is a detailed plan of trains departing and arriving at stations.

- Pattern: the time slots arrangement pattern for all the trains in the nominal timetable, e.g. the mixture patterns for fast trains and slow trains. This would affect the resilience of the nominal timetables.
- Allowance time: the time added into the nominal timetable to compensate the additional train sectional running times, dwell times and other scheduled process times due to the unavoidable variability of physical characteristics, driver behaviours, passengers boarding and alighting variations and other potential influencing factors to train operations in real life conditions.

- Buffer time: the time added into the nominal timetable (between train slots) to reduce or avoid propagation of knock-on delays among running trains due to initial and/or primary train delays.
- Recovery time: the time added into the nominal timetable to be reserved for the trains to be recovered from initial and/or primary delays by using effective train operation strategies.

Capability: Operational rules

Operational Rules are the short-term requirements in practice. The main aspects are:

- Train operational rules: Long term regulations for train operations.
- Infrastructure operational rules: Long term regulations for infrastructure operations.
- Traffic operational rules: Conflict/ Delay management plan, Priority, Train Mix etc.
- Crew operational rules: The allocation plan of crew.

Dependability: Traffic management

Traffic Management controls the movement of rolling stocks in short term practice. The content of traffic management includes:

- Priority/ Objectives: This is the importance level of trains and target of service level.
- Conflict detection: The system should be able to detect conflicts in time.
- Conflict resolution: When a conflict occurs, effective measures should be taken to resolve the conflict.
- Delay management: If there is lateness, there should be plans to reduce the delay or to recover from a major disruption.

Dependability: Operational management

- Resource allocation: Rolling stock, crew and other resource planning.
- Incident management: This deals with faults and break-downs in the operation.

Dependability: Human factors

There are a number of human factors in the system. They introduce uncertainties into the practice.

- Planners: These are the people creating long term and ad-hoc timetables.
- Dispatchers: These people monitor the system running and make decisions when incidents and delay occur.
- Drivers: These are the people driving the trains. Their driving style and behaviour has an influence on the trains' actual journey time.

Dependability: System maintenance

The equipment and facilities are essential foundations of the railway system. The condition of them should be observed and maintained regularly. The practices are:

- Condition Monitoring: It monitors and reports on the state and quality of the railway hardware.
- Maintenance Plan: A regular maintenance plan is also vital in keeping the “health” of the system.

Dependability: Environmental factors

Environmental factors such as wind, rain, snow and lightning are the source of many railway accidents. The measures taken to protect against environmental factors are listed below:

- Technical Protection Facilities: These are the facilities equipped to the vulnerable parts, including wind shields, rain shields, lighting conductors, etc.
- Environmental Incident Handling: Plans are made to deal with emergencies caused by environmental factors.

4 UNDERSTANDING OF THE ALLOWANCES IN RAILWAY OPERATIONS

In railway timetable planning, the minimum sectional running times, minimum dwell times and other scheduled process times (e.g. shunting, reversing, etc.) for certain types of train need to be computed as the basis of the nominal timetable regulation, using nominal values for all the variables involved in the computation (e.g. track length, gradient, curvature, traction and braking characteristics, train length, train weight and weight distribution, rolling resistances, adhesion, diameter of the wheels, voltage in the power line, etc.). Moreover, computation is usually done with a "stressed" driving behaviour (i.e. the train starts immediately with no reaction time, accelerates as hard as possible to reach the maximum allowed speed as early as possible, keeps maximum speed as long as possible, brakes at the latest moment with the service deceleration to come to its halt, and passengers board and alight immediately when the train stops without any conflicts).

Due to the unavoidable variability of physical characteristics in practical railway operations, and also to the variability in driving behaviour, in real life conditions, most trains cannot achieve the minimum sectional running times, dwell times and other scheduled process times. Therefore, one of the fundamental processes in timetabling is to add allowances in the nominal timetable to make it achievable by the majority of trains. To make the nominal timetable more robust to individual train delays, some buffer times need to be added into the timetable to decrease knock-on delays due to one or more train delays. This will make the timetables more stable in practise. The more allowances inserted into nominal timetables, the higher the train punctuality will be, but the less capacity can be achieved commercially because of the longer sectional occupation time of the trains. A commercial trade-off needs to be made to determine the allowances in the nominal timetables.

In this report, a structured vision of allowances is proposed such that the allowances can be classified into three main parts, which are Allowance time, Buffer time and Recovery time.

4.1 Definition of allowance times, buffer times and recovery times

The configuration of allowances in timetabling can be presented as shown in Figure 12. The figure shows a general sketch map for the elements included in the nominal timetables. The dotted line denotes a theoretical train trajectory with minimum running time, process times and dwell time, and the solid lines are the scheduled train trajectories with the addition of allowances in nominal timetables.

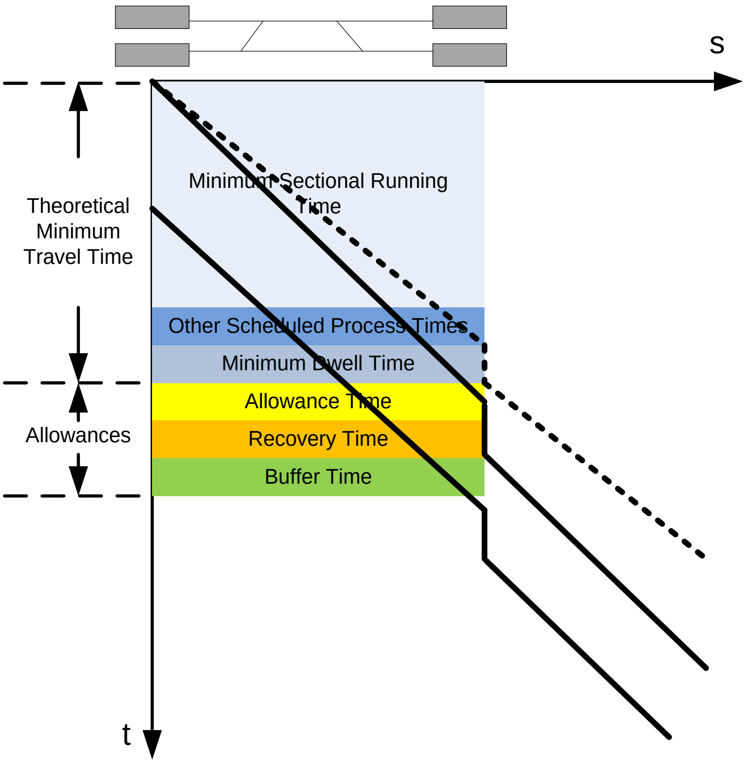


Figure 12: Allowances in Timetabling

The definitions of Allowance time, Buffer time and Recovery time are given as follows:

Allowance time: the time added into the nominal timetable to compensate the additional train sectional running times, dwell times and other scheduled process times due to the unavoidable variability of physical characteristics, driver behaviours, passengers boarding and alighting variations and other potential influencing factors to train operations in real life conditions.

Buffer time: the time added into the nominal timetable (between train slots) to reduce or avoid propagation of knock-on delays among running trains due to initial and/or primary train delays.

Recovery time: the time added into the nominal timetable to be reserved for the trains to be recovered from initial and/or primary delays by using effective train operation strategies.

4.2 Allowance time

Generally the minimum sectional running time, minimum dwell times and other scheduled process times are computed for timetabling in ideal conditions without any uncertain variability. In real life conditions, strictly speaking, no train can achieve the minimum sectional running time, minimum dwell times and other scheduled process times due to the unavoidable variability of physical characteristics and human factors, e.g. the variation of the power network voltage, different driving skills of drivers, reaction time to signals, system response time, inaccuracy of stopping, operation time of traffic dispatchers, passengers boarding and alighting variations, etc. To make the sectional running times, train dwell times and other scheduled process times in the nominal timetable achievable, a number of allowance times need to be added into the nominal timetable to compensate the additional required running times and dwell times due to these perturbations and variations. The addition of an allowance time will make the nominal timetable robust in punctuality withstanding the unavoidable variations.

Generally, the amount of allowance time in the nominal timetable depends on each case. Operational experience is usually applied to determine how much allowance time should be added. In railway timetabling, system simulation is a recommended approach to determine the amount of allowance. With good stochastic models for the physical variations, quantitative results of allowance time can be computed with Monte-Carlo simulation methodology. Statistical analysis of operations data can also be used to determine the amount of allowance time, which is one of the sub-tasks in the ON-TIME project.

4.3 Buffer time

Usually there is no nominal conflict between trains in railway timetabling. In the nominal timetable, if there is no buffer time between following trains, a slight delay to one train will lead to knock on delays to following trains. The knock-on delays could rapidly propagate in railway networks. Generally, certain buffer times are inserted between train slots in the nominal timetable to absorb the initial and/or primary train delays. The more buffer time added, the longer initial and/or primary delays can be absorbed to avoid knock on delays, but less line capacity can be achieved. The addition of buffer time also requires a trade off between capacity and robustness.

The determination of the amount of buffer time to be added requires a comprehensive analysis of the train delay probability distributions. A decision regarding how many delays are expected to be absorbed in the nominal timetable can then be made according to the delay probability distributions, with consideration of the commercial trade-off.

4.4 Recovery time

In addition to Allowance time and Buffer time, this report suggests that Recovery time can also be added into the nominal timetable. During real life train operations, some small time variations can be eliminated with Allowance times, as defined above. However, certain slight delays often happen for various reasons. It is important to recover from the slight delays to the timetable to avoid an accumulation of train delays, which may lead to significant conflicts with other trains. Recovery time is expected to be added into the nominal timetable, which is reserved for trains to recover from initial and/or primary delays by using effective train operation strategies.

One of the common approaches to reserve recovery time is to make the train operational speed under the maximum line speed, e.g. train operational speed is set to be 80% of the line speed restriction. With advanced traffic management and train control systems, it is expected that drivers will be provided with more information on driving strategies. When a delay has occurred, drivers could take actions such as increasing the train speed to recover from the slight delays. This has been simulated and proved to be an effective delay recovery measure with advanced traffic management systems.

Although the addition of allowances would reduce the theoretical railway capacity in terms of tph, it increases the resilience of railway operations, which leads to a capability improvement of a railway system to deliver the level of QoS, as shown in Figure 11. The distribution of Allowance times, Buffer times and Recovery times in railway timetabling is a trade-off between the key performance indicators in the proposed QoS, and depends on the specific requirements of the railway networks.

5 ROOT CAUSES OF CUSTOMER DISSATISFACTION

5.1 Planning (Path request process)

The current process complies with the European standard process. However, RU customers consider the current process to be too long from path order to the timetable change. They ask for changes to be made or new concepts introduced both at short notice and also for the annual timetable. Generally, they have to start the activities 8-11 months before application. A common request is to reduce the "time to market" for passenger transport and, in particular, for freight.

Furthermore, we have to consider that about 25% of scheduled freight trains are partially or totally cancelled. In addition, there is a high number of "ad hoc requests" with respect to path requests for the annual timetable (i.e. according DB Netz data: 850.000 versus 56.322)

In the future, a suggested innovation would be to shorten the negotiation phase for freight and to introduce a multilayer path offer, at different average speeds, for the residual capacity.

It is recommended that a time interval tolerance should be introduced, that can be utilized without consulting the applicant to change the requested departure/arrival time.

In addition, RUs should know in advance the available paths and related costs (a practice which is already followed in Germany).

At an international level there are some issues, which can be easily resolved, if IMs improve their communication and standardised procedures. For example:

- There is no common view from the infrastructure managers on rules for international long or short time applications.
- Priority rules for international traffic have to be defined.
- The planning of work (track possessions) that influences the international traffic is not coordinated among the IMs. Only on RNE corridor 1 (Germany – Denmark – Sweden – Norway/Finland) is this process under development.
- There is no coordination between the IMs on how to handle holidays (i.e. Trafikverket works with "trafikkalender", Bane Danmark with calendar days).
- The possibilities to adapt train paths and train numbers in a running timetable are not harmonised between the IMs.

5.2 Operations

The major problems for operations and "real time" management are related to the communication between the Operational Centre of the IM and the RUs or between the IM Operational centre and Crew management units.

There is a need to define clear rules at European level concerning priority management, owing to different rulings, with different parameters.

In every country performance regimes are already in use.

There are some main points to consider:

- How IMs should have to handle trains which do not respect scheduled paths or running time.
- How to avoid or reduce the knock on effect on other trains.
- To introduce a bonus-malus policy and how to handle this at European level in case of delay propagation of different RU trains.

6 SYSTEM ASPECTS

The project is considered from three viewpoints:

1. High level project view – describes the main functions in timetable planning and train control and relates them to ON-TIME work packages;
2. High level context view – describes how the actors and stakeholders in the timetable planning and train control process interact with each of the work packages;
3. Detailed system view – describes the main functions of the railway that are relevant to the project how those functions interact with one another, and the required resources and constraints.

The results of the detailed system view are shown at a high level using IDEF0 notation. They are also used to identify the principle stakeholders in the ON-TIME project and the principal capability requirements that they have for an improved system.

6.1 High Level Project view

The project is depicted in Figure Figure 13. The key technical work packages, WP3-6 can be seen.

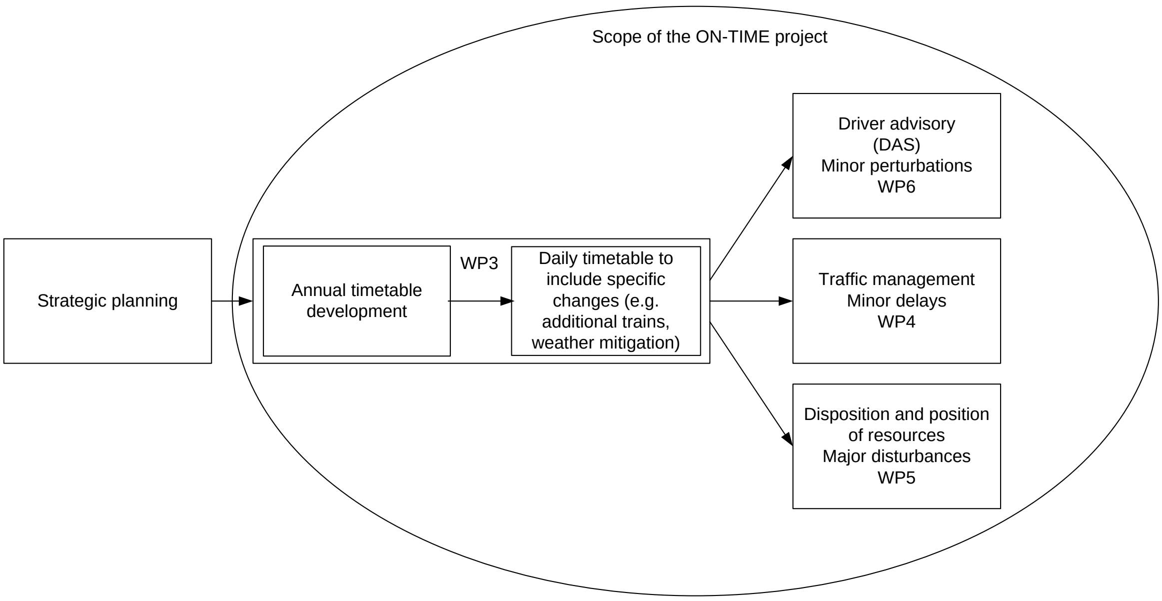


Figure 13

6.2 Context view

At the context level, the railway actors and stakeholders that are the subject of ON-TIME are mapped against a basic Control Loop that puts each Work Package into context.

The overall timetable planning and train control process is shown in the diagram of Figure 14. This was developed in an outline form as part of the consortium's work responding to the Commission's Call. Since the start of the project, it has been further developed to arrive at its current state.

Starting from the left and moving to the right, it shows that demand for rail transport drives development of the timetable by the IM; at the same time development of rolling stock and crew schedules is carried out by the RU, and there is an important interface between the two. Both of these processes form the principal focus for the research of WP3. Moving further to the right, attention turns to managing the train service: service disruption that requires a change to the way that Infrastructure is used (eg diversionary route) is the responsibility of the IM and changes to the use of resources such as crew and rolling stock is the responsibility of the RU. Management of major disruptions that needs this redisposition of assets or resources is the research topic for WP5. Minor service disruption that can be corrected as a result of the Traffic Management system adjusting the regulation of trains is the responsibility of the IM and the research topic for WP4. Moving to the right again, the diagram shows driver advisory systems falling under the control of the RU, and being researched by WP6. In addition, the diagram shows the 'actors' involved in the whole process of timetabling and running a train service and how these entities relate to one another.

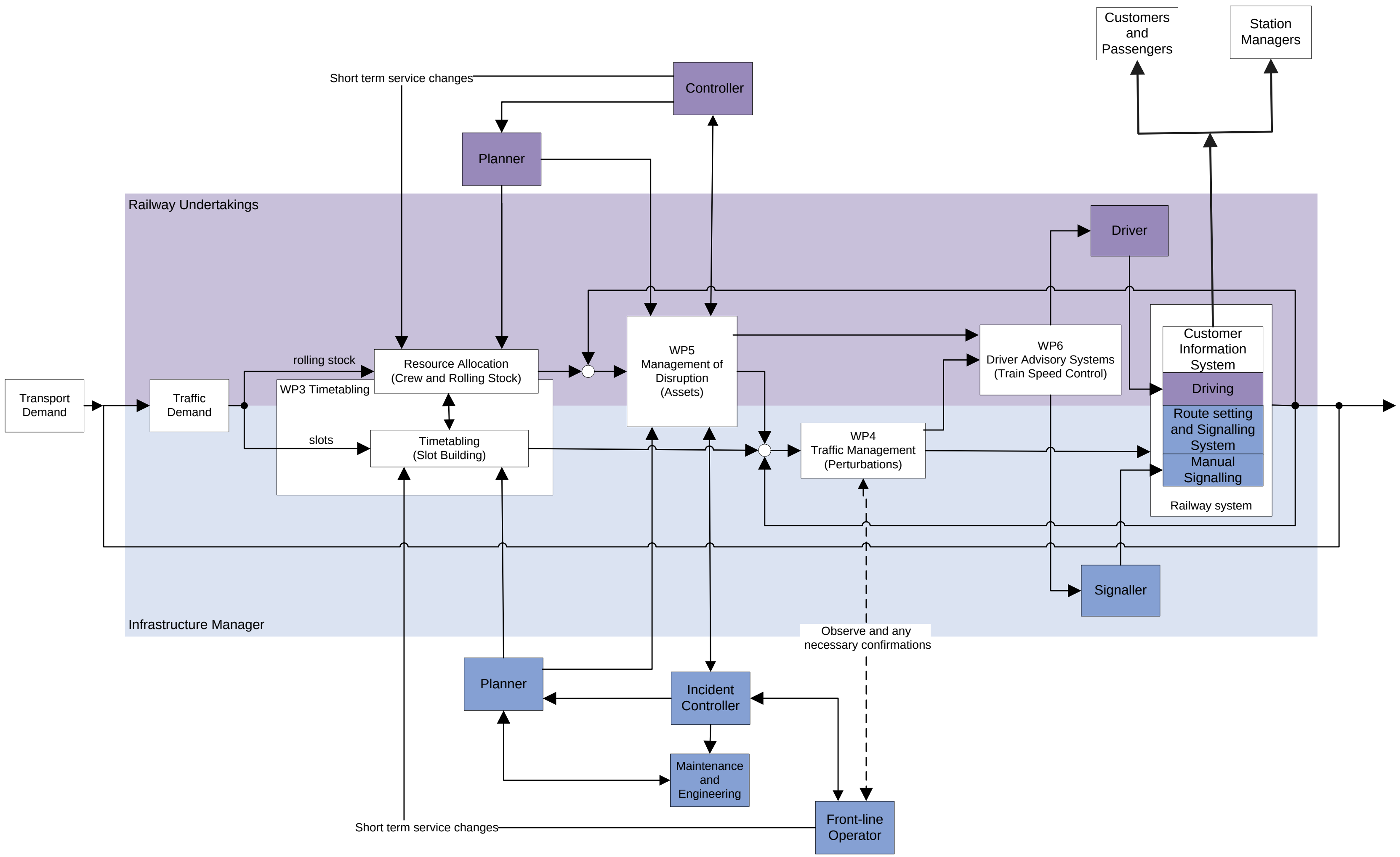


Figure 14 Diagram Showing the Timetable Planning, Train Control and ON-TIME project System Context

6.3 Detailed System view

In order to identify the detailed functions involved in timetable planning and conflict management meetings were held with timetable planners and train controllers working for both infrastructure managers (IM) and railway undertakers (RU). Time constraints meant that the interviews were restricted to British IMs and RUs; however, the findings provide a clear indication of appropriate notations for modelling the function, namely IDEF0. This provides a good foundation to the work of WP2, which is carrying out a wider survey of IMs and RUs around Europe.

6.3.1 System view: Timetable planning: British legislation

The British government decides in a five-yearly cycle what level of service it wants from the railway's infrastructure and how much it is willing to pay for it (H.M. Government, 2005). The government works with Network Rail (the IM) and the Office of Rail Regulation in an iterative process to arrive at a set of requirements for demands such as the capacity of the network and its reliability. The iterations in the process are there to ensure, among other things, that the requirements identified are in line with the level of funding available. The finalised set of requirements is described in the government's High Level Output Statement (HLOS); the current set of requirements, covering the period from 2009 to 2014, were issued as an appendix to the Government's most recent railway White Paper (Department for Transport, 2007).

The infrastructure requirements set out in the HLOS influence timetable development through their impact on network capacity: a dependable railway service can only operate if the appropriate supporting infrastructure is in place. However, specification of the actual train service is not covered in the HLOS process: instead it is part of passenger franchising. The passenger franchising process selects the TOCs that will actually operate the train service. The TOCs bid for franchises based on minimum service requirements set out by the government in their invitation to tender; the bidders are free to include a higher level of service in their tenders if they wish. As part of the bidding process, TOCs also liaise with Network Rail to confirm sufficient capacity is available to support the planned service (Network Rail, 2011). When a TOC wins a franchise, it is contractually committed to delivering the results as set out in its bid.

With the infrastructure and franchise agreements in place, there still remains the task of preparing the necessary timetables, as described below.

6.3.2 System view: Timetable planning: British process

Network Rail has two main timetable planning processes. The first is the Long Term Planning (LTP) process, which concentrates on producing two timetables per year: the principal timetable, which starts in December each year (commonly known as the winter timetable), and the subsidiary timetable, which starts in May each year (commonly known as the summer timetable). Preparation of these timetables is completed 26 weeks before the respective dates of introduction; they are made public 12 weeks before introduction as part of the Informed Traveller scheme, which aims to ensure that passengers can buy tickets and book seats confident in the knowledge that their service will operate. The timetables are published in the form of working timetables (WTT - for railway use) and the National railway timetable (NRT), which the public see and which is used in on-line timetable applications.

The Short Term Planning (STP) process covers things like: applications to run trains that missed the LTP deadlines, and Network Rail applications for engineering access. A new cycle of STP is started every week, for implementation 18 weeks in the future; however, changes generated in the STP are still made public 12 weeks before going live.

The basic steps involved in the timetable development process are shown in the Gantt chart in Figure 15.

The next day's train operation is input to TOPS (Total Operations Processing System) on the evening before running is due to commence. TOPS is a database of trains running that day, but it is not used to provide input to customer information systems (CIS). The TRUST system deals with train timings, both planned and actual, and consequently train lateness. Both of these systems are managed for Network Rail by ATOS, an information services technology company.

The Integrated Timetable Planning System (ITPS) is used for both LTP and STP. For changes that miss both the LTP and STP deadlines, ITPS can still be used until 17:00 on the day before the service is due to run. For very short term planning (changes after 17:00 normally relating to freight trains), changes are made directly into TOPS and ITPS is not used.

Both LTP and STP use a bid and offer process: TOCs 'bid' for track access and Network Rail make 'offers' in response. TOCs use the Voyager Plan system (managed by ATOC) to make their bids. There is an electronic data exchange between Voyager Plan and ITPS. PEX and PIF files are used, which causes some problems: files with the PIF extension are already used by Microsoft's operating system, so Voyager Plan has to rename its PIF files.

Network Rail validates the bids it receives from Voyager Plan: for example, checks are carried out to ensure that services are not duplicated, and that the rules of the plan have been complied with.

The rules of the plan contain all of the margins used to translate the technical headway into the planning headway. The margins are specific to routes, junctions etc, and are not built into ITPS. What ITPS does contain are the mileages, gradients, line speeds and traction characteristics. Signal positions can also be added if required.

ITPS will flag up timetable conflicts, but not margin erosion: for example, ITPS will warn planners that two trains are trying to occupy the same track circuit berth at the same time, but will not warn that a train is running on yellow rather than green aspects (which is generally a contravention of the plan rules, except in the south east of England, where traffic densities are such that running on yellow is an accepted fact of life).

Planning of international trains is done according to the process agreed by Rail Net Europe and uses ITPS.

ITPS employs sectional running times. In the past these were taken from tables and were quite 'coarse' in terms of the limited number of factors used in their calculation. Things have improved since then; however, unlike other major European infrastructure managers, Network Rail cannot calculate scenario-specific running times, because the run times have been previously agreed with the TOCs. Any changes have to go through a change control process.

ITPS still relies significantly on the experience and skill of the planner. An example is the interface between ITPS and the engineering access database: on a 4-track railway, ITPS will see closure of one track for engineering as closure of all four. It is down to the planner to spot this and come up with a plan for how the other three tracks might be best used. Work is underway to correct this problem.

Operation of timetables is simulated using RailSys. RailSys can be used to explore how a timetable would behave in a situation where train services are delayed. Rather than simulating the network-impact of one late train, a number of simulations are carried out, each time using a different figure for lateness applied to all trains.

To produce an effective timetable, it helps if the planner has a good knowledge of how the signaller will operate the service. Without such knowledge, the planner can make incorrect assumptions about how, for example, the signaller will route trains through a station or complex junction. This can have adverse effects on the robust operation of the timetable. However, despite this being such an important issue, there is no systematic process for ensuring that signallers and planners communicate effectively.

There is an on-going programme of work to improve both the way in which ITPS is used and the quality of its output. This includes efforts to increase the speed and accuracy with which data can be entered. More work is required to improve the objectivity of the bid/offer process. Part D of the Network Code sets out the generality of what planners should do where bid/offer conflicts exist, but does not provide them with a systematic process for resolving them.

Planners tend not to get involved with development of the contingency plans used by control centres; however; a new process was introduced in 2011, which allowed pre-bid contingency timetables from Operators to be processed and published the day before the revised service was due to operate. Such a process is designed to handle adverse weather conditions, such as heavy snow, when pre-planned strategies are implemented to protect train services on main routes.

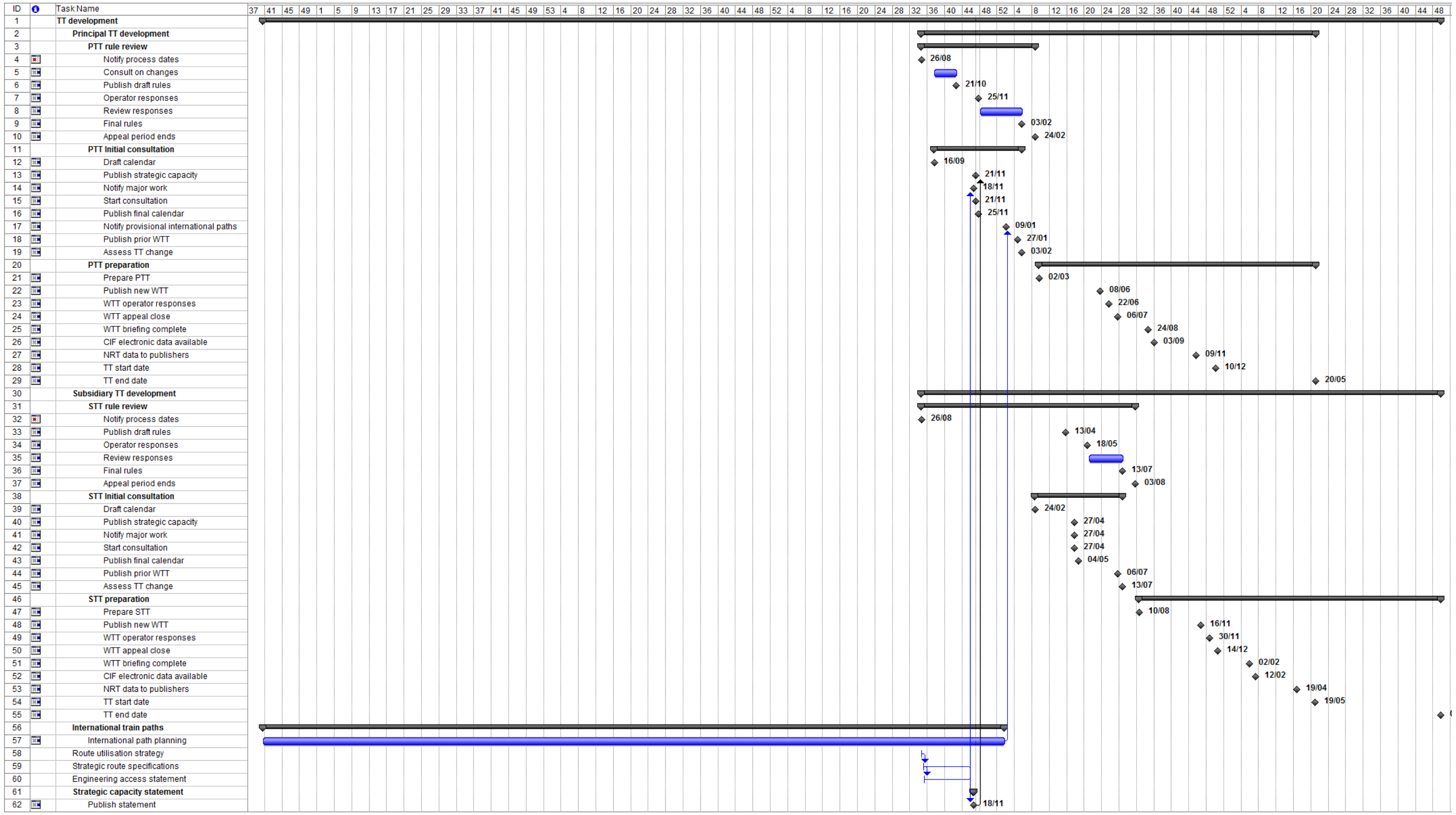


Figure 15 Gantt Chart Showing the Principal Steps in the LTP Timetable Planning Process

6.3.3 System view: Train service disruption management: British legislation and standards

Processes for dealing with disrupted train services are described in a hierarchy of documents. From top to bottom these are the **Network Code** (Network Rail, 2011), the **Railway Operational Code** (Network Rail), and finally the **National Control Instructions** standard (Network Rail, 2011).

Network Code

The Network Code is a set of rules which is incorporated by reference into, and therefore forms part of, each bilateral access contract between Network Rail and a holder of access rights (normally a train operating company (TOC) or a freight operating company (FOC)).

The purpose of the Network Code is:-

- *To regulate change, including change to the working timetable, change to railway vehicles specified in an access contract, change to the network, change to computer systems and change to the Network Code itself;*
- *To establish procedures relating to environmental damage;*
- *To establish a performance monitoring system, and;*
- *To establish procedures for implementation in the event of operational disruption.*

The Network Code is comprised of 12 parts. Part H sets out the requirement for Network Rail, in consultation with the industry, to establish a Railway Operational Code (ROC).

Railway Operational Code (ROC)

The objective of the ROC is to sustain and, where necessary, restore as quickly as possible the operation of the Working Timetable in a manner consistent with the Office of Rail Regulation's (ORR) ROC criteria , having regard to:

- *The needs of passengers and freight customers;*
- *The interests of safety and security, and;*
- *The efficient and economical operation of the network and of trains operating on it.*

There are ROC sections dealing with:

- Disruptive events;
- Train regulation policies;
- Emergency timetables in the event of extended disruption;
- Arrangements for clearance of track blockages and assistance for failed trains;
- Preparation for and response to seasonal disruptions, and;
- Control arrangements.

The requirements of the ROC have been incorporated into Network Rail's standard covering National Control Instructions.

National Control Instructions

This Network Rail standard covers a wide range of topics relevant to controllers of the network. Of particular interest to ON-TIME is section 2.4, which covers control actions and procedures relating to disrupted train services. It requires Network Rail controllers, on a 'real time' basis as operators of the Network to:

- *Direct and manage the movements of trains on the Network thereby sustaining the operation of the Network, and;*
- *Determine the capacity of the Network and direct and manage the movements of trains on the Network in the event of degraded operations, subject to the availability and provision of Train Operators' operational resources.*

Figure 16 sketches out a process and timeline for incident management:

Service Recovery Process Chart

(For guidance only)

INCIDENT OCCURS

Incident Management

0 mins

10 mins — ICC or Route Control to Codify Incident

Code 1 activates SR2009 process

- TRC to advise Operators of Conference call details
- Operators to assess the situation and start to look at service alterations.

30 mins — "Fact Finding" Conference Call

All operators affected and adjacent Route Controls to attend

Establish section of route affected, provisional service alterations, identification of trapped trains, Contingency plan and agreement of SRCT.

45-60 mins — "Network Rail Internal" Conference Call

Discuss issues from site and establish estimates

Operators to implement agreed contingency plans and service alterations, ensuring customer flows are maintained where possible.

Inter-TOC working (bus plans, customer flows)

90 mins — "TOC / NR" Conference Call

All operators affected and adjacent Route Controls to attend.

Establish service plan alterations, update of estimates, progress on trapped trains and service recovery plans.

Conference calls to take place every 60 – 90 minutes

(Continued)

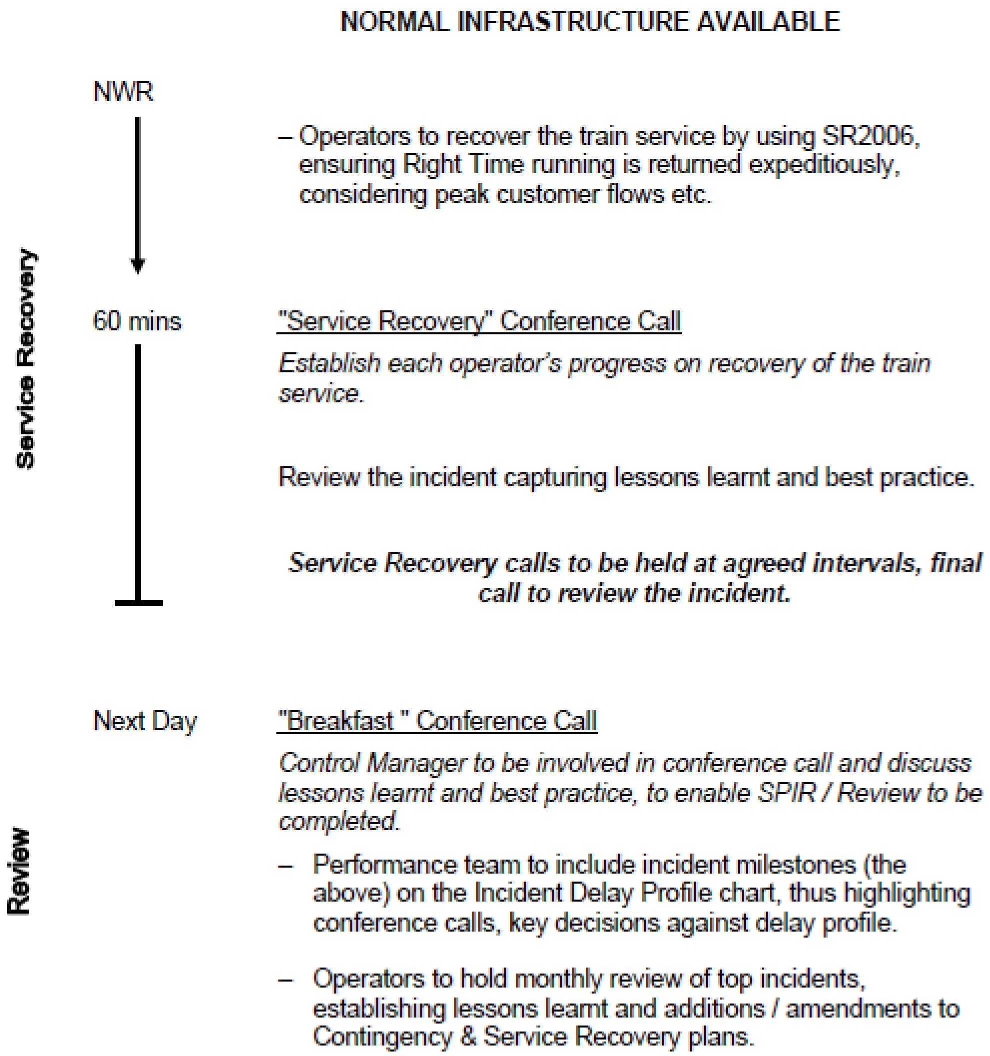


Figure 16 A Flow Chart Showing the Process for Incident Management and Train Service Recovery

6.3.4 System view: Train service disruption management: British control processes

In Great Britain train control can be broken down into two distinct categories: that carried out by the infrastructure manager, Network Rail and that carried out by the Train Operating Companies (TOC) and the Freight Operating Companies (FOC).

6.3.5 System view: Network Rail control

The train control organisational structure is based on the principal routes. Nationally there are ten control areas of varying sizes and traffic densities. One of the largest and most heavily trafficked areas is the West Coast Main Line. As the name suggests, this is the principal route running up the west side of Britain, from London in the south to Glasgow in the north. For train control purposes the route is divided into two control sub-areas: London and North Western (LNW) covering from London to the Scottish border, and Scotland, covering the remainder. The LNW control area is further divided into two parts: a southern part controlled from Birmingham and a northern part controlled from Manchester. The Birmingham control centre covers the West Coast Main Line from its London terminus at Euston to just south of Crewe; the Chilterns route from its London terminus at Marylebone to Birmingham, and; the West Midlands conurbation centred on Birmingham and extending to Redditch and Worcester in the south and west, Shrewsbury in the north-west and Tamworth in the east.

In each control centre there are a number of distinct roles: **Duty Controller**, **Incident Manager**, **Train Running Controller**, and **Information Manager**. **The Duty Controller** is the person with overall responsibility for running the control room. Their responsibilities include dealing, in the first instance, with calls that come in from train drivers. Normally when a train encounters a problem, the driver will contact the signaller, who will then contact control if necessary. In emergency situations the driver can use the emergency button (via NRN and increasingly, GSM-R communication links) to broadcast simultaneously to the signaller and the duty controller.

In the Birmingham control centre train incidents are handled by four **incident managers**. The incident managers deal with incidents such as failed trains, failed points, etc. They are responsible for dealing with the incident itself (arranging for the points to be repaired, arranging for the failed train to be rescued, etc.). They are not responsible for recovery of the train service after the incident. Data relating to the incident is logged in a system called the Control Centre Incident Log (CCIL). Additionally, actions taken relating to infrastructure failure are logged in the Fault Management System (FMS).

At Birmingham there are 2 **train running controllers** who deal with incident-related train service disruption. Their job is to try to recover the timetable as quickly as possible. They are the people responsible for implementing contingency arrangements previously agreed with the Train Operating Companies and Freight Operating Companies. They are also responsible for making short-notice changes to the timetable using the VSTP system (an updated version of VSTP is to be introduced, which checks proposed changes for conflicts). When it comes to train service recovery there are some principles (fairness between operators' trains); however there are no hard and fast rules, nor any expert tools to help. Rules-of-thumb and experience are important, together with an appreciation that the railway is a service industry and that the quality of service provided to customers is important. The train running controllers liaise regularly with the TOC controllers. In some cases, decisions to alter the train service come from the TOC controller: for example, the TOC controller may decide that a late train should miss out some station stops in order to get back on time. The decision will be taken bearing in mind the time of day, the frequency of service, the number of people on the train, and the number of people likely to be waiting at the stations where the train should have stopped.

The contingency plans used by the train running controllers are incident and time specific: for example, one might cover closure of 2 lines out of Euston on Friday evening at peak holiday time. The plans show which services will be removed from the timetable, and will include arrangements for train diversions and provision of bus replacement services if necessary. The signal box and station managers/staff will be made aware of which trains are running and which are not; they then have responsibility for platforming. Taking Birmingham New Street as an example, under normal working conditions the signal box platforms trains according to the 'station working' booklet, produced as part of the timetable development process. However, when contingency plans are in place, the panel works with the station controller and the signal box to agree which train will go to which platform.

A great deal of effort goes in to making sure that Network Rail and the TOCs provide customers with consistent delay information; there have been embarrassing occasions where this has not happened and customer information systems (CIS) have shown contradictory information. The control room has an **information manager** who organises provision of information both to customers and within Network Rail. It is this person who decides, in conjunction with the delay attribution team, how the incident will be described: for example, train delayed due a preceding late-running train. Provision of information is handled through the Passenger Information During Disruption (PIDD) system. A set of information templates is currently being produced for use with this. TOC controllers are responsible for inputting incident data to their Customer Information Systems (CIS) and making their staff aware.

The control room has a number of systems in place to aid controllers; one of these is the TRUST system. This gathers train delay/early running information. Delay/early running is measured at the timing points shown in the working timetable (WTT), and is the difference between the time booked in the WTT and the time a train actually passes a timing point. Timing points relate to specific track circuit 'berths' in the signalling system; a timing point is generally deemed to have been passed at the moment a train occupies that berth (as indicated by the train describer (TDM) in the signal box). One exception to this is at stations, where the TDM may show the platform to be occupied before the train has come to a stand. In those circumstances, the system is programmed to add an allowance to give a better approximation of the time the train came to a stand at the station.

Another system is the Control Centre of the Future (CCF). This displays track diagrams, signal sections and aspects and shows the location of trains in real time (basically provides signal box information to controllers). Train movements are depicted by boxes containing the train head code, stepping from signal to signal. The boxes are colour-coded to indicate the extent to which the train is either early or late: green means on time, yellow means up to 5 minutes late, orange is 5 to 10 minutes late, red is 10 to 20 minutes late and scarlet means over 20 minutes late.

A big concern for controllers is how quickly the timetabled service can become seriously disrupted following an incident: for example, a problem at Euston in the morning peak can very quickly result in large numbers of trains stacked up on the approach. Controllers have to look well beyond the immediate incident area when deciding how to manage the situation. The ability to know where train crew are at any given time is an important factor in service recovery. There are also unknown unknowns: for example, if a Manchester – London train is delayed due to an incident at Stafford, it may make sense to turn the train back to Manchester; however, if the driver is due to book-off at Euston, he may refuse to turn back.

Control does not carry out remote condition monitoring; it is done elsewhere. However, control may be advised that a potential problem has been spotted and that fault teams have been sent to investigate. Significant incidents are subject to review, to see whether any lessons can be learned. This is the Significant Performance Incident Review (SPIR – pronounced 'spire').

6.3.5.1 Train operating companies

One of the TOCs located with Network Rail in the Birmingham Control is London Midland (LM). The following is a description of their control arrangements, which are assumed to be similar to those of other TOCs. London Midland staffing arrangements are similar to those of Network Rail in that they have a duty manager and information manager on the team. At any one time, LM has three train running managers working in control: one covers the lines out of Snow Hill, one covers the West Midlands and one covers the west coast mainline. In addition, they have a fleet manager and crew manager.

London Midland has developed its own Incident Management Checklist, designed to remind controllers about the things they may need to do during an incident. This covers requirements like: information controllers to send out holding/core messages during disruption, and to update every 20 minutes; duty controllers to email conductors with specific information, and; controllers to contact sister companies if a major incident occurs to assist at our locations. London Midland recently installed the Passenger Delay During Disruption (PIDD) system.

London Midland has its own local contingency plans, as well as the route plans managed by Network Rail. London Midland is responsible for updating the Customer Information System (CIS) at the stations it manages with details of incidents. Where other TOCs share the station, those TOCs input their own information direct to the CIS. The base information for the CIS seems to be driven by Network Rail's Total Operations Processing System (TOPS), linked to the signalling system. In terms of ensuring that a consistent message appears on the screens and other media, Network Rail Control takes the lead in deciding the underlying cause of an incident. It is necessary to state the underlying cause for all delays of over 5 minutes.

There is a national system called TYRELL, which is used to disseminate templated messages regarding incidents. Dissemination can be to email accounts, Blackberry, the media, etc. Nowadays, the information goes to a central server and users filter off what they need.

London Midland has a service level grid. In the grid, green denotes that trains are running normally. Yellow denotes minor disruption, which is defined as 3 or more cancellations or delays over 20 minutes, with disruption expected to last not more than 2 hours. Red denotes the highest level of disruption, defined relative to specific routes: for example, on the Euston lines, 5 or more trains either cancelled or running over 30 minutes late, with the disruption expected to last more than 2 hours. In these situations, buses may be called on to substitute for train services, and on-call/management direction may be required. Collectively, this situation is known as Customer Service Level 2 (CSL2).

It is difficult to monitor the whereabouts of train crew at all times. Ideally they would be fitted with GPS, but staff and unions are not keen. It is one of the tasks of the duty train crew managers to monitor train crew position as best they can. London Midland also use an Excel spreadsheet called the Unit Mark-up Simplifier. This links rolling stock movements to train crew and helps controllers to assess the potential impact during disruption of re-assigning crew to other trains. The spreadsheet is not very advanced, and it stills leaves a lot to the skills of the controller, which are assessed every 6 months. Therefore, effort is made to stick to the rostered crew arrangements as much as possible.

Controller contact with drivers can be difficult, because of the view that they should not be disturbed when they are driving. Drivers are not given mobile phones. If they want to contact control they can do it through in-cab radio (NRN or GSM-R) or via the train manager.

LM is responsible for micro-changes to the train service, designed to improve overall service: for example, where a Cross-City line train to Longbridge is late at New Street, LM may decide to run it non-stop to Longbridge. This decision is made taking account of the time of day, level of demand, etc.

Delays can build up very quickly: for example, a 1 hour delay can affect 12 trains, 24 train crew and 24 rolling stock sets.

6.3.6 System view: Formal notation for process descriptions

The descriptions provided above of train planning and train control processes are adequate in terms of giving an overview of the inputs, outputs, control mechanisms (such as rules of the plan) and resources involved. However, WPs 3, 4, 5 and 6 require a more concise description of the current processes in order to properly focus their research. Therefore, a formal method is required that will allow WP2 to describe the current processes more accurately and at varying levels of detail.

Preliminary investigations by WP1 suggest that the IDEF0 notation is a suitable candidate. The IDEF0 notation was developed during the 1970s, as part of the U.S. Air Force Program for Integrated Computer Aided Manufacturing (ICAM). This sought to 'increase manufacturing productivity through systematic application of computer technology. The ICAM program identified the need for better analysis and communication techniques, for people involved in improving manufacturing productivity (National Institute of Standards and Technology 1993). IDEF0 is used to produce a "function model", which provides a structured representation of the functions, activities or processes within the modelled system.

The highest level of IDEF0 diagram is termed the A-0 diagram; the A-0 diagram for the railway as a whole is shown below in Figure 17.

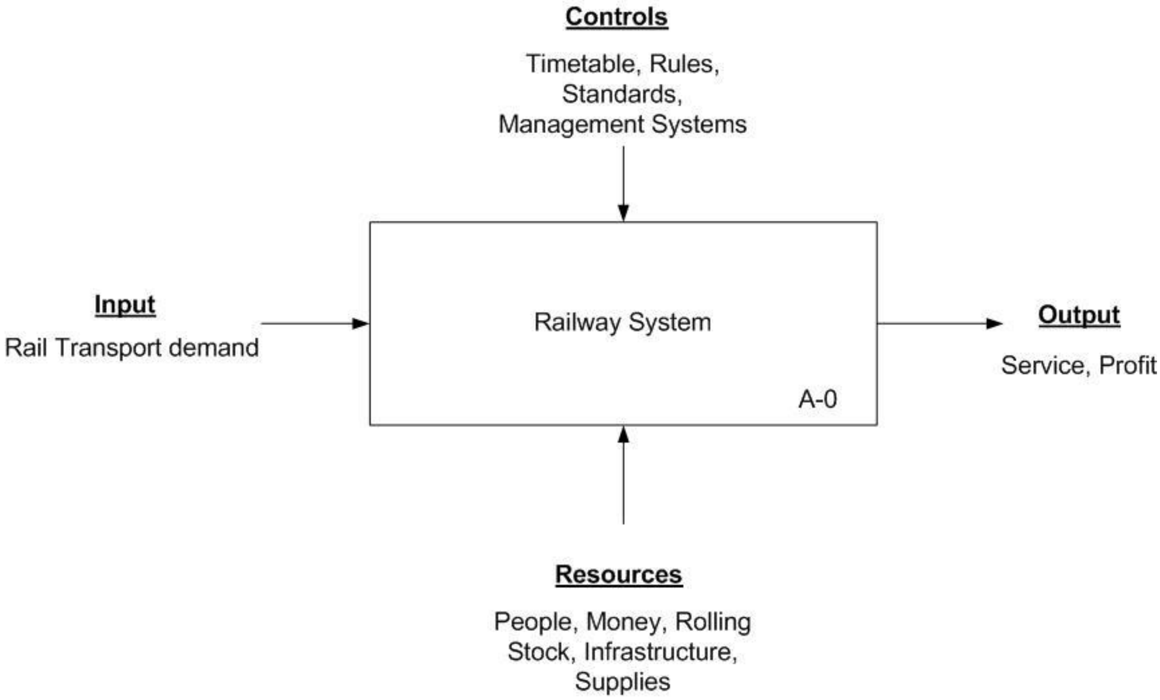


Figure 17 Diagram showing the IDEF0 level A-0 system description

The railway system 'function' is shown in the central box, with system inputs to the left, outputs to the right, controls such as timetables coming down from the top, and resources such as labour and money coming up from below. IDEF0 notation provides a way of decomposing functions to greater levels of detail. An example of this is in Figure 18, which shows the railway system at IDEF0 level A0. The 'railway system' function from the A-0 diagram has been decomposed to provide the next level of detail. Inspection of the diagram suggests that the 'Plan Operations' and 'Manage services' functions will be of particular interest to the ON-TIME project. The IDEF0 approach offers a method for decomposition of those functions to the levels of detail required by WPs 3, 4, 5, and 6.

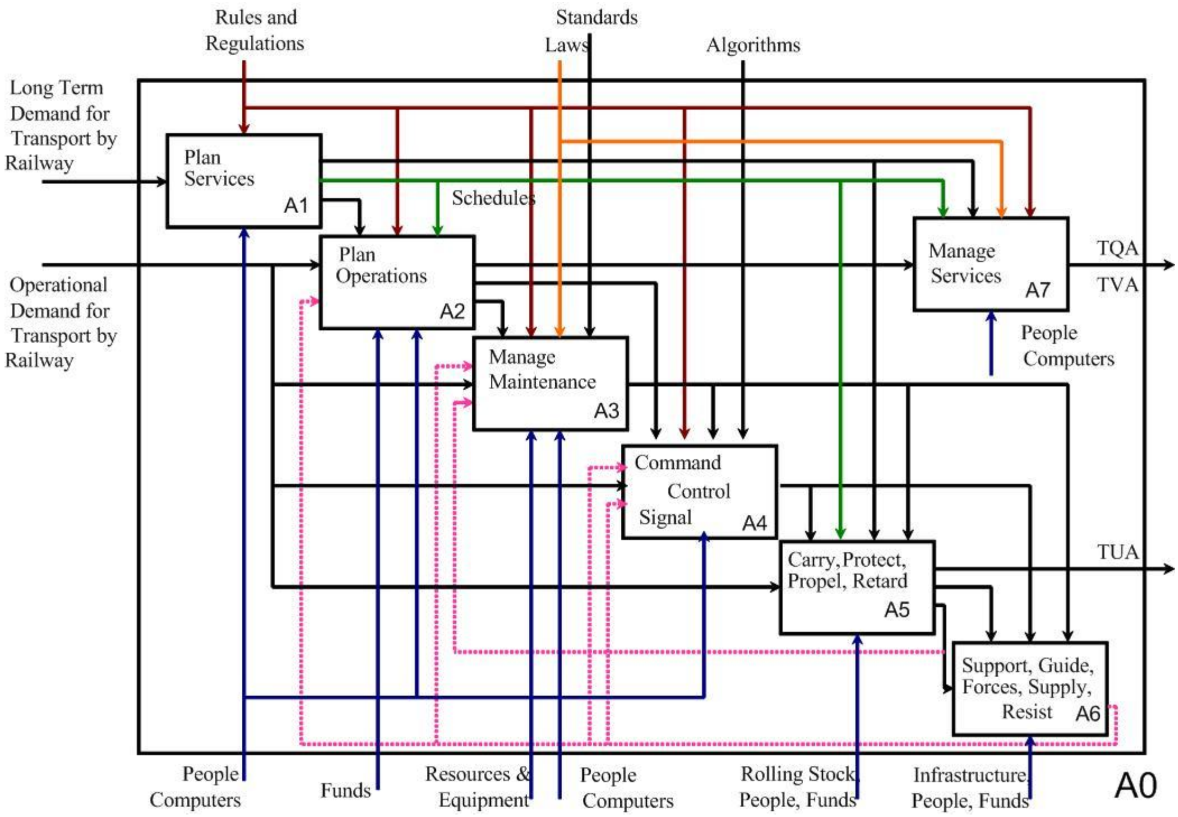


Figure 18 Diagram showing the railway IDEF0 level A0 system description

6.4 Stakeholders

An analysis of the interviews described above identified the following stakeholders:

<u>Timetable Development</u>
Department for Transport (government)
Network Rail infrastructure investment (infrastructure manager - IM)
Network Rail infrastructure maintenance (IM)
Train operating companies (railway undertaking - RU)
Network Rail long term planners (IM)
Network Rail short term planners (IM)
Network Rail signallers (IM)
The Office of Rail Regulation (independent regulator)
ATOC (Association of Train Operating Companies - umbrella organisation for RUs)

<u>Train Service Disruption Management</u>
Passengers
Freight shippers
Network Rail Duty Controller (IM)
Network Rail Incident Manager (IM)
Network Rail Train Running Manager (IM)
Network Rail Information Manager (IM)
Network Rail fault correction teams (IM)

Network Rail signallers (IM)
TOC Duty Manager (RU)
TOC Train Running Manager (RU)
TOC Information Manager (RU)
TOC Crew Manager (RU)
TOC Fleet Manager (RU)
TOC train drivers (RU)
TOC train managers (RU)

6.5 High-level capability requirements

The current timetable planning and train control processes described above give an indication of where improvements are required. The areas for improvement have been written as capability requirements, which describe the new functionality the system should be capable of delivering. Each capability requirement is linked to the appropriate innovation topic as described in the ON-TIME proposal. The innovation topics are:

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

The capability requirements and innovation topics are listed below:

6.5.1.1 Network Rail (IM) Timetable Development Strategy Requirements

1. Timetable sub-systems shall be capable of transferring data between one another (Innovation 2);
2. The system shall be capable of objective allocation of capacity in accordance with the relevant standards (Innovation 2);
3. The system shall be capable of validating timetable requirements in accordance with the relevant standards (Innovation 2);
4. The system shall be capable of verifying timetable design (Innovation 2), and;
5. The system shall be capable of identifying timetable conflicts (Innovation 2).

6.5.1.2 Network Rail (IM) Network Control Requirements

1. The system shall be capable of optimising train recovery plans in accordance with the relevant standards (Innovation 4);
2. The system shall be capable of providing early warning of incipient infrastructure failures (Innovation 4);

3. The system shall be capable of optimising platforming of trains during perturbed operation (Innovation 3);
4. The system shall be capable of optimising design of train service contingency plans in accordance with the relevant standards (Innovation 4);
5. The system shall be capable of integrating all communications relating to train service disruption (Innovations 5 and 6);
6. The system shall be capable of predicting the network impact of local service disruption (Innovation 4);
7. The system shall be capable of supporting integration of NR and TOC controller actions (Innovations 1, 5 and 6);
8. The system shall be capable of providing early warning of resource constraints (Innovation 4);
9. The system shall be capable of supporting integration of NR controller and station staff actions (Innovations 1, 4, 5 and 6);
10. The system shall be capable of learning from previous disruption (Innovation 3);
11. The system shall be capable of supporting real-time decision-making (Innovation 4), and;
12. The system shall be capable of supporting engineering access (Innovation 4).

6.5.1.3 Train Operating Company (RU) Control Requirements

1. The system shall be capable of integrating rolling stock and train crew rostering during service disruption (Innovation 4);
2. The system shall be capable of providing advanced warning of delays elsewhere on the network likely to impact on the local service (Innovation 4);
3. The system shall be capable of providing advanced warning of emerging train diagram problems (Innovation 4);
4. The system shall be capable of monitoring the location of rolling stock and train crew relevant to service operation (Innovation 3);
5. The system shall be capable of monitoring the operational status of train crew and rolling stock (Innovation 3);
6. The system shall be capable of communicating safely with drivers while they are on-duty (Innovations 3 and 5);
7. The system shall be capable of optimised rescue of failed trains (Innovation 4);
8. The system shall be capable of optimised recovery of train service (Innovation 4), and;
9. The system shall be capable of advanced warning of train diagram/crew roster problems (Innovation 4).

6.5.1.4 Network Rail (IM) Operations Planner

1. The system shall be capable of checking ‘on-the-day’ timetable changes for conflicts (Innovation 2);
2. The system shall be capable of checking ‘on-the-day’ timetable changes for compliance against relevant standards (Innovation 2);
3. The system shall be capable of generating probability-based values for timetable margins (Innovation 2);

4. The system shall be capable of automated inclusion of the 'rules-of-the-plan' into timetable development (Innovations 1 and 2);
5. The system shall be capable of identifying 'margin erosion' (Innovation 2);
6. The system shall be capable of generating ad-hoc, scenario-specific point-to-point running times (Innovation 2);
7. The system shall be capable of providing accurate information on planned engineering access (Innovations 1 and 2);
8. The system shall be capable of integrating the different operating assumptions of planners, controllers and signallers (Innovations 1 and 2), and;
9. The system shall be capable of providing a systematic approach for dealing with scheduling conflicts that is in accordance with the relevant standards (Innovations 1 and 2).

7 CONCLUSIONS AND RECOMMENDATIONS

- UIC 405, 406 and the British RUI address capacity from particular standpoints, rather than providing a holistic view. The work of ON-TIME aims to rectify this, and to cover the main concerns of IMs, RUs and Users (Passengers and Freight shippers) with an overall output QoS.
- There are a wide range of static and dynamic factors affecting capacity to varying degrees. Further work in the main work packages of the ON-TIME project is required to understand more clearly what impacts the factors have, both individually and in combination.
- Allowances play an important part in the development of timetables and railway operations; however, they tend to be based on experience gathered over time, rather than deterministic scientific approaches. Further work is required to better understand how allowances should be applied to timetables and railway operations, and how more accurate allowances models can be developed.
- The analysis of the context within which ON-TIME is working in WP1 has shown that the work packages align well with the major components of the timetable planning and train control process.
- The research in WP1 has provided a comprehensive description of the British timetable planning and train control processes. This has provided the basis for identification of the principal stakeholders and their requirements in terms of the development of innovative new techniques and processes to improve capacity utilisation. Further work is required in WP2 to provide an overall description of the processes, stakeholders and requirements for all of the ON-TIME partners.
- The research in WP1 has shown clearly how complex the timetable planning and train control processes are. The ability to describe these processes clearly is vital to providing WP3, 4, 5 and 6 with the information necessary to create a firm foundation for the development of innovative techniques and processes. To ensure that process descriptions passed to the other work packages are rigorous, it is recommended that WP2 uses 'formal methods, such as IDEF0 or SysML to describe existing process functionality.

8 GLOSSARY

Algorithm	A defined procedure to find a feasible solution of a particular problem in a finite number of steps.
Allowance time	The time added into the nominal timetable to compensate the additional train sectional running times, dwell times and other scheduled process times due to unavoidable variability of physical characteristics, driver behaviours, passengers boarding and alighting variations and other potential influencing factors to train operations in real life conditions.
Arrival delay	A deviation of the arrival time from the scheduled arrival time at a station. (Yuan, 2007)
Blocking time	The time interval in that a section of track is allocated to the exclusive use of one train and therefore blocked to other trains.
Buffer time	The time added into the nominal timetable (between train slots) to reduce or avoid propagation of knock-on delays among running trains due to initial and/or primary train delays.
Capability	Maximum throughput that can be maintained with the technical and organised characteristics of a railway.
Crossing	An assembly of rails that enables two tracks or two pair of tracks to cross each other at grade. (UIC, 2004)
CSP	Constraint satisfaction problems.
Delay	The deviation from either a scheduled event or process time of this train.
Departure delay	A deviation of the departure time from the scheduled departure time at a station.

Dwell time	The elapsed time from the time that a train stops at a station platform until it starts moving again.
Dispatchers	The crews or the agents who monitor and control the train running and routing.
Freight operating company	A company with access rights to operate freight trains on the railway network.
Headway	The necessary time interval or space between two successive trains on the same track. From precedence train's head to the following train's head.
Initial delay (entry delay)	A delay recorded at the cordons of an investigate network when a train enters. (Hansen and Pachl, 2008)
Infrastructure manager	A body responsible for development, operation and maintenance of the railway infrastructure.
Inter locking	An arrangement by which points and signals are electrically or otherwise interconnected in a way so that each movement follows the other in a sequence. (Hansen and Pachl, 2008)
Infrastructure	The fixed and capital equipment needed for running, maintaining, signalling and dispatching trains.
Knock-on delay	The secondary delay due to either a short headway times or late transfer connection. (Hansen and Pachl, 2008)
Long term planning	The planning process used to develop the annual timetable.
Node	Points of a network in which at least two lines converge. (UIC, 2004)

Original delay (primary delay)	A delay generated within the network and not caused by other trains. (Hansen and Pachl, 2008)
Objective function	A mathematical representation of the objective that is aimed at in terms of the decision variables.
Punctuality	Defined as the percentage of the trains that arrive at a location with a delay less than a certain time in minutes. (Hansen and Pachl, 2008)
Perturbation	An extra influence on a system that causes it to deviate slightly. (Hansen and Pachl, 2008)
Railway undertaking	Bodies, such as train operating companies and freight operating companies, responsible for the operation of passenger and freight trains.
Route	Consecutive lines and nodes as a whole, between a defined source and target. (UIC, 2004)
Recovery time	The time added into the nominal timetable to be reserved for the trains to be recovered from delays by using effective train operation strategies.
Railway network	A train system or a particular area including all train running elements which can communicate with other networks.
Route planning	Planning the train route at the station for the sake of the minimum pass time of the passing trains.
Reliability	The ability of a system or component to perform as designed.
Rescheduling	Identifying and resolving conflict which may arise during actual operations. The goals are to minimise the overall delay and return as fast and as close as possible

	to the original timetable. (Hansen and Pachl, 2008)
Short term planning	The planning process used to handle changes to the published annual timetable.
Station	Points of a network where overtaking, crossing or direction reversals are possible, including marshalling yards. (UIC, 2004)
Stability	The ability of a system or component to compensate for delays and return to the desired state. (Hansen and Pachl, 2008)
Switch	Another term for a pair of points.
Track	Tracks are the route ways of a railway system to support and guide trains.
Train operating company	A company with access rights to operate passenger trains on the railway network.
Train path	That part of capacity of the railway infrastructure which is necessary to schedule or run a train with a requested speed profile.
Traffic diagram	A time-distance diagram that contains the train paths of all trains that run on a line. (Hansen and Pachl, 2008)
Timetabling	Aim at determining a periodic for a set of trains that does not violate track capacities and satisfies some operational constraints.

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