

The effects on operation and capacity on railways deriving from the switching to continuous signals and tracing systems (ERTMS)

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FOREWORD

This work is part of my Civil Engineer education and was performed from 10-2006 to 5-2007 in the department of Transportation and Logistic at the Royal Institute of Technology of Stockholm. I want to thank all the people in the Railway Group that during my period there supported and advised me. A special thank goes to Anders Lindahl.

Ringrazio i miei genitori e tutti i parenti ed amici che appoggiandomi e standomi vicino mi hanno permesso di vivere questi anni d'università nel modo più sereno possibile rendendoli una bell'esperienza. Un grazie speciale a Claudio.

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1 INTRODUCTION

1.1 BACKGROUND

Train control is an important part of the railway operations management system. Until few time ago it has been thought as the connection between the fixed infrastructures and the trains. If we refer to European context, over the years, different Countries developed what they thought be the best way to achieve this task. This behaviour conducted to a situation of a too spread train control scenario that steered to difficulties in railway communication among States. These difficulties can be grouped in lost of time at the boundaries (to switch control system or worst the locomotive) and major cost that comes from a not economy of scale (the major cost to develop singular approaches and the major cost to equip trains with more devices).

By a project has seen its conceptual birth more than a decade ago, ERTMS/ETCS project (European Railway Transport Management System/European Train Control System) has the goal to replace all the great train control systems in use around Europe with a standardized one. The technical harmonisation that allow trains from every country to work on every other country's railway systems is known as interoperability and will eventually create a single European market for rail products.

As reported in the texts adopted by the European Parliament about deployment of the European rail signalling system (15 June 2006): [...] *the deployment of ERTMS is a major cross-border European economic project and whereas progress as regards a standard train protection and signalling system could play a central role in the strategy of easing the strain on the roads and shifting transports flows to the railways and as part of a European policy for harmonising the conditions of competition between the different modes of transport. [...] ERTMS will give to the railway industry a historic opportunity to*

exploit digital technology to the full for the benefit of railways, gain in competitiveness, and make up ground on the other modes of transport, especially since trains will be able to “steal march” by transporting goods in cross-border carriage over long stretches at a time.

From these words it is possible understand how many expectations revolve around the project and that investigate part of that can be an interesting topic of discussion.

The project has been thought in three stages (level 1, level 2, and level 3) to simplify the mitigation. While level 1 is practically a reality around European infrastructures and level 2 is at testing level, level 3 is still at a groundwork level.

The ERTMS/ETCS is divided up into different equipment and functional levels. The definition of the level depends on how the route is equipped and the way in which information is transmitted to the train.

At the final stage of ETCS implementation more or less all train control infrastructure will be either on-board the trains or distributed in control centres. There will be no more need for optical signals, wheel counters and in general for the division of the track into fixed block allowing the moving of train separation to the so called “moving blocks”.

Main goals of level 3 can be listed in:

- *interoperability*, of course this is the surround inspiration of the all project. Anyhow this task is already achieved by the previous levels;
- *reducing the cost of track equipment and maintenance costs*, railway signalling has traditionally required a large amount of expensive hardware to be distributed all along a route which is exposed to variable climatic conditions, wear, vandalism, theft and heavy usage. Because of the widely spaced distribution, maintenance is expensive and often restricted to times when trains are not running. Failures are difficult to locate and difficult to reach. Reduced wayside equipment can also lead to reduced installation costs;

- *increase track utilization*, this represents the new intention. This expectation comes from the obvious observation that, dropping the standards block synchronization of trains and migrating to a virtual block system, can have the potential of allowing closer distances between trains.

1.2 REACH AND GOAL

Objective of the present work is, looking at the final level of implementation of ERTMS (level 3), to try to carry out if the switch from the fixed block to the moving block operation really leads to an increment of capacity and, in case of positive feedback, trying to quantify and analyze this last.

In fact, as seen before, the increase of track utilization is the main goal that level 3 proposes to achieve allowing to introduce a braking separation among trains. So study this aspect seems a quite important matter to consider the goodness of such introduction.

From a first roughly approach, it could appear quite out of question that capacity utilization might not than upgrading in a basic scenario. If we would move the problem to a dimension closer to our experience, as road traffic is, we can just agree on the fact that would be a downgrading of capacity (and our patience) if we were blind to fix separation (if an example is possible as traffic lights were everywhere). As we think “braking” separation leads to more flexible car traffic, we could be taken to think that set trains free from the “discretization” of space given by blocks surely represents a successful improvement. This probably is true in a scenario in which same performances trains just run following each others, but what does happen if different performances trains are mixed, stations are introduced and delays fall into as in reality?

1.3 TECNHIQUE

The first part the work deals with an analysis of a basic scenario composed by same performance trains following each other on a test distance. This will be make with a here so called “formula approach” and then, to have a comparison, with a “graphical approach”.

Then the work moves on studying a more complicated model that try to represent closer the reality. Being this step too articulated to be done by hand methods an appropriate software tool becomes necessary to be introduced. The software will be helping to have a more comprehensive investigation is *RailSys* (RMCon).

It will be interesting observe how traffic reacts to the switching of signalling system. In particular, it appears interesting try to find out if some kind of relation between separation distant and train performances exists. This also means know if an improvement like ERTMS level 3 can interest all traffic stocks or if, at contrary, some categories will have more benefits over others.

It must be emphasized that being based on mobile communication this kind of separation can face with communication failure problems and so to capacity degradation (see Zimmermann and Hommel [10]). Anyway we will just consider the working principle behind moving block theory comparing results with those coming from the application of the working principle of block theory.

1.4 THESIS ORGANIZATION

As first a brief overview of signals for train movement and an indication of actual spacing trains (in particular block theory) around Europe are given (chapter 2). This is a testimony how to achieve more or less the same basic, or less basic, task every Country adopted over years different ways, even

arriving in some cases having the same kind of signal showing a different command!

As next it follows an introduction of radio-based systems in signalling (chapter 3). This represents the basis of automatic train protection and then of ERTMS. Despite of it is not easy find technical information about ERTMS in the chapter an attempt to describe the functioning of the three levels is given. In particular, at the time of document writing, find specifications concerning the level 3 it was a quite unfeasible task.

In chapter 4 the capacity issue has been coped with a previous analytical approach and then with a simulation one.

Finally the conclusions, included in chapter 5, where results are analyzed and commented.

2 POINT ON ACTUAL SIGNALLING SYSTEM AND SPACING FOR TRAIN MOVEMENTS

In the following chapter an overview about signalling system and spacing for trains is provided.

It has seemed of interest, considering the nature of ERTMS project itself, to address examples both of signals and train separation around five European countries. This is to testimony how spread the situation appears nowadays. Choose of the States has been made thinking to the crossing corridors that are in phase of project. In particular it appeared relate to choose States will be part of the Corridor B (Napoli - Stockholm), as representative of a railway reality from south to north Europe.

2.1 DEFINITIONS

In a territory with lineside signals, train movements are governed by fixed signals installed alongside the track.

There are two main kinds of lineside signals:

- ✓ semaphore signals;
- ✓ light signals.

Semaphore signals give the aspect by the position of movable arms. They are used in old installations.

On light signals the aspects are given by lights. Lights signals are used in three forms (Figure 1):

- ✓ colour light signals;
- ✓ position light signals;
- ✓ colour position light signals.

On *colour light signals*, that are the most common, the aspects are displayed by the colours of the different lamps. The way how the colour is obtained can change. Some railways use multi-unit light signals with independent light units, others prefer light unit in which the aspect is given by a mechanism placing a different roundels in front of the lamp according with the colour that have to be showed.

On *position light signal*, the aspects are given by the position of two or more lights. The position of the lights matches those of similar semaphore aspects.

Colour position light signals are a combination of the previous two. The aspects are given by the position and the colour of two or more lights.

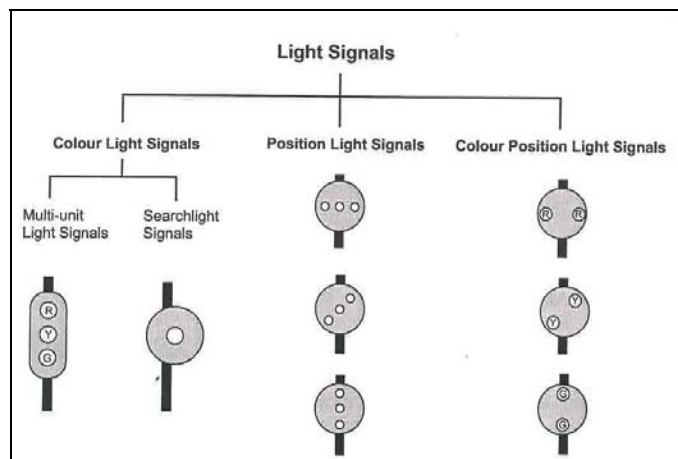


Figure 2.1 - Different kinds of light signals [2]

2.2 PRINCIPLE OF SIGNALLING

Roughly, concerning the classification of signal aspects, signals systems can be divided in two basic principles of signalling:

- ✓ speed signalling;
- ✓ route signalling.

In a *speed signalling* system, the signals indicate the speed not to be exceeded by a train. In *route signalling* the facing point signals indicate the route over which the train is being sent.

In how to show these information it lie the railway equivalent of the Tower of Babel, the multiplicity of aspects that every Country claim to be the optimum. It is true that there are two signals aspects that are almost universal amongst the European railways and indeed, worldwide:

- red means STOP;
- green means PROCEED, except for flashing green on Sweden railways.

But then all the other indications are given in different way in every European country!

Apart from the stop indication, all signal aspects give some information about the state of the line ahead. This information may be quite basic, as with the proceed aspect of a two aspect system: proceed until you come to a stop aspect, or as the majority of the shunting proceed aspects: proceed as far as the line is clear and be prepared to stop on sight of an obstruction.

However with three or four aspects a proceed signal aspect must give information, not only on the state of the line up to the next signal, but also on the aspect being displayed by that signal. In speed signalling systems, this must include the speed at which next signal must be passed if this will (or may) entail a reduction, on the basis that trains cannot change their speed instantaneously.

2.3 ASPECT IN USE IN EUROPE

To have an idea how signals can be so vary to represent a difficult in Countries crossing, the following sections discuss the meaning of the principals aspects grouped by colours, on: Italian, Swedish, Austrian and German railways.

2.3.1 Single green

Although precise definitions vary slightly, on most railways one steady green light means line clear, proceed at maximum permitted speed.

Railway		Steady	Flashing
FS (Italian)	Stop signal	Line clear	None
	Warning Signal	Line clear at maximum permissible speed	None
BV (Swedish)	Stop signal	Line clear	None
	Warning Signal	None	Next signal is a stop
ÖBB (Austrian)	Stop signal	Proceed at maximum local speed	Departure signal (displayed with proceed aspect)
DB AG (German)	System L - Stop signal	Proceed at line speed unless speed restriction indicated	None
	System N	Proceed at line speed unless speed restriction indicated	Procede; reduce to speed indicated

Table 2.1 - Single green [3]

2.3.2 Double green

The principle use of two greens lies with those railways which use separate warning aspects.

Railway		Steady	Flashing
FS (Italian)		None	None
BV (Swedish)	Stop signal	(I) Proceed at 40 km/h (40-80km/h with ATC), except to stop at next signal	None
	Warning Signal	None	Next signal shows 2 or 3 green lights
ÖBB (Austrian)	Stop signal	(I) Proceed at 60 km/h	None
	Warning Signal	(I) Next stop is a proceed	None
DB AG (German)	System HV - Warning Signal	(I) Next signal shows clear	None
	System KS	None	None

Table 2.2 - Double green [3]

2.3.3 Single yellow

Flashing single yellow has a variety of meanings.

Railway		Steady	Flashing
FS (Italian)	Warning Signal	Prepare to stop at next signal	The next signal displays a proceed
BV (Swedish)		None	None
ÖBB (Austrian)		None	None
DB AG (German)	System HV - Warning signal	Braking distance from level crossing	None
	System KS	Caution: next signal shows STOP	None

Table 2.3 - Single yellow [3]

2.3.4 Double yellow

Steady double yellow is especially popular amongst the railways which use dedicated warning signal aspect and it is displayed vertically, horizontally and inclined (/ and \).

Railway		Steady	Flashing
FS (Italian)	Warning signal	(I) Warning of occupied track at abnormally reduced bd or occupied or short track	None
	Substitutional signal	(-)For departure signal (includes warning signal)	(-) For departure signal (not including warning signals)
BV (Swedish)		None	None
ÖBB (Austrian)	Warning signal	(-) next stop is a stop	None
DB AG (German)	System N	None	None
	System HV - Warning	(/) Caution, next signal shows stop	None

Table 2.4 - Double yellow [3]

2.3.5 Green and yellow together

Since all railways except BV use both yellow and green aspects, it is not surprising that, when an additional aspect was called for, simultaneous display of yellow and green came to be considered on economic grounds. However, both the meaning and the dispositions vary.

Railway		Steady	Flashing
FS (Italian)	Warning Signal	(I: Y or G) reduce speed to 30 km/h by next signal	(I: Y or G: flashing in phase): reduce speed to 60/km/h by next signal (I: Y or G: flashing alternately): reduce speed to 100 km/h by next signal
BV (Swedish)		None	None
ÖBB (Austrian)	Stop signal	(I: G over Y) Proceed at 40 km/h	None
DB AG (German)	System HV - Stop signal	(I:G over Y) Pass at 40 km/h unless otherwise indicated (ex. by numeral)	None
	System HV - Warning signal	(I G over Y) Next stop signal at (G over Y)	None
	System KS	None	None

Table 2.5 - Green & yellow together [3]

2.3.6 Single red

Steady red means stop in all signalling systems. At the contrary flashing red has a number of meanings.

Railway		Steady	Flashing
FS (Italian)	Stop signal	Stop	None
BV (Swedish)	Stop signal	Absolute Stop	None
ÖBB (Austrian)	Stopsignal	Stop	Caution signal
DB AG (German)	System HV - Stop signal	Stop	None
	System KS	Stop	None

Table 2.6 - Single red [3]

2.3.7 Single white

Not much in use as a running signal aspect, except in Sweden. The relative unpopularity of white as a railway signalling colour probably stems from the desire to avoid confusion with sundry lights outside the railway. However, the almost universal employment at present of sodium vapour lamps for street and motorway lighting means that steady single yellow aspects are also at risk from misinterpretation. Perhaps BV is right after all!

Railway		Steady	Flashing
FS (Italian)		None	Automatic open level crossing with road signal: road signals operating
BV (Swedish)	Stop signal Warning Signal	Level crossing barriers closed None	None Next signal shows 1 green light
ÖBB (Austrian)	Stop signal	None	Substitution signal
DB AG (German)	Stop, warning and shunting signals	Signal switched off for shunting	Substitution signal (System KS)

Table 2.7 - Single white [3]

2.3.8 Other combinations

Most railways use other combinations of colours and/or patterns for specific meanings. Some of these are related to more precise indications to reduce or maintain speeds at diverging junctions or others sites (ÖBB, FS and BV). German and Swedish railways use flashing white over steady yellow and a triangle of yellow respectively to indicate level crossing and DB AG uses an additional white light in their warning signals to indicate less than braking distance to the associated stop signal.

Several railways use white light arrays to indicate divergences. ÖBB uses white over white as its protection signal proceed aspect and DB AG uses triangles of white and yellow for substitution signals (proceed and caution respectively).

Using searchlight units, FS, can generate impressive displays of various colours, up to three lights, plus qualifying ciphers.

2.4 TRAIN SEPARATION

In railway mode the braking distance significantly exceed the viewing range of the driver. This because of the low coefficient of adhesion (on average eight times less than in road traffic) which correspond to as well as low braking force that can be transmitted by the vehicle to the track. "Sight separation" is

thus possible only in case of low speed ($<25\text{km/h}$); situation this that happens for shunting movements and for train movements in non regular operations. For regular operations procedure requires that train separation is independently by the view range of the driver. This is satisfied with three basic theoretical principles:

- ✓ train separation in relative braking distance,
- ✓ train separation in absolute braking distance,
- ✓ train separation in fixed block distance.

2.4.1 Train separation in Relative Braking Distance

As showed in the figure next (2.2) the spacing between two trains in relative braking distance equals to the difference of the braking distances of the trains ($d_{\text{brake},2} - d_{\text{brake},1}$) plus an additional safety distance (S). The braking distance is calculated with braking curves as a function of speed.

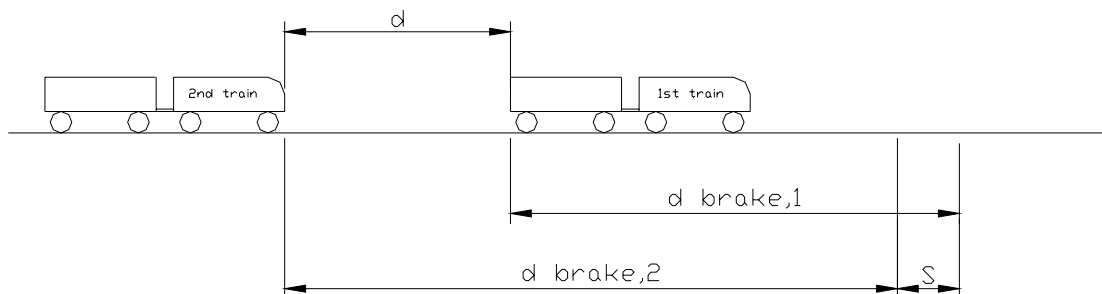


Figure 2.2 - Train separation in relative braking distance

This kind of separation leads to a maximum of line capacity.

Nevertheless this solution is only a theoretical idea with no realistic chance to be adopted in railway transportation, this because of evident problems of security.

2.4.2 Train separation in Fixed Block Distance

With this kind of separation the track is divided in block sections.

The basic principle is that a block can be occupied by only one train at time. The distance between two following trains is showed in figure (2.3) and is equals to the maximum braking distance ($d_{brake,max}$) plus the length of the block section (L_{block}) plus an additional safety factor (S).

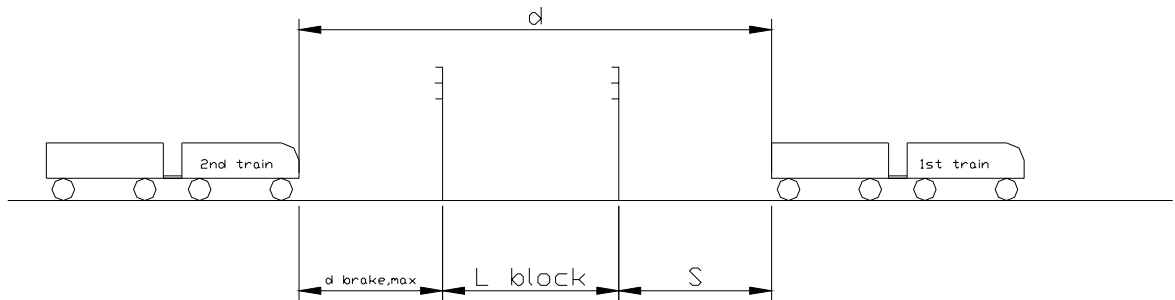


Figure 2.3 - Train separation in fixed block distance

Nowadays, running in fixed block sections is the most common principle of train separation worldwide control.

2.4.3 Train separation in Absolute Braking distance

In this kind of spacing the distance between two following trains equals the braking distance of the second train ($d_{brake,2}$) plus an additional safety factor (S).

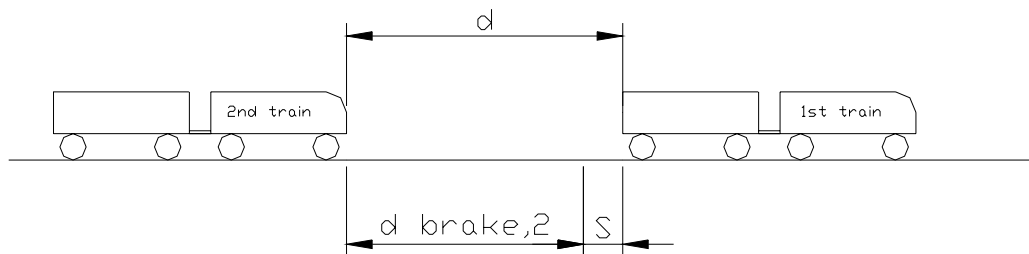


Figure 2.4 - Train separation in absolute braking distance

This principle is considered by the most as the best-suited principle of train separation that can allow railway operation improvements. The only problem

with this principle is that it is connected with the technology for safe train end location still object of development (the work will focus the attention just on the principles of this method and not how this is achieved, being quite hard find information about that).

Train separation in absolute braking distance is also called *moving block*.

2.5 NON SIGNAL-CONTROLLED OPERATION

In a non signal controlled operation the train movements are regulated by a dispatcher. The communication between the dispatcher and the train crews is made via telephone or radio. Nevertheless in Europe this kind of operation is quite rare and can only be found on branch lines with a very low density of traffic.

2.6 SIGNALLED FIXED BLOCK OPERATION

As said, a signalled operation with a fixed block system is the most common form of operation.

Signalling with lineside signals is still typical but there is also an increasing use of cab signal systems, in particular with the development of the high-speed lines (where lineside signals can not be seen safely by the crew).

2.7 SURVEY OF BLOCK SYSTEMS

2.7.1 Definitions

As said the spacing of trains is achieved by dividing the line into one or several block sections of different length, according with the traffic density. A block section is protected by a signal (lineside or cab signal).

A block system is said to be:

- with *closed track* if the block signals are normally closed. The block signal is only cleared to permit a train in a non-occupied section;
- with *open track* if the block signals are normally showing proceed. The block signal returns only to danger when a train occupies the section.

Moreover it is:

- *automatic*, when the detection of a train in a block section is achieved automatically by track circuits or axle counters;
- *manual*, when acting of signals and observation of the presence of a train requires the presence of a local signaller.

To clear a signal for a train that is to enter a block section, the following conditions must have been fulfilled:

- the train ahead must have cleared the block section;
- the train ahead must have cleared the overlap behind the next signal (only on lines where block overlaps are used);
- the train ahead must be protected from following train movements by a stop signal;
- the train is protected against opposing movements.

Regarding the principle of providing the approach aspect there are two kinds of signalling:

- ✓ one block signalling;
- ✓ multiple block signalling.

In *one block signalling*, a block signal can only give information about the block section behind the signal but not approach information for the next signal. So, every block signal must have a special distant signal whose only purpose it is to give the required approach information. The distant signal whose only purpose it is placed at the braking distance before the block signal. On lines with short block sections, the distant signal is placed at the rear block signal. In such systems, the head of the block signal and the head of the distant signal belonging to the next block signal are often mounted one above

the other on the same post. Other solution is to place the signals at intervals of half the braking distance with a double approach aspect.

In *multiple block signalling*, a block signal gives information about two or more following block sections. Very common is two-block signalling in which the approach information is integrated in the aspect of the rear block signal without need for special distant signals. Because in two blocks signalling, in its simplest form, a block signal can show three different aspects, it is also called “three aspect signalling”. Anyway in combination with a progressive speed signalling, a two block signalling system can also be used with more than three signal aspects.

Multiple block signalling renders very effective signalling but requires block sections not much longer than the braking distance. In fact on lines with very long sections, multiple block signalling is not useful because the information are showed too much earlier, reducing the capacity of the line by increasing the signal headway of the following train.

To better understand the principle of one block and multi block signalling see at figure 2.5.

a) One-block signalling

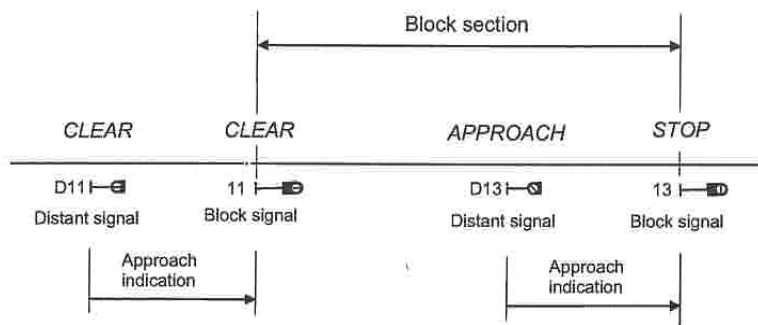
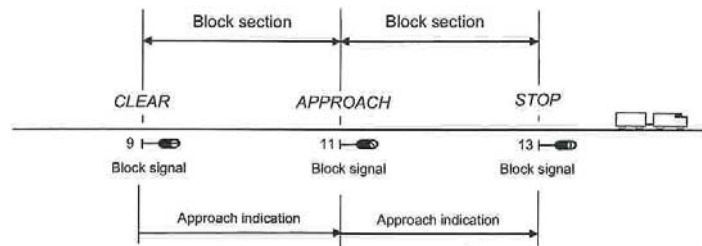
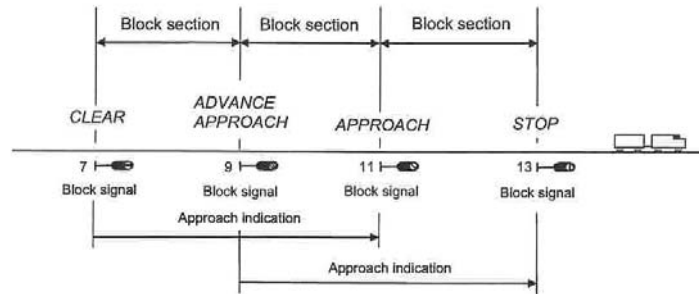


Figure 2.5 - Different principles in the application of the approach indication [2]

b) Two-block signalling



c) Three-block signalling



2.7.2 Automatic train stops

Automatic train stops have long been feature of rail transit.

These prevent a train running through a red signal by automatically applying the emergency brakes should the driver ignore the signal.

Called a trip stop, the system consists of a short mechanical arm beside the outer running rail that is pneumatically or electrically raised when the adjacent signal shows a stop aspect. If a train run through this signal, the raised arm strikes and actuates a trip cock on the train that evacuates the main air brake pipe. Full emergency braking is then applied along the length of the train.

To reset the system the operator must get off the train and close manually the valve.

2.7.3 Blocking time and headway theory

The *headway* between two trains is the amount of time (usually in minutes) that elapses between two trains passing the same point travelling in the same direction on a given route.

The minimum headway on a line with fixed block system depends on the so-called “blocking time”. The blocking time is the time interval in which a section of track (usually a block section) is exclusively allocated to a train and therefore blocked for other trains. The blocking time of a track element is usually much longer than the time the train occupies the track element. In a territory with lineside signals, for a train without a scheduled stop, the blocking time of a block section is showed in the following figure:

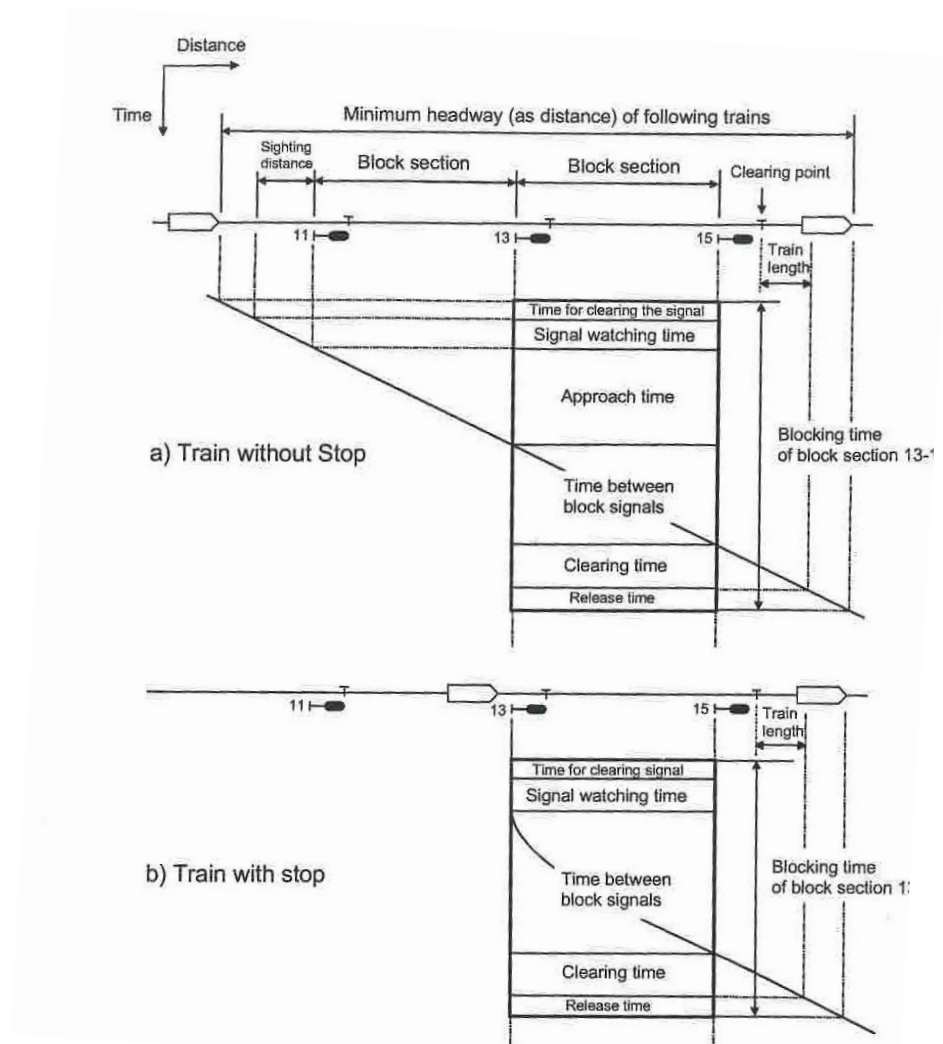


Figure 2.6 - Blocking of a block section [2]

Figure above shows the following times:

- the time for clearing the signal (by the ahead train);
- the time for the driver to view the clear aspect at the signal in rear that gives the approach aspect to the signal at the entrance of the block section (this can be the block signal in rear or a separate block signal);
- the approach time between the signal that provides the approach aspect and the signal at the entrance of the block section;
- the time between the block signals;
- the clearing time to clear the block section (and if required the overlap with the full length of the train);
- the release time to unlock the system.

In a territory with cab signalling, the approach time is the time the train runs through the braking distance that is signalled by the cab signal system. It is also to emphasise that for trains with a scheduled stop at the entrance of the block section, the approach time is not applied and the signal watching time is applied to the signal.

Drawing the blocking times of all block sections it is possible draw a time-over-distance diagram, the so-called "blocking time stairway" (figure 2.7).

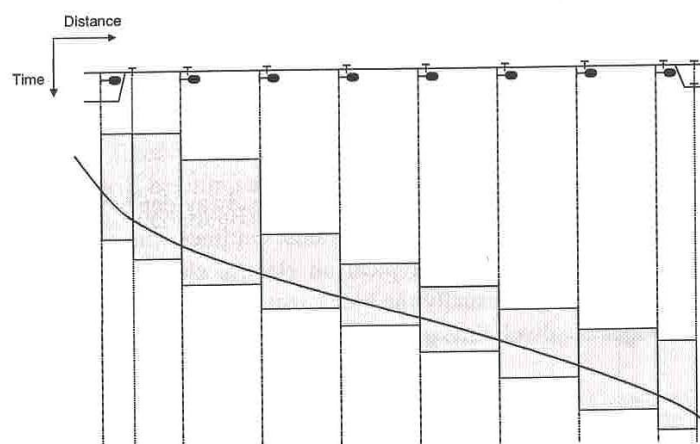


Figure 2.7 - Representation of the "blocking time stairway" [2]

By the blocking time stairway diagram it is possible to determine the minimum headways of two trains. The blocking time directly establishes the signal headway as the minimum time interval between two following trains in each block section.

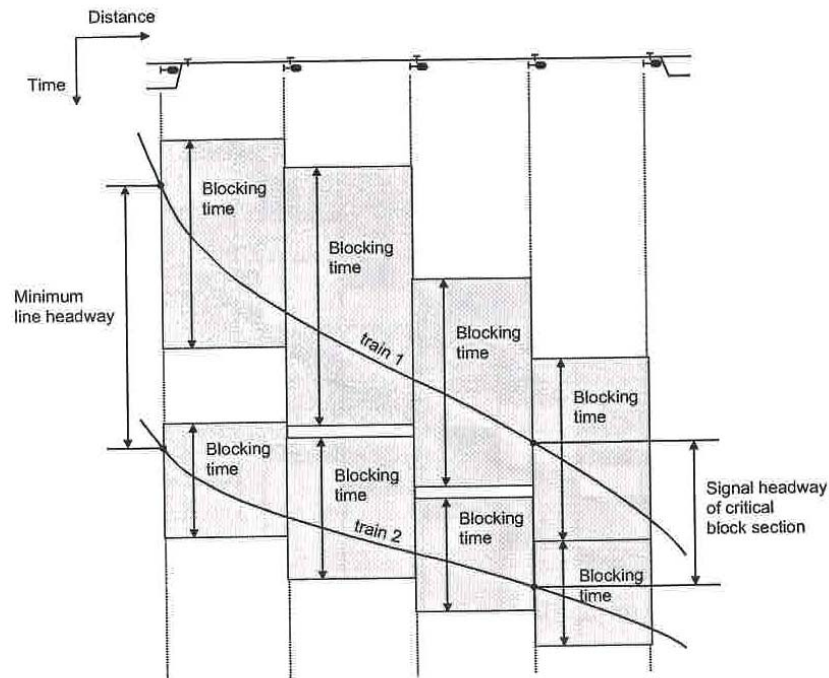


Figure 2.8 – Blocking time and Signal headway [2]

As showed in picture above (2.8), the line headway is the minimum headway between two trains not only considering one block section but the whole blocking time stairways of the line. In this case the blocking time stairways of two following trains touch each other without any tolerance in at least one block section (the “critical block section”).

On lines with mixed traffic, as a railway line is, the minimum line headway depends significantly on the speed differences between trains.

On lines where all trains run with quite the same speed, as an electric city railway is, the critical block section usually represents the block section in which the dwell is done (figure 2.9). On such lines it is easier calculate the headway rate, in fact been the traffic characteristic constant it is possible assume the capacity in train-pairs per hour. The number of train-pairs per

hour is twice the number of trains that pass a given point during the course of sixty minutes. Train-pairs per hour can be converted into headway as follows:

$$1 \text{ hr} / x \text{ trains} = 60 \text{ min} / x \text{ trains} = 60 / x \text{ minutes (headway per train)}$$

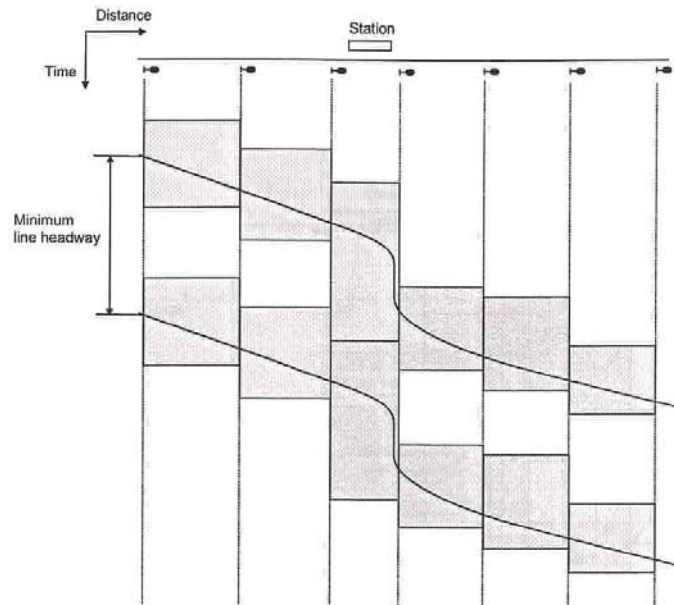


Figure 2.9 - Minimum line headway on an electric city railway [2]

On lines that are operated with a moving block system, there can also be determined a blocking time. On a moving block line, the length of a block section is reduced to zero. That means that the running time between the block signals will be eliminated. But all other components of the blocking time can also be found in moving blocks. So in difference to a line with fixed block sections, only the steps of the blocking time stairways will be eliminated and the blocking time diagram will be transformed into a continuous time channel (figure 2.10).

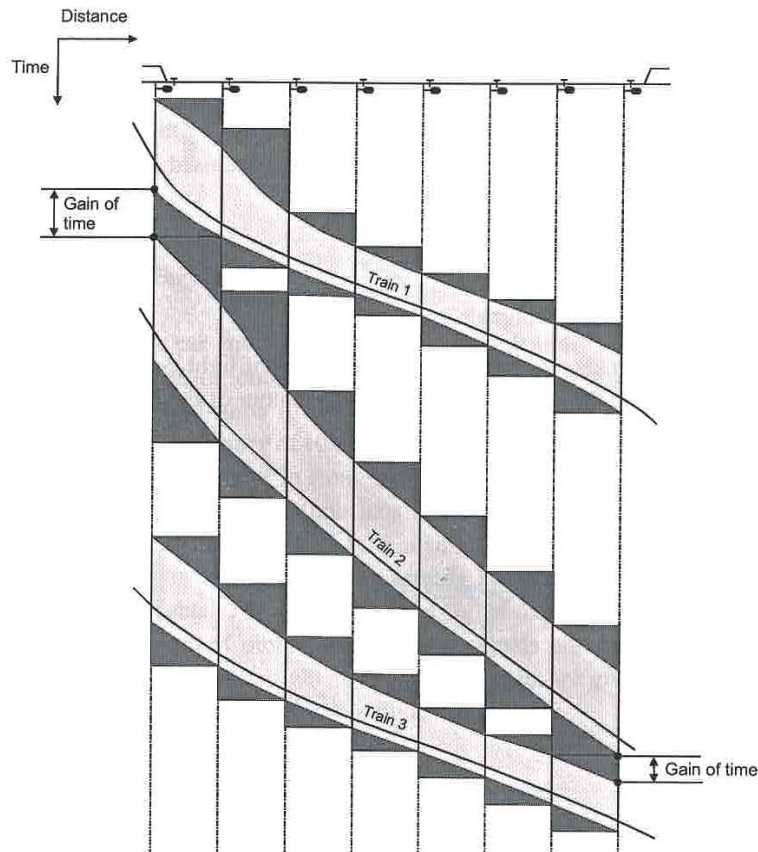


Figure 2.10 - Blocking time in moving block compared with fixed block regulation [2]

2.8 NON-AUTOMATIC BLOCK SYSTEMS

In the spread environment in which railway operations appear around Europe, each Country adopted several solutions to achieve non-automatic block systems. To give an idea, in table 2.8 and next explained, examples from five Countries (Sweden, Denmark, Germany, Austria and Italy) are addressed. The chosen of the Countries has been made with the intention to have some examples from north to south Europe.

2.8.1 Telephone block

Telephone block is used mainly on low traffic lines, with small or no passenger traffic, and low speed. Signalmen communicate by means of telephone between neighbouring stations following a standard procedure in prescribed repeated wording.

Telephone block procedure is also frequently used on lines when block equipment is inoperative.

It requires entirely on the integrity of the people involved and on strict adherence to the rules.

This system, though not forming a safety system itself, makes a contribution to improving the safety and operation of single track lines with light traffic.

2.8.2 Manual block with electromechanical interlocking

With the invention of the dynamo electrical principle it was only a matter of time until it was applied to provide electromechanically enforced interlocking of signals while using the same operation sequence as the telephone block.

At each end of the line a block apparatus is installed. This apparatus is electrically linked.

The operation is such that blocking of signals is effected locally by hand, and unblocking is effected electrically from the remote end. Adherence to the operation sequence is electromechanically enforced, including signal operation and train presence in advance of home signals. No train detection equipment other than rail treadle and overlaid insulated rail is required. The operation sequence can change slightly in each Country.

To each block line with unidirectional traffic the direction of travel is allocated permanently. On bidirectional lines the block maintains its set direction until it is changed manually.

2.8.3 Relay Block

Relay block is used in relay interlocking linked to interlocking equipped with electromechanical block apparatus. The operation of the block is simulated with relay circuits to provide an acceptable interface.

Transmission is by means of low frequency AC or encoded pulse.

	Block System	Telephone Block	Manual Block Electromechanical Interlocking	Relay Block	Normal traffic direction (L=left R=right)	Routes single and Double track
Railway						
Austrian (ÖBB)		1730km 520km <i>Zugleitbetrieb</i>	<i>Feldeblock</i> 176km	ZG62 1823Km	L/R	5623Km
German (DB GB)		300 Km <i>Zugleitbetrieb</i> 190km <i>Signalisierte Zugleitbetrieb</i>	<i>Felderblock</i> 5350Km carrier frequency block TF-block 71 1050Km	Relaisblock 1320Km	R	27070 Km
Italian (FS)		3150Km	5094Km	X	L	16066 Km
Swedish (BV)		5360Km decreasing< 5%of all traffic	X	X	L	11030Km

Table 2.8 – Non-automatic block systems in 5 European Countries [3]

2.9 AUTOMATIC BLOCK SYSTEMS

The automatic block systems are widely used by the European networks. The principle of the pick up of the Countries follows what said before.

2.9.1 Non-centralized automatic block

Non-centralized automatic block is used for single and double track lines.

The block is locked by a set route into the block section or by a track occupation. The starting signal is unblocked automatically after the train has released the route, has left the block section and the next block signal has changed to stop (the home signal of the next station if no block signals).

The normal status of a block signal for normal direction is free. It changes its aspect to danger only when a train has entered the block section behind the signal.

On Swedish railways (BV) first block signal (at station limit) is normally closed for safety reasons. Proceed aspect is displayed when the next block section is cleared, direction locked and departure route set with the signal.

The aspects of the intermediate signals are transmitted back to the interlocking cabin on Austrian railways (ÖBB) and German one (DB AG), or are transmitted from signal to signal on Italian railways (FS), at example.

The block signal displays a proceed aspect again as soon as the block section is free and the next signal covers the previous train.

The whole track must be equipped with track circuits or axle counters.

When a departure route is set up, the block system is checked as regards correct direction and block in normal condition, including no occupation of the block section. The block is now locked: any other departure route as well as changing of the direction is inhibited.

When the exit route is set, the starting signal displays then a proceed aspect. The next exit route may be set for a subsequent train when the previous train has passed the first block signal.

All European railway administrations here invented different names for their non-centralized automatic block systems (see table 2.9).

2.9.2 Centralised automatic block

Centralised automatic block equipment is installed in adjacent stations cabins for easier maintenance and better protection. It controls intermediate block signals.

A further advantage is being able to have the train detection information of the line available in the signalbox. This may be used, for example, to set a suitable signal. If the distances allow it all the block signals of both directions are controlled from one station.

Train detection is mostly carried out by axle counters.

As the block signals are controlled from the equipment room of the signal box, the block function between starting and block signals in one direction and between the block and home signal in the opposite direction are provided by a

centralized block system. There is no transmission over line cable required between the signal controls.

2.9.3 Coded current automatic block

The system is installed on FS network. It is based on coded track circuits covering the whole line. Every code is associated with a given situation of the line ahead.

At every boundary between block sections a coded current equipment associated with relay logic is provided to receive and identify the incoming coded current, to control the block signal accordingly and to generate and transmit the coded current to the adjacent block system.

Lineside wires are used when additional functions are to be supplied, such as additional speed value information or change of traffic direction on the line.

The operation is fully automatic and allows for the continuous updating of signal aspects according to the situation of the line ahead (see also paragraph 3.7.4).

	Block System	Non-centralized Automatic Block	Centralized Automatic Block	Code Current Automatic Block	Normal traffic direction (L=left R=right)	Routes single and Double track
Railway						
Austrian (ÖBB)		<i>Selbstblock</i> 924Km	<i>Zentralblock</i> 450km	X	L/R	5623Km
German (DB GB)		<i>Selbstblock</i> 15260Km	<i>Zentralblock</i> Zb S65 Zb S600 3600km	X	R	27070 Km
Italian (FS)		Axle counter block: 3306km Fixed current block: 704Km	X	3812 Km	L	16066 Km
Swedish (BV)		Single line: 4470 Km Double line: 1200Km	X	X	L	11030Km

Table 2.9 - Automatic block systems in 5 European Countries [3]

3 RADIO-BASED SYSTEMS IN SIGNALLING

The application of radio systems to signalling has developed by varying degrees within railway administrators over the past two decades. The development of these systems aims at reducing the cost of fixed installations by eliminating signals and devices for track clear detection. This represents the basic for Automatic Train Protection (ATP) systems which themselves are the grounds for ERTMS/ETCS.

3.1 DEFINITION OF RADIO-BASED SYSTEMS

Radio is defined as the transmission and reception of messages by electromagnetic waves of radio frequency without connecting wires.

The normal frequency ranges available are:

- very high frequency (VHF 70-88 MHz);
- very high frequency (VHF 155-220 MHz);
- ultra high frequency (UHF 420-470 MHz).

3.2 BASIC PRINCIPLES

Radio-based train control is based on the principles showed in figure 3.1.

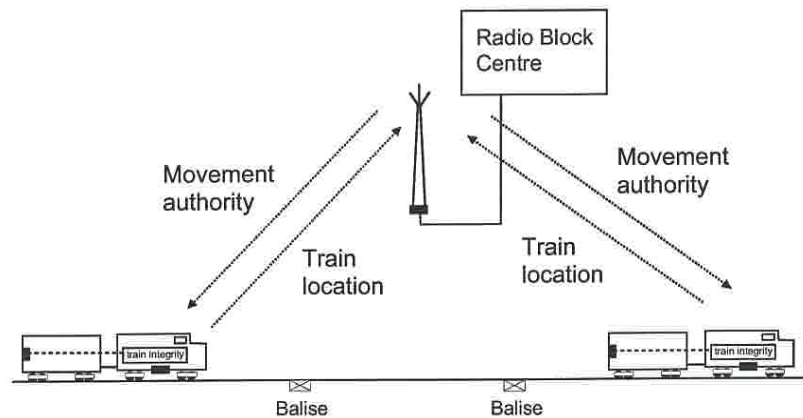


Figure 3.1 - Basic principle of radio-based Train Control

The *train location* is achieved by train-borne device, which possible technical solutions are:

- GPS technology;
- transponder tags on the track (the so called balises) used as reference points for an odometer (counter of wheel revolution);

The *train integrity* is realised by on board devices of the train (ex. End of Train Telemetry EOT device).

Trains transmit their *locations* in determined intervals by radio to a Radio Block Centre (RBC).

The *RBC* issues movements authority to trains by radio. The movement authority work like electronic track warrants. Without valid movement authority, the train borne computer prevents the train movements.

Although all radio-based train control systems follow these basic principles, there are different possibilities to realise the block logic of a radio based system.

3.3 NETWORK REQUIREMENTS

The application of radio communications within an administration network varies according to functional needs, but an integrated network of communication is required, radio forming a constituent part of the network.

For local communications where the operating range is short and the operating site is not static, single frequency and mobile radios are usually employed.

For sites where a wider coverage is required and where a static area is concerned such as control centre, station or depot, fixed station radio with an aerial system is usually employed.

For wide area network requirements which encompass more operational systems such as train radio and other functional needs radio control areas covering 200-300km² are established. This requires anything up to 20 fixed station sites, positioned according to topology and operational need, to be established.

3.4 CAB SIGNALLING

Cab signalling works on the principle of catch by an antenna, positioned on each train, codes that indicate the maximum allowable speed for the block occupied and may be termed the reference or authorized speed. This speed is indeed displayed in the driver's cab, typically on a dual concentric speedometer, or a bar graph where both the authorized and actual speed can be seen together.

A typical selection of reference speed would be 80, 70, 50, 35 and 0 km/h.

The authorized speed can change while a train is in a block as the train ahead proceeds. Compared to colour-light signals, the driver can more easily adjust the speed close to the optimum and has less concern about overrunning a trip stop (see cap. 2.4.2). Also problems of signals visibility on curves or sight problem in bad weather conditions are reduced or solved.

Cab signalling avoids much of the capital and maintenance costs of multiple colour-lights signals.

3.5 GSM-R

GSM-R (GSM-Railway) is the new wireless communication standard for railway networks. It has a 4MHz frequency for up link and down link GSM (900MHz) radio specific to the Railways. It has been developed under European Union sponsorship to assist railways in achieving their goals of network interoperability, reduced operational costs, improved safety at higher speeds, and delivery of new services for the benefit of passengers and employees.

GSM-R is built on GSM technology, and benefits from the economies of scale of its GSM technology heritage, aiming at being a cost efficient digital replacement for existing incompatible in-track cable and analog radio networks for railways. Over 35 different such systems are reported to exist in Europe alone.

GSM-R is a secure platform for voice and data communication between the operational staff of the railway companies including drivers, dispatchers, shunting team members, train engineers, and station controllers. It delivers features such as group calls (Voices Group Call Service VGCS), voice broadcast (Voice Broadcast Service VBS), location based connections, and call pre-emption in case of an emergency. This will support applications such as to support circulation activities, maintenance, operative management, activities in shunting yards and in the stations, train command and control and diagnostic supervision of the rolling stock and new application oriented to the qualitative improvement of the transport services offered to the users.

The standard is the result of over ten years of collaboration between the various European railway companies, achieving interoperability using a single communication platform.

The features of the GSM-R format can be summarized in figure 3.2, below showed.

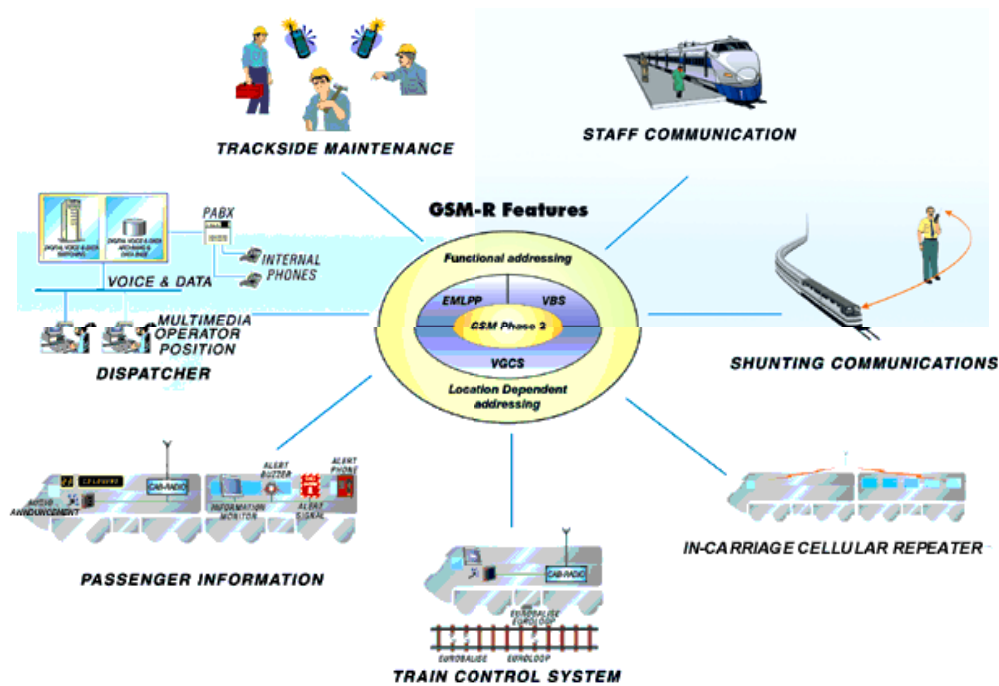


Figure 3.2 –GSMR-features [a]

3.5.1 GSM-R and ERTMS

GSM-R is part of the new European Rail Traffic Management System (ERTMS) standard and carries the signalling information directly to the train driver, enabling higher train speeds and traffic density with a high level of safety.

The specifications were finalized in 2000, based on the EU-funded MORANE (Mobile Radio for Railways Networks in Europe) project. The specification is being maintained by the International Union of Railways project ERTMS.

GSM-R has been selected by 38 countries across the world, including all member states of European Union, and countries in Asia, Eurasia and northern Africa.

GSM-R is typically implemented using dedicated base station towers close to the railway. The distance between the base stations are 3-4 km. This creates a high degree of redundancy and higher availability and reliability. In fact in case of fault or out of service, the radio coverage is normally assured by the neighbouring stations.

Two coverage classes are defined:

- ✓ *Class 2*: that corresponds to a vehicle (train) endowed with external omnidirectional antennas installed on its roof. The radio coverage requirement for this class demand that the downlink electromagnetic field, measured every 100 metres along the track, must be higher than -85 dBm with a probability of 95%.
- ✓ *Class 4*: that is for palm computers, requires that the downlink electromagnetic field, measured every 100 metres along the track, must be higher than -92 dBm with a probability of 95%.

In case of BTS (Base T Station) single fault the adjacent base stations must assure a field level higher than -98 dBm for the vehicles, so that the base services provided by GSM-R can continue to be supplied.

The train maintains a circuit switched modem connection to the train control centre at all times. This is moded operates with higher priority than normal users (eMLPP). If the modem connection is lost, the train will automatically stop.

In Germany, Italy and France the GSM-R network has between 3000 and 4000 base stations.

3.6 AUTOMATIC TRAIN CONTROL

Automatic Train Control adds further features to basic signalling. The term itself is an all-defined term but usually encompass three levels:

- ✓ Automatic Train Protection (ATP);
- ✓ Automatic Train Operation (ATO);
- ✓ Automatic Train Supervision (ATS).

Automatic Train Protection is the basic separation of trains and protection at interlockings.

Automatic Train Control adds speed control and often automatic train operation. This can extend to automatically driven trains also if more commonly it includes staff.

Automatic Train Supervision attempts to regulate train service. The capabilities of this feature vary widely from little more than a system that reports the location of the train to a central control office, to an intelligent system that automatically adjust the performance and stop times of trains to maintain either a timetable or a suitable headway spacing.

ATP and ATO maintain the fail-safe principles of signalling and are referred to as vital or safety critical systems. ATS cannot override the safety features of these two systems, and so it is not a vital system.

3.7 ATP

Automatic train protection (ATP) was born, together with cab signalling at the beginning of the twentieth century.

One of the main reasons leading to the introduction of ATP and control was the need to increase train speeds to above 200 km/h. In fact at such speed human beings cannot react to conventional signalling in a safe manner. The prevention of accidents and single driver operation were also good reasons to install ATP and control on all railway networks.

Under this system the driver remains the operator with all his actions under the check of the ATP system, which permanently determines if the train run is following instructions the driver has to respect.

So ATP systems transmit information about movement authorities and speed limits from the line to the train to cause automatic braking if the train ignores the valid limits.

There are two kinds of ATP concerning the form of data transmission between track and train:

- ✓ intermittent ATP;
- ✓ continuous ATP.

3.7.1 Intermitted ATP

In an intermittent ATP data is transmitted from place to place, from the train to a discrete point along the track.

The operational program of an intermitted ATP system may have three functions (that are not necessarily implemented in every system):

- automatic warning system;
- braking curve supervision,
- train stop.

Data points are placed at least at all points that may limit movement authorities (for train stop) and the braking distance in front of those points (for automatic warning and braking curve supervision).

The systems works in this way: when the train passes a signal that gives the indication “approach, stop at next signal”, the automatic warning system comes into action. If the driver does not action an acknowledge button the train will be stopped automatically. If the acknowledge test is satisfied the train born system will initiate a braking curve supervision. If this is not followed, the train will be automatically stopped. The braking curve supervision ends with a supervised constant speed at which the train could pass the signal. At this speed a train that passes a stop signal can be safely stopped by a train stop within the overlap. All this process is showed in figure 3.3.

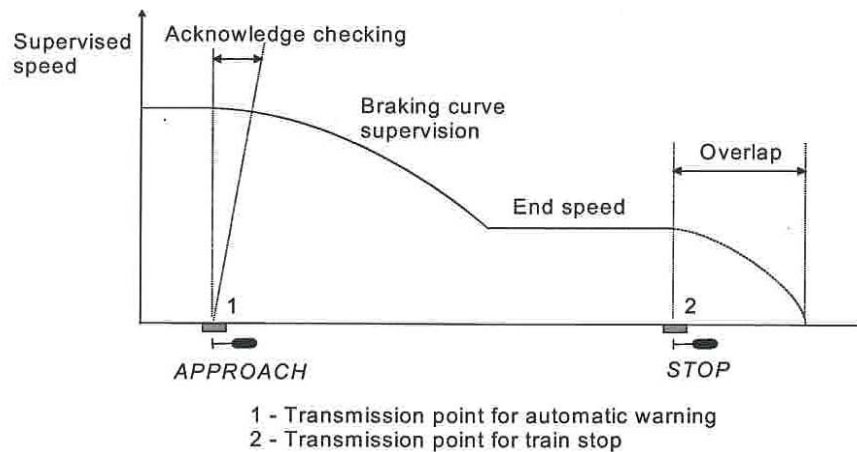


Figure 3.3 - Principle of intermitted ATP working [2]

The disadvantage coming from this solution is the lower capacity of the line. This because a train after passing a signal showing “approach, stop at next signal” must obey the braking curve supervision even if the next has been cleared later on (the principle of blocking is kept with the disadvantages it brings). To avoid this problem, modern systems added additional data points in front of the stop point to release the braking curve supervision after the signal has been cleared (but this add cost to the infrastructure).

3.7.2 Continuous ATP

This is the more significant system in terms of performance but it is very costly, especially the track equipment. A continuous system means that data is transmitted permanently between lineside equipment and trains. The train receives data at all times in order to control the protection system. The speed limits of the train are supervised continuously.

In some systems, the whole track is equipped with the transmission system. In other systems, the installation of the transmission system is limited to track sections where the transmission of data is necessary in order to supervise the speed of the line. A continuous ATP is always combined with cab signalling.

On lines where all trains are equipped with a continuous ATP, lineside signals are obsolete.

For data transmission, the following principles are common:

- ✓ data transmission by coded track circuits (coded by pulsating current or frequency);
- ✓ data transmission by using a cable as track antenna;
- ✓ radio-based data in combination with balises (transponders) for the purpose of train location.

And a division in two categories derives:

- ✓ centralized systems (LZB);
- ✓ decentralized systems (BACC).

3.7.3 German LZB

Linienzugbeeinflussung (also *linienförmige Zugbeeinflussung*, short form LZB, literally German: *linear train influencing*) is a cab signalling and train control system used on selected German and Austrian railway lines as well as the AVEin Spain. In these countries, the system is mandatory on all lines where trains exceed speeds of 160 km/h, but it is also used on some slower lines to increase capacity.

LZB is a system in which a continuous cable loop forms the track antenna. The loop has cross points (also called “zero points”) in specified distances (usually 100m) where the cables cross to get reference points for the train location. Between two cross points a wheel counter is used to locate the train. The centralized line centre may monitor up to 16 loops of a maximum 12.7 kilometres length (ex about a maximum 100 km of double track section line). This centre is connected to all interlockings, as well as to adjacent centres for in and out relationship between centres. Both links are permanent.

When entering a LZB section, trains transmit to the centre their specific characteristics such as braking performances, train length and category once and thereafter continuously repeat their localization. The ATP system transmits information about the static speed profile to the train; this depends on the state of the line. At the target point of the movement authority, the static speed profile has the value zero. The train-borne system generates a

dynamic speed profile (braking curves) the train must follow so it will not exceed the static speed profile.

So the train is guided by the following information:

- current speed limit;
- target speed (the speed the train must not exceed at the next executive point);
- target distance (the distance from the actual location of the train to the next executive point).

Figure 3.4 help understanding the functioning.

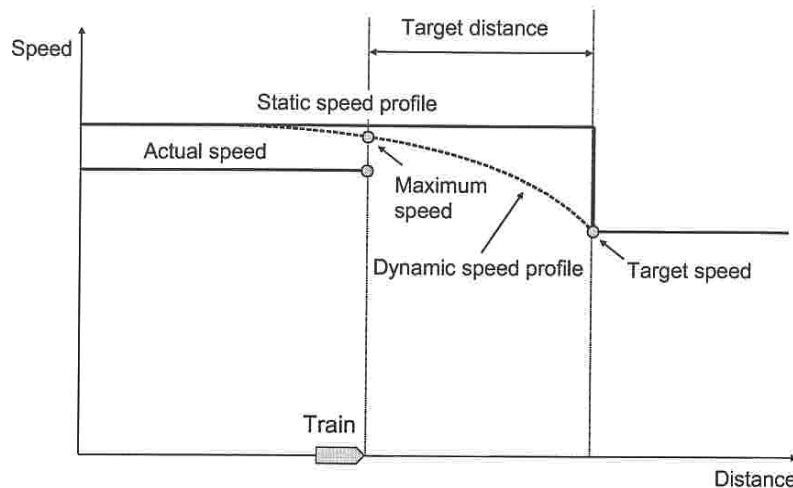


Figure 3.4 - Principle of LZB in speed control [2]

The guidance information is displayed to the driver on a cab-signalling display, this are additional information compared to what they would see without LZB. If the train's computer decides that, based on the train's braking characteristics, the target speed cannot be reached, it initiates an emergency stop. Another system, the AFB (*Automatische Fahr- und Bremssteuerung, automatic driving and braking control*), enables the driver to let the computer drive the train on auto-pilot, automatically driving at the maximum speed currently allowed by the LZB. In this mode, the driver only monitors the train and watches for unexpected obstacles on the tracks.

3.7.4 Italian BACC

BACC (*Blocco Automatico a Correnti Codificate*, that means automatic block with encoded currents) is a system adopted on Italian railways which, thanks the repetition of the signals onboard, allow the circulation at a speed major than 160 km/h ensuring the comparison between actual speed and limit speed. When actual speed exceeds the limit speed, emergency breaking is applied until the speed comes below the authorized speed, resetting of brake is under the control of the driver.

This technique utilizes the presence of track circuits (figure 3.5), that are already present in automatic blocks with the scope of check the presence of the train.

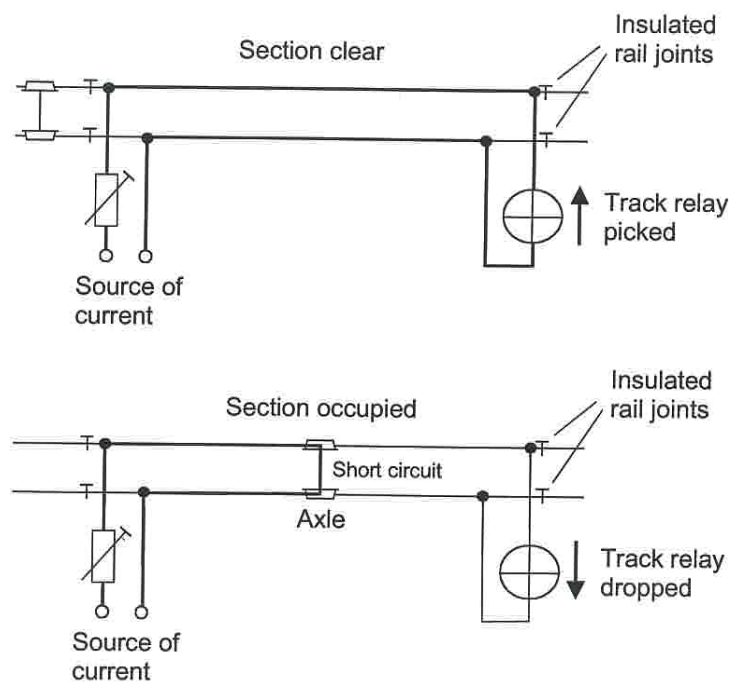


Figure 3.5 - Principle of track circuit

Here the current instead to be continue is alternate with determined frequency (50 and 178 Hz) and modulated with several break per minute so to be able to transmit at the train information.

With the modulation at 50 Hz it is possible transmit four code. These are extended up to nine codes with a modulation of 178 Hz for high speed.

3.8 THE FUTURE

The two above were just two examples of the very different techniques and technologies, as well as very different driver operating rules, adopted by the several European countries. ERTMS/ETCS represent the challenge for the future. It is the result of multi-functional railway requirements and technical specification by the industry.

3.9 ERTMS – General issues

As viewed in the chapter about signalling, every European country throughout the ages adopted an own way how to achieve this task. The Community railway network grew as separate national networks that have little more in common than standard gauge. This steered to a present situation in which trains are equipped with up to six different navigational systems, which is not suitable for a competitive railway transport system around Europe. In fact a train crossing from one Country to another must switch the operating standard as it crosses the border. This adds costs to the overall system (travel time, operational time and all the costs that derives from a non exploited economy of scale).

Beside, it is arisen the want to higher the travel speed to cover long distances in less time, trying so to render train transport more competitive over airplane.

The *European Railway Train management System* (ERTMS) is a signalling and control system that has the scope of develop a unique European system downing “technical boundaries” and overcoming these problems. This is achieved with a standard for all the apparatus and the on board devices (task not easy considering the several devices developed so far and the all different languages).

Other goal is to render dynamic and flexible the railway traffic management. Nowadays traffic regulation is realized by lineside signals that allow the control

centre to slow or speed a train in function of the line traffic (at example slowing a local train to allow the overtake from a high speed train in delay). The problem is that it is not possible deliver the orders instantly, but only at discrete time.

Exploiting the GSM-R radio communication between train and control centre this lack will be overcome. Thanks to this technology, the control centre can regularly collect information from all operational trains on the line, elaborates these and establishes the best traffic schedule that optimize both capacity and travel time. The new speed limit, calculated from data coming from the control centre by the on board computer, is showed to driver on his display. If the driver will not follow the procedure will be the on board computer to work over and slow down the train according with the imposed limits.

The ERTMS system is composed by:

- ETCS (*European Traffic Control System*), is the signalling and control system designed to replace the 14 incompatible safety systems currently used by European Railways; this can be divided as two parts:
 - o Trackside equipment: the equipment with the aim of exchanging information with the vehicle for safely supervising train circulation,
 - o Train borne equipment: the equipment with the aim of supervising vehicle operation according to the information received from trackside equipment.
- GSM-R (*Global System for Mobile Communications - Railway*), the new radio communication system derived from GSM (see paragraph 3.5)

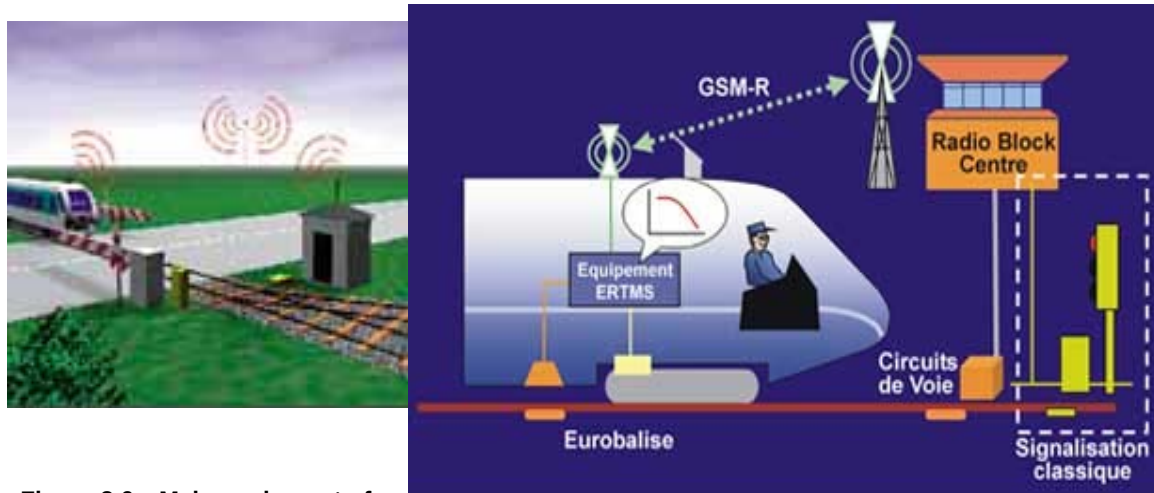


Figure 3.6 – Main equipment of ERTMS [b]

3.9.1 Chronological history

As testimony of the fact that trying join different technical reality, as signalling around Europe are, is not an easy matter that takes time; it briefly follows a chronologic history with the highlights of the almost twenty years old ERTMS process.

Since December 1989, following the decision taken by the European transport minister, the EC embarked upon a project to analyse the problems relating to signalling and train control. At the end of 1990, ERRI (European Railway Research Institute) created a group of experts to develop the requirements of ETCS. In June 1991, Industry and railways agreed the principles of tight cooperation in order to consider the requirement specifications as the base of industrial development. At the end of 1993, the EU council issued an Interoperability Directive and a decision was taken to create a structure to define the Thecnical Specification for Interoperability. At the beginning of the 4th Framwork Programme, in 1995 the EC defined a global strategy for the further development of ERTMS with the aim to prepare its future implementation on the European rail Network. In the summer of 1998, Unisig, comprising the European Signalling companies was formed to finalise the specifications. The class P SRS was delivered on 23rd April 1999. On 25th April 2000 the final signature on ERTMS specification, Class 1, was made. Test Track Italy has carried out trials in 2001. The revised specification SRS 2.2.2

(System Requirement Specification version 2.2.2) have been approved in February 2002. ETCS Level 2 is used on the Rome-Naples line, opened in December 2005.

3.10 ERTMS/ETCS: 3 levels

ERTMS/ETCS is divided up to three different levels according with different equipments and functional level. The definition of the level depends on how the route is equipped and the way in which the information is transmitted to the train. Basically, to the train are transmitted the movement authority and the corresponding route information showed to the driver in the cab by the so called cab signalling.

3.10.1 ERTMS/ETCS – level 0

This level refers to that situation in which an ETCS vehicle is working on a non-ETCS route. The task of the train borne equipment is reduced to monitors train maximum speed and the driver leads the train observing the national lineside signals.

3.10.2 ERTMS/ETCS – level 1/level 1+infill

This level is designed as a conventional line having lineside signals and train detection equipments which locates the train. In ERTMS/ETCS level 1 *balises* (a

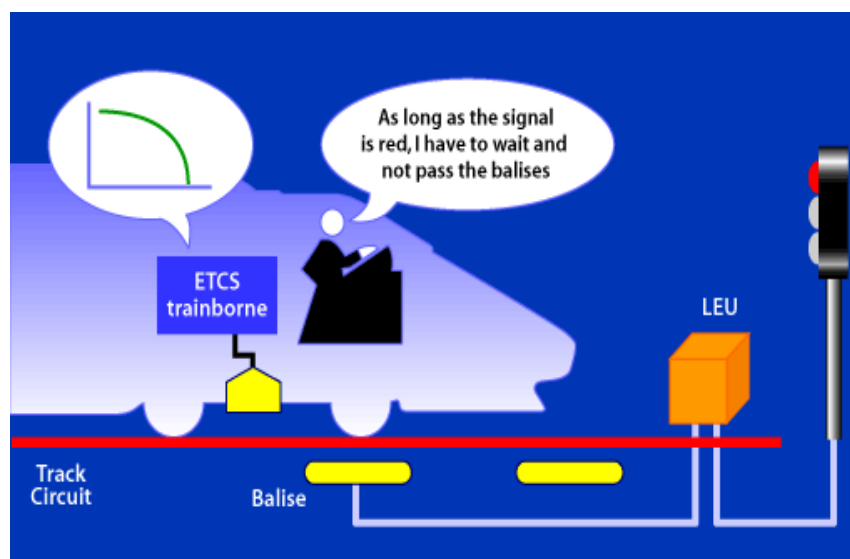


Figure 3.7 - ERTMS ETCS level1 [c]

passive transponder mounted on the track which can communicate with a train passing over it) are linked to the control centre. The balises contain pre-programmed track data. The train position equipment send the position of the train to the control centre. The control centre, which receives the position of all the trains circulating on the line, determines the new movement authority and send it to the balise. Train passes over the balise and receives the new movement authority and track data. The on board computer then determine the speed profile from the movement authority and the next braking point, this information is displayed to the driver.

This system is thus fundamentally discontinuous, since the exchange of information is only present in certain points and not all over the line.

To partially cover this spot transmission of data and so improving the line capacity of level 1, loops (figure 3.8) are added ahead the balises. Information from the next balise is sent into the loop and transmitted to the train as it passes over the loop. The infill information must include the identity of the balise group at the next main signal, i.e. the identity of the balise group giving the information that is repeated by the infill device. The onboard computer therefore receives advanced information of the next movement authority and the characteristic of the line ahead. This advanced information of the new movement authority indicates a new braking point to the driver that avoids the train brakes too soon. This significantly improves journey time.

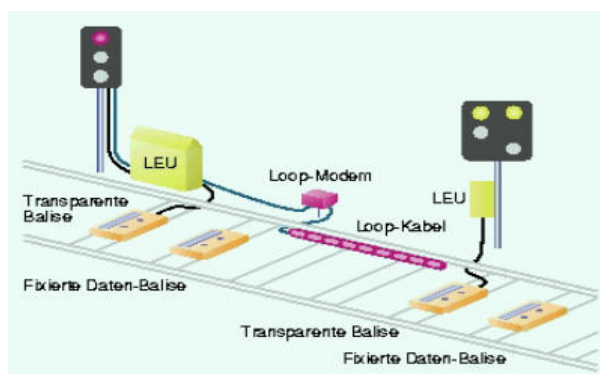
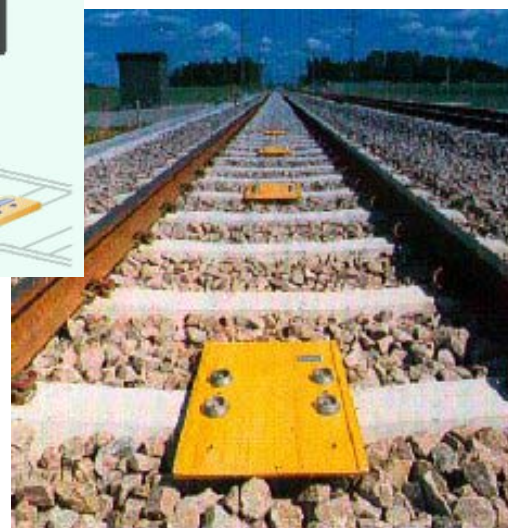


Figure 3.8 - Above representation of loop [d], on the left a picture of loops disposition along the track [ADTranz brochure]



3.10.3 ERTMS/ETCS - level 2

Level 2 is a digital radio-based signal and train protection system. It does not require, apart from a few indicators panels, lineside signals but still need train detection

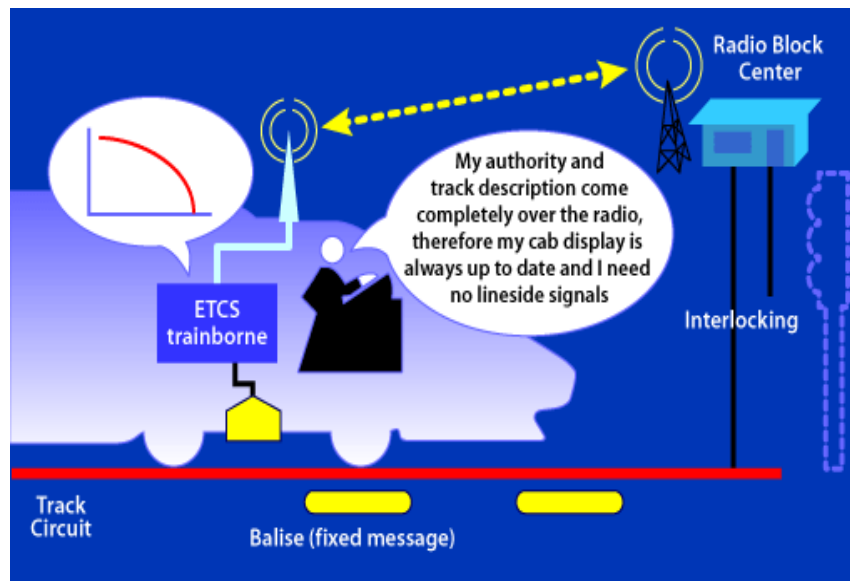


Figure 3.9 - ERTMS/ETCS level2 [c]

equipment on the track. ERTMS/ETCS level 2 has an on board system allowing the on board computer to communicate with the Radio Block Centre (RBC). The balises on the track become autonomy and are simply electronic position markers or “electronic milestones”. The track characteristics are pre-programmed in the on board computer. The train detection equipment sends the train position to the control centre. The control centre that receives the train position from all trains circulating on the line determines the new movement authority and transmits continuously by GSM-R it to the train. The onboard computer then calculates its speed profile to the movement authority and the next braking point. This information is displayed to the driver. The train passes over the balise and receives a new position indication. Between two positioning beacons the train determines its position via sensors (axle transducers, accelerometer and radar). To ensure safe travels the on board computer continuously determines the train position and checks if the current speed is correct for the distance travelled.

3.10.4 ERTMS/ETCS – level3

In level 3, ETCS goes beyond the pure train protection functionally with the implementation of full radio-based train spacing.

It has an onboard train integrity system, which monitors if the train is complete.

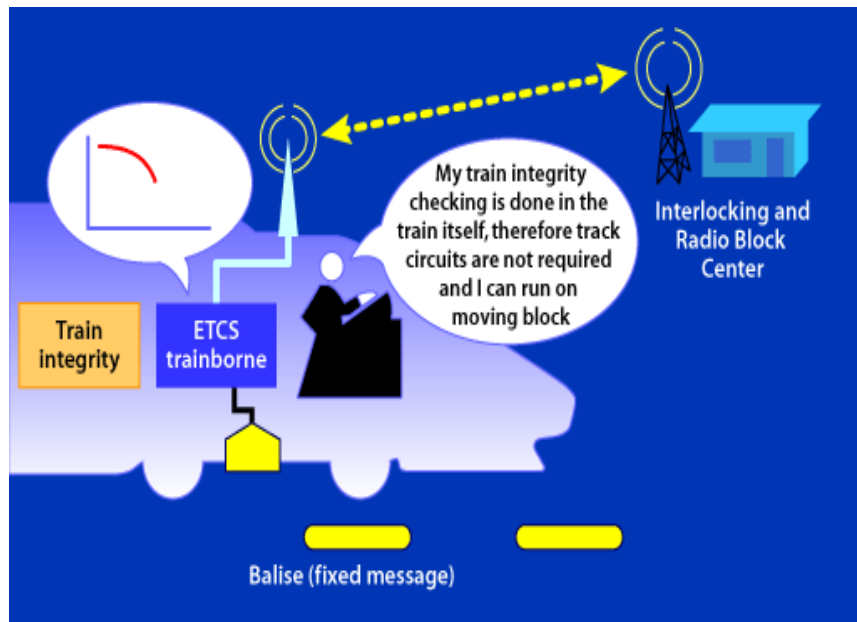


Figure 3.10 - ERTMS/ETCS level 3 [c]

Therefore there is not requirement for train detection equipment, which can be removed from the track.

As in level 2 train requires onboard radio system that allow the on board computer to communicate with the control centre. Balises are simply electronic kilometres markers. Track characteristic are pre-programmed in the onboard computer. The train passes over the balise receive a new position indication. The onboard computer determines the train position and checks if the current speed is correct for the distance travelled. The train sends his position to the RBC, which receives the position of all the trains circulating, determines the new movement authority and radios it to the train. The onboard computer then calculate the speed profile and the next braking point, this information is displayed to the driver. The route is thus no longer cleared in fixed track sections.

The possibilities of frequent update of movement authority through radio transmission enables trains to run closer together and the line capacity been increased by significantly (*moving blocks*).

There are two types of moving block:

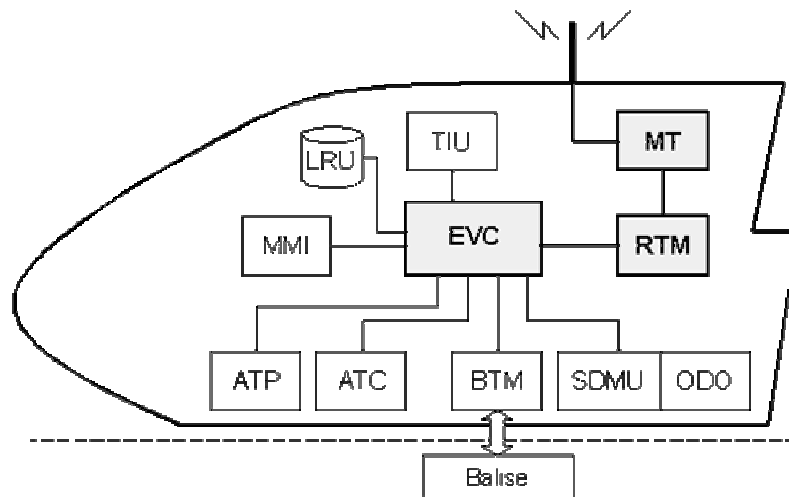
- ✓ static block;
- ✓ dynamic block;

In the first one is kept the idea of safety distance between trains with an absolute braking distance. Even if the movement authority is not anymore on fixed lengths but on moving ones, two consecutive trains must maintain the same mutual distance imposed for previous levels.

The second one takes into account the fact that the train ahead has a minimum emergency braking distance and uses this as separation distance to allow the train following to stop in safety. Of course this level of moving block requires a great amount of real-time data that must be absolutely reliable. One of the solutions at stake to collect most of these data is the use of Galileo satellite solution to monitor train run.

3.10.4.1 TRAINSIDE EQUIPMENT IN LEVEL 3

In level 3, on board subsystem can be schematized as in figure 6.6.



EVC	European Vital Computer
RTM	Radio Transmission Module
MT	Mobile Termination
BTM	Balise Transmission Module
MMI	Man Machine Interface
ODO	Odometer Card
SDMU	Speed and Distance Measurement Unit
LRU	Legal Recorder Unit
TIU	Train Interface Unit
ATP	Automatic Train Protection
ATC	Automatic Train Control

Figure 3.11 - Architecture of the onboard system for level 3

The several devices are here briefly explained:

- *European Vital Computer (EVC)*, it is the central component of the system. Its task is controlling the right and secure running of the train. EVC both receive data from trackside, Eurobalise and Euroradio, and from onboard, as SDMU and TIU.
- *Automatic Train Control and Automatic Train Protection (ATC and ATP)*, they interact with lineside signals to guarantee the respect of signals themselves (see chapter 5).
- *Balise Transmission Module (BTM)*, it is the interface between the EuroBalise system and the EVC. It has the task to receive messages from balises, elaborate them and send to EVC.

- *Speed and Distance Measurement Unit (SDMU)*, thanks to sensors it gives information about speed and run distance.
- *Train Interface Unit (TIU)*, it allows EVC to interface with all the others onboard subsystems as emergency brake, the automatic open/close door device.
- *Radio Transmission Module (RTM) and Mobile Termination (MT)*, they represent the interface between EVC and the Radio Block Centre.
- *Man Machine Interface (MMI)*, it allows to the driver interacting with the EVC and in general with the others subsystem devices.
- *Legal Recorder Unit (LRU)*, it records all the onboard events, as vocal communications, RBC instructions, train instant speed, allowing a postponed analysis in case an accident occurs.

4 CAPACITY RESEARCH STUDY

4.1 CAPACITY

Capacity is a complex term which universal and punctual definition is difficult to carry out. This is a term widely exploited in technical definitions in the most different fields.

Even if we refer to a specific field as railway it is difficult find a unique definition, as the several authors' attempts to find the best suitable explanation of the parameter proof.

At example if we choose the definition given by Krueger:

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

It is possible to see how this definition does not give a specific frame at the problem. In fact it could mean anything from the number of tons moved, speed of trains, maximum number of trains per day, passengers... that can be fitted on the line.

So, railway capacity is an elusive concept that is not easily defined or quantified. Difficulties include the numerous interacting/interrelated factors, the complex structure of the railway layout, and the magnitude of terminology required.

Different kinds of capacity can be used:

- *theoretical capacity (or physical)*: is the number of trains per a defined period of time that could route in a strictly perfect, mathematically generated environment. It represents the maximum upper boundary of capacity and it is achieved with the assumption that all the trains are

the same, with equal priority and spaced during the time interval without disruption;

- *practical capacity (or achievable)*: is determined by simulations considering that is not actually possible to run all the trains determined mathematically, and it is more representative of a scenario with train mix, priorities etc..
- *commercial capacity*: is the actual volume occurring over the territory. It is the number of trains that could reasonably expected to run over the considered period after removing all the trains that are not needed (ex. night commuter trains);
- *available capacity*: is the difference between practical and commercial capacity. It shows the additional traffic volume that could be fitted in the line.

The study of capacity is a powerful parameter tool in railways field in all its different steps, from design to operation.

The application that derives from capacity research can be several as follow:

- project planning and operations analysis for new starts and extensions,
- evaluating transit line performance,
- establishing and updating service standards,
- studying environmental impacts,
- *assessing the capacities of new signalling and control technologies,*
- *estimating changes in system capacity and operations over time.*

4.2 COMPONENTS IN CONSIDERATION

As demonstrated in [1] railway capacity rate is controlled by three major components:

- ✓ train control and signalling;
- ✓ station dwells;

- ✓ passengers loading levels.

In this study not all these aspects are taken in account.

As the target of the study suggest (the effects on capacity operation deriving from a switch in signalling system), more attention will be given to the signalling aspects than the other components above mentioned, before with an analytical approach that will look for the theoretical capacity and, later on, with a simulation that will investigate the practical capacity.

Anyway for completes it is necessary state that stations represent a considerable part in the overall capacity value; in particular they do become a factor in capacity when they combine with minimum operating headway to create a constraining headway bottleneck in the system. As showed in [1] station dwells are governed by several components:

- train characteristic:
 - door operation, actual opening and closing time, plus door warning time and any other fixed system constraints on door operation;
 - number, width and spacing of vehicle doors;
- passenger volume, average number of passengers boarding and alighting;
- passenger crowding, efficiency of pedestrian movement is very sensitive to crowding;
- platform circulation, if platforms are too narrow, or exit path limited, congestion on the platform can cause delays in unloading a train;
- single/dual platform loading/unloading, door operation on a single side is the norm; however, some systems configure busy stations with platforms on both sides of a train;
- high or low level platform loading/unloading.

So, being aware of the importance of all these parameters (and the improvement of capacity that can derive working on these) we will not focus the attention on such parameters. Also trains will be introduced just from their

different performances studying how these affect each other and the final capacity of the line.

4.3 QUANTITATIVE ANALYSIS

4.3.1 Definitions

This part of the work is dedicated to study the theoretical capacity over the two signalling systems.

As first, following the treatment in [4], it is necessary give some more definitions.

Traffic net can be defined, in general terms, as a set of branches connected by nodes: the branch is where the movement happens, the node is where the compartment choices of the vehicle happen. (A. ORLANDI)

Said that, if we simplify the analysis at the branches, it is possible define the capacity (C) as the maximum limit of two parameters as throughput or density. These two parameters are so defined:

- *throughput (q)*: the numbers of train that run through a generic point of a branch in a time unit interval (train/hour or train/day);
- *density (K)*: the number of trains present in a particular instant, on a unitary branch section (train/km).

As trains can only enter and exit the branch at the two nodes, throughput is constant throughout a branch ($q = \text{cost}$). Moreover, by definition throughput cannot exceed the capacity ($q \leq C$).

4.3.2 Theoretical branch capacity

Throughput and capacity can be expressed with the next formulas (note that an omotaxic speed is here assumed):

$$q = \frac{1}{T} = \frac{v}{\delta} \quad (1)$$

$$C = q_{\max} = \frac{1}{T_{\min}} = \frac{v^*}{\delta_{\min}} \quad (2)$$

where:

T : train headway (temporal train spacing between two following trains);

v : train speed;

v^* : critical train speed (the highest speed allowed with the given braking distance);

δ : distance spacing (between two following trains);

$$\delta_{\min} = d + L_t + f$$

where:

L_t : train length;

f : safety margin (usually 20m);

d : the minimum distance between two trains that allows the one behind to run not being slowed by the one ahead.

Once calculated $\delta_{\min}$ it is possible compute the throughput as function of train speed ($q = q(v)$).

According with the objective of the study, some considerations about fixed blocks and moving blocks follows in the next two paragraphs.

4.3.3 Fixed blocks

As said we assume that the actual situation is represented by a line with fixed blocks (the theory behind this kind of separation has been explained in chapter 2).

In a regulation like this the train in rear can run without interferences if always sees green signals. So, if we consider a multiple fixed block condition, the line is divided in $n-2$ yellow signalling posted at the distance $b/(n-2)$; where b becomes the length of the "separation section" and goes from the first yellow encountered from the following train to the red signal.

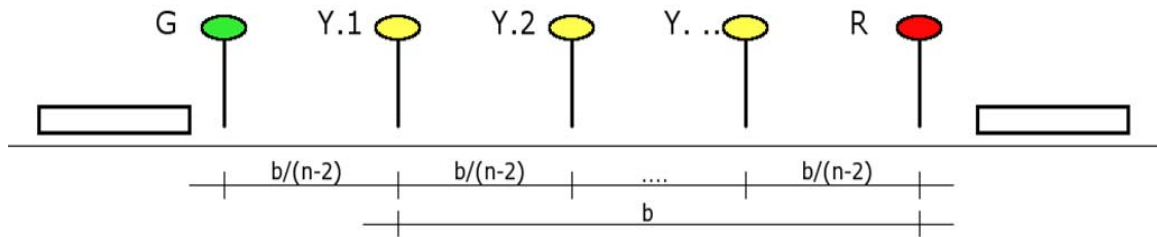


Figure 4.1 – Division in block system with the two main signals and the $n-2$ yellow signals

In order for the train in rear to always see a green aspect it is necessary that this one is located at a distance major (or equal) to b (that itself must be major or equal the braking distance). This distance can be expressed by the following equation:

$$d = b + \frac{b}{n-2} = \frac{n-1}{n-2}b \quad (3)$$

(if $n \rightarrow \infty, d = b$)

and:

$$\delta_{\min} = \frac{n-1}{n-2}b + L_t + f \quad (4)$$

Once obtained the minimum headway it is possible calculate the expression of the throughput as:

$$q = \frac{v}{\frac{n-1}{n-2}b + L_t + f} \quad (5)$$

4.3.4 Moving blocks

In moving block, as said previously (see paragraph 2.4.3), the running distance between two trains is reduced to the space needed to the train in rear to completely stop from the actual speed. This space is represented by the coefficient η :

$$\eta = k \frac{v^2}{2\gamma} \quad (6)$$

where:

v : train speed

γ : deceleration rate (assumed constant)

k : safety coefficient (normally equal to 1.1)

So the throughput can be expressed by:

$$q = \frac{v}{k \frac{v^2}{2\gamma} + L_t + f} \quad (7)$$

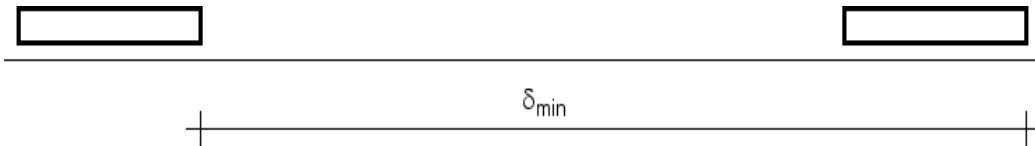


Figure 4.2 - Minimum headway in moving blocks

Note. As demonstrated in [4] the equation (7) represent the maximum theoretical limit for each q - v curve.

4.3.5 Formulas method

Before to apply the formulas just introduced, we need consider a rolling stock. We have decided it represented by three trains, each one chosen from the three categories commonly running on railways, which are:

- long distance trains,
- regional trains,
- freight trains.

4.3.5.1 TRAINS

The three trains, circulating on the Swedish infrastructures, are next described.

X2 – long distance train



Figure 4.3 - Train x2 [7]

	V (km/h)				
top speed	200	m (ton)			
mass		342	m (ton)		
dynamic mass			362	d (m/s ²)	
deceleration				0,8	Lt (m)
train length					136

X60 – regional train



Figure 4.4 - Train x60 [7]

	V (km/h)				
top speed	160	m (ton)			
mass		412	m (ton)		
dynamic mass			437	d (m/s ²)	
deceleration				0,8	Lt (m)
train length					214

Rc4 – freight train



Figure 4.5 - Train Rc4 [7]

	V (km/h)				
top speed	95	m (ton)			
mass		1000	m (ton)		
dynamic mass			1060	d (m/s ²)	
deceleration				0,4	Lt (m)
train length					600

4.3.5.2 RUNNING TIME CURVES

Before being able to use (5) formula we need to calculate n and b .

To do this for each train a "running time curve" has been handy calculated. These curves are useful to determine parameters for the determination of q but will be useful in the method proposed next.

Curves are obtained running the trains on a hypothetical 100 km line with no middle stations and divided in blocks of 1500 metres each (the most common value on Swedish tracks). An example of a full calculation is addressed in appendix A.

Passages and relations used for the calculation of these curves are next briefly posted; these are grouped for the three phases of the mote (acceleration, constant speed and deceleration).

Acceleration part of the mote

⇒ division of the speed between 0 and top speed every kilometre per hour

⇒ calculation of ΔV

⇒ calculation of acceleration as

$$a = \frac{F - D}{m_d} \quad (8)$$

where F = tractive effort [KN] (given)

D = resistances [KN] (given)

M_d = dynamic mass [ton]

Note that whether the F overcome the adhesion this takes its place in the formula.

⇒ calculation of the interval of time between a successive increment of acceleration Δt as

$$\Delta t = \frac{\Delta V}{a} \quad (9)$$

⇒ the time when the actual speed happens

$$t = \sum \Delta t \quad (10)$$

⇒ and finally the space covered at the actual speed

$$S = \frac{V_2 - V_1}{2} \Delta t \quad (11)$$

Braking part of the mote:

⇒ same passages than before (of course the division of the speed is from the top speed to 0) are applied. The difference here is that the tractive force is substituted by the braking force ($F=m*a$) summed to the resistances (which in this phase help the mote).

Constant speed part of the mote:

⇒ space run in this phase is calculated starting from the arrival distance in the acceleration mote with the relation:

$$S = S_0 + V(t_2 - t_1) \quad (12)$$

This relation is applied until the distance obtained from the subtraction at the total track length of the braking space.

Next the three curves are reported.

- X2 -

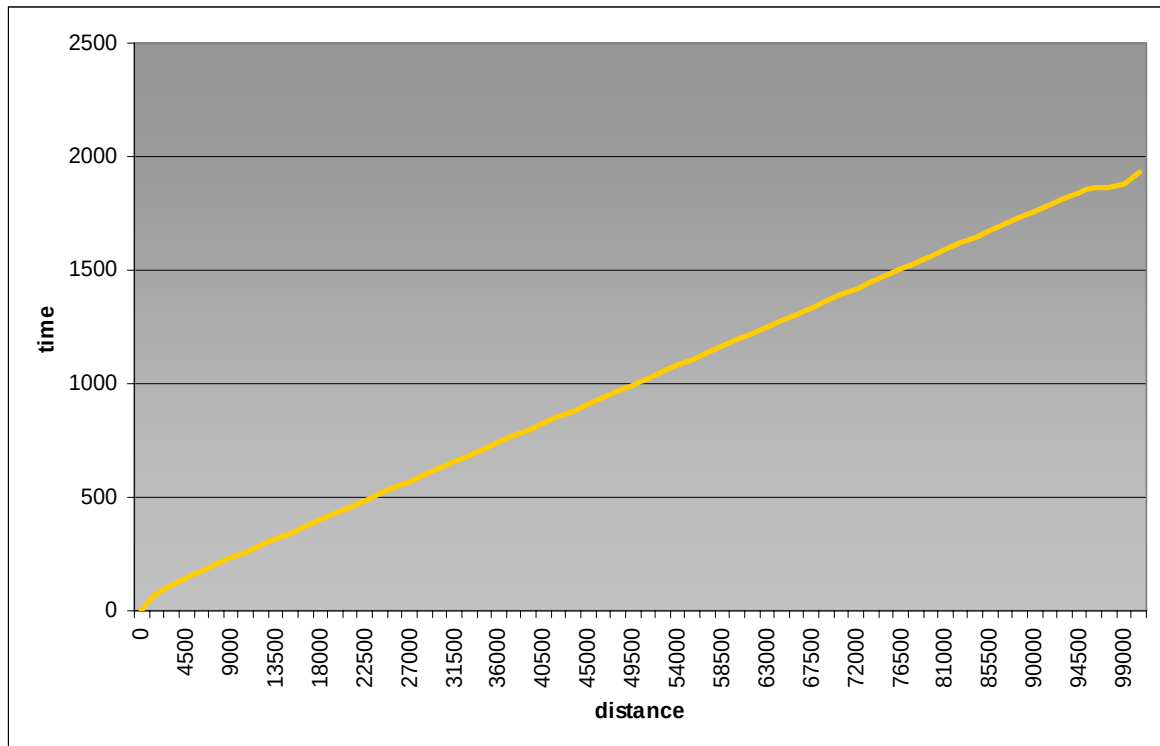


Figure 4.6 - Running time of x2

- X60 -

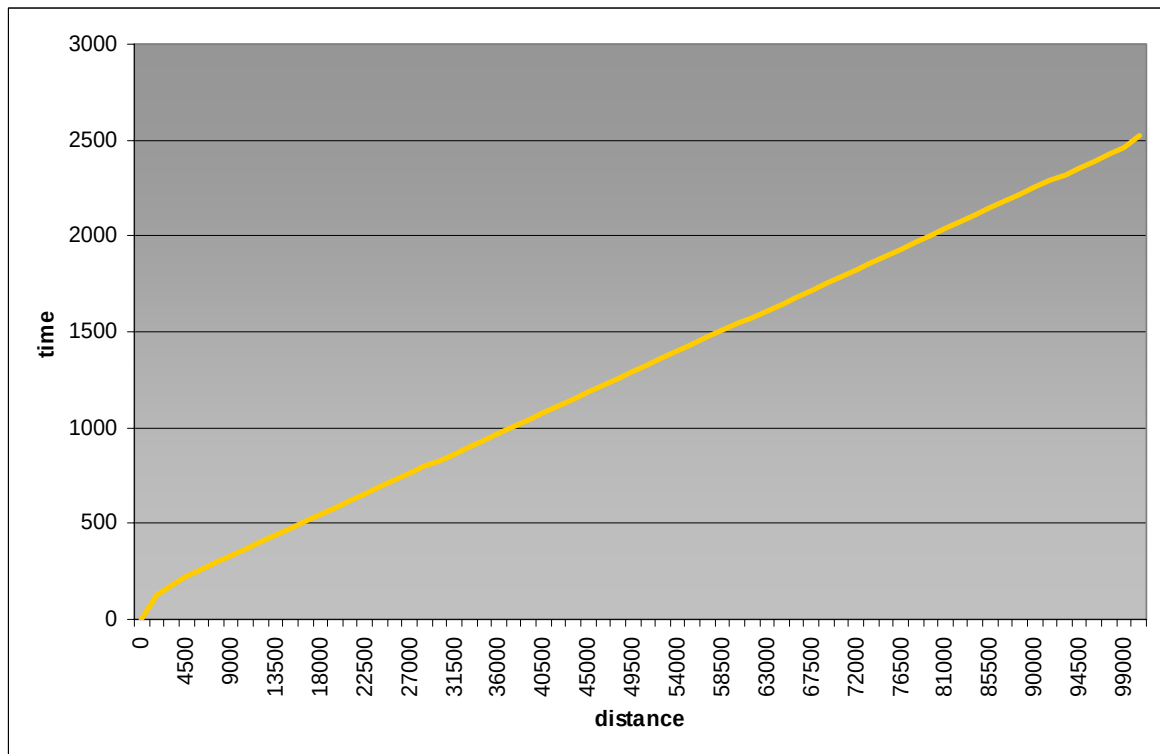


Figure 4.7 - Running time of x60

- Rc4 -

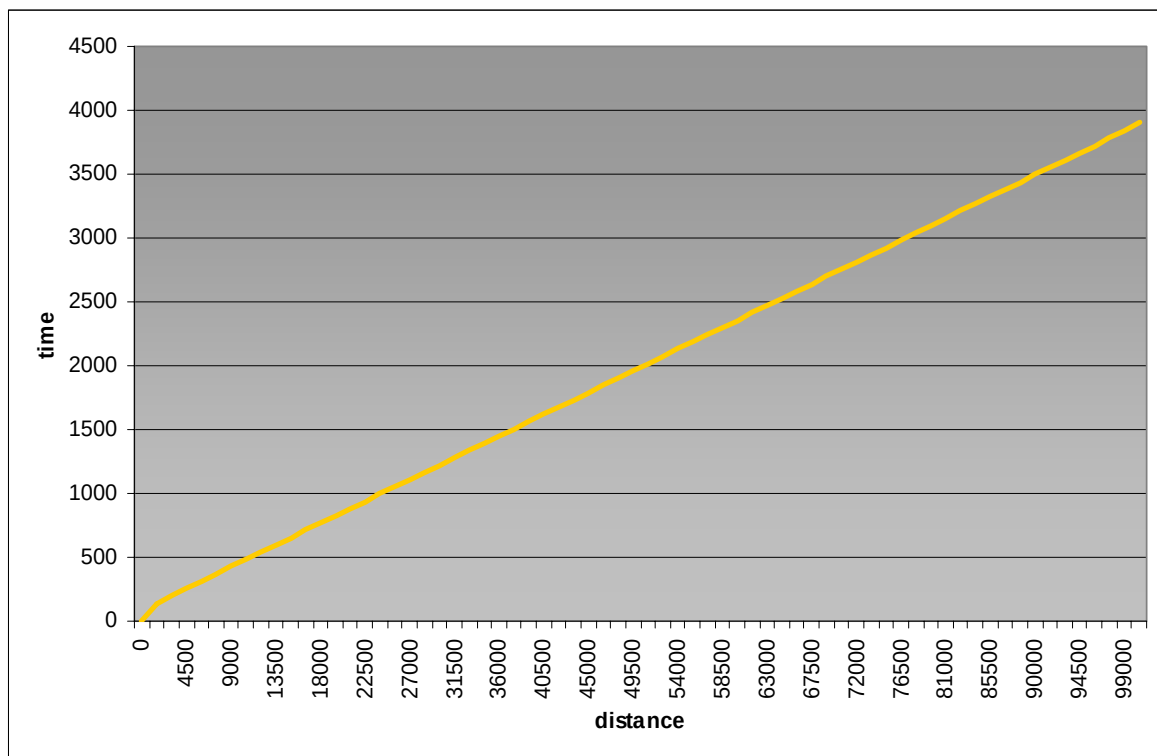


Figure 4.8 - Running time rc4

Thanks to these curves the time and the space used from each train in each phase of the mote are known. These are reported in the figures next.

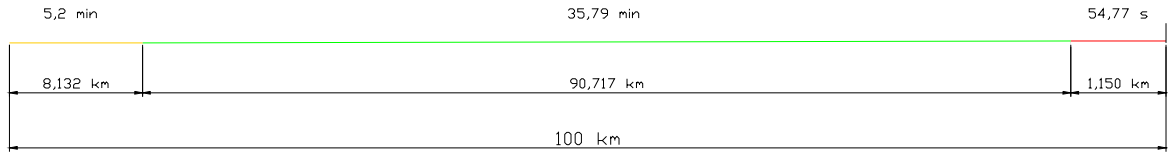
X2 – long distance

	time (min)	distance (km)
acceleration	2,44	4,496
const. speed	29,5	93,759
deceleration	1,12	1,745



X60 – regional train

	time (min)	distance (km)
acceleration	5,2	8,132
const. speed	35,79	90,717
deceleration	54,77(s)	1,150



Rc4 – freight train

	time (min)	distance (km)
acceleration	1,55	3,094
const. speed	60,8	96,321
deceleration	44,83(s)	0,585



4.3.5.3 THROUGHPUT CALCULATION: BLOCK SYSTEM

As said to be able to use formula (5) we need to know the values of b and n . To obtain these we use the longest braking distance (d_{brake}) among the three trains. In our case this is represented by the X2's, so:

if d_{brake} is 1745 m $\rightarrow b = 3000$ m $\rightarrow n = 4$ aspects (see paragraph 4.3.3)

Once got these we are able to evaluate the throughput for fixed block. The values are reported in the table below for the three components of the railway stock.

<i>Train</i>	V^* [km/h]	b [m]	n	L_t [m]	f [m]	q [train / hour]
<i>X2</i>	190	3000	4	139	20	40,81
<i>X60</i>	152	3000	4	214	20	32,13
<i>Rc4</i>	95	3000	4	600	20	18,57

Table 1 - Value of q in block system using formula method

* the value of V corresponds to the maximum speed achievable by the train reduced by the 5%. This, as in practise happens, to roughly introduce a “delay time” over the line.

4.3.5.4 THROUGHPUT CALCULATION: MOVING BLOCK

Knowing from train characteristics all data to directly apply relation (7), it is possible evaluate the throughput for the moving block.

<i>Train</i>	V^* [km/h]	k	γ [m/s ²]	L_t [m]	f [m]	q [train / hour]
<i>X2</i>	190	1,1	0,8	139	20	91,54
<i>X60</i>	152	1,1	0,8	214	20	104,23
<i>Rc4</i>	95	1,1	0,4	600	20	60,21

Table 2 - Values of q in moving blocks with formula method

Note_ for the values of V the same considerations before are used.

4.3.6 Considerations

As data in tables above suggest, values of q increase moving from fixed blocks to moving blocks.

This happens because the train is independent from a track side approach aspect (the difference would be even higher if we considered more “components” of the block aspect and not just this as a space divisor). On a line with lineside signals, the signalled approach distance has to meet the braking distance of the faster train. If we look at our example, the signalled approach distance has been calculate for the X2 and is equal by 3000 metres

that is much longer than the braking distance needed for the Rc4 that is of 585 metres (actually even for X2 this distance could be shorter considering that it can stop in 1745 m; but the blocks of 1500 m impose this distance!). So this is why for a moving block, in which the signalled approach distance meets the real braking distance, if we study basic scenario the value of q can only increase.

Besides using the relations (5) and (7) this is a logic feedback. In fact, with the use of these all the “frame” is not relevant and just the main train characteristic are taken in consideration.

This can be clearer if we look at the relation of capacity C (as defined before the maximum throughput) for moving block. Remembering that:

$$C = \frac{v^*}{\delta_{\min}}$$

and that v^* is the value that renders maximum the throughput; therefore the value obtained nullifying the q' :

$$v^* = \sqrt{\frac{2\gamma(L_t + f)}{k}} \quad (13)$$

The capacity C becomes:

$$C = \sqrt{\frac{\gamma}{2k(L_t + f)}} \quad (14)$$

Here we can easily notice how the results are strictly connected to train performances. In fact they are directly proportional to the deceleration rate and indirectly proportional to the train length. In this relation, more the train has good braking performance and more it is compact more the value of C that derives is higher.

As we look at our example the values of q for X2 and X60 well testimony this situation. Indeed, despite of the worst running performance, the second kind of train not only increases the value of capacity in the switching of signalling but also overcome the value of the X2 (the braking performance is assumed the same and the train length little change).

4.3.7 A further approach: graphical method

Approach proposed by the relations (formula method) considers calculation take place in a generic point enough distant from the double end, as in the Saint-Venant solid model, so that no perturbations occurs.

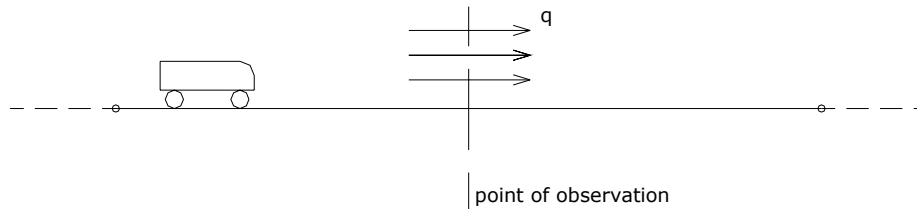


Figure 4.9 - Imaginary "point of observation" in the formula method

This seems to be a first limitation because acceleration characteristics and running performances (top speed over a distance) are not taken in consideration.

Trying introduce these factors the study is moved on an imaginary 100 km track over which we run the three trains from a point A to a point B (departing station and arriving station or starting and arrival points) and the number of train reaching the B point during the observation time are studied.

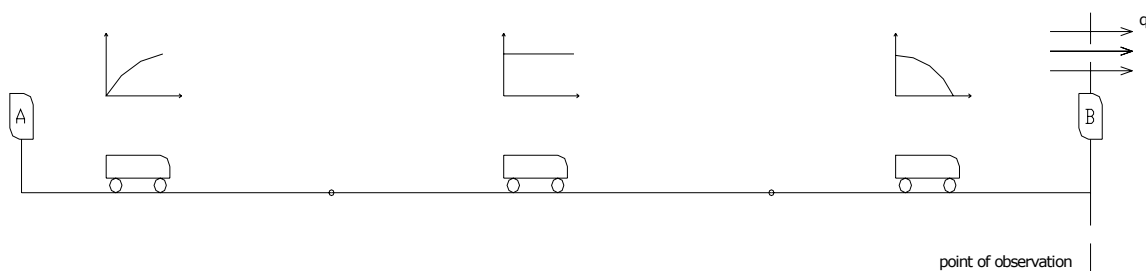


Figure 4.10 - Imaginary "point of observation" in the graphic method

To achieve this task the running time curves introduced before are used. We look to how many trains for each typology, distanced by the space required from the regulation taken in exam it is possible fit over 24 hours (1 hour is a too narrow window of observation).

4.3.7.1 FIXED BLOCKS

In figure below (figure 4.11) a representation tries to show the working principle of the method.

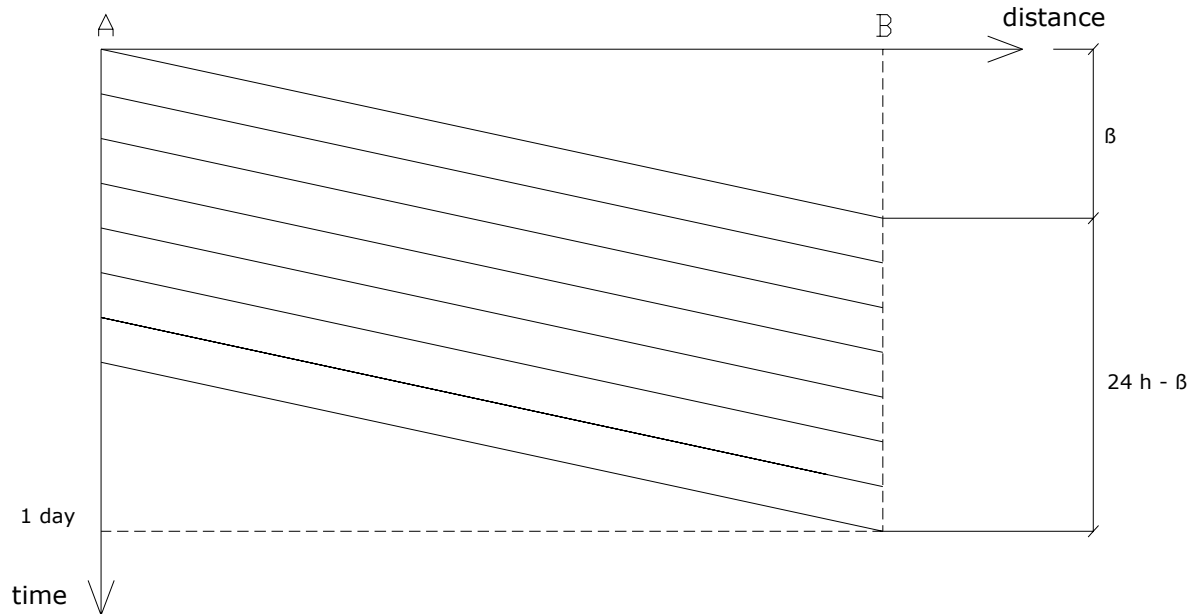


Figure 4.11 - Graphical representation of the method

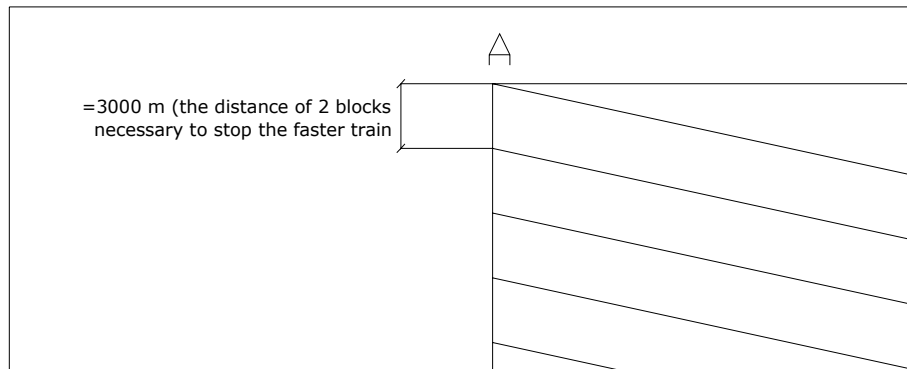


Figure 4.12 - Detail showing the distancing

Note_ the shape of the running curves is that reported previously (paragraph 4.3.5.2). Being separated by a fix distance and having all the same shape they are here represented for commodity by a straight line (the distancing remain the same all along the curve).

This basically consists in run a first train from A followed by some other trains spaced by the time to cover the two separation blocks (this value depends on

the acceleration performance of each train) required from this regulation. The value we are looking for is given by the number of trains that following the first one can complete the path within the 24 hours.

Note that we are aware that consider block regulation just from the time that the train spend inside the separating distance is a simplification.

In fact, to be more accurate we should introduce times suggested by railroad literature and addressed in [10]. In specific the minimum distance between two trains in block operation also needs to obey a time to prepare the travel path (10 s), signal view time (12 s) and time to resolve the travel time (6 s). These times would lead to a bigger separation distances compared to the one given by blocks considered as we did (in particular with high speed, if we think that at 200 km/h about 1555 metres are covered in 28 seconds). But being difficult introduce these times in a dynamic treatment and considering that even in reality they are not fully considered because would reduce the separation to lower distances rendering operation with such distances not feasible, it does not seem be a big blank doing this simplification.

It follows the calculation of the throughput for each train.

X2

Running time (A to B) = 33,06 min = 1983,6 s

Time to run over 2 blocks (3000 m) = Ω = 116,08 s

24 h = 1440 min = 86400 sec

$\alpha = 24 \text{ h} - \beta = 86400 - 1983,6 = 84416,4 \text{ s}$

$$q = \frac{\alpha}{\Omega} = \frac{84416,4}{116,08} = 727 \text{ train/day} \quad (15)$$

With the previous calculation the value of q was:

$q = 40,8 \text{ train/h} = 979 \text{ train/day}$

that is about 27% more.

X60

Running time (A to B) = 42 min = 2515 s

Time to run over 2 blocks (3000 m) = Ω = 176,97 s

$$24 \text{ h} = 1440 \text{ min} = 86400 \text{ sec}$$

$$\alpha = 24 \text{ h} - \beta = 86400 - 2515 = 83885 \text{ s}$$

$$q = \frac{83885}{176,97} = 474 \text{ train/day}$$

With the previous calculation the value of q was:

$$q = 32,13 \text{ train/h} = 771 \text{ train/day}$$

that is about 39% more.

Rc4

$$\text{Running time (A to B)} = 61 \text{ min} = 3660 \text{ s}$$

$$\text{Time to run over 2 blocks (3000 m)} = \Omega = 199,34 \text{ s}$$

$$24 \text{ h} = 1440 \text{ min} = 86400 \text{ sec}$$

$$\alpha = 24 \text{ h} - \beta = 86400 - 3660 = 82740 \text{ s}$$

$$q = \frac{82740}{199,34} = 415 \text{ train/day}$$

With the previous calculation the value of q was:

$$q = 18,57 \text{ train/h} = 445 \text{ train/day}$$

that is about 6% more.

4.3.7.2 MOVING BLOCKS

The working principle of the method is the same than before except for the separation that in this case is given by the time to cover the distance given by the braking distance, the length of the train and a safety margin (figure 4.14).

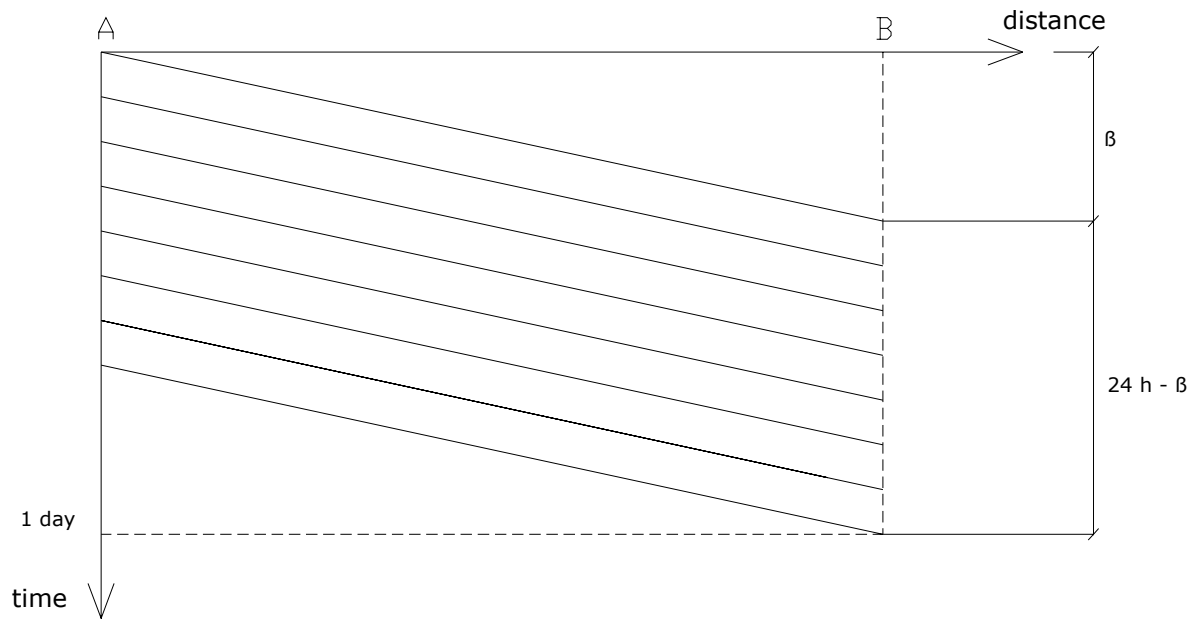


Figure 4.13 - Graphical representation of the method

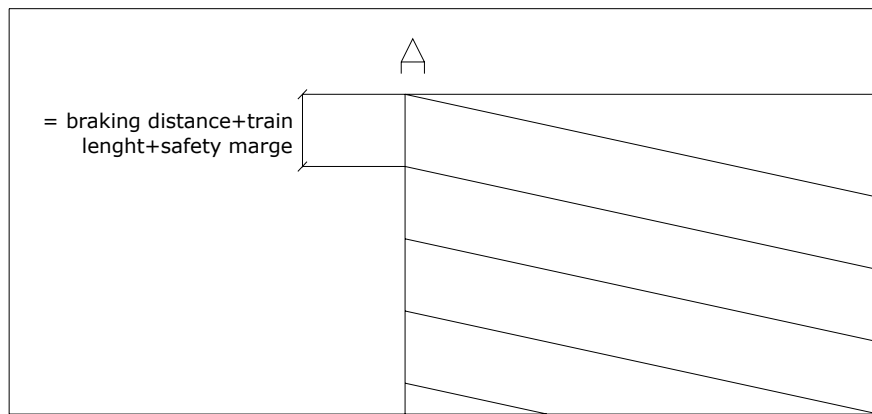


Figure 4.14 - Detail showing the distancing

Note_ the shape of the curves follows the same observations before.

It follows the calculation of the throughput for each train.

X2

$$\eta = \text{braking at the top speed} + Lt + f = 1745 + 139 + 20 = 1904 \text{ m}$$

$$\text{Time to cover } \eta = 90,4 \text{ s}$$

$$q = \frac{\alpha}{\eta} = \frac{84416,4}{90,4} = 933,8 \text{ train/day} = 933 \text{ train/day} \quad (16)$$

X60

$$\eta = \text{braking at the top speed} + Lt + f = 1150,218 + 214 + 20 = 1384,218 \text{ m}$$

$$\text{Time to cover } \eta = 118,531 \text{ s}$$

$$q = \frac{\alpha}{\eta} = \frac{83885}{118,531} = 707,70 \text{ train/day} = 707 \text{ train/day}$$

Rc4

$$\eta = \text{braking at the top speed} + Lt + f = 858 + 600 + 20 = 1478 \text{ m}$$

$$\text{Time to cover } \eta = 133,542 \text{ s}$$

$$q = \frac{\alpha}{\eta} = \frac{82740}{133,542} = 619,58 \text{ train/day} = 619 \text{ train/day}$$

4.3.8 Observations

In all the approaches proposed moving blocks seems to be a good improvement. In fact, despite of the difference in values between the two methods, the values of q and so of C increase in all the cases.

q (train/day)	Fixed blocks		Moving Blocks	
	formula method	graphic method	formula method	graphic method
X2	979	727	2196	933
X60	771	474	2813	707
Rc4	445	415	1445	619

Table 3 - Comparison of the throughput q with formula and graphic method

Looking at table 3, moving block operations could seem, in terms of system capacity, a sure way to improve line capacity and with that the service offered. Results carry out the main problem of blocking operation, the “discretization” of track space, which leads to a waste of track utilization (see 4.3.6). What just said suggest therefore that to avoid this waste blocks should be as small as possible, that is indeed what moving blocks symbolized (an infinity series of blocks which length tend to zero).

Anyway from the table observation some further observations come out.

- *Formula approach gives higher values for q than graphic method.* In particular for moving block the values of throughput appear overestimated. If the formula gives in average values 30% major for fixed block, in moving blocks the average becomes 200%.

For what concern moving blocks this can be attributed in a small part to the basis assumption of the method itself (paragraph 4.3.7). In fact, being the generic point of observation in formula method considered enough distant to the double end, here we can fit trains all over the observation time interval. This does not happen with the graphical approach where, taking in consideration a running time over a distance, we have to subtract from the all period the time that first train need to reach the final point of observation.

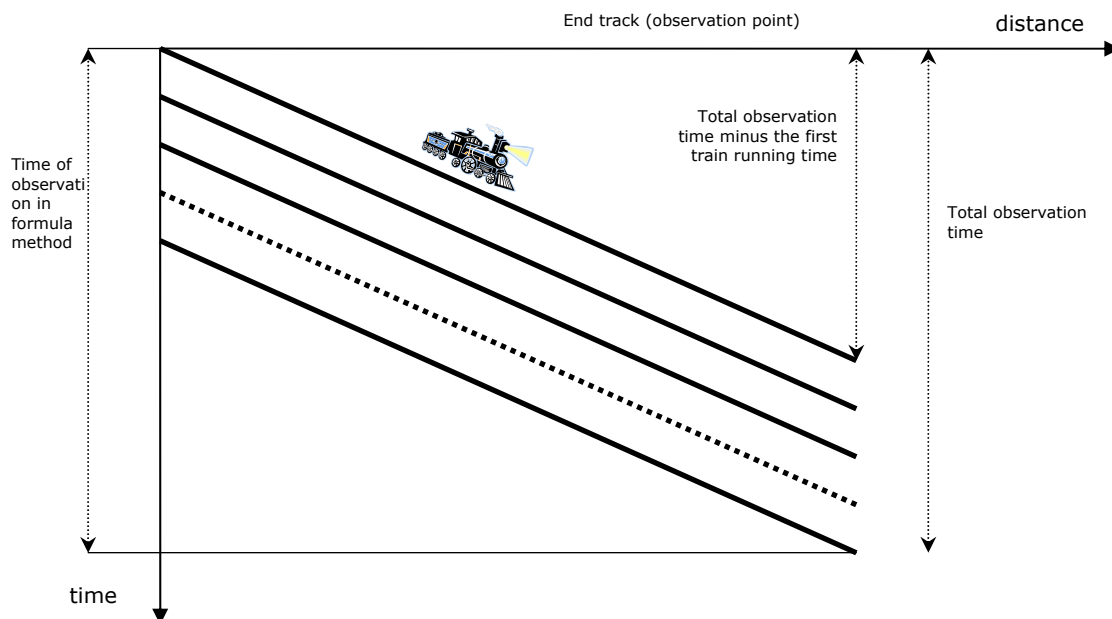


Figure 4.15 - The "extra time" in graphic method

But the main reason is that with formulas the approach is at the top speed. Instead, in graphic method (trying to more emphasis the running performances) we consider the train starting from a zero speed condition. This leads, besides a quite similar space separation needed,

to a more final time distancing. If, in moving blocks, we had considered the top speed too the separation times would change in this way:

<i>X2</i>	<i>from 90,4 s to 36 s</i>
<i>X60</i>	<i>from 118,52 to 32 s</i>
<i>Rc4</i>	<i>from 133,54 to 56 s</i>

Using these values in (16) the throughput values become really close to the values from formula approach.

For what concern fixed blocks using graphic approach the values of q are in all cases minor compared with formulas. However this difference is much major for the X2 and the X60 than for Rc4 (that is around 6%). This is because both low speed and high length lead, for Rc4, to a separation quite similar between the two methods.

Train type	Formula	Graphic	Difference
X2	89	116	26
X60	112	178	66
Rc4	194	199	5

Table 4 - Separation time in formula and graphic method

- If we compare the results within the graphical approach itself, it is easily notice that the amounts of trains increase in moving blocks, but not proportionally with the gaining in separation time.

Train type	Fix blocks [train/day]	Moving blocks [train/day]	Difference [train/day]
X2	727	933	206
X60	474	707	233
Rc4	415	619	204

Table 5 - Difference in throughput q between fixed and moving blocks in graphic approach

Train type	Fix blocks [s]	Moving blocks [s]	Gaining [s]
X2	116	90	26
X60	176	118	58
Rc4	199	133	66

Table 6 - Separation time in the two regulation systems in graphical approach

In fact if the gaining would lead to a linear increment of trains we should had 240 trains for the Rc4 component and not the 204 obtained. This can be explained with the less performances of the freight train. Moreover this testimonies the existence of a relation between separation and performances (braking and top speed).

After this first approach and the observations pointed out, it arises to question if the values obtained are weak and/or in general how much they can represent reality. In fact the basic scenario proposed simulates more a running over an underground line (with no middle stations) than on a railway one. So the main question comes out is: what would happen if we move the calculation closer to reality?

To bring our calculation more near to reality next steps seem necessary:

- ✓ *merge the different traffic stock* so that the different running characteristics wave together creating the typical situation of overlap of routes;
- ✓ *insert middle stations* so that the different characteristics of acceleration and deceleration are more pointed out (approach to the station and readmission in the line); and allowing overtaking.

To move the study this way it is necessary introduce a more powerful tool. This is represented by a simulator program that allows more complicated calculations. In our case this tool is represented by *Railsys*

4.4 SIMULATION

As said capacity analysis and planning in general is a quite important task through the most dependable and economical method of operating a given railroad infrastructure is determined. The by hand approach to evaluate different alternatives in order to find at least seemingly acceptable solutions is time-consuming and often hard to verify, so nowadays they are hardly applied.

Presently, simulation modelling is the only way in which each step of the transportation process can be included in the plan. [...] Depending on the nature and complexity of the problem, simulation modelling may be as simple as the use of paper and pencil track of the process, as complex as the use of sophisticated computer programs, or may involve some combination of both methods. [T. White]

The simulation presented in this work has not the pretence to be a detailed representation of the reality or to carry out a suitable timetable. The simulation has been carried on trying to have an as much possible simplified model, with enough data and parameters to evaluate in the most realistic manner what we are looking for.

4.4.1 RailSys®

The timetable and infrastructure management program *RailSys 5.0* is a software system for analysis, planning and optimization of operational procedures and facilities in rail born transport networks of any size. Operational procedures are realistically displayed on desktop computers and the investigation of whole systems is just as easily accomplished as the processing of specific, local problems.

The program has been developed by the University of Hannover and RMCon (Rail Management Consultations). It has been applied successfully in different

projects such as the high speed lines Cologne – Rhein/Main and Sydney – Canberra, the city railways of Munich, Cologne, Sydney, Melbourne... or the rail network in Berlin and Copenhagen. [RMCon]

RailSys consists on four components:



Figure 4.16 - RailSys structure [f]

4.4.1.1 INFRASTRUCTURE MANAGER

The function of infrastructure manager is to model the infrastructure. Infrastructure data includes switches, signals, stations, speed indicators, platforms, stop boards, routes... and they contain attributes about track parameters like length, gradient, max speed ... The data can be entered either graphical or in tabular form. The infrastructure is built up as a succession of nodes and links, where a link symbolises a track and a node is either a

connecting point of several links or location for signals and other elements. The accuracy is up to 1 metre.

Various protection systems are installed in the infrastructure manager. Most of these are German systems, such as ATC (LZB).

4.4.1.2 TIMETABLE MANAGER

Thanks to the timetable manager it is possible set exact routes and different alternatives for every train in the line network that was created in the infrastructure manager.

The main task of the program is the optimal allocation of locomotives in large lines or networks, showing inconsistencies such as unfeasible connection time, not enough headways and conflicts with other trains. To do this it uses many functions as the network-wide continuous conflict recognition and the continuous calculation of the minimum running time.

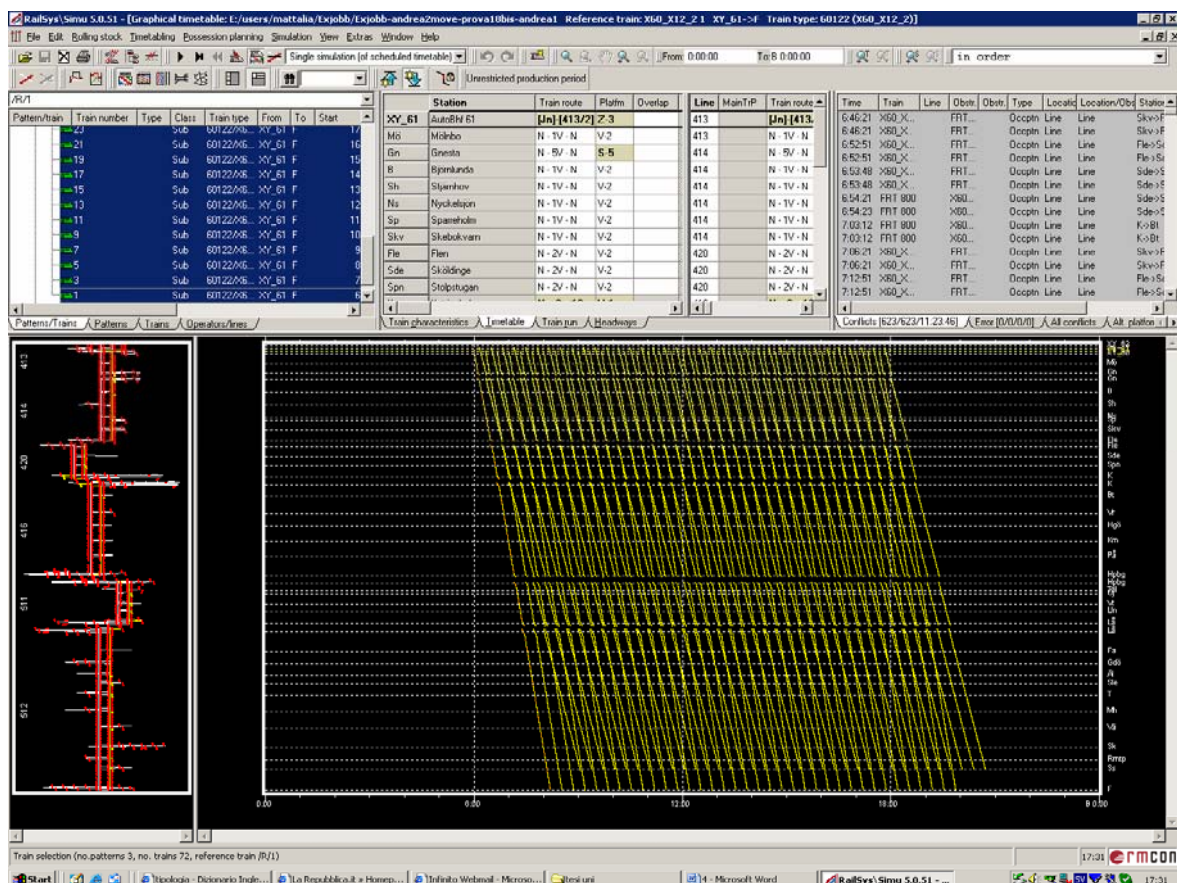


Figure 4.17- Main screen of the timetable manager

4.4.1.3 SIMULATION MANAGER

It is possible to run a nominal or a perturbed simulation.

Nominal (or single) simulation serves normally to check that everything is working fine (some conflicts may not have been detected previously).

Perturbed simulation is necessary to emulate real train operation and the very complex relationship when a train is delayed. These simulations can be edited according to several criteria as delays in dwell time, accumulated delays at the departure of some trains.

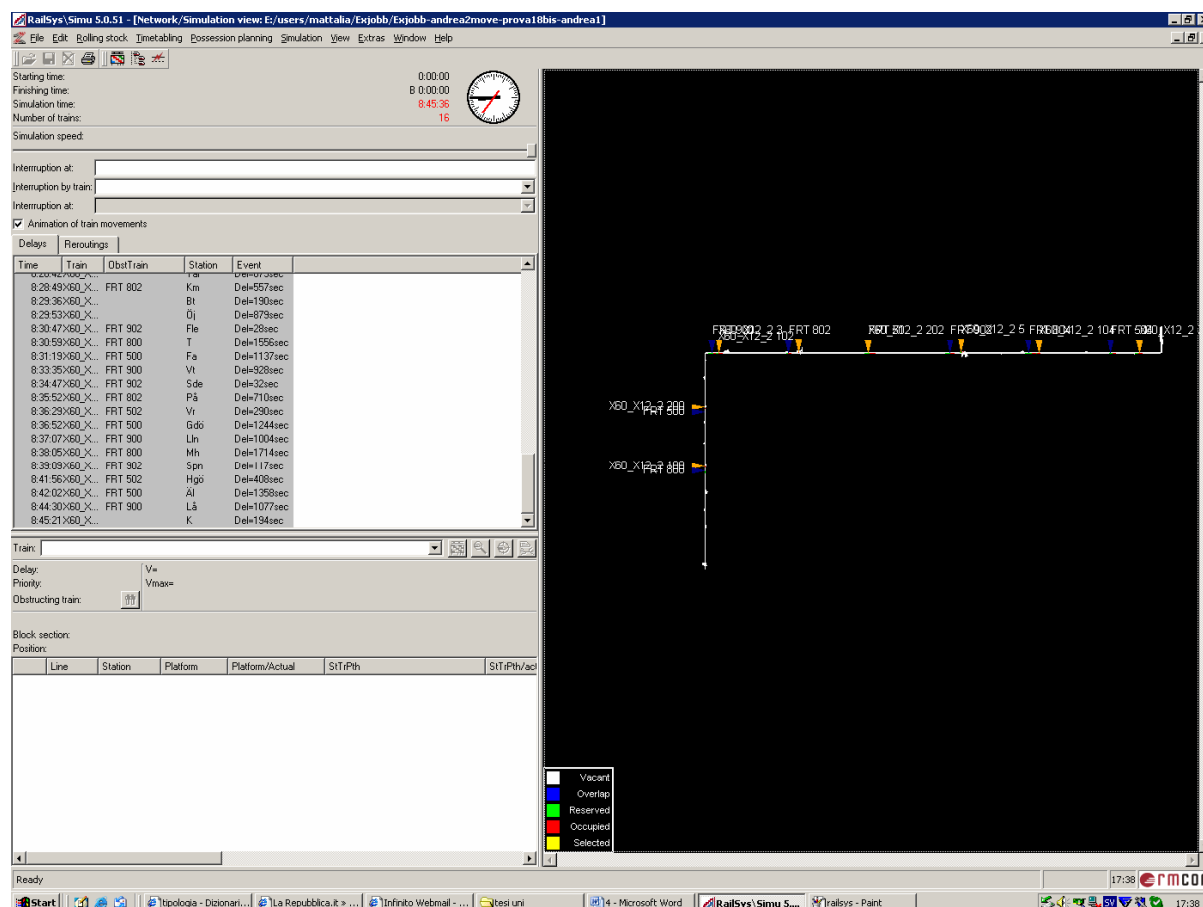


Figure 4.18 - Screen from a single simulation in the timetable manager

4.4.1.4 EVALUATION MANAGER

This module has been developed to evaluate the impact of the infrastructure or timetable alternatives. It evaluates the performance of the simulated operational program, by means of preparing and analysing the delay data. To identify the most favourable option, comparisons should be made. The results can be displayed as performance of the whole network, for lines only, in

stations, for the total amount of trains or for different patterns and different parameters can be analysed: arrival and departure delays, additional generated delays (which could identify critical sections), on time running performances at stations, number of delayed trains, number of operational manoeuvres (or rerouting), block occupation...

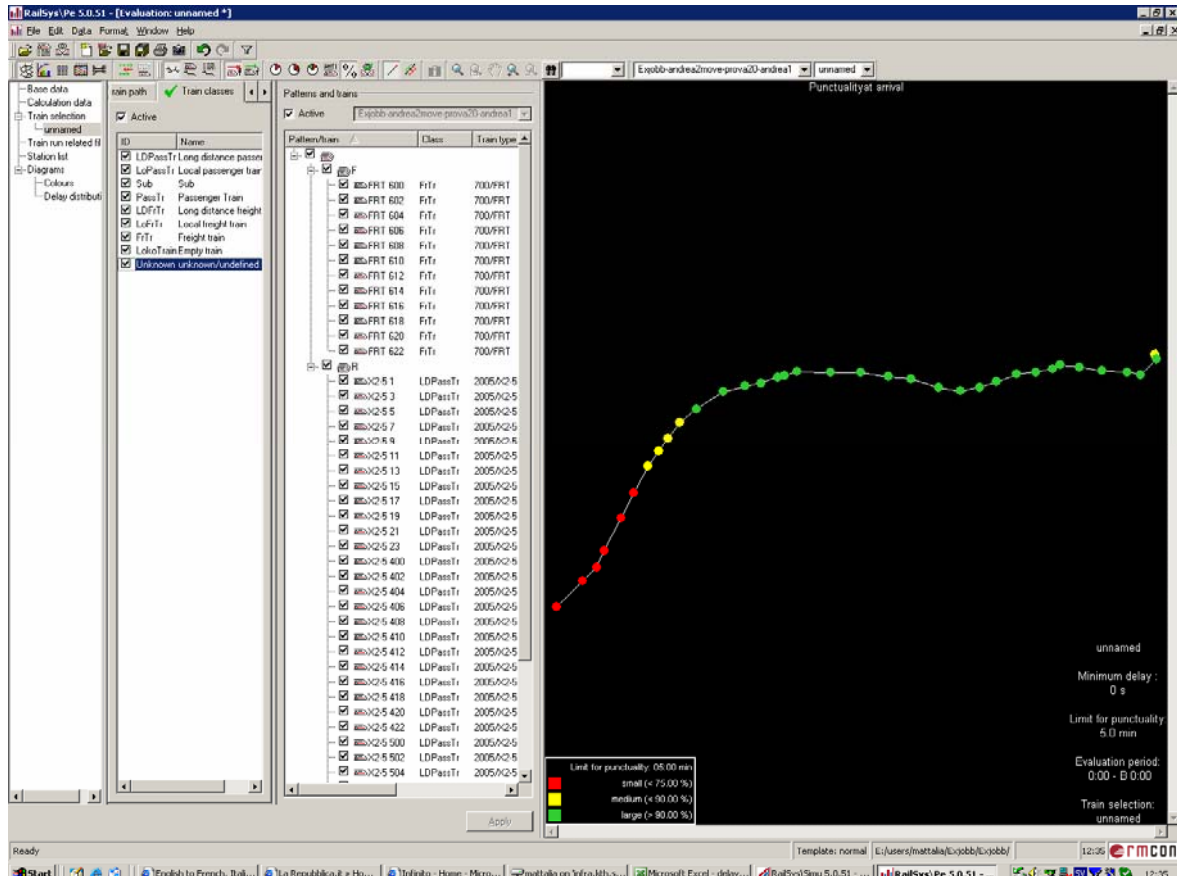


Figure 4.19 - Main screen of the evaluation manager

4.4.2 The single simulation

The simulation is firstly approached by the single simulation.

Basically the operation consist in run over a track from the Swedish infrastructure (built in the infrastructure manager) several combination of traffic pattern to study how capacity vary within both rolling stock and signalling system (fix block and moving block) changing.

The *simulation track* has been chosen on the main link Stockholm–Goteborg.

It has been decided to cut out the two main stations for simplicity reasons. The criterions that have led up to choose these almost 300 km as test track over others are, of course the importance of the line, but also the “basically” output of this (no important gradient and curves). The last principle appears important to give to results a general interpretation.

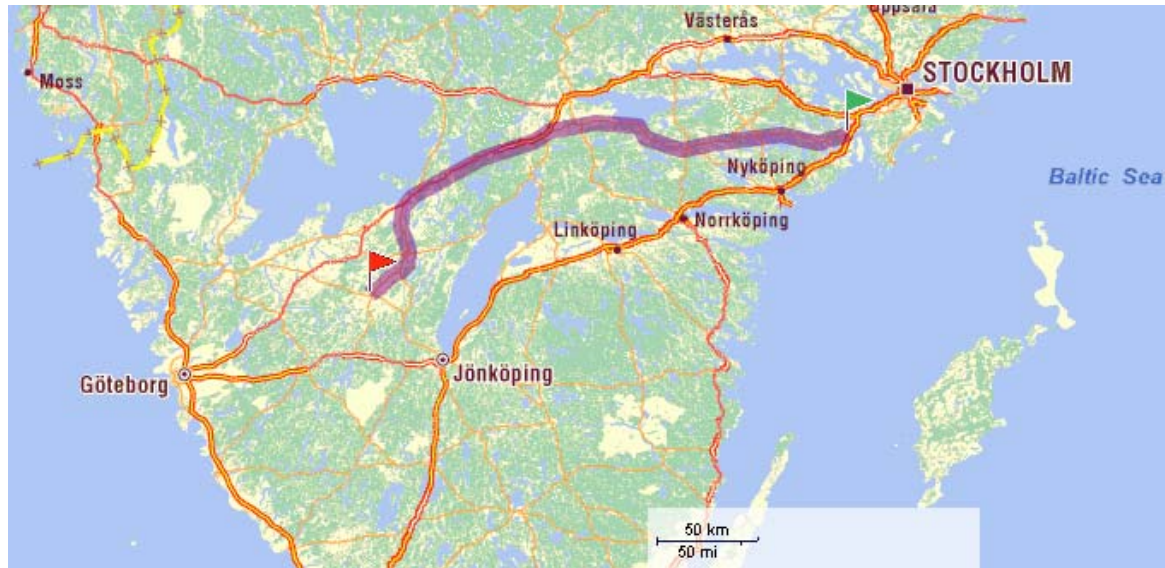


Figure 4.20 - Route of the track in exam

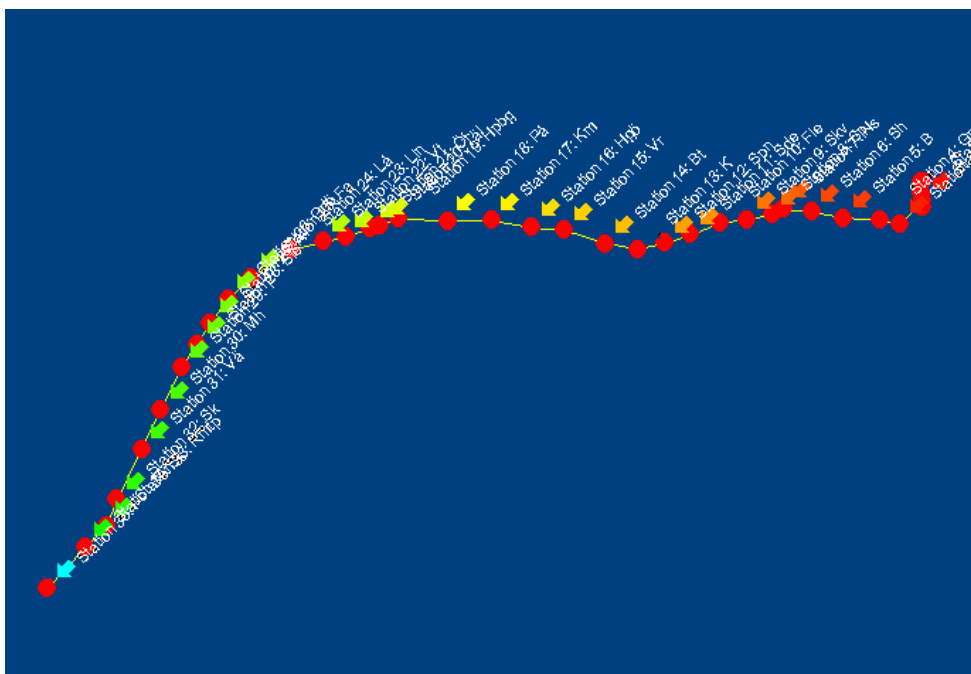


Figure 4.21 - Macroscopic view of the track in RailSys

The *trains* are the same introduced before (chapter 4.3.5.1) and they are combined to create as much as possible interesting fleets to ponder on.

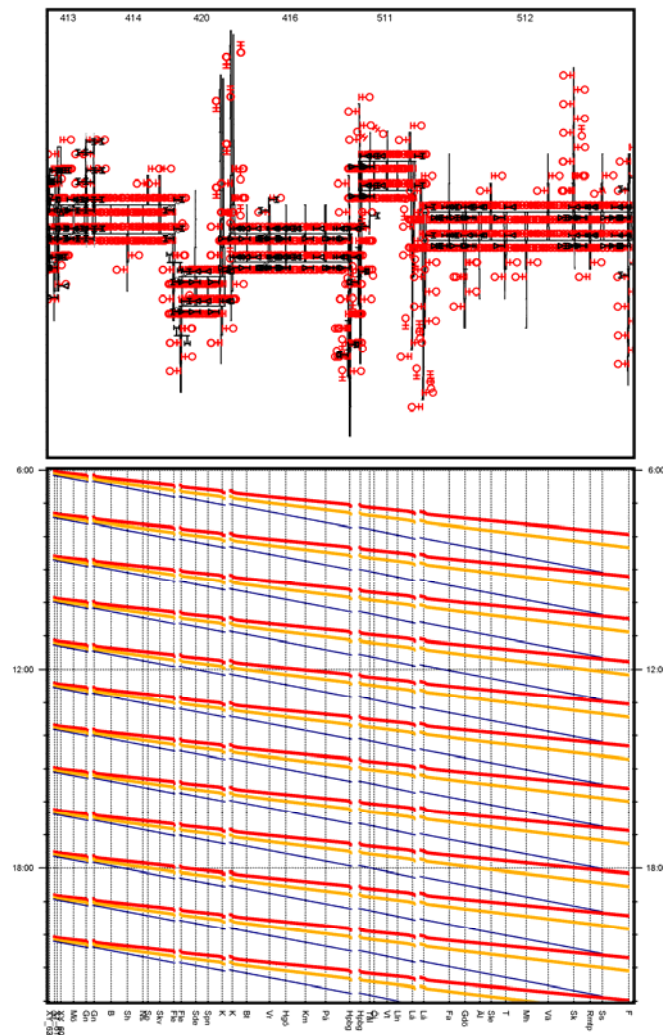
4.4.2.1 HYPOTHESIS

Not studying an existing timetable we need to introduce a certain amount of trains (fleets) to simulate. Looking for a scenario as much as possible close to reality but also that can give results of general interpretation, we assumed following starting hypothesis to puts some pickets to describe “the simulation reality”.

So, our assumptions are:

- i. trains in consideration are: X2 long distance trains, X60 regional trains and Rc4 freight train (the same used in the previous part and described in 4.3.5.1);
- ii. in every scheduled hour can run 3 long distance trains, 3 regional trains and 1 freight train (so the amount of trains per hour would vary from 4 to 9 according with the different pattern compositions);
- iii. the observation time is from 6 am for 16 hours (the last train scheduled departs is by 6 pm)
- iv. long distance and regional trains make 5 stops in station (Gnesta, Flen, Katrineholm, Hallsberg, Laxa);
- v. each stop is estimated of 60 sec (as suggested in literature [1]);
- vi. freight train does not make any stops;
- vii. trains have different priorities (the highest for long distance and the lowest for freight train);
- viii. dispatching is applied, this means according with the program that an unscheduled intervention in the course of a train run, whether it has begun or not, is applied. Dispatching measures aim at influencing a disrupted operating sequence in such a way that: higher-priority trains are given priority over lower-priority trains, deadlocks are avoided on sections with bidirectional traffic or on single-track lines and if the scheduled tracks in stations are occupied, alternative tracks are selected;

4.4.2.2 CAPACITY UTILIZATION

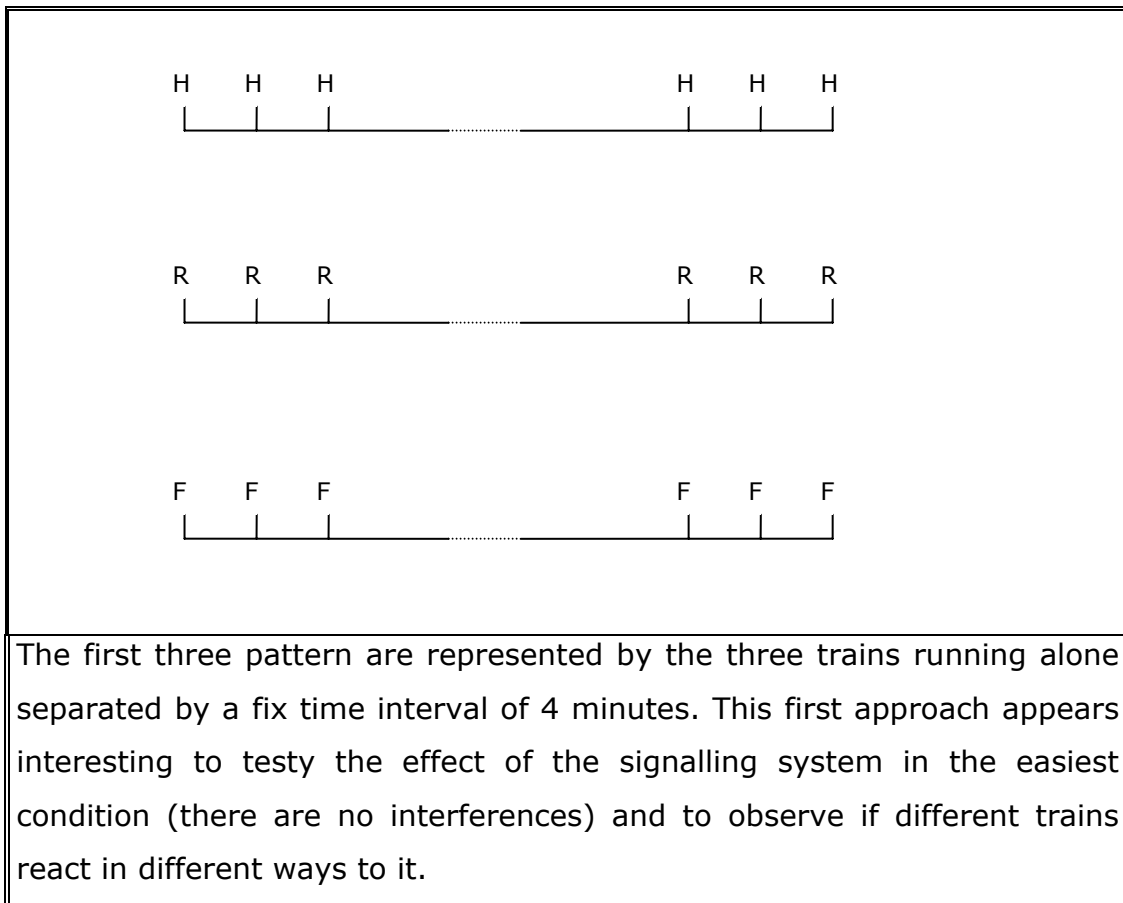


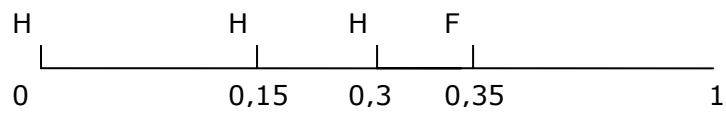
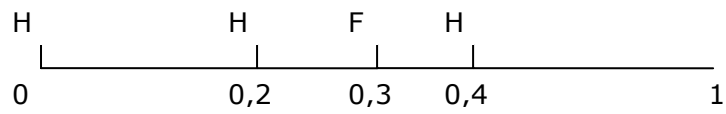
4.4.2.3 TRAFFIC PATTERNS

Trains have been combined together trying to create train fleets which observation result interesting in analyzing.

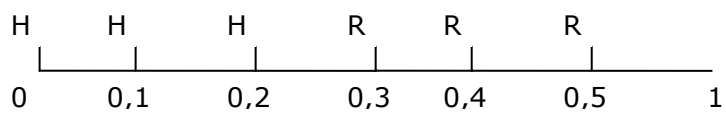
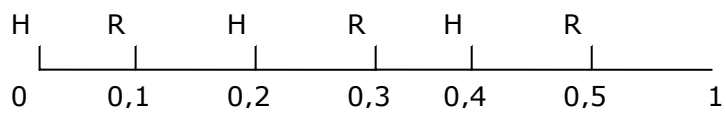
In table next, it follows an indication of train combinations made with a brief explanation why of the choice (letters indicate: H long distance train, R regional train, F freight train).

Every pattern has been thought in a double vest, which is with trains mixed within the operation hour and then grouped according with their typology. This has been done with the intention to look for improvements in putting close running time curves with the same shape.

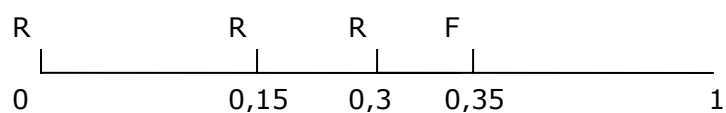
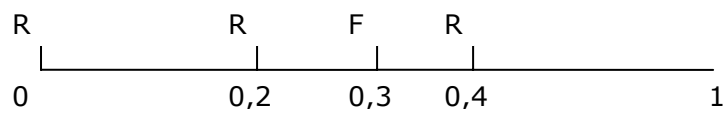




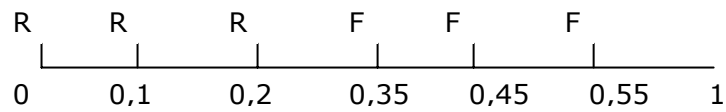
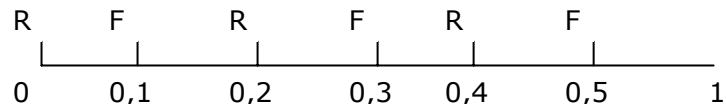
This combination has been thought to observe the effects of freight train on long distance trains.



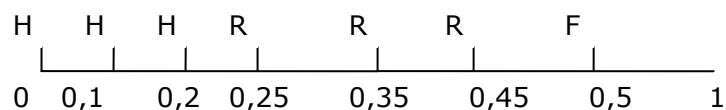
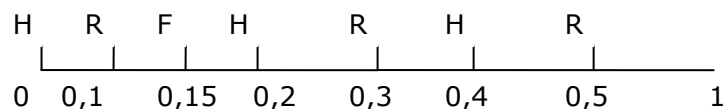
This as before has been thought to study how the two components affect each other.



The interaction between regional and freight train appear very interesting to study especially thinking to a future scenario in which these trains could run on dedicated lines (lines dedicated for long distance/high speed and lines for other trains).



This is a further study of the case before. In here the hour traffic in hypothesis has been changed from 1 to 3 freight trains, this for strongly study the effects of the two patterns running together.



This wants to represent the generic traffic over a line. Here in fact all the three components are present together.

4.4.2.4 RESULTS

After have created the timetable, for every traffic pattern just described two simulations have been run looking for the capacity utilization rate. The two simulations are referred to fix block (ATC see paragraph 3.6) and moving block operations.

It is to notice that before start a simulation with moving blocks it is necessary create a new infrastructure changing the one used for fix blocks regulation by the “infrastructure manager”, rendering this last suitable to that purpose.

Once run the simulation these are results of percentage capacity utilization:

Train pattern (1 hour)	Fix blocks	Moving blocks	Relative difference	Absolute difference	Gain in grouping
H H H ...H	43,8%	14,7%	29,1%	- 197%	
R R R ...R	41,8%	13,7%	28,1%	- 205%	
F F F ...F	24,3%	9,5%	14,8%	- 156%	
H / H / F / H	95,7%	87,1%	7,9%	- 9%	+ 6,5%
H H H / F	68,6%	59,4%	9,2%	- 15,5%	
H / R / H / R / H / R	104%	76,5%	27,5%	- 36%	+ 8,6%
H H H / R R R	48,6%	33,6%	15%	- 44,6%	
R / R / F / R	73,2%	64,4%	8,8%	- 13,7%	+ 1,6%
R R R / F	68,7%	59,6%	9,1%	- 15,3%	
R / F / R / F / R / F	184,7%	175%	9,7%	- 5,6%	+ 17,1%
R R R / F F F	76,8%	62,6%	14,2%	- 22,7%	
H / R / F / H / R / H / R	145%	136,5%	8,5%	- 6,2%	+ 12%
H H H / R R R / F	105%	88,8%	16,2%	-18,2%	

Table 7 - Capacity utilization in percentage obtained from the single simulation

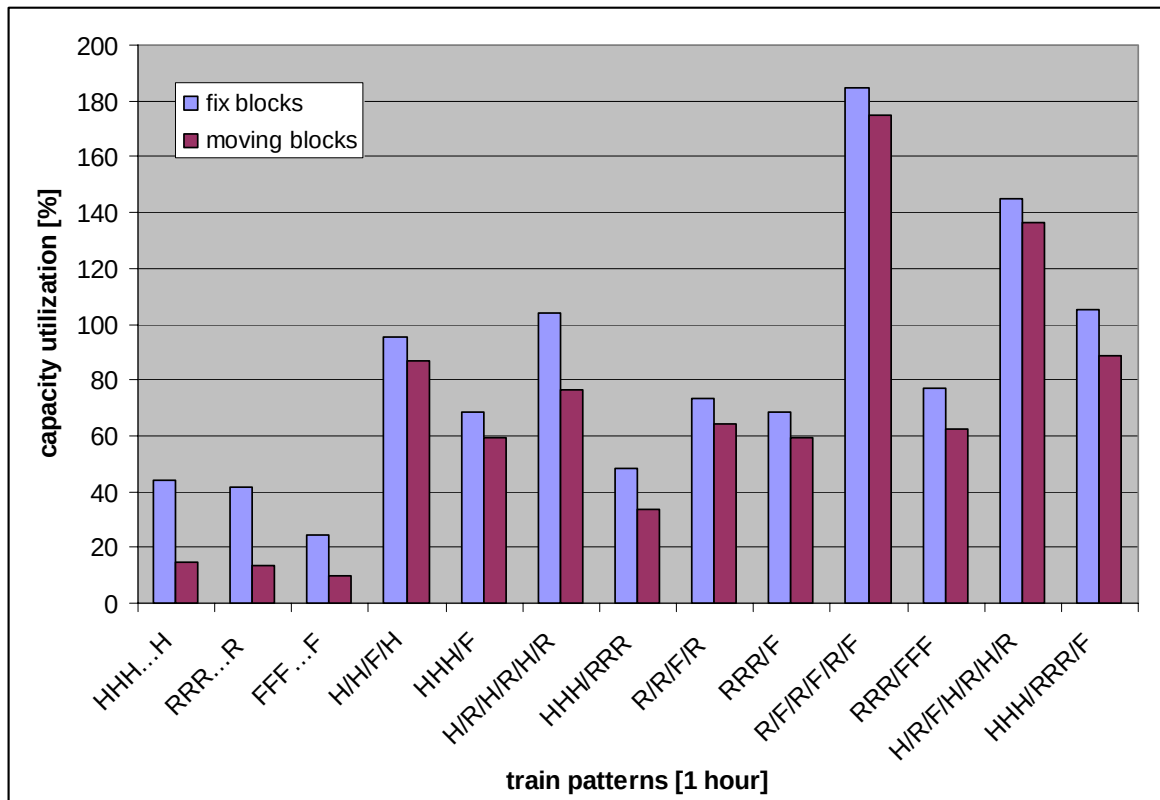


Figure 4.23 - Comparison between capacity utilization in fix and moving blocks for several patterns

4.4.3 The multiple simulation

As said the one studied so far is the theoretical capacity. Being aware that this is an unrealistic data, what we are trying to do in this part of the work is move the discussion toward the practical capacity (paragraph 4.1).

This is strictly connected with the concept of quality of circulation. This last is the attitude to avoid or limit the impact that a train delay can have on others [5].

The multiple simulation consists in test the line against the effects introduced delays have on the switching in signalling system.

The nominal timetable can be tested in Railsys for its stability against perturbations in actual operation. For this purpose train run in the nominal timetable is overlaid with perturbations and a number of perturbed timetables are generated. In reality, the perturbed timetables constitute various days of operation (in our case we decided for ten days of operation).

The nominal timetable has been obstructed by two kinds of perturbations:

- ✓ *initial delay*, the scheduled time of entry into the system is delayed by the corresponding value from the distribution area;
- ✓ *dwell time extension*, the stochastically determined value is added to the minimum dwell time.

4.4.3.1 INITIAL DELAY

Initial delay is applied to the first station where trains enter in the system. We decide freight trains are not up for this delay.

This kind of delay is typically represented by a negative exponential distribution. In probability theory and statistics, the exponential distributions are a class of continuous probability distribution. They are often used to model the time between independent events that happen at a constant average rate.

Such distribution is represented by the formula:

$$f_x(x) = \frac{1}{\lambda} e^{-\lambda x} \quad (12)$$

Where $\frac{1}{\lambda}$ is the mean or expected value of an exponentially distributed random variable X with rate parameter λ . Typical values for λ are between 200 and 500 s.

What the program requires to input is:

- *Proportion of trains*: 100% (the delay is applied to all the train that are not freight trains)
- *Average delay*: 180 s
- *Max delay*: 60min (after this value the tail of the distribution is chopped)

4.4.3.2 DWELL DELAY

This kind of delay is introduced by an empirical distribution.

In statistics, an empirical distribution function is a cumulative probability distribution function that concentrates probability $1/n$ at each of the n numbers in a sample.

The empirical distribution function $F_n(x)$ based on sample is a step function defined by:

$$f_n(x) = \frac{\text{number_of_elements_in_the_sample} \leq x}{n} = \frac{1}{n} \sum_{i=1}^n (x_i \leq x) \quad (13)$$

What the program requires is to introduce the sample in the format number of trains and dwell times corresponding. The distribution comes from manually measured on regional train stops at Sundbyberg. Delays have been adjusted by 20 seconds in order to fit the more heavily utilized stations on western main line.

Number of trains	Dwell times (s)
21	60
34	70
28	80
11	90
12	100
2	110
4	120
1	130
2	140

Table 8 – Manually measured delays used for the dwell distribution

Dwell delay is applied in three of the scheduled stops, these are: Jarna, Katrineholm and Laxa.

4.4.3.3 RESULTS

After ran the multiple simulation results have been analyzed thanks to the evaluation manager (4.4.1.4).

One way to analyze timetables (others several combination are possible) is creating a “bar chart with delays”. In particular, as first in our case, we carry out the arrival average delays. Diagrams for all the patterns simulated are addressed in appendix; here next two diagrams as example are reported.

Different patterns react in different ways to disturbance application.

The chart in figure 4.24 shows a situation of “not stability”, in fact the system can not absorb the introduced delays but at the contrary they increase along the line.

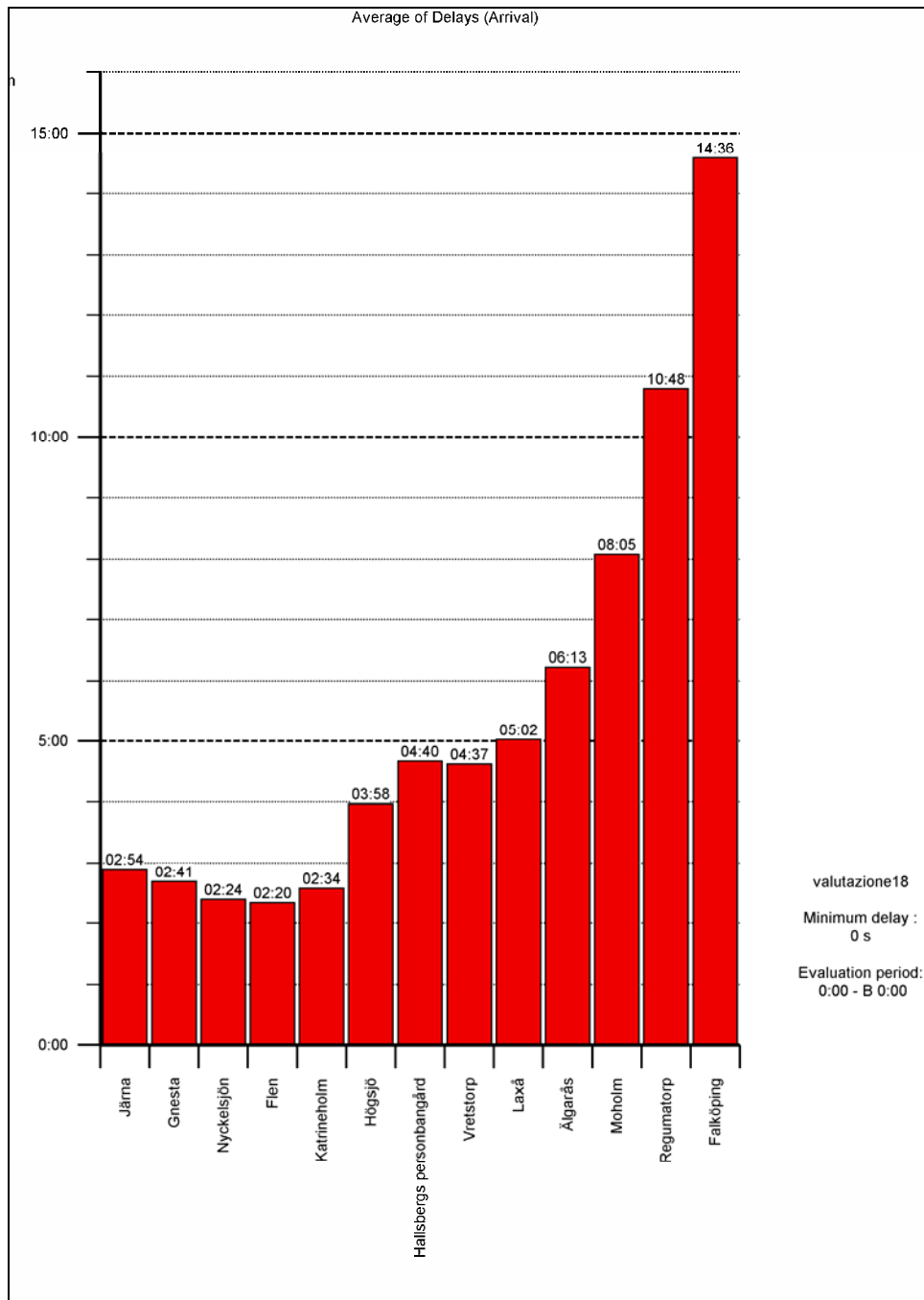


Figure 4.24 – “Bar chart with delays” for the pattern R/R/F/R in moving block operation, from the evaluation manager

At contrary, the second chart (figure 4.25) shows a situation of “stability”. Here delays are smoothed along the line obtaining, comparing with the initial delay, lower average delay at the last station.

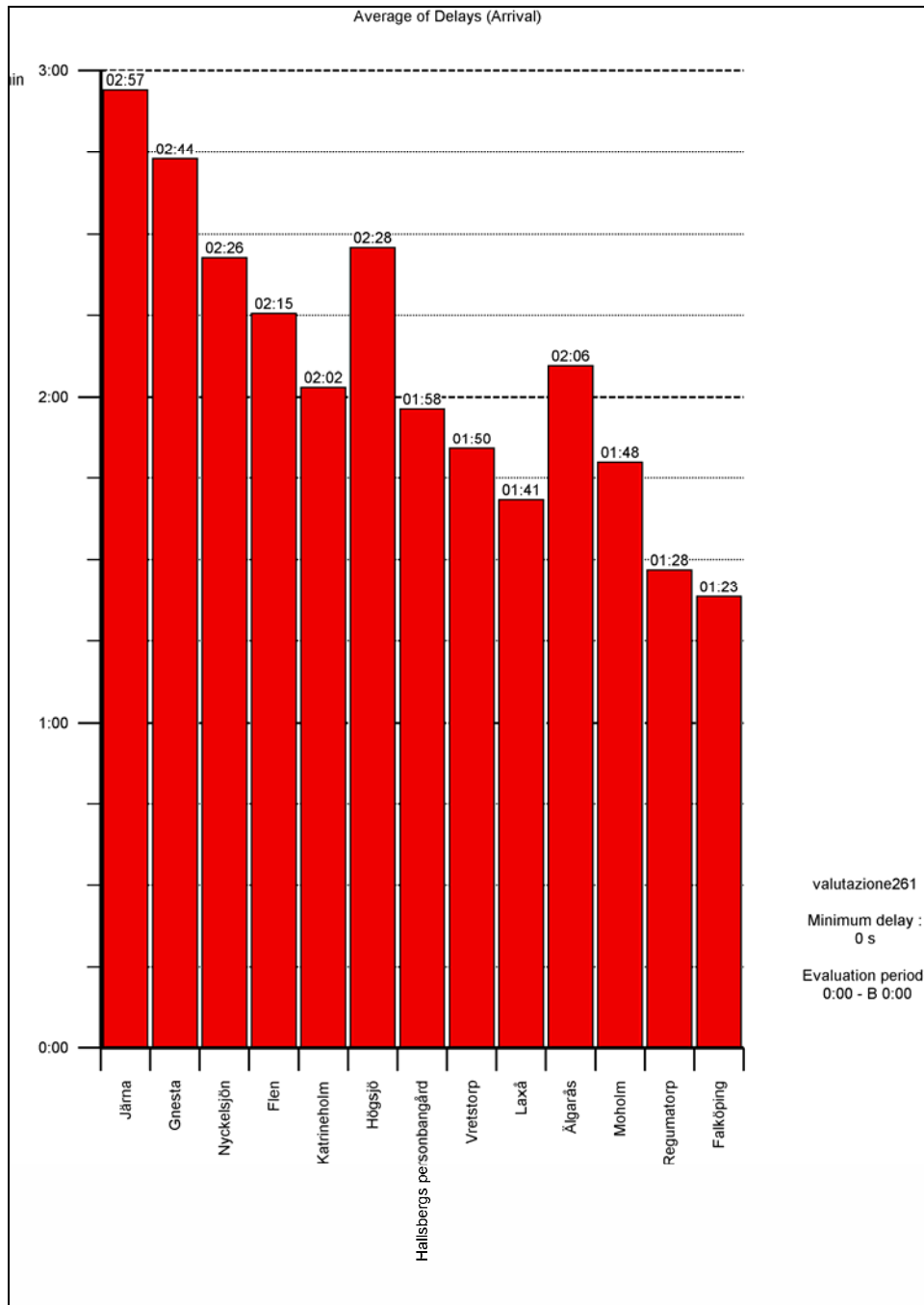


Figure 4.25 - "Bar chart with delays" for the pattern H R in moving blocks signalling, from the evaluation manager

For time reasons (simulations, especially for moving blocks, takes long time to be run) not all the traffic patterns introduced in paragraph 4.4.2.2 have been simulated. The eight patterns have been chosen both from their interest in being investigated and to have a broad investigated sample that covers as much as possible the capacity utilization scale (it has been tried to have a pattern in every decade of capacity utilization).

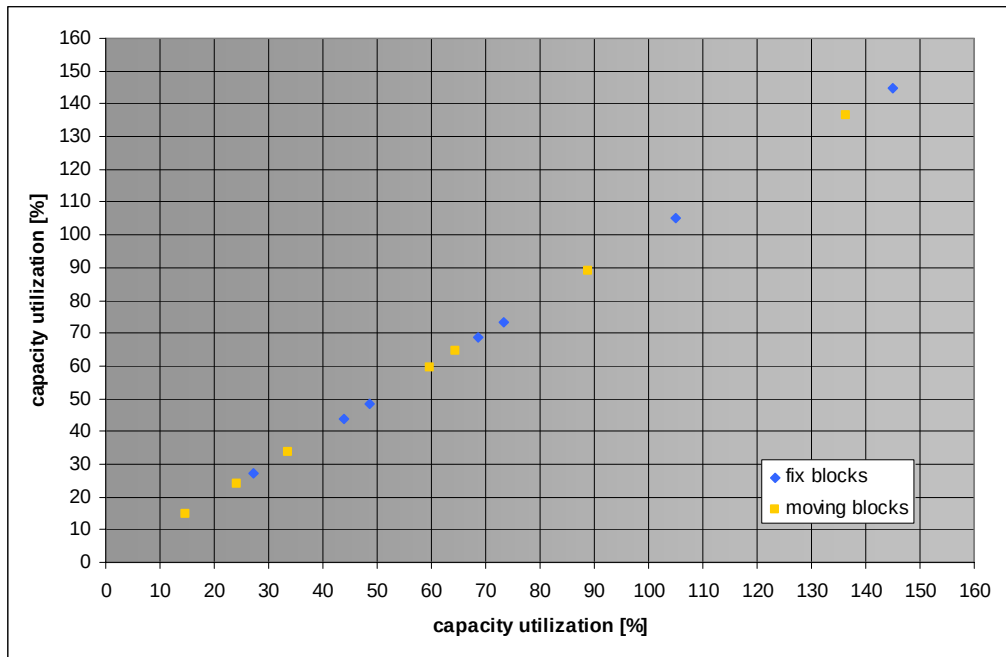


Figure 4.26 - Capacity utilization sample used for pick the patterns for multiple simulations

Results are reported in table 9 and 10. In this approach we though results represented by the “net line delay”, that is the difference before the initial delay at first station and the arrival one at last station (last column). Negative results (shading in green) shows a stable situation, positive (shading in red) one a not stable situation (as introduced above).

FIX BLOCKS				
Train pattern [1 hour]	Capacity utilization [%]	Delay at the first station [s]	Delay at the last station [s]	Difference [s]
H R	27,3	153	75	-78
HHH...H	43,8	181	86	-95
HHH/RRR	48,6	182	202	20
RRR/F	68,7	130	308	178
R/R/F/R	73,2	137	723	586
H/R/H/R/H/R	104	152	265	113
HHH/RRR/F	105	139	780	641
H/R/F/H/R/H/R	145	134	922	787

Table 9 – “Net line delay” from the multiple simulation in fix blocks operation

MOVING BLOCKS				
Train pattern [1 hour]	Capacity utilization [%]	Delay at the first station [s]	Delay at the last station [s]	Difference [s]
HHH...H	14,7	155	82	-73
H R	24,1	154	74	-80
HHH/RRR	33,6	183	123	-60
RRR/F	59,6	187	668	482
R/R/F/R	64,4	152	862	709
H/R/H/R/H/R	76,5	186	364	178
HHH/RRR/F	88,8	142	995	853
H/R/F/H/R/H/R	136,5	137	1345	1208

Table 10 – “Net line delay” in the multiple simulation in moving blocks operation

In both signalling systems the pattern composed by long distance and regional trains following each others (H/R/H/R/H/R) appears a kind of “stable pattern”. In fact, despite the quite high capacity utilization rate (104% and 76,5% respectively for fix and moving blocks), this pattern shows a much less “net station delay” than others pattern with high capacity utilization.

Noticed this, these results have been left out from charts next. The charts try to point out a possible trend for the two signalling systems plotting the capacity utilization over the net delay (in the second chart these are inverted just to have another view).

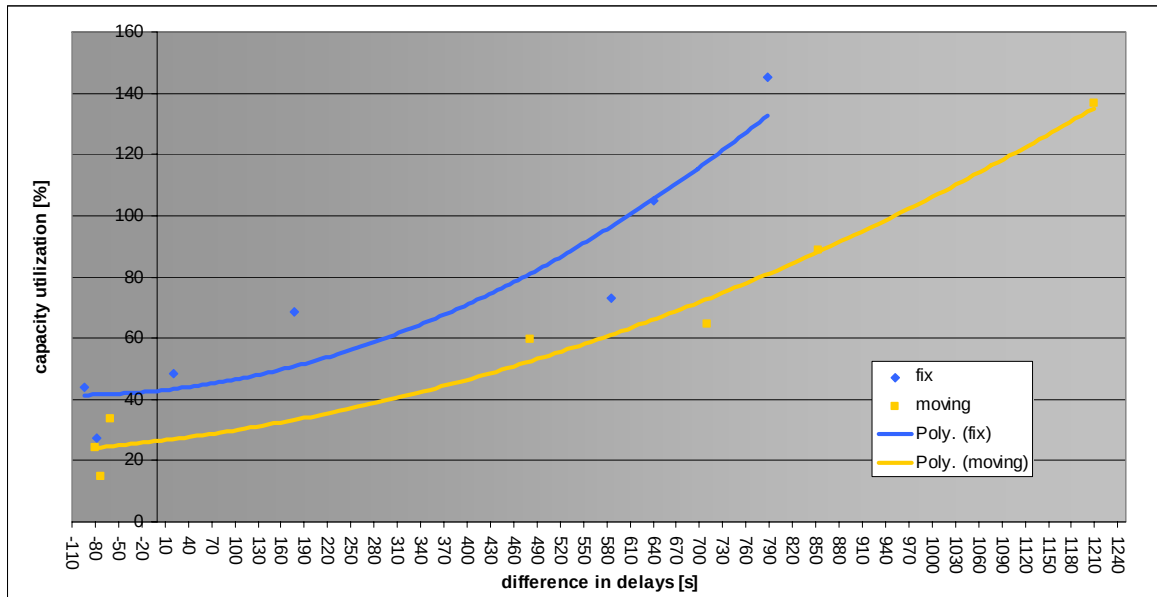


Figure 4.27 - Capacity utilization over the "net" delay at last station chart

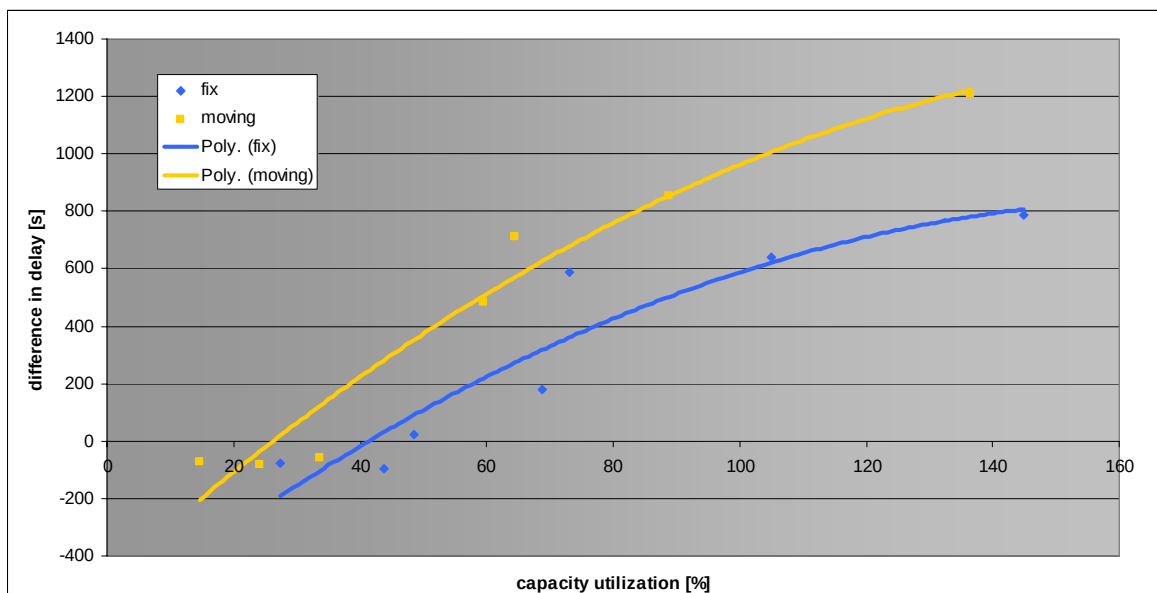


Figure 4.28 - "Net " delay at last station over capacity utilization chart

The tables and the charts give us results that seem go against moving blocks. In fact, if from the single simulation we had a general decreasing of our comparison parameter (capacity utilization rate) from the switching, so that we could state the switching was an effective improvement, here the situation seems be different. In fact if we introduce a further comparison parameter, as delay is, trend go in another direction. After multiple simulations results would lead us to say that moving blocks react in less stable manner to perturbations.

In fact the net delay over the line on equal terms of capacity utilization is minor for fix blocks (more stable).

Anyway even if this would be a trend it seems risky to assume it. This because, beside the fact that in these simulations only a line has been exploited, we have to remember that the capacity utilization used comes from different patterns.

To move the discussion more faraway from this single case we must further analyze the results.

A proper way seems to “split” delays in:

- delay between stations,
- stations delay.

To obtain these we need to look also for departure delays at stations in the evaluation manager analysis.

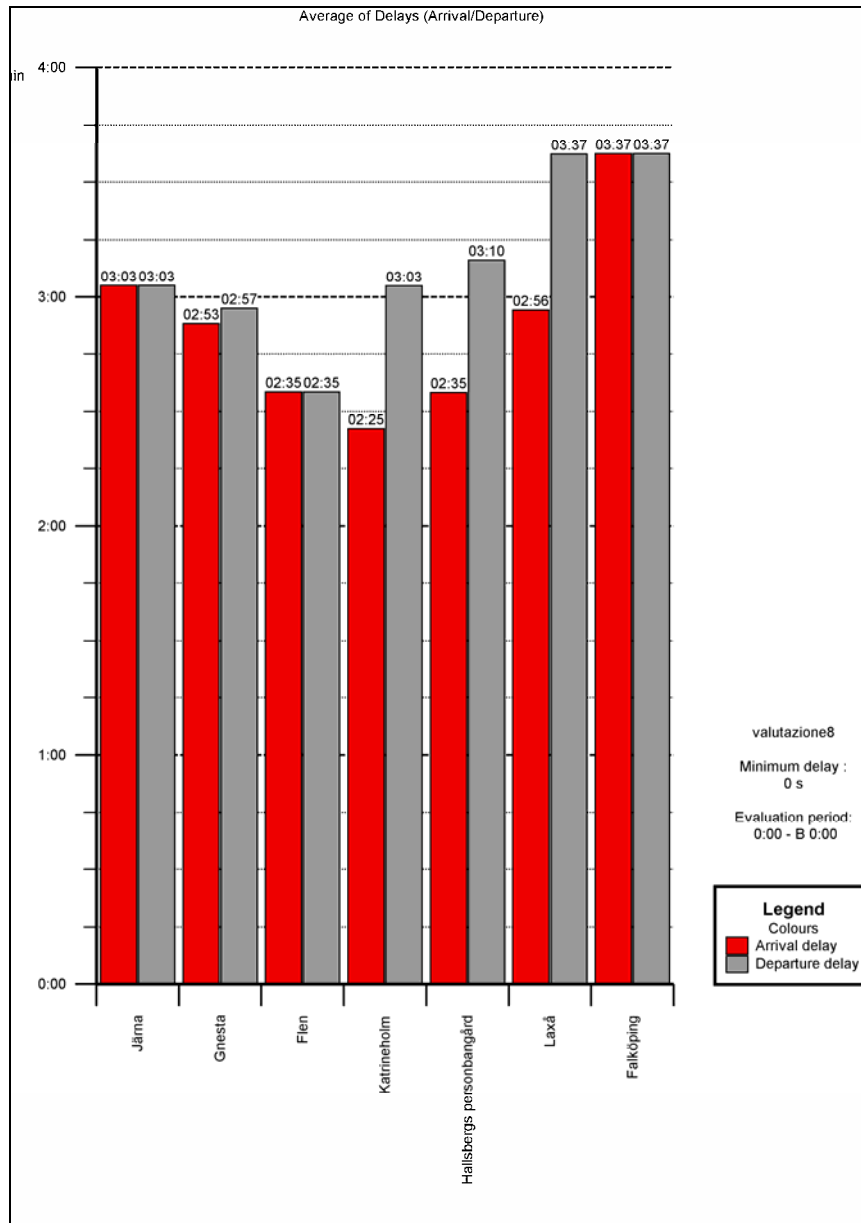


Figure 4.29 - "Bar chart with delays" (arrival and departing delays), from the evaluation manager

Thanks to the analysis of these further data we can obtain the delay at the stopping stations, as the difference between the arrival and the departing delay (tables with calculation are reported in appendix C). Next, two charts shows these delays respectively for fix and moving blocks.

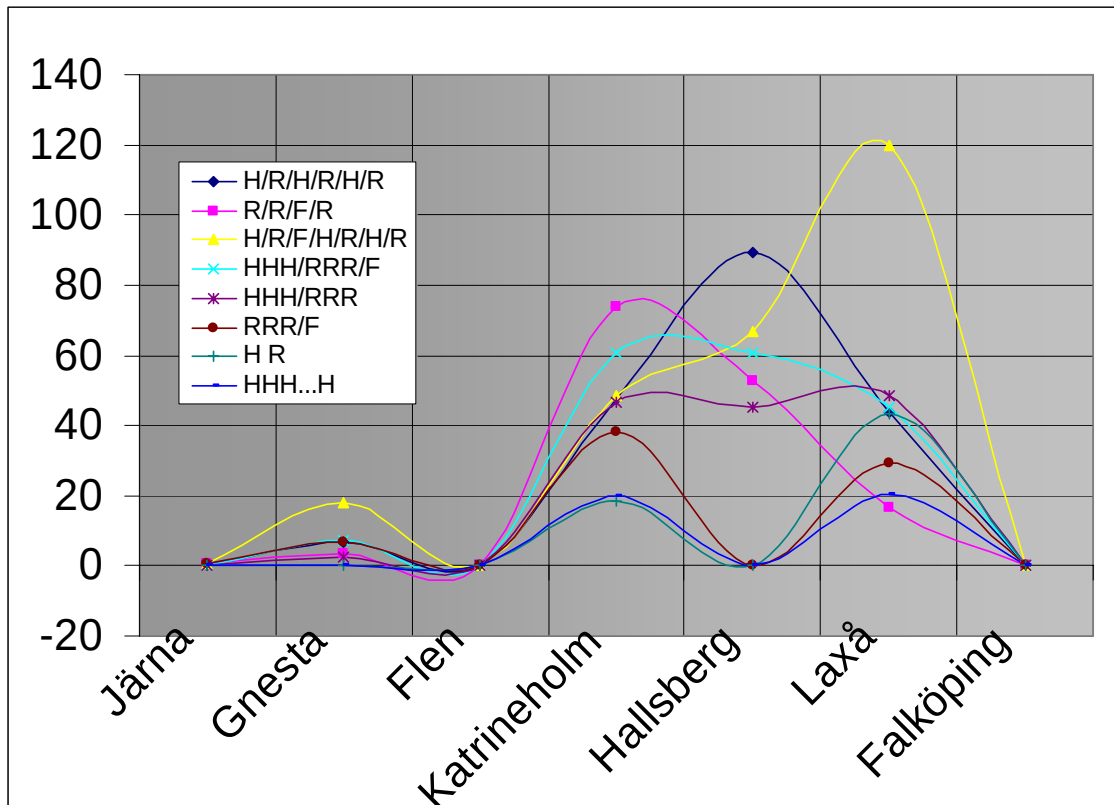


Figure 4.30 – Absolute station delay in fix blocks operation

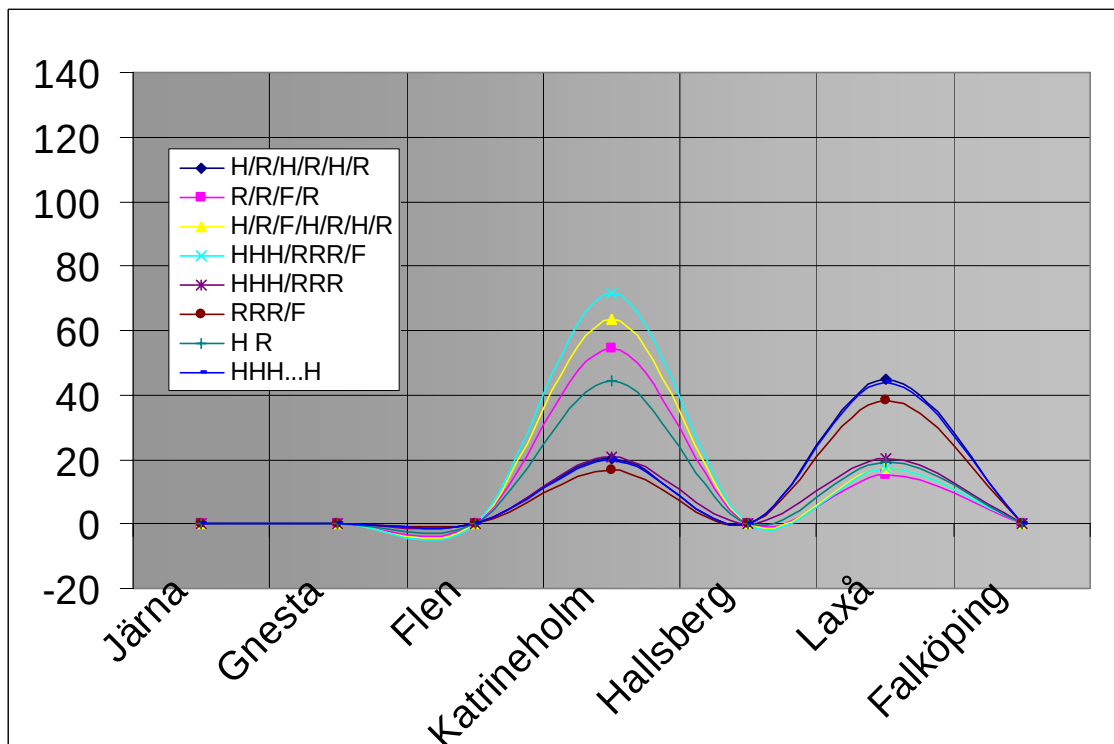


Figure 4.31 – Absolute station delay in moving block operation

Instead, to focus the attention on delay occurring between stations, we have to calculate the difference between the arrival delay and the departing delay at the previous station (values appendix C).

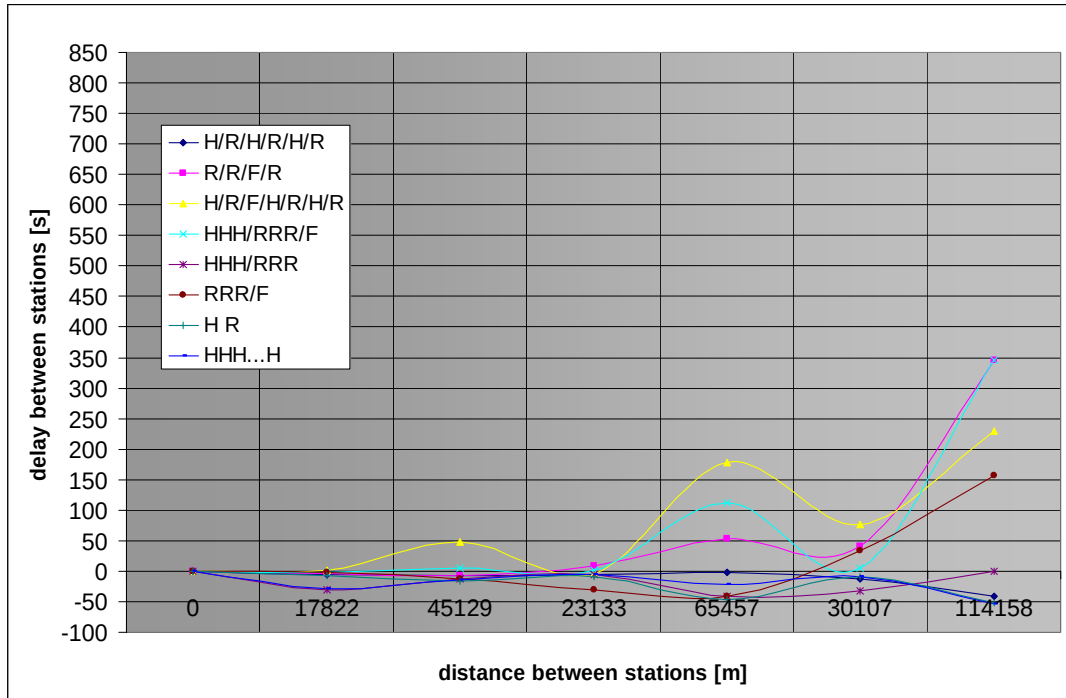


Figure 4.32 - Absolute delay between station in fix blocks operation

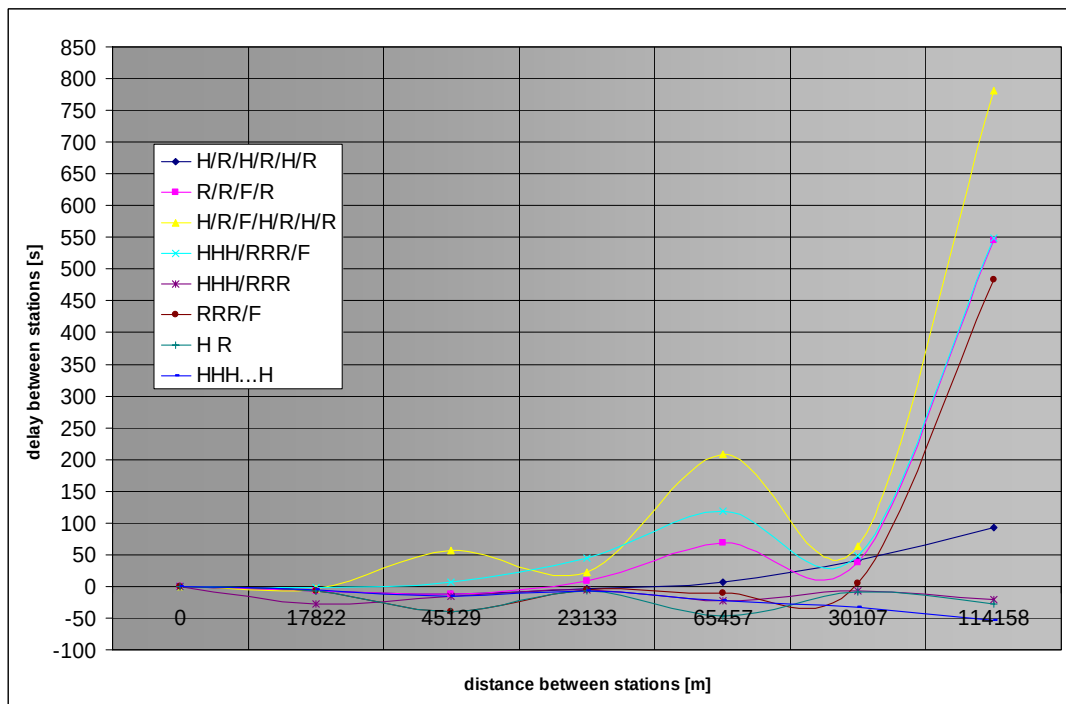


Figure 4.33 - Absolute delay difference between stations in moving blocks operation

After introducing these others point of observation, we can now approach the problem in more exhaustive way.

From observation of the new displays of the results some interesting issues are observable.

- If we compare the absolute station delays one thing comes evidently out. This is fix blocks are less stable in perturbations applied to stopping stations. Indeed, if we observe figure 4.31 we notice that in moving blocks the difference in delays occurs only in perturbed stations and the system is able to keep it stable in next station. This does not happen in fix blocks where the delay usually increases, especially for patterns with high capacity utilization.
- Observing instead the absolute line delay between stations it is possible observe that, expect for little changing, the situation is nearly the same until the distance between the stopping stations stay in relative lower values. When space increases delays for the two signalling systems start differ. This until the last station where, after the longest separation distance, five over the eight patterns differ (four more noteworthy and one slightly) have in moving blocks a much bigger delay. It is to notice that also in this case there is a connection with the kind of patter. In fact the four patterns that more differ contain freight train within.

We can now try to apply these considerations to the system in analysis to see if we can find out something more.

Trying to emphasize the dependence of results on distance between stations (meant as the places where overtaking are possible) we can easily leave out from the analysis the last station (which is the one with the longer approach distance). If we do that, charts next are the results.

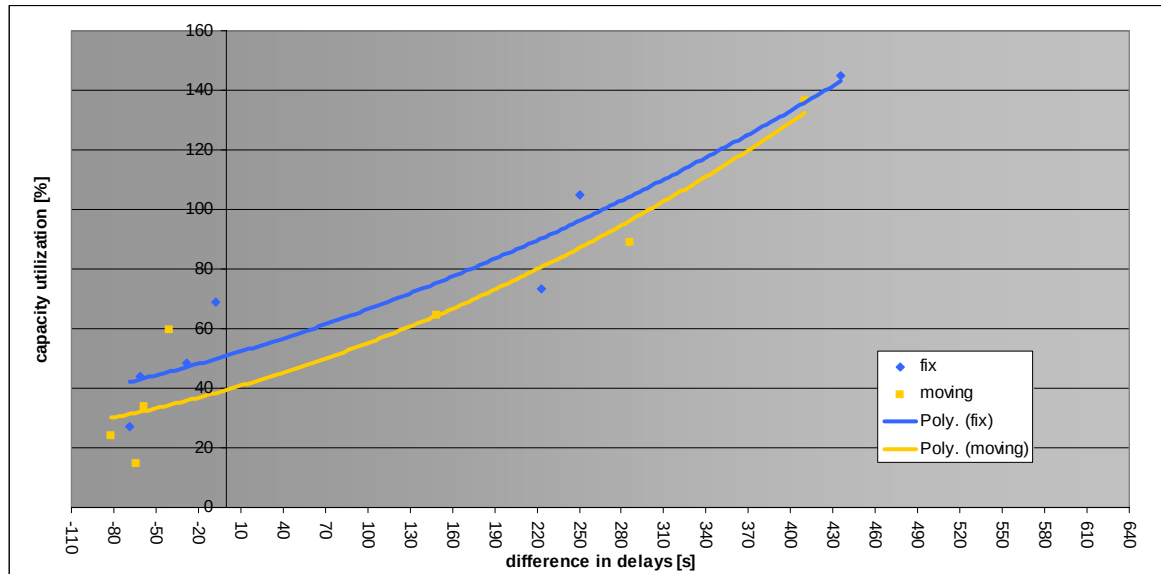


Figure 4.34 - Capacity utilization over the "net" delay at next-to-last station chart

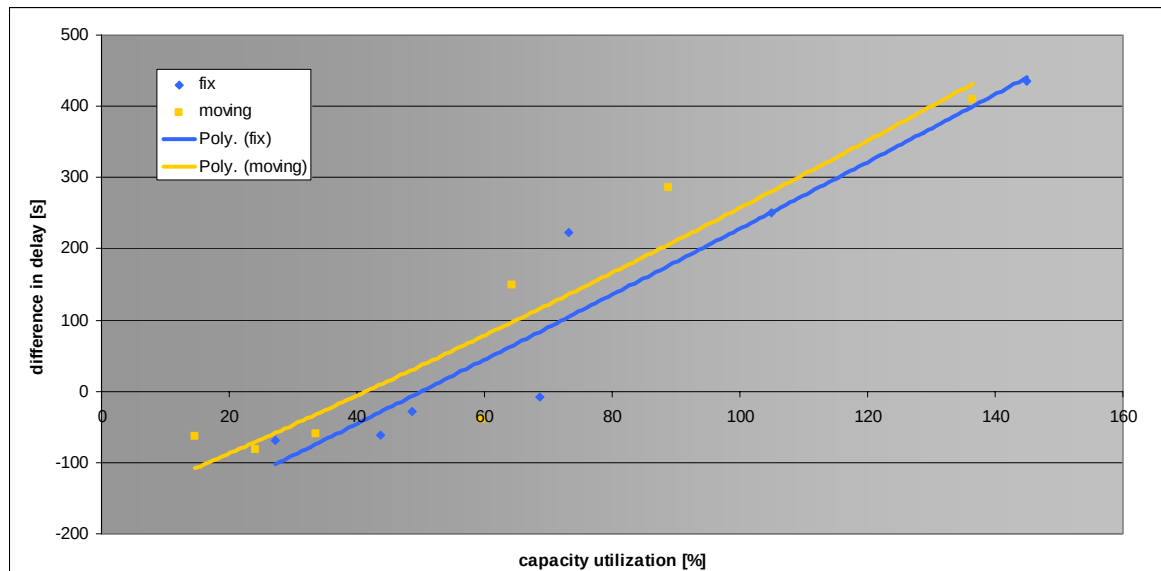


Figure 4.35 - "Net" delay at next-to-last station over capacity utilization chart

Comparing these with the all line case results (figure 4.27 and 4.28), it is possible to see how moving block, even being still less stable, goes very closer to fix blocks outputs.

To have a numerical parameter we can think of the "stability limit", that is the capacity utilization that gives a zero result in net delay. This goes:

from 47% to 69 % for fix blocks

from 36% to 61% for moving blocks

It has to be noticed that this results comes just reducing the average distance between stations (from 49 km to 36 km approximately).

Instead, if we want look at pattern composition we can observe significant changing in final behaviour if, for example, we move out from analysis all the components that have a freight train in it. So if we look at just patterns that contain long distance and regional trains, results shift to what charts in figure 4.36 and 4.37 show.

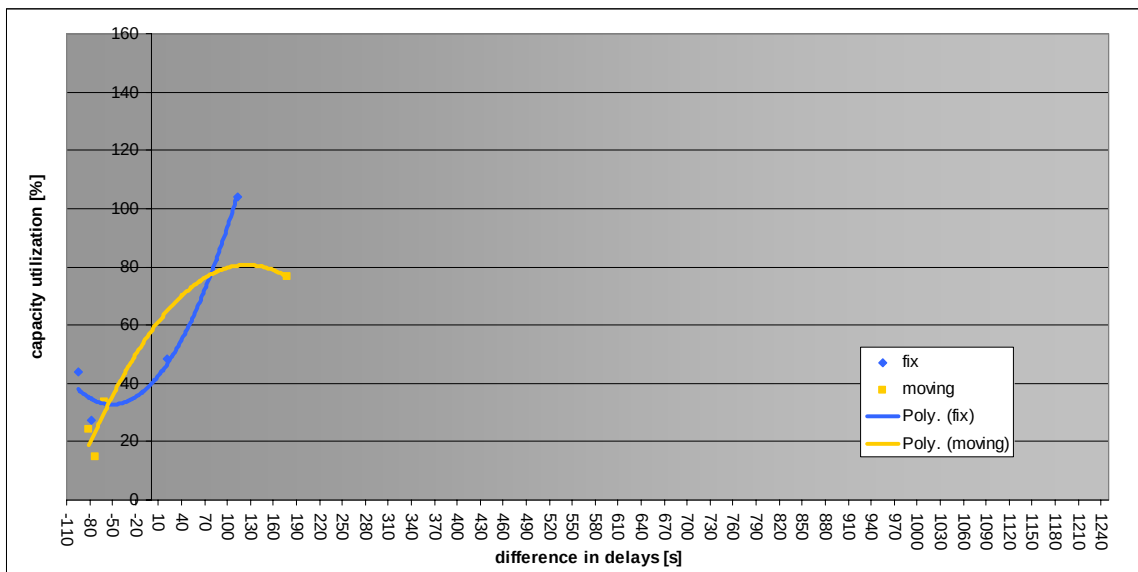


Figure 4.36 - Capacity utilization over the "net" delay for patterns not including freight trains

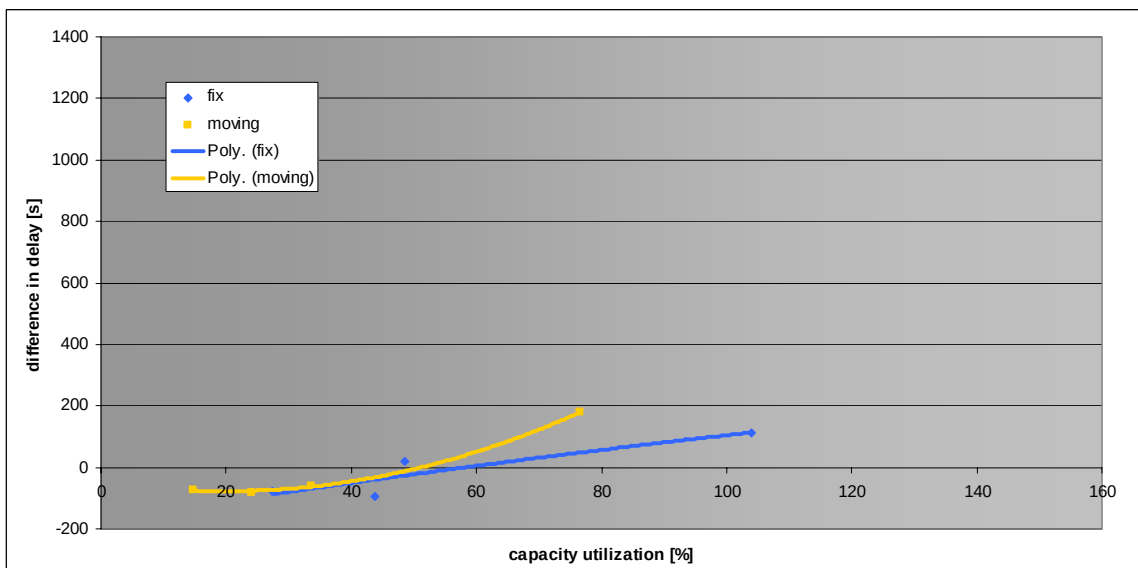


Figure 4.37 - "Net" delay at last station over capacity utilization for patterns not including freight trains

In this case the two signalling systems behave really close each others with an “overtaking” for middle capacity slot in moving blocks.

If, as before, we consider as comparison parameter the value of capacity utilization which gives a zero net delay, we can observe the following move in association with the basic scenario:

from 47% to 47% for fix blocks (no changing),
from 36% to 44% for moving blocks

So, looking at these last charts, where starting scenario has been changed in medium length distance between stations or pattern composition, appears quite evident being a connection among parameter as:

- capacity utilization rate,
- distance between stations where overtaking is possible,
- composition of patterns.

Next step is just to consider together these parameters in a whole approach trying to point out a trend over these three parameters. This is done diagramming the total delay in lines between stations, meant as the difference between the departure delay and the arrival one in previous station, over the distance where this last occurs and the pattern interested.

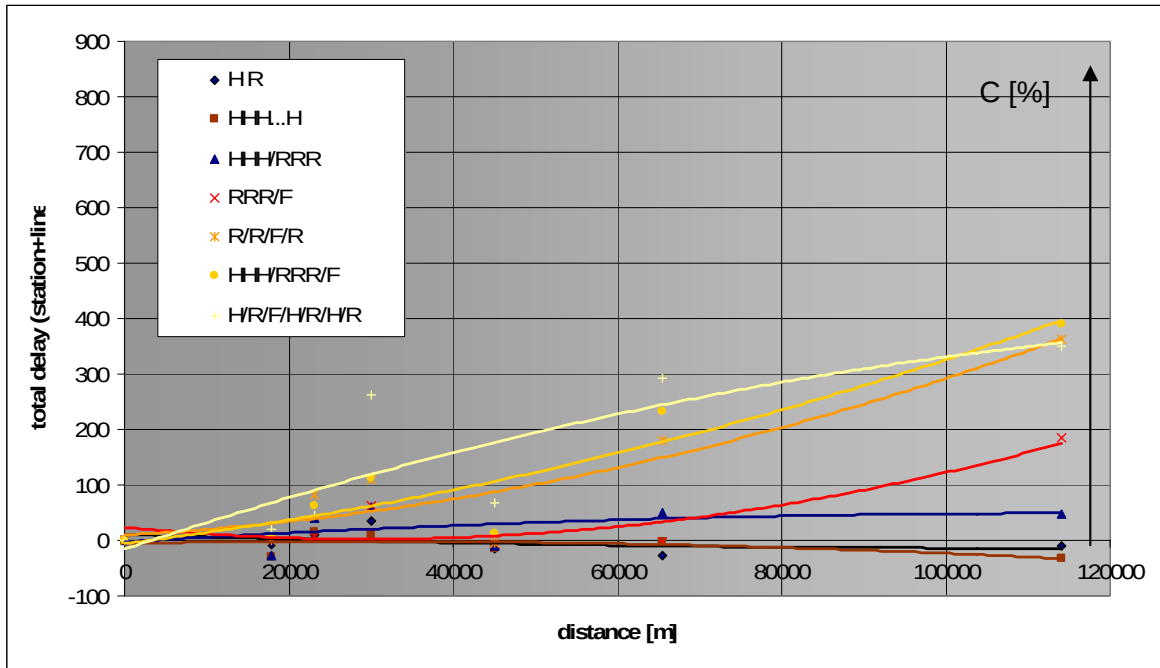


Figure 4.38 - Delay time over distance over capacity chart in fix blocks

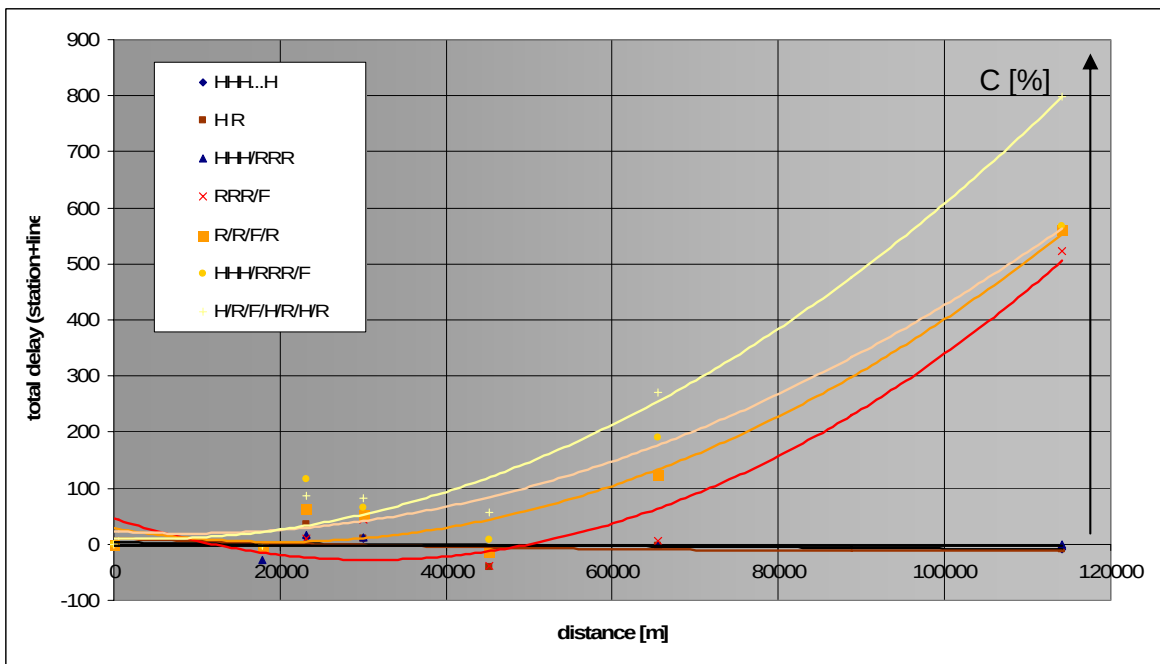


Figure 4.39 - Delay time over distance over capacity chart in moving blocks

These charts (figure 4.38 and 4.39) appear quite interesting in observing.

First of all we notice that both operating systems increase delays for most of train patterns as both distance and capacity assume higher rates. Anyway, besides this general trend, they differ in absolute terms.

In moving blocks all the patterns not including freight trains are stable all over the distance considered while, in fix blocks, HHH/RRR pattern accuse a smoothed increasing delay. But what we have mainly to notice is moving blocks record a quite huge gap in last part of considered distance (from 80 to 120 km), between patterns within freight trains and ones with not. This gap moves output delays in high range, emphasizing the bad behaviour of moving blocks operations with patterns including trains with different performances, at high distances between stations where overtake is possible.

In fix operations we do not observe this trend and all patterns are quite alike distributed increasing delay as distances and capacity increase.

If we observe moving along the distance axe we can say that:

- in lower distances, between 0 and 60 kilometres, moving block has a better medium feedback;
- if we consider the gap between 60 and 80 kilometres the behaviour is on average the same;
- over 80 kilometres we observe the situation of instability described above, so that we can say for patterns including a slow train and high capacity fix blocks are more responding.

So if charts above were referred to a more general situation we would say that to decide which between the two signalling systems is more performing, or in general if the switching is convenient, we need to dispose of some inputs (as line capacity, line length etc...) and enter in the charts. At example, if we had as input data a pattern like the RRR/F with 69% of capacity utilization, we would say that if we have a distance between stations included in the range 40 and 60 kilometres moving blocks are the most performing choice but, if this distance (because at example the line is designed in this way and we do not want modify it) is between 100 and 200 kilometres, fix blocks operation is the better choice in punctuality terms.

5 CONCLUSIONS

5.1 DATA ANALYSIS

As seen capacity got from analytical approaches (theoretical capacity) is usually higher than reality. In the quantitative analysis, even if with some differences between the two approaches proposed (reduced enhancement through graph approach have been recorded), we showed how moving blocks in fleets composed by same performances trains represents an upgrading in terms of capacity, especially for slower trains then the faster (28% for the long distance, 49% for the regional, 49% for the freight). This last result emphasises the “discretization” of space from blocking operation and the resulting waste of track utilization.

The main problem of this kind of approach is, as partly demonstrated introducing the graphical method, it does not consider the complex reality in which trains run. So, the following step of the analysis consisted in moving attention toward practical capacity and concepts as quality of circulation, recognizing that, if trains run at a critical distance a delay occurring to one of them can affect the others leading, in worst cases, to a downgrading of all the line.

To bring analysis closer to reality the simulation way has been undertaken. In this approach the capacity is meant as capacity utilization (line exploitation), and traffic has been created on the base of assumptions (4.4.2.1).

After the first phase of the simulation (the single simulation) has been concluded, results still confirm the goodness of moving block operation. In fact, in all cases the capacity utilization decreases, more significantly for patterns composed just by a train type and in less significant manner if trains with different performances run mixed together (table7).

In the second part of the simulation work (the multiple simulation), nominal timetables, created with the patterns analyzed in the previous phase, have been tested against perturbations (initial and dwells delays).

At first, applying these perturbed timetables at the test-line as it is, no positive feedback has been got. In fact, moving blocks respond with a medium stability against delays inferior than fix blocks (table 9 and 10).

A further analysis on the results, coming from splitting delays got previously in stations and lines ones, has given interesting results, confirmed then by applying two easy changes in the basic scenario (figure 4.32 and 4.34).

From this splitting we basically observed two things:

- the difference in behaviour between the two systems in stations;
- the connection between signalling system, distance between overtaking places (commonly stations) and fleets composition.

The first observation comes out from noticing that in moving operations feedback is much more stable. Delays in stations occur only in stations where delay disturbances are applied. Where graph (figure 4.29) shows a zero delay it means that trains do not lose additional time in overtaking operations. This can be attributable to the major flexibility of the moving blocks operations. In fact running at closer distance (braking distance plus safety margin) the train in rear can initiate in advance the operation of overtaking and train surpassed can before enter back in the line (not having to wait a fix separation distance is set free). This phenomenon is as much noticeable as much the differences in performances of the trains are higher (at example the overtaking of a freight train by a high speed one).

The second observation comes from noticing a dependency between delay and line delay for both operation systems. Even if moving blocks more follow this trend. Noticing that component that worst react to long distances are those within freight trains or though ones with high capacity utilization rate, we can attribute this behaviour to the same reason with operation in station are more

slender. In fact, running closer each others trains tend to “pack” along the line behind the train/trains that should be overtaken.

So, after these last considerations it has appeared evident being a thigh relation between capacity, line distance and pattern composition.

Trying to put together these factors we got figure 4.36 and 437 that give a kind of summary of the problem. If we characterize our input by a pattern, capacity utilization and a distance between stations, we can point out which of the two signalling systems is the more performing in punctuality terms. As result it can happen that for certain pattern at a certain distance is more performing one system but if we change one of these parameters the output can go in favour of the other one.

5.2 FUTURE

It is necessary remember once again that the study just deal with capacity problems and do not want be a general suggestion on the goodness or less of moving blocks systems. Moreover just one line has been tested and this seems to be too few to render results absolutely right.

From the analysis carried out so far, it is possible affirm that moving blocks enhancements can not generally be judged.

What discovered move the discussion from the signalling system itself to the goodness of lines and stations to allow moving blocks work as best they can. In fact, as seen, according with these two components of railway system, the switching to moving operations can be a good upgrading in some circumstances, less good in others and even not at all in others more.

It appears advisable not limit the ERTMS/ETCS level 3 discussion to the level of the technique itself, but accompany this with some claims. Such claims could look frame the problem from a too broad point of view on railway circulation and not be so relevant with the discussion itself. But, at the

contrary, they give the impression to be essential in being questioned for a successful applies of moving blocks operations.

The most important can be listed in:

- *How long should be the average distance between stations?*
- *Should slow and heavy (as freight are) trains or other components of the traffic (as regional or commuter) have the priority? And so, connected with this, will be better a line with few big stations, where long trains can set apart taking the side track, or a line with smaller and more densely distributed stations, where the other component of the traffic are set apart?*
- *Should trains with different performances travel on dedicated lines (as freight and high speed are)?*
- *Do stations turnouts allow suitable speed to take advantages in overtakes coming from moving blocks?*
- *What does happen if the moving blocks are applied to a single track line?*

However, if we want to give a general indication besides the general framing just discussed, we can say that in a future scenario a dynamic separation will give more appreciable feedback when applied on lines where freight components do not run together others.

So, a quite sure successful application can be seen in a “commuter line” where, thanks to this kind of separation, a dense distribution can be achieved allowing a high rate of trains following each others during the rush hours. This aspect can be seen as a very useful application of level 3. In fact on such lines the not concentration of the demand during the day can be a problem in scheduling. In this way it is possible power the line when it is wanted with trains running very close each others, emulating the underground traffic, or anyhow taking just the advantages in using very long trains.

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Appendix

(A) Calculation of running time curve

The example of a running curve for the train x2 is next showed.

The data for the train in exam that have been used are the following:

Train: X2 MkII			
Antal sittplatser:	231	Last [ton]:	24
Total static mass [ton]:	342	Train lenght	139
Dynamic mass [ton]:	364	Max. dec. [m/s ²]:	0,8
Adhesionsvikt [ton]:	73		
Gångmotstånd [N], v=[km/tim]:	A =	without wind	with wind
		1905	2032
D = A + B*v + C*v ²	B =	16,9	33,88
	C =	0,566	0,566
			Wind [km/tim]: 15

Table 1 - Train data

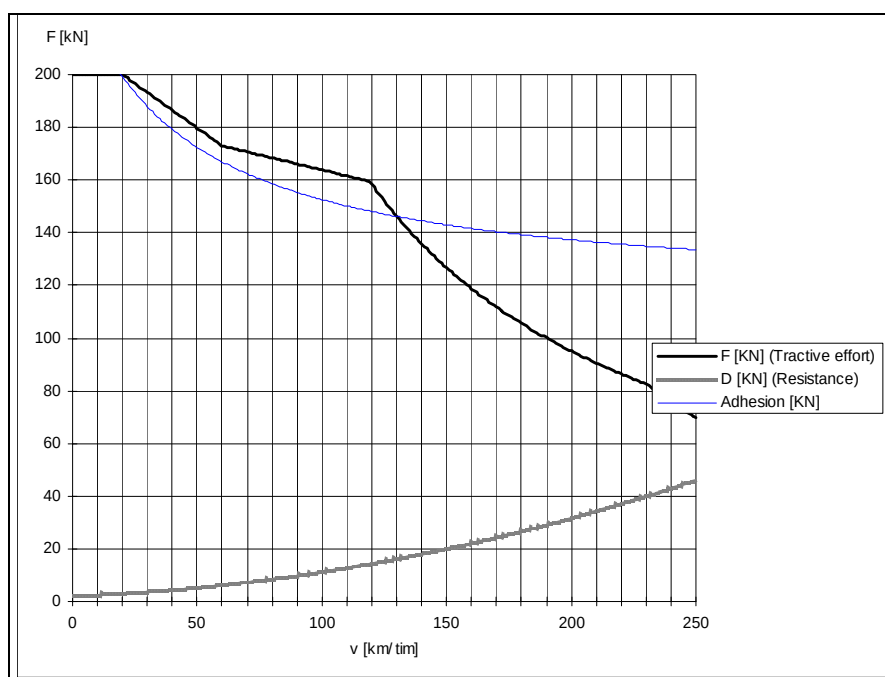


Figure 1 - Tractive effort/adhesion graph

The running of the train has been divided in three main phases: the acceleration, the running at constant speed and the braking. For each a curve speed over distance has been determined.

Acceleration

V [km/h]	v [m/s]	v [m/s]	F [KN] (Tractive effort)	D [KN] (Resistance)	Adhesion [KN]	m [ton]	Xt	met [ton]	F-D [KN]	a [m/s ²]	t [s]	t [s]	S [m]	S [m]
0	0	0	200	2,03235	237,36454	342	0,06	362,52	197,9677	0,5460875	0	0	0	0
1	0,278	0,278	200	2,066796	234,65193	342	0,06	362,52	197,9332	0,5459925	0,509164	0,509164	0,07077	0,070774
2	0,556	0,278	200	2,102374	232,05726	342	0,06	362,52	197,8976	0,5458944	0,509256	1,018421	0,21236	0,283134
3	0,834	0,278	200	2,139084	229,57299	342	0,06	362,52	197,8609	0,5457931	0,509351	1,527771	0,354	0,637132
4	1,112	0,278	200	2,176926	227,19224	342	0,06	362,52	197,8231	0,5456887	0,509448	2,037219	0,49569	1,132825
5	1,39	0,278	200	2,2159	224,90866	342	0,06	362,52	197,7841	0,5455812	0,509548	2,546767	0,63744	1,77027
6	1,668	0,278	200	2,256006	222,71643	342	0,06	362,52	197,744	0,5454706	0,509652	3,056419	0,77926	2,549528
7	1,946	0,278	200	2,297244	220,61017	342	0,06	362,52	197,7028	0,5453568	0,509758	3,566177	0,92113	3,47066
8	2,224	0,278	200	2,339614	218,58491	342	0,06	362,52	197,6604	0,5452399	0,509867	4,076044	1,06307	4,533733
9	2,502	0,278	200	2,383116	216,63608	342	0,06	362,52	197,6169	0,5451199	0,50998	4,586024	1,20508	5,738815
10	2,78	0,278	200	2,42775	214,75943	342	0,06	362,52	197,5723	0,5449968	0,510095	5,096118	1,34716	7,085975
11	3,058	0,278	200	2,473516	212,95102	342	0,06	362,52	197,5265	0,5448706	0,510213	5,606331	1,48931	8,575287
12	3,336	0,278	200	2,520414	211,2072	342	0,06	362,52	197,4796	0,5447412	0,510334	6,116665	1,63154	10,20682
13	3,614	0,278	200	2,568444	209,52456	342	0,06	362,52	197,4316	0,5446087	0,510458	6,627124	1,77384	11,98067
14	3,892	0,278	200	2,617606	207,89995	342	0,06	362,52	197,3824	0,5444731	0,510585	7,137709	1,91623	13,89689
15	4,17	0,278	200	2,6679	206,3304	342	0,06	362,52	197,3321	0,5443344	0,510715	7,648425	2,05869	15,95559
16	4,448	0,278	200	2,719326	204,81318	342	0,06	362,52	197,2807	0,5441925	0,510849	8,159273	2,20125	18,15683
17	4,726	0,278	200	2,771884	203,3457	342	0,06	362,52	197,2281	0,5440475	0,510985	8,670258	2,34389	20,50072
18	5,004	0,278	200	2,825574	201,92556	342	0,06	362,52	197,1744	0,5438994	0,511124	9,181382	2,48662	22,98734
19	5,282	0,278	200	2,880396	200,5505	342	0,06	362,52	197,1196	0,5437482	0,511266	9,692648	2,62944	25,61678
20	5,56	0,278	200	2,93635	199,21841	342	0,06	362,52	197,0637	0,5435939	0,511411	10,20406	2,77236	28,38914
21	5,838	0,278	199,325	2,993436	197,92731	342	0,06	362,52	194,9339	0,537719	0,516999	10,72106	2,94638	31,33552
22	6,116	0,278	198,65	3,051654	196,67534	342	0,06	362,52	193,6237	0,5341048	0,520497	11,24155	3,11101	34,44653
23	6,394	0,278	197,975	3,111004	195,46074	342	0,06	362,52	192,3497	0,5305907	0,523944	11,7655	3,27727	37,7238
24	6,672	0,278	197,3	3,171486	194,28186	342	0,06	362,52	191,1104	0,5271719	0,527342	12,29284	3,44513	41,16893
25	6,95	0,278	196,625	3,2331	193,13715	342	0,06	362,52	189,904	0,5238443	0,530692	12,82353	3,61454	44,78347
26	7,228	0,278	195,95	3,295846	192,02514	342	0,06	362,52	188,7293	0,5206038	0,533995	13,35753	3,78549	48,56896
27	7,506	0,278	195,275	3,359724	190,94447	342	0,06	362,52	187,5847	0,5174466	0,537254	13,89478	3,95795	52,52691
28	7,784	0,278	194,6	3,424734	189,89381	342	0,06	362,52	186,4691	0,5143691	0,540468	14,43525	4,13188	56,65879
29	8,062	0,278	193,925	3,490876	188,87193	342	0,06	362,52	185,3811	0,5113678	0,54364	14,97889	4,30726	60,96605
30	8,34	0,278	193,25	3,55815	187,87767	342	0,06	362,52	184,3195	0,5084396	0,546771	15,52566	4,48407	65,45011
31	8,618	0,278	192,575	3,626556	186,90993	342	0,06	362,52	183,2834	0,5055814	0,549862	16,07552	4,66228	70,11239
32	8,896	0,278	191,9	3,696094	185,96765	342	0,06	362,52	182,2716	0,5027904	0,552914	16,62844	4,84187	74,95427
33	9,174	0,278	191,225	3,766764	185,04985	342	0,06	362,52	181,2831	0,5000637	0,555929	17,18437	5,02282	79,97709
34	9,452	0,278	190,55	3,838566	184,15558	342	0,06	362,52	180,317	0,4973988	0,558908	17,74327	5,20511	85,18219
35	9,73	0,278	189,875	3,9115	183,28396	342	0,06	362,52	179,3725	0,4947933	0,561851	18,30513	5,38871	90,5709
36	10,008	0,278	189,2	3,985566	182,43412	342	0,06	362,52	178,4486	0,4922447	0,56476	18,86988	5,57361	96,14452
37	10,286	0,278	188,525	4,060764	181,60526	342	0,06	362,52	177,5445	0,4897509	0,567635	19,43752	5,7598	101,9043
38	10,564	0,278	187,85	4,137094	180,79663	342	0,06	362,52	176,6595	0,4873098	0,570479	20,008	5,94724	107,8516
39	10,842	0,278	187,175	4,214556	180,00747	342	0,06	362,52	175,7929	0,4849192	0,573291	20,58129	6,13594	113,9875
40	11,12	0,278	186,5	4,29315	179,23711	342	0,06	362,52	174,944	0,4825774	0,576073	21,15736	6,32586	120,3134
41	11,398	0,278	185,825	4,372876	178,48487	342	0,06	362,52	174,112	0,4802825	0,578826	21,73619	6,517	126,8304
42	11,676	0,278	185,15	4,453734	177,75013	342	0,06	362,52	173,2964	0,4780326	0,58155	22,31774	6,70935	133,5397
43	11,954	0,278	184,475	4,535724	177,03227	342	0,06	362,52	172,4966	0,4758263	0,584247	22,90199	6,90288	140,4426
44	12,232	0,278	183,8	4,618846	176,33074	342	0,06	362,52	171,7119	0,4736618	0,586917	23,4889	7,09758	147,5402
45	12,51	0,278	183,125	4,7031	175,64496	342	0,06	362,52	170,9419	0,4715377	0,58956	24,07846	7,29345	154,8336

46	12,788	0,278	182,45	4,788486	174,97443	342	0,06	362,52	170,1859	0,4694526	0,592179	24,67064	7,49047	162,3241
47	13,066	0,278	181,775	4,875004	174,31863	342	0,06	362,52	169,4436	0,4674049	0,594773	25,26542	7,68864	170,0127
48	13,344	0,278	181,1	4,962654	173,67709	342	0,06	362,52	168,7144	0,4653935	0,597344	25,86276	7,88793	177,9007
49	13,622	0,278	180,425	5,051436	173,04935	342	0,06	362,52	167,9979	0,463417	0,599892	26,46265	8,08834	185,989
50	13,9	0,278	179,75	5,14135	172,43496	342	0,06	362,52	167,2936	0,4614742	0,602417	27,06507	8,28986	194,2789
51	14,178	0,278	179,075	5,232396	171,83351	342	0,06	362,52	166,6011	0,4595639	0,604921	27,66999	8,49249	202,7713
52	14,456	0,278	178,4	5,324574	171,24459	342	0,06	362,52	165,92	0,4576851	0,607404	28,2774	8,69621	211,4676
53	14,734	0,278	177,725	5,417884	170,66781	342	0,06	362,52	165,2499	0,4558367	0,609868	28,88726	8,90102	220,3686
54	15,012	0,278	177,05	5,512326	170,1028	342	0,06	362,52	164,5905	0,4540176	0,612311	29,49957	9,1069	229,4755
55	15,29	0,278	176,375	5,6079	169,5492	342	0,06	362,52	163,9413	0,4522269	0,614736	30,11431	9,31386	238,7893
56	15,568	0,278	175,7	5,704606	169,00668	342	0,06	362,52	163,3021	0,4504636	0,617142	30,73145	9,52188	248,3112
57	15,846	0,278	175,025	5,802444	168,4749	342	0,06	362,52	162,6725	0,4487268	0,619531	31,35098	9,73097	258,0422
58	16,124	0,278	174,35	5,901414	167,95355	342	0,06	362,52	162,0521	0,4470157	0,621902	31,97288	9,9411	267,9833
59	16,402	0,278	173,675	6,001516	167,44232	342	0,06	362,52	161,4408	0,4453294	0,624257	32,59714	10,1523	278,1356
60	16,68	0,278	173	6,10275	166,94092	342	0,06	362,52	160,8382	0,443667	0,626596	33,22374	10,3645	288,5001
61	16,958	0,278	172,771429	6,205116	166,44907	342	0,06	362,52	160,244	0,4420279	0,62892	33,85266	10,5778	299,0779
62	17,236	0,278	172,542857	6,308614	165,96651	342	0,06	362,52	159,6579	0,4404113	0,631228	34,48389	10,7921	309,87
63	17,514	0,278	172,314286	6,413244	165,49296	342	0,06	362,52	159,0797	0,4388164	0,633522	35,11741	11,0075	320,8775
64	17,792	0,278	172,085714	6,519006	165,02818	342	0,06	362,52	158,5092	0,4372426	0,635803	35,75321	11,2238	332,1013
65	18,07	0,278	171,857143	6,6259	164,57193	342	0,06	362,52	157,946	0,4356891	0,63807	36,39128	11,4412	343,5425
66	18,348	0,278	171,628571	6,733926	164,12398	342	0,06	362,52	157,39	0,4341555	0,640324	37,0316	11,6597	355,2022
67	18,626	0,278	171,4	6,843084	163,68409	342	0,06	362,52	156,841	0,432641	0,642565	37,67417	11,8791	367,0813
68	18,904	0,278	171,171429	6,953374	163,25206	342	0,06	362,52	156,2987	0,431145	0,644795	38,31896	12,0996	379,1808
69	19,182	0,278	170,942857	7,064796	162,82768	342	0,06	362,52	155,7629	0,429667	0,647013	38,96598	12,3211	391,5019
70	19,46	0,278	170,714286	7,17735	162,41075	342	0,06	362,52	155,2334	0,4282064	0,64922	39,6152	12,5436	404,0455
71	19,738	0,278	170,485714	7,291036	162,00106	342	0,06	362,52	154,71	0,4267627	0,651416	40,26661	12,7671	416,8126
72	20,016	0,278	170,257143	7,405854	161,59844	342	0,06	362,52	154,1926	0,4253354	0,653602	40,92021	12,9916	429,8042
73	20,294	0,278	170,028571	7,521804	161,2027	342	0,06	362,52	153,6809	0,4239239	0,655778	41,57599	13,2172	443,0214
74	20,572	0,278	169,8	7,638886	160,81367	342	0,06	362,52	153,1748	0,4225278	0,657945	42,23394	13,4438	456,4652
75	20,85	0,278	169,571429	7,7571	160,43117	342	0,06	362,52	152,6741	0,4211466	0,660103	42,89404	13,6714	470,1366
76	21,128	0,278	169,342857	7,876446	160,05506	342	0,06	362,52	152,1786	0,4197799	0,662252	43,55629	13,9	484,0366
77	21,406	0,278	169,114286	7,996924	159,68515	342	0,06	362,52	151,6882	0,4184272	0,664393	44,22068	14,1296	498,1662
78	21,684	0,278	168,885714	8,118534	159,32132	342	0,06	362,52	151,2028	0,4170881	0,666526	44,88721	14,3603	512,5265
79	21,962	0,278	168,657143	8,241276	158,96339	342	0,06	362,52	150,7221	0,4157622	0,668651	45,55586	14,592	527,1185
80	22,24	0,278	168,428571	8,36515	158,61124	342	0,06	362,52	150,2461	0,4144491	0,67077	46,22663	14,8247	541,9432
81	22,518	0,278	168,2	8,490156	158,26473	342	0,06	362,52	149,7746	0,4131484	0,672882	46,89951	15,0584	557,0016
82	22,796	0,278	167,971429	8,616294	157,92372	342	0,06	362,52	149,3074	0,4118598	0,674987	47,5745	15,2932	572,2948
83	23,074	0,278	167,742857	8,743564	157,58807	342	0,06	362,52	148,8445	0,4105829	0,677086	48,25159	15,529	587,8238
84	23,352	0,278	167,514286	8,871966	157,25767	342	0,06	362,52	148,3857	0,4093173	0,67918	48,93076	15,7658	603,5896
85	23,63	0,278	167,285714	9,0015	156,9324	342	0,06	362,52	147,9309	0,4080627	0,681268	49,61203	16,0037	619,5932
86	23,908	0,278	167,057143	9,132166	156,61212	342	0,06	362,52	147,48	0,4068188	0,683351	50,29538	16,2426	635,8358
87	24,186	0,278	166,828571	9,263964	156,29674	342	0,06	362,52	147,0328	0,4055853	0,685429	50,98081	16,4825	652,3183
88	24,464	0,278	166,6	9,396894	155,98613	342	0,06	362,52	146,5892	0,4043618	0,687503	51,66832	16,7235	669,0418
89	24,742	0,278	166,371429	9,530956	155,6802	342	0,06	362,52	146,1492	0,4031481	0,689573	52,35789	16,9656	686,0074
90	25,02	0,278	166,142857	9,66615	155,37883	342	0,06	362,52	145,7127	0,4019438	0,691639	53,04953	17,2087	703,2161
91	25,298	0,278	165,914286	9,802476	155,08193	342	0,06	362,52	145,2795	0,4007488	0,693701	53,74323	17,4528	720,6689
92	25,576	0,278	165,685714	9,939934	154,78939	342	0,06	362,52	144,8495	0,3995627	0,695761	54,43899	17,6981	738,367
93	25,854	0,278	165,457143	10,078524	154,50113	342	0,06	362,52	144,4226	0,3983852	0,697817	55,13681	17,9444	756,3113
94	26,132	0,278	165,228571	10,218246	154,21704	342	0,06	362,52	143,9988	0,3972161	0,699871	55,83668	18,1917	774,5031
95	26,41	0,278	165	10,3591	153,93704	342	0,06	362,52	143,5779	0,3960552	0,701922	56,5386	18,4402	792,9433
96	26,688	0,278	164,771429	10,501086	153,66104	342	0,06	362,52	143,16	0,3949022	0,703972	57,24257	18,6897	811,633
97	26,966	0,278	164,542857	10,644204	153,38895	342	0,06	362,52	142,7447	0,3937569	0,706019	57,94859	18,9404	830,5734
98	27,244	0,278	164,314286	10,788454	153,1207	342	0,06	362,52	142,3322	0,392619	0,708066	58,65666	19,1921	849,7655
99	27,522	0,278	164,085714	10,933836	152,8562	342	0,06	362,52	141,9224	0,3914884	0,710111	59,36677	19,445	869,2105
100	27,8	0,278	163,857143	11,08035	152,59537	342	0,06	362,52	141,515	0,3903647	0,712155	60,07892	19,6989	888,9094

Appendix

101	28,078	0,278	163,628571	11,227996	152,33814	342	0,06	362,52	141,1101	0,3892479	0,714198	60,79312	19,954	908,8634
102	28,356	0,278	163,4	11,376774	152,08443	342	0,06	362,52	140,7077	0,3881376	0,716241	61,50936	20,2102	929,0735
103	28,634	0,278	163,171429	11,526684	151,83417	342	0,06	362,52	140,3075	0,3870338	0,718284	62,22764	20,4675	949,541
104	28,912	0,278	162,942857	11,677726	151,5873	342	0,06	362,52	139,9096	0,3859362	0,720326	62,94797	20,726	970,267
105	29,19	0,278	162,714286	11,8299	151,34374	342	0,06	362,52	139,5138	0,3848445	0,72237	63,67034	20,9856	991,2525
106	29,468	0,278	162,485714	11,983206	151,10343	342	0,06	362,52	139,1202	0,3837588	0,724413	64,39475	21,2463	1012,499
107	29,746	0,278	162,257143	12,137644	150,8663	342	0,06	362,52	138,7287	0,3826786	0,726458	65,12121	21,5082	1034,007
108	30,024	0,278	162,028571	12,293214	150,63229	342	0,06	362,52	138,3391	0,381604	0,728504	65,84972	21,7713	1055,778
109	30,302	0,278	161,8	12,449916	150,40134	342	0,06	362,52	137,9514	0,3805347	0,730551	66,58027	22,0356	1077,814
110	30,58	0,278	161,571429	12,60775	150,17339	342	0,06	362,52	137,5656	0,3794705	0,7326	67,31287	22,3011	1100,115
111	30,858	0,278	161,342857	12,766716	149,94838	342	0,06	362,52	137,1817	0,3784113	0,73465	68,04752	22,5677	1122,683
112	31,136	0,278	161,114286	12,926814	149,72626	342	0,06	362,52	136,7994	0,377357	0,736703	68,78422	22,8356	1145,518
113	31,414	0,278	160,885714	13,088044	149,50696	342	0,06	362,52	136,4189	0,3763073	0,738758	69,52298	23,1047	1168,623
114	31,692	0,278	160,657143	13,250406	149,29044	342	0,06	362,52	136,04	0,3752622	0,740815	70,26379	23,3749	1191,998
115	31,97	0,278	160,428571	13,4139	149,07665	342	0,06	362,52	135,6627	0,3742214	0,742876	71,00667	23,6465	1215,644
116	32,248	0,278	160,2	13,578526	148,86552	342	0,06	362,52	135,287	0,3731849	0,744939	71,75161	23,9192	1239,564
117	32,526	0,278	159,971429	13,744284	148,65702	342	0,06	362,52	134,9127	0,3721525	0,747006	72,49861	24,1933	1263,757
118	32,804	0,278	159,742857	13,911174	148,4511	342	0,06	362,52	134,5399	0,3711241	0,749076	73,24769	24,4686	1288,226
119	33,082	0,278	159,514286	14,079196	148,2477	342	0,06	362,52	134,1685	0,3700996	0,751149	73,99884	24,7451	1312,971
120	33,36	0,278	158,4	14,24835	148,04678	342	0,06	362,52	133,7984	0,3690787	0,753227	74,75206	25,0229	1337,994
121	33,638	0,278	157,090909	14,418636	147,84829	342	0,06	362,52	133,4297	0,3680615	0,755309	75,50737	25,3021	1363,296
122	33,916	0,278	155,803279	14,590054	147,6522	342	0,06	362,52	133,0621	0,3670477	0,757395	76,26477	25,5825	1388,878
123	34,194	0,278	154,536585	14,762604	147,45846	342	0,06	362,52	132,6959	0,3660373	0,759485	77,02425	25,8643	1414,742
124	34,472	0,278	153,290323	14,936286	147,26702	342	0,06	362,52	132,3307	0,3650302	0,761581	77,78583	26,1474	1440,89
125	34,75	0,278	152,064	15,1111	147,07785	342	0,06	362,52	131,9667	0,3640261	0,763681	78,54952	26,4318	1467,322
126	35,028	0,278	150,857143	15,287046	146,8909	342	0,06	362,52	131,6039	0,3630251	0,765787	79,3153	26,7176	1494,039
127	35,306	0,278	149,669291	15,464124	146,70614	342	0,06	362,52	131,242	0,362027	0,767899	80,0832	27,0047	1521,044
128	35,584	0,278	148,5	15,642334	146,52353	342	0,06	362,52	130,8812	0,3610317	0,770016	80,85322	27,2932	1548,337
129	35,862	0,278	147,348837	15,821676	146,34303	342	0,06	362,52	130,5214	0,360039	0,772138	81,62536	27,5831	1575,92
130	36,14	0,278	146,215385	16,00215	146,1646	342	0,06	362,52	130,1625	0,359049	0,774268	82,39962	27,8744	1603,795
131	36,418	0,278	145,099237	16,183756	145,98822	342	0,06	362,52	128,9155	0,3556093	0,781757	83,18138	28,3614	1632,156
132	36,696	0,278	144	16,366494	145,81383	342	0,06	362,52	127,6335	0,352073	0,789609	83,97099	28,8657	1661,022
133	36,974	0,278	142,917293	16,550364	145,64142	342	0,06	362,52	126,3669	0,3485792	0,797523	84,76851	29,3768	1690,398
134	37,252	0,278	141,850746	16,735366	145,47095	342	0,06	362,52	125,1154	0,3451268	0,805501	85,57401	29,8946	1720,293
135	37,53	0,278	140,8	16,9215	145,30238	342	0,06	362,52	123,8785	0,3417149	0,813544	86,38756	30,4192	1750,712
136	37,808	0,278	139,764706	17,108766	145,13568	342	0,06	362,52	122,6559	0,3383425	0,821653	87,20921	30,9508	1781,663
137	38,086	0,278	138,744526	17,297164	144,97083	342	0,06	362,52	121,4474	0,3350087	0,829829	88,03904	31,4895	1813,153
138	38,364	0,278	137,73913	17,486694	144,80778	342	0,06	362,52	120,2524	0,3317126	0,838075	88,87711	32,0354	1845,188
139	38,642	0,278	136,748201	17,677356	144,64652	342	0,06	362,52	119,0708	0,3284532	0,846392	89,72351	32,5886	1877,777
140	38,92	0,278	135,771429	17,86915	144,48701	342	0,06	362,52	117,9023	0,3252297	0,85478	90,57829	33,1492	1910,926
141	39,198	0,278	134,808511	18,062076	144,32923	342	0,06	362,52	116,7464	0,3220414	0,863243	91,44153	33,7174	1944,643
142	39,476	0,278	133,859155	18,256134	144,17314	342	0,06	362,52	115,603	0,3188873	0,871781	92,31331	34,2933	1978,937
143	39,754	0,278	132,923077	18,451324	144,01872	342	0,06	362,52	114,4718	0,3157667	0,880397	93,19371	34,8769	2013,813
144	40,032	0,278	132	18,647646	143,86595	342	0,06	362,52	113,3524	0,3126789	0,889091	94,0828	35,4685	2049,282
145	40,31	0,278	131,089655	18,8451	143,71479	342	0,06	362,52	112,2446	0,3096231	0,897866	94,98066	36,0682	2085,35
146	40,588	0,278	130,191781	19,043686	143,56522	342	0,06	362,52	111,1481	0,3065985	0,906723	95,88739	36,676	2122,026
147	40,866	0,278	129,306122	19,243404	143,41722	342	0,06	362,52	110,0627	0,3036045	0,915665	96,80305	37,2923	2159,318
148	41,144	0,278	128,432432	19,444254	143,27076	342	0,06	362,52	108,9882	0,3006405	0,924693	97,72774	37,917	2197,235
149	41,422	0,278	127,57047	19,646236	143,12582	342	0,06	362,52	107,9242	0,2977056	0,933808	98,66155	38,5504	2235,786
150	41,7	0,278	126,72	19,84935	142,98237	342	0,06	362,52	106,8707	0,2947993	0,943014	99,60457	39,1926	2274,978
151	41,978	0,278	125,880795	20,053596	142,84039	342	0,06	362,52	105,8272	0,291921	0,952312	100,5569	39,8438	2314,822
152	42,256	0,278	125,052632	20,258974	142,69986	342	0,06	362,52	104,7937	0,28907	0,961705	101,5186	40,5041	2355,326
153	42,534	0,278	124,235294	20,465484	142,56076	342	0,06	362,52	103,7698	0,2862458	0,971193	102,4898	41,1737	2396,5
154	42,812	0,278	123,428571	20,673126	142,42307	342	0,06	362,52	102,7554	0,2834477	0,980781	103,4706	41,8529	2438,353
155	43,09	0,278	122,632258	20,8819	142,28675	342	0,06	362,52	101,7504	0,2806752	0,990469	104,461	42,5416	2480,895

156	43,368	0,278	121,846154	21,091806	142,15181	342	0,06	362,52	100,7543	0,2779277	1,00026	105,4613	43,2402	2524,135
157	43,646	0,278	121,070064	21,302844	142,0182	342	0,06	362,52	99,76722	0,2752047	1,010157	106,4714	43,9489	2568,084
158	43,924	0,278	120,303797	21,515014	141,88592	342	0,06	362,52	98,78878	0,2725057	1,020162	107,4916	44,6678	2612,752
159	44,202	0,278	119,54717	21,728316	141,75493	342	0,06	362,52	97,81885	0,2698302	1,030277	108,5219	45,3971	2658,149
160	44,48	0,278	118,8	21,94275	141,62524	342	0,06	362,52	96,85725	0,2671777	1,040506	109,5624	46,1371	2704,286
161	44,758	0,278	118,062112	22,158316	141,49681	342	0,06	362,52	95,9038	0,2645476	1,050851	110,6132	46,8879	2751,174
162	45,036	0,278	117,333333	22,375014	141,36962	342	0,06	362,52	94,95832	0,2619395	1,061314	111,6746	47,6498	2798,823
163	45,314	0,278	116,613497	22,592844	141,24367	342	0,06	362,52	94,02065	0,259353	1,071898	112,7465	48,423	2847,246
164	45,592	0,278	115,902439	22,811806	141,11893	342	0,06	362,52	93,09063	0,2567876	1,082607	113,8291	49,2077	2896,454
165	45,87	0,278	115,2	23,0319	140,99537	342	0,06	362,52	92,1681	0,2542428	1,093443	114,9225	50,0042	2946,458
166	46,148	0,278	114,506024	23,253126	140,873	342	0,06	362,52	91,2529	0,2517182	1,104409	116,0269	50,8128	2997,271
167	46,426	0,278	113,820359	23,475484	140,75179	342	0,06	362,52	90,34488	0,2492135	1,115509	117,1424	51,6336	3048,905
168	46,704	0,278	113,142857	23,698974	140,63172	342	0,06	362,52	89,44388	0,2467281	1,126746	118,2692	52,4669	3101,372
169	46,982	0,278	112,473373	23,923596	140,51278	342	0,06	362,52	88,54978	0,2442618	1,138123	119,4073	53,3131	3154,685
170	47,26	0,278	111,811765	24,14935	140,39494	342	0,06	362,52	87,66241	0,241814	1,149644	120,5569	54,1724	3208,857
171	47,538	0,278	111,157895	24,376236	140,27821	342	0,06	362,52	86,78166	0,2393845	1,161312	121,7182	55,045	3263,902
172	47,816	0,278	110,511628	24,604254	140,16256	342	0,06	362,52	85,90737	0,2369728	1,17313	122,8914	55,9313	3319,834
173	48,094	0,278	109,872832	24,833404	140,04797	342	0,06	362,52	85,03943	0,2345786	1,185104	124,0765	56,8317	3376,665
174	48,372	0,278	109,241379	25,063686	139,93443	342	0,06	362,52	84,17769	0,2322015	1,197236	125,2737	57,7463	3434,412
175	48,65	0,278	108,617143	25,2951	139,82193	342	0,06	362,52	83,32204	0,2298412	1,209531	126,4832	58,6755	3493,087
176	48,928	0,278	108	25,527646	139,71045	342	0,06	362,52	82,47235	0,2274974	1,221992	127,7052	59,6198	3552,707
177	49,206	0,278	107,389831	25,761324	139,59998	342	0,06	362,52	81,62851	0,2251697	1,234625	128,9399	60,5793	3613,286
178	49,484	0,278	106,786517	25,996134	139,49051	342	0,06	362,52	80,79038	0,2228577	1,247433	130,1873	61,5546	3674,841
179	49,762	0,278	106,189944	26,232076	139,38202	342	0,06	362,52	79,95787	0,2205613	1,260421	131,4477	62,5459	3737,387
180	50,04	0,278	105,6	26,46915	139,2745	342	0,06	362,52	79,13085	0,21828	1,273594	132,7213	63,5536	3800,94
181	50,318	0,278	105,016575	26,707356	139,16793	342	0,06	362,52	78,30922	0,2160135	1,286957	134,0083	64,5782	3865,518
182	50,596	0,278	104,43956	26,946694	139,06231	342	0,06	362,52	77,49287	0,2137616	1,300514	135,3088	65,62	3931,138
183	50,874	0,278	103,868852	27,187164	138,95761	342	0,06	362,52	76,68169	0,211524	1,314272	136,6231	66,6796	3997,818
184	51,152	0,278	103,304348	27,428766	138,85384	342	0,06	362,52	75,87558	0,2093004	1,328234	137,9513	67,7572	4065,575
185	51,43	0,278	102,745946	27,6715	138,75097	342	0,06	362,52	75,07445	0,2070905	1,342408	139,2937	68,8535	4134,429
186	51,708	0,278	102,193548	27,915366	138,649	342	0,06	362,52	74,27818	0,204894	1,356799	140,6505	69,9688	4204,397
187	51,986	0,278	101,647059	28,160364	138,5479	342	0,06	362,52	73,48669	0,2027107	1,371412	142,0219	71,1036	4275,501
188	52,264	0,278	101,106383	28,406494	138,44768	342	0,06	362,52	72,69989	0,2005404	1,386255	143,4082	72,2585	4347,76
189	52,542	0,278	100,571429	28,653756	138,34832	342	0,06	362,52	71,91767	0,1983826	1,401332	144,8095	73,434	4421,194
190	52,82	0,278	100,042105	28,90215	138,24981	342	0,06	362,52	71,13996	0,1962373	1,416652	146,2261	74,6306	4495,824

Table 2 - Acceleration phase calculations

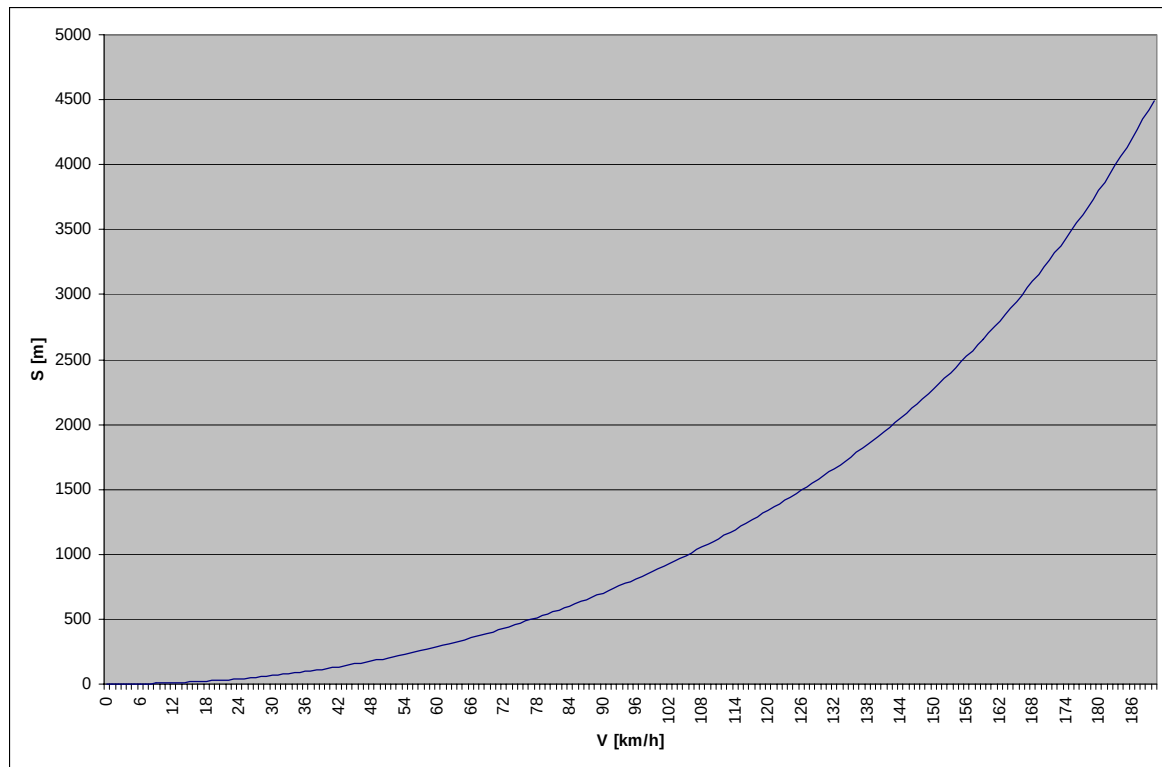


Figure 2 - Acceleration curve

Braking

V2 [Km/h]	v2 [m/s]	v [m/s]	MAXdec [m/s^2]	F break [KN]	D [KN]	R [KN] (Fbrak+D)	Adhesion	F dec [KN]	a [m/s^2]	t [s]	t [s]	S [m]	S [m]
190	52,82	0	0,8	273,6	28,902	302,502	132,25	302,502	-0,8344422	0	0	0	0
189	52,542	-0,278	0,8	273,6	28,654	302,254	138,348	302,254	-0,8337581	0,33343	0,3334	17,56543	17,5654
188	52,264	-0,278	0,8	273,6	28,406	302,006	138,448	302,006	-0,833074	0,3337	0,6671	17,48708	35,0525
187	51,986	-0,278	0,8	273,6	28,16	301,76	138,548	301,76	-0,8323955	0,33398	1,0011	17,40849	52,461
186	51,708	-0,278	0,8	273,6	27,915	301,515	138,649	301,515	-0,8317196	0,33425	1,3354	17,32972	69,7907
185	51,43	-0,278	0,8	273,6	27,6715	301,2715	138,751	301,2715	-0,8310479	0,33452	1,6699	17,25073	87,0414
184	51,152	-0,278	0,8	273,6	27,429	301,029	138,854	301,029	-0,830379	0,33479	2,0047	17,17155	104,213
183	50,874	-0,278	0,8	273,6	27,187	300,787	138,958	300,787	-0,8297115	0,33506	2,3397	17,09222	121,305
182	50,596	-0,278	0,8	273,6	26,947	300,547	139,062	300,547	-0,8290494	0,33532	2,675	17,01265	138,318
181	50,318	-0,278	0,8	273,6	26,707	300,307	139,168	300,307	-0,8283874	0,33559	3,0106	16,93295	155,251
180	50,04	-0,278	0,8	273,6	26,469	300,069	139,275	300,069	-0,8277309	0,33586	3,3465	16,85302	172,104
179	49,762	-0,278	0,8	273,6	26,2321	299,8321	139,382	299,8321	-0,8270774	0,33612	3,6826	16,77289	188,877
178	49,484	-0,278	0,8	273,6	25,9961	299,5961	139,491	299,5961	-0,8264264	0,33639	4,019	16,69259	205,569
177	49,206	-0,278	0,8	273,6	25,7613	299,3613	139,6	299,3613	-0,8257787	0,33665	4,3557	16,61209	222,181
176	48,928	-0,278	0,8	273,6	25,5276	299,1276	139,711	299,1276	-0,8251341	0,33691	4,6926	16,53141	238,713
175	48,65	-0,278	0,8	273,6	25,2951	298,8951	139,822	298,8951	-0,8244927	0,33718	5,0297	16,45053	255,163
174	48,372	-0,278	0,8	273,6	25,0637	298,66369	139,934	298,66369	-0,8238544	0,33744	5,3672	16,36947	271,533
173	48,094	-0,278	0,8	273,6	24,8334	298,4334	140,048	298,4334	-0,8232191	0,3377	5,7049	16,28822	287,821
172	47,816	-0,278	0,8	273,6	24,6043	298,2043	140,163	298,2043	-0,8225872	0,33796	6,0428	16,20678	304,028
171	47,538	-0,278	0,8	273,6	24,3762	297,9762	140,278	297,9762	-0,821958	0,33822	6,3811	16,12516	320,153
170	47,26	-0,278	0,8	273,6	24,1492	297,7492	140,395	297,7492	-0,8213318	0,33847	6,7195	16,04336	336,196
169	46,982	-0,278	0,8	273,6	23,9236	297,5236	140,513	297,5236	-0,8207095	0,33873	7,0583	15,96136	352,158

168	46,704	-0,278	0,8	273,6	23,6989	297,2989	140,632	297,2989	-0,8200897	0,33899	7,3973	15,87918	368,037
167	46,426	-0,278	0,8	273,6	23,4754	297,0754	140,752	297,0754	-0,8194731	0,33924	7,7365	15,79682	383,834
166	46,148	-0,278	0,8	273,6	23,2532	296,8532	140,873	296,8532	-0,8188602	0,3395	8,076	15,71426	399,548
165	45,87	-0,278	0,8	273,6	23,0139	296,6139	140,995	296,6139	-0,8182001	0,33977	8,4158	15,63249	415,18
164	45,592	-0,278	0,8	273,6	22,8118	296,4118	141,119	296,4118	-0,8176426	0,34	8,7558	15,54862	430,729
163	45,314	-0,278	0,8	273,6	22,5928	296,1928	141,244	296,1928	-0,8170385	0,34025	9,096	15,46553	446,195
162	45,036	-0,278	0,8	273,6	22,375	295,975	141,37	295,975	-0,8164377	0,3405	9,4365	15,38225	461,577
161	44,758	-0,278	0,8	273,6	22,1583	295,7583	141,497	295,7583	-0,81584	0,34075	9,7773	15,29879	476,876
160	44,48	-0,278	0,8	273,6	21,9427	295,5427	141,625	295,5427	-0,8152452	0,341	10,118	15,21515	492,091
159	44,202	-0,278	0,8	273,6	21,7283	295,3283	141,755	295,3283	-0,8146538	0,34125	10,46	15,13133	507,222
158	43,924	-0,278	0,8	273,6	21,515	295,115	141,886	295,115	-0,8140654	0,3415	10,801	15,04733	522,269
157	43,646	-0,278	0,8	273,6	21,3028	294,9028	142,018	294,9028	-0,8134801	0,34174	11,143	14,96316	537,233
156	43,368	-0,278	0,8	273,6	21,0918	294,69181	142,152	294,69181	-0,8128981	0,34199	11,485	14,8788	552,111
155	43,09	-0,278	0,8	273,6	20,8819	294,4819	142,287	294,4819	-0,812319	0,34223	11,827	14,79426	566,906
154	42,812	-0,278	0,8	273,6	20,6713	294,2713	142,423	294,2713	-0,8117381	0,34247	12,169	14,70964	581,615
153	42,534	-0,278	0,8	273,6	20,4654	294,0654	142,561	294,0654	-0,8111701	0,34271	12,512	14,62467	596,24
152	42,256	-0,278	0,8	273,6	20,2589	293,8589	142,7	293,8589	-0,8106005	0,34296	12,855	14,5396	610,78
151	41,978	-0,278	0,8	273,6	20,0536	293,6536	142,84	293,6536	-0,8100342	0,3432	13,198	14,45436	625,234
150	41,7	-0,278	0,8	273,6	19,8496	293,4496	142,982	293,4496	-0,8094715	0,34343	13,542	14,36893	639,603
149	41,422	-0,278	0,8	273,6	19,6462	293,24624	143,126	293,24624	-0,8089105	0,34367	13,885	14,28336	653,886
148	41,144	-0,278	0,8	273,6	19,444	293,044	143,871	293,044	-0,8083526	0,34391	14,229	14,19761	668,084
147	40,866	-0,278	0,8	273,6	19,2434	292,8434	143,417	292,8434	-0,8077993	0,34414	14,573	14,11166	682,196
146	40,588	-0,278	0,8	273,6	19,04	292,64	143,565	292,64	-0,8072382	0,34438	14,918	14,02573	696,221
145	40,31	-0,278	0,8	273,6	18,8451	292,4451	143,715	292,4451	-0,8067006	0,34461	15,262	13,93928	710,161
144	40,032	-0,278	0,8	273,6	18,6476	292,2476	143,866	292,2476	-0,8061558	0,34485	15,607	13,85283	724,013
143	39,754	-0,278	0,8	273,6	18,4513	292,0513	144,019	292,0513	-0,8056143	0,34508	15,952	13,76621	737,78
142	39,476	-0,278	0,8	273,6	18,2561	291,8561	144,173	291,8561	-0,8050759	0,34531	16,298	13,67942	751,459
141	39,198	-0,278	0,8	273,6	18,8691	292,4691	144,329	292,4691	-0,8067668	0,34459	16,642	13,55495	765,014
140	38,92	-0,278	0,8	273,6	17,677	291,277	144,487	291,277	-0,8034784	0,346	16,988	13,51424	778,528
139	38,642	-0,278	0,8	273,6	17,4866	291,0866	144,617	291,0866	-0,8029532	0,34622	17,335	13,42683	791,955
138	38,364	-0,278	0,8	273,6	17,2971	290,8971	144,809	290,8971	-0,8024305	0,34645	17,681	13,33927	805,294
137	38,086	-0,278	0,8	273,6	17,1088	290,70877	144,971	290,70877	-0,801911	0,34667	18,028	13,25153	818,546
136	37,808	-0,278	0,8	273,6	16,9215	290,5215	145,136	290,5215	-0,8013944	0,3469	18,375	13,16364	831,709
135	37,53	-0,278	0,8	273,6	16,7353	290,3353	145,302	290,3353	-0,8008808	0,34712	18,722	13,07558	844,785
134	37,252	-0,278	0,8	273,6	16,55	290,15	145,471	290,15	-0,8003696	0,34734	19,069	12,98737	857,772
133	36,974	-0,278	0,8	273,6	16,3664	289,9664	145,641	289,9664	-0,7998632	0,34756	19,417	12,89897	870,671
132	36,696	-0,278	0,8	273,6	16,1837	289,7837	145,814	289,7837	-0,7993592	0,34778	19,764	12,81042	883,482
131	36,418	-0,278	0,8	273,6	16,0022	289,60215	145,988	289,60215	-0,7988584	0,348	20,112	12,72171	896,204
130	36,14	-0,278	0,8	273,6	15,8216	289,4216	146,165	289,4216	-0,7983604	0,34821	20,461	12,63284	908,836
129	35,862	-0,278	0,8	273,6	15,6423	289,24233	146,343	289,24233	-0,7978659	0,34843	20,809	12,54381	921,38
128	35,584	-0,278	0,8	273,6	15,4641	289,06412	146,524	289,06412	-0,7973743	0,34864	21,158	12,45462	933,835
127	35,306	-0,278	0,8	273,6	15,287	288,887	146,706	288,887	-0,7968857	0,34886	21,506	12,36527	946,2
126	35,028	-0,278	0,8	273,6	15,111	288,711	146,891	288,711	-0,7964002	0,34907	21,856	12,27577	958,476
125	34,75	-0,278	0,8	273,6	14,9362	288,5362	147,078	288,5362	-0,795918	0,34928	22,205	12,18611	970,662
124	34,472	-0,278	0,8	273,6	14,7626	288,3626	147,267	288,3626	-0,7954391	0,34949	22,554	12,09628	982,758
123	34,194	-0,278	0,8	273,6	14,59	288,19	147,459	288,19	-0,794963	0,3497	22,904	12,00631	994,765
122	33,916	-0,278	0,8	273,6	14,4186	288,0186	147,652	288,0186	-0,7944902	0,34991	23,254	11,91618	1006,68
121	33,638	-0,278	0,8	273,6	14,2484	287,84835	147,848	287,84835	-0,7940206	0,35012	23,604	11,8259	1018,51
120	33,36	-0,278	0,8	273,6	14,0792	287,6792	148,047	287,6792	-0,793554	0,35032	23,954	11,73546	1030,24
119	33,082	-0,278	0,8	273,6	13,9111	287,5111	148,248	287,5111	-0,7930903	0,35053	24,305	11,64488	1041,89
118	32,804	-0,278	0,8	273,6	13,7443	287,34428	148,451	287,34428	-0,7926301	0,35073	24,656	11,55413	1053,44
117	32,526	-0,278	0,8	273,6	13,5785	287,1785	148,657	287,1785	-0,7921728	0,35093	25,007	11,46324	1064,9
116	32,248	-0,278	0,8	273,6	13,41	287,01	148,866	287,01	-0,791708	0,35114	25,358	11,37236	1076,28
115	31,97	-0,278	0,8	273,6	13,25	286,85	149,077	286,85	-0,7912667	0,35134	25,709	11,28103	1087,56
114	31,692	-0,278	0,8	273,6	13,088	286,688	149,29	286,688	-0,7908198	0,35153	26,061	11,18968	1098,75

Appendix

113	31,414	-0,278	0,8	273,6	12,926	286,526	149,507	286,526	-0,7903729	0,35173	26,412	11,09822	1109,85
112	31,136	-0,278	0,8	273,6	12,7667	286,36672	149,726	286,36672	-0,7899336	0,35193	26,764	11,00656	1120,85
111	30,858	-0,278	0,8	273,6	12,6078	286,20775	149,948	286,20775	-0,7894951	0,35212	27,116	10,91478	1131,77
110	30,58	-0,278	0,8	273,6	12,4499	286,0499	150,173	286,0499	-0,7890596	0,35232	27,469	10,82286	1142,59
109	30,302	-0,278	0,8	273,6	12,2932	285,89321	150,401	285,89321	-0,7886274	0,35251	27,821	10,73079	1153,32
108	30,024	-0,278	0,8	273,6	12,1376	285,7376	150,632	285,7376	-0,7881982	0,3527	28,174	10,63859	1163,96
107	29,746	-0,278	0,8	273,6	11,9832	285,58323	150,866	285,58323	-0,7877723	0,35289	28,527	10,54623	1174,51
106	29,468	-0,278	0,8	273,6	11,8299	285,4299	151,103	285,4299	-0,7873494	0,35308	28,88	10,45374	1184,96
105	29,19	-0,278	0,8	273,6	11,6777	285,2777	151,344	285,2777	-0,7869295	0,35327	29,233	10,36111	1195,32
104	28,912	-0,278	0,8	273,6	11,5268	285,1268	151,587	285,1268	-0,7865133	0,35346	29,587	10,26833	1205,59
103	28,634	-0,278	0,8	273,6	11,3767	284,9767	151,834	284,9767	-0,7860992	0,35364	29,94	10,17543	1215,76
102	28,356	-0,278	0,8	273,6	11,288	284,888	152,084	284,888	-0,7858546	0,35376	30,294	10,08025	1225,84
101	28,078	-0,278	0,8	273,6	11,08	284,68	152,338	284,68	-0,7852808	0,35401	30,648	9,989199	1235,83
100	27,8	-0,278	0,8	273,6	10,9338	284,5338	152,595	284,5338	-0,7848775	0,3542	31,002	9,895865	1245,73
99	27,522	-0,278	0,8	273,6	10,7884	284,3884	152,856	284,3884	-0,7844764	0,35438	31,357	9,802408	1255,53
98	27,244	-0,278	0,8	273,6	10,6442	284,2442	153,121	284,2442	-0,7840787	0,35456	31,711	9,708814	1265,24
97	26,966	-0,278	0,8	273,6	10,5	284,1	153,389	284,1	-0,7836809	0,35474	32,066	9,615125	1274,86
96	26,688	-0,278	0,8	273,6	10,3591	283,9591	153,661	283,9591	-0,7832922	0,35491	32,421	9,521231	1284,38
95	26,41	-0,278	0,8	273,6	10,2182	283,8182	153,997	283,8182	-0,7829036	0,35509	32,776	9,427243	1293,8
94	26,132	-0,278	0,8	273,6	10,07	283,67	154,217	283,67	-0,7824948	0,35527	33,131	9,333402	1303,14
93	25,854	-0,278	0,8	273,6	9,94	283,54	154,501	283,54	-0,7821362	0,35544	33,487	9,23887	1312,38
92	25,576	-0,278	0,8	273,6	9,8	283,4	154,789	283,4	-0,78175	0,35561	33,842	9,144573	1321,52
91	25,298	-0,278	0,8	273,6	9,666	283,266	155,082	283,266	-0,7813803	0,35578	34,198	9,049992	1330,57
90	25,02	-0,278	0,8	273,6	9,53	283,13	155,379	283,13	-0,7810052	0,35595	34,554	8,955385	1339,53
89	24,742	-0,278	0,8	273,6	9,397	282,997	155,68	282,997	-0,7806383	0,35612	34,91	8,860593	1348,39
88	24,464	-0,278	0,8	273,6	9,2639	282,8639	155,986	282,8639	-0,7802712	0,35629	35,266	8,765714	1357,15
87	24,186	-0,278	0,8	273,6	9,1321	282,7321	156,297	282,7321	-0,7799076	0,35645	35,623	8,670707	1365,82
86	23,908	-0,278	0,8	273,6	9	282,6	156,612	282,6	-0,7795432	0,35662	35,979	8,57562	1374,4
85	23,63	-0,278	0,8	273,6	8,87	282,47	156,932	282,47	-0,7791846	0,35678	36,336	8,480381	1382,88
84	23,352	-0,278	0,8	273,6	8,7435	282,3435	157,258	282,3435	-0,7788357	0,35694	36,693	8,38495	1391,26
83	23,074	-0,278	0,8	273,6	8,6162	282,2162	157,588	282,2162	-0,7784845	0,3571	37,05	8,289457	1399,55
82	22,796	-0,278	0,8	273,6	8,49	282,09	157,924	282,09	-0,7781364	0,35726	37,407	8,193846	1407,75
81	22,518	-0,278	0,8	273,6	8,3651	281,9651	158,265	281,9651	-0,7777918	0,35742	37,765	8,098113	1415,85
80	22,24	-0,278	0,8	273,6	8,2412	281,8412	158,611	281,8412	-0,7774501	0,35758	38,122	8,002266	1423,85
79	21,962	-0,278	0,8	273,6	8,1185	281,7185	158,963	281,7185	-0,7771116	0,35773	38,48	7,906301	1431,75
78	21,684	-0,278	0,8	273,6	7,997	281,597	159,321	281,597	-0,7767765	0,35789	38,838	7,810219	1439,56
77	21,406	-0,278	0,8	273,6	7,876	281,476	159,685	281,476	-0,7764427	0,35804	39,196	7,71404	1447,28
76	21,128	-0,278	0,8	273,6	7,7571	281,3571	160,055	281,3571	-0,7761147	0,35819	39,554	7,617722	1454,9
75	20,85	-0,278	0,8	273,6	7,6388	281,2388	160,431	281,2388	-0,7757884	0,35835	39,913	7,521306	1462,42
74	20,572	-0,278	0,8	273,6	7,5218	281,1218	160,814	281,1218	-0,7754656	0,35849	40,271	7,424775	1469,84
73	20,294	-0,278	0,8	273,6	7,4	281	161,203	281	-0,7751296	0,35865	40,63	7,328289	1477,17
72	20,016	-0,278	0,8	273,6	7,291	280,891	161,598	280,891	-0,774829	0,35879	40,989	7,231389	1484,4
71	19,738	-0,278	0,8	273,6	7,17735	280,77735	162,001	280,77735	-0,7745155	0,35893	41,348	7,134533	1491,54
70	19,46	-0,278	0,8	273,6	7,06479	280,66479	162,411	280,66479	-0,774205	0,35908	41,707	7,03757	1498,57
69	19,182	-0,278	0,8	273,6	6,9533	280,5533	162,828	280,5533	-0,7738974	0,35922	42,066	6,940504	1505,51
68	18,904	-0,278	0,8	273,6	6,843	280,443	163,252	280,443	-0,7735932	0,35936	42,425	6,843331	1512,36
67	18,626	-0,278	0,8	273,6	6,7339	280,3339	163,684	280,3339	-0,7732922	0,3595	42,785	6,746053	1519,1
66	18,348	-0,278	0,8	273,6	6,6259	280,2259	164,124	280,2259	-0,7729943	0,35964	43,144	6,648672	1525,75
65	18,07	-0,278	0,8	273,6	6,519	280,119	164,572	280,119	-0,7726994	0,35978	43,504	6,551192	1532,3
64	17,792	-0,278	0,8	273,6	6,4132	280,0132	165,028	280,0132	-0,7724076	0,35991	43,864	6,453611	1538,76
63	17,514	-0,278	0,8	273,6	6,3	279,9	165,493	279,9	-0,7720953	0,36006	44,224	6,356124	1545,11
62	17,236	-0,278	0,8	273,6	6,2	279,8	165,967	279,8	-0,7718195	0,36019	44,584	6,258264	1551,37
61	16,958	-0,278	0,8	273,6	6,1	279,7	166,449	279,7	-0,7715436	0,36032	44,945	6,160333	1557,53
60	16,68	-0,278	0,8	273,6	6	279,6	166,941	279,6	-0,7712678	0,36045	45,305	6,062333	1563,59
59	16,402	-0,278	0,8	273,6	5,9	279,5	167,442	279,5	-0,7709919	0,36057	45,666	5,964262	1569,56

58	16,124	-0,278	0,8	273,6	5,8	279,4	167,954	279,4	-0,7707161	0,3607	46,026	5,866121	1575,42
57	15,846	-0,278	0,8	273,6	5,7	279,3	168,475	279,3	-0,7704403	0,36083	46,387	5,76791	1581,19
56	15,568	-0,278	0,8	273,6	5,75	279,35	169,007	279,35	-0,7705782	0,36077	46,748	5,666584	1586,86
55	15,29	-0,278	0,8	273,6	5,6	279,2	169,549	279,2	-0,7701644	0,36096	47,109	5,569281	1592,43
54	15,012	-0,278	0,8	273,6	5,5123	279,1123	170,103	279,1123	-0,7699225	0,36108	47,47	5,470652	1597,9
53	14,734	-0,278	0,8	273,6	5,4178	279,0178	170,668	279,0178	-0,7696618	0,3612	47,831	5,372092	1603,27
52	14,456	-0,278	0,8	273,6	5,3224	278,9224	171,245	278,9224	-0,7693987	0,36132	48,193	5,273482	1608,54
51	14,178	-0,278	0,8	273,6	5,2323	278,8323	171,834	278,8323	-0,7691501	0,36144	48,554	5,174706	1613,72
50	13,9	-0,278	0,8	273,6	5,1413	278,7413	172,435	278,7413	-0,7688991	0,36156	48,915	5,075883	1618,8
49	13,622	-0,278	0,8	273,6	5,0514	278,6514	173,049	278,6514	-0,7686511	0,36167	49,277	4,976976	1623,77
48	13,344	-0,278	0,8	273,6	4,9626	278,5626	173,677	278,5626	-0,7684062	0,36179	49,639	4,877985	1628,65
47	13,066	-0,278	0,8	273,6	4,875	278,475	174,319	278,475	-0,7681645	0,3619	50,001	4,778911	1633,43
46	12,788	-0,278	0,8	273,6	4,78848	278,38848	174,974	278,38848	-0,7679259	0,36201	50,363	4,679757	1638,11
45	12,51	-0,278	0,8	273,6	4,7	278,3	175,645	278,3	-0,7676818	0,36213	50,725	4,580572	1642,69
44	12,232	-0,278	0,8	273,6	4,6188	278,2188	176,331	278,2188	-0,7674578	0,36223	51,087	4,481208	1647,17
43	11,954	-0,278	0,8	273,6	4,53	278,13	177,032	278,13	-0,7672128	0,36235	51,45	4,381905	1651,55
42	11,676	-0,278	0,8	273,6	4,45	278,05	177,75	278,05	-0,7669922	0,36245	51,812	4,282404	1655,84
41	11,398	-0,278	0,8	273,6	4,3728	277,9728	178,485	277,9728	-0,7667792	0,36256	52,175	4,182802	1660,02
40	11,12	-0,278	0,8	273,6	4,2931	277,8931	179,237	277,8931	-0,7665594	0,36266	52,537	4,083183	1664,1
39	10,842	-0,278	0,8	273,6	4,2145	277,8145	180,008	277,8145	-0,7663425	0,36276	52,9	3,98349	1668,08
38	10,564	-0,278	0,8	273,6	4,137	277,737	180,797	277,737	-0,7661288	0,36286	53,263	3,883726	1671,97
37	10,286	-0,278	0,8	273,6	4,06	277,66	181,605	277,66	-0,7659164	0,36296	53,626	3,783899	1675,75
36	10,008	-0,278	0,8	273,6	3,9855	277,5855	182,434	277,5855	-0,7657109	0,36306	53,989	3,683983	1679,44
35	9,73	-0,278	0,8	273,6	3,9115	277,5115	183,284	277,5115	-0,7655067	0,36316	54,352	3,584008	1683,02
34	9,452	-0,278	0,8	273,6	3,83	277,43	184,156	277,43	-0,7652819	0,36326	54,715	3,484073	1686,5
33	9,174	-0,278	0,8	273,6	3,7666	277,3666	185,05	277,3666	-0,765107	0,36335	55,079	3,383859	1689,89
32	8,896	-0,278	0,8	273,6	3,696	277,296	185,968	277,296	-0,7649123	0,36344	55,442	3,283684	1693,17
31	8,618	-0,278	0,8	273,6	3,6265	277,2265	186,91	277,2265	-0,7647206	0,36353	55,806	3,183445	1696,36
30	8,34	-0,278	0,8	273,6	3,5581	277,1581	187,878	277,1581	-0,7645319	0,36362	56,169	3,083144	1699,44
29	8,062	-0,278	0,8	273,6	3,49	277,09	188,872	277,09	-0,764344	0,36371	56,533	2,98279	1702,42
28	7,784	-0,278	0,8	273,6	3,4247	277,0247	189,894	277,0247	-0,7641639	0,3638	56,897	2,882358	1705,3
27	7,506	-0,278	0,8	273,6	3,3597	276,9597	190,945	276,9597	-0,7639846	0,36388	57,261	2,781875	1708,09
26	7,228	-0,278	0,8	273,6	3,2958	276,8958	192,025	276,8958	-0,7638083	0,36397	57,625	2,681335	1710,77
25	6,95	-0,278	0,8	273,6	3,2331	276,8331	193,137	276,8331	-0,7636354	0,36405	57,989	2,580737	1713,35
24	6,672	-0,278	0,8	273,6	3,171	276,771	194,282	276,771	-0,7634641	0,36413	58,353	2,480088	1715,83
23	6,394	-0,278	0,8	273,6	3,111	276,711	195,461	276,711	-0,7632986	0,36421	58,717	2,379376	1718,21
22	6,116	-0,278	0,8	273,6	3,051	276,651	196,675	276,651	-0,7631331	0,36429	59,081	2,27862	1720,49
21	5,838	-0,278	0,8	273,6	2,9934	276,5934	197,927	276,5934	-0,7629742	0,36436	59,446	2,177801	1722,66
20	5,56	-0,278	0,8	273,6	2,9363	276,5363	199,215	276,5363	-0,7628167	0,36444	59,81	2,076937	1724,74
19	5,282	-0,278	0,8	273,6	2,8803	276,4803	200,551	276,4803	-0,7626622	0,36451	60,175	1,976023	1726,72
18	5,004	-0,278	0,8	273,6	2,82557	276,425574	201,926	276,42557	-0,7625112	0,36458	60,539	1,87506	1728,59
17	4,726	-0,278	0,8	273,6	2,77188	276,371884	203,346	276,37188	-0,7623631	0,36466	60,904	1,77405	1730,37
16	4,448	-0,278	0,8	273,6	2,7193	276,3193	204,813	276,3193	-0,7622181	0,36473	61,269	1,672994	1732,04
15	4,17	-0,278	0,8	273,6	2,6679	276,2679	206,33	276,2679	-0,7620763	0,36479	61,633	1,571892	1733,61
14	3,892	-0,278	0,8	273,6	2,6176	276,2176	207,9	276,2176	-0,7619375	0,36486	61,998	1,470748	1735,08
13	3,614	-0,278	0,8	273,6	2,56844	276,16844	209,525	276,16844	-0,7618019	0,36492	62,363	1,369561	1736,45
12	3,336	-0,278	0,8	273,6	2,5204	276,1204	211,207	276,1204	-0,7616694	0,36499	62,728	1,268332	1737,72
11	3,058	-0,278	0,8	273,6	2,4735	276,0735	212,951	276,0735	-0,7615401	0,36505	63,093	1,167064	1738,89
10	2,78	-0,278	0,8	273,6	2,42775	276,02775	214,759	276,02775	-0,7614139	0,36511	63,458	1,065757	1739,95
9	2,502	-0,278	0,8	273,6	2,3831	275,9831	216,636	275,9831	-0,7612907	0,36517	63,823	0,964412	1740,92
8	2,224	-0,278	0,8	273,6	2,3396	275,9396	218,585	275,9396	-0,7611707	0,36523	64,189	0,863031	1741,78
7	1,946	-0,278	0,8	273,6	2,2972	275,8972	220,61	275,8972	-0,7610537	0,36528	64,554	0,761615	1742,54
6	1,668	-0,278	0,8	273,6	2,256	275,856	222,716	275,856	-0,7609401	0,36534	64,919	0,660165	1743,2
5	1,39	-0,278	0,8	273,6	2,2159	275,8159	224,909	275,8159	-0,7608295	0,36539	65,285	0,558682	1743,76
4	1,112	-0,278	0,8	273,6	2,1769	275,7769	227,192	275,7769	-0,7607219	0,36544	65,65	0,457168	1744,22

3	0,834	-0,278	0,8	273,6	2,139	275,739	229,573	275,739	-0,7606173	0,36549	66,016	0,355624	1744,57
2	0,556	-0,278	0,8	273,6	2,1023	275,7023	232,057	275,7023	-0,7605161	0,36554	66,381	0,254051	1744,83
1	0,278	-0,278	0,8	273,6	2,0668	275,6668	234,652	275,6668	-0,7604182	0,36559	66,747	0,15245	1744,98
0	0	-0,278	0,8	273,6	2,03235	275,63235	237,365	275,63235	-0,7603232	0,36563	67,112	0,050823	1745,03

Table 3 - Braking calculations

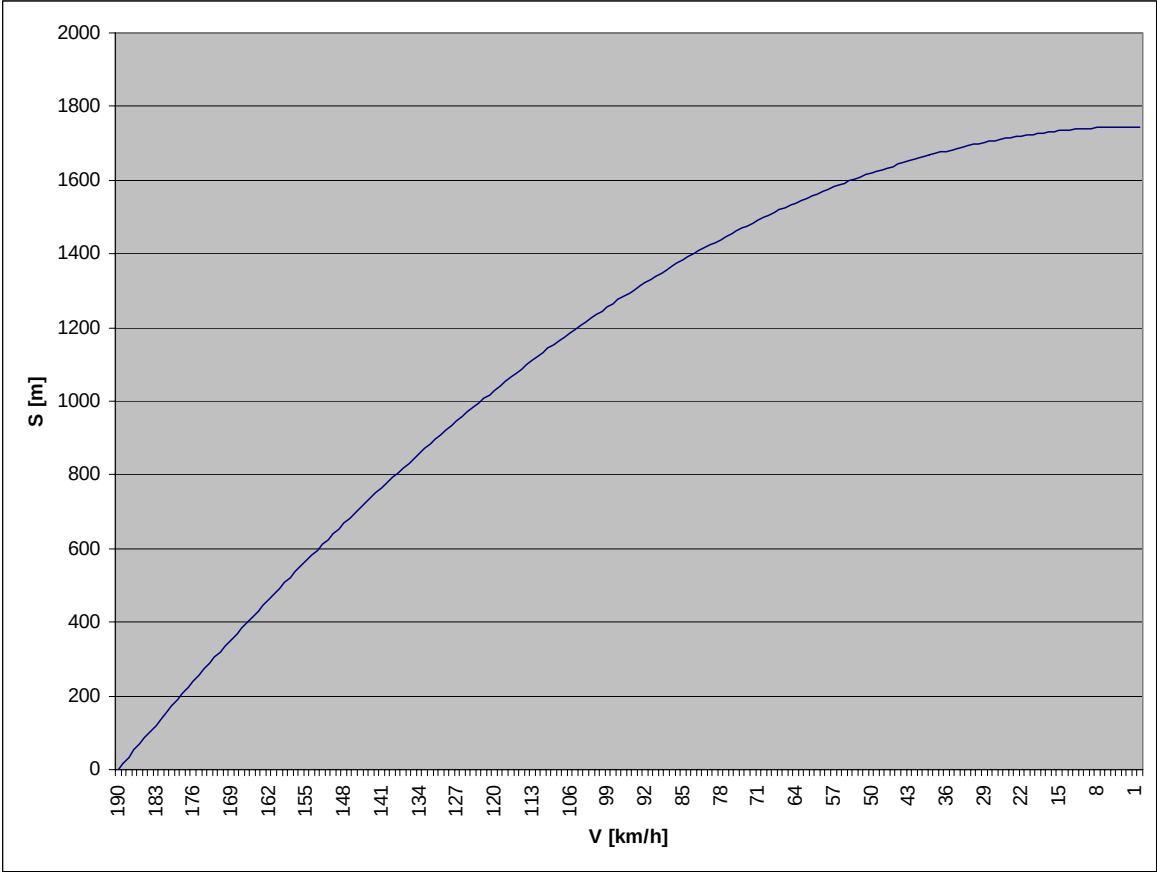


Figure 3 - Braking curve

Constant speed

Once calculated the space covered in the acceleration and the braking phases, knowing that the total running distance is 100 km, for subtraction is it possible obtain the data of the constant speed phase.

V (m/s)	t (sec)	s (m)
52,82	0	4495,824
52,82	1	4548,644
52,82	2	4601,644
52,82	3	4654,644
52,82	4	4707,644
52,82	5	4760,644
52,82	6	4813,644
52,82	7	4866,644
52,82	8	4919,644
52,82	9	4972,644
52,82	10	5025,644
52,82	11	5078,644
52,82	12	5131,644
52,82	13	5184,644
52,82	14	5237,644
52,82	15	5290,644
52,82	16	5343,644
52,82	17	5396,644
52,82	18	5449,644
52,82	19	5502,644
52,82	20	5555,644
52,82	21	5608,644
52,82	22	5661,644
52,82	23	5714,644
being the speed constant so that the values follows the same expression ($S=S_0 + V(t-t_0)$) the middle values are here omitted and only the last values closed to the braking point are addressed		
52,82	1740	96715,64
52,82	1741	96768,64
52,82	1742	96821,64
52,82	1743	96874,64
52,82	1744	96927,64
52,82	1745	96980,64
52,82	1746	97033,64
52,82	1747	97086,64
52,82	1748	97139,64
52,82	1749	97192,64
52,82	1750	97245,64
52,82	1751	97298,64
52,82	1752	97351,64

52,82	1753	97404,64
52,82	1754	97457,64
52,82	1755	97510,64
52,82	1756	97563,64
52,82	1757	97616,64
52,82	1758	97669,64
52,82	1759	97722,64
52,82	1760	97775,64
52,82	1761	97828,64
52,82	1762	97881,64
52,82	1763	97934,64
52,82	1764	97987,64
52,82	1765	98040,64
52,82	1766	98093,64
52,82	1767	98146,64
52,82	1768	98199,64
52,82	1769	98252,64

Table 4 - Constant speed calculations

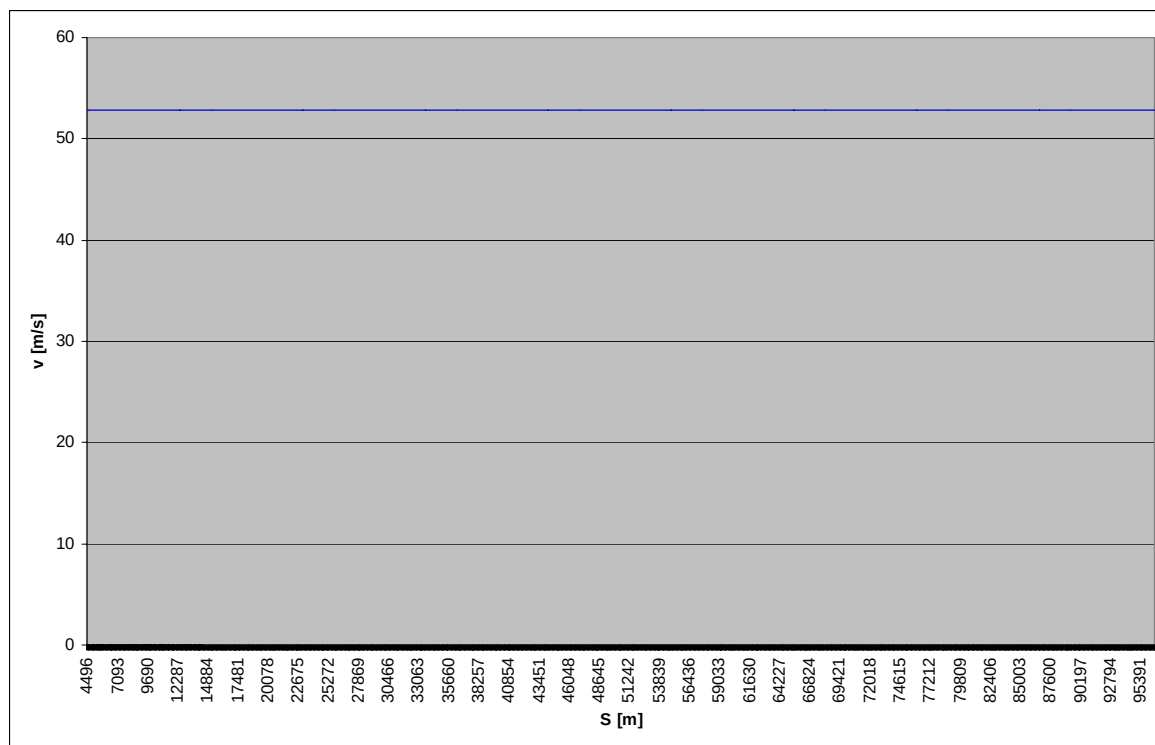


Table 5 - Constant speed curve

Once had had got this data they has been put together obtaining progressive data from the beginning to the end of the running. Values of time, speed and distance covered (every 1km/h in case of acceleration and braking and every

second in case of constant speed) are obtained. The last step has been to calculate these values every 1500 metres (one block length).

Section number (l=1500m)	Progressive [m]	Running time [s]	Running time in each block [s]
-	0	0	0
1	1500	79,48480341	79,48480341
2	3000	116,0858652	36,60106181
3	4500	146,3052028	30,21933763
4	6000	174,6102174	28,30501452
5	7500	202,9121042	28,30188679
6	9000	231,213991	28,30188679
7	10500	259,5158777	28,30188679
8	12000	287,8177645	28,30188679
9	13500	316,1196513	28,30188679
10	15000	344,4215381	28,30188679
11	16500	372,7234249	28,30188679
12	18000	401,0253117	28,30188679
13	19500	429,3271985	28,30188679
14	21000	457,6290853	28,30188679
15	22500	485,9309721	28,30188679
16	24000	514,2328589	28,30188679
17	25500	542,5347457	28,30188679
18	27000	570,8366325	28,30188679
19	28500	599,1385193	28,30188679
20	30000	627,4404061	28,30188679
21	31500	655,7422928	28,30188679
22	33000	684,0441796	28,30188679
23	34500	712,3460664	28,30188679
24	36000	740,6479532	28,30188679
25	37500	768,94984	28,30188679
26	39000	797,2517268	28,30188679
27	40500	825,5536136	28,30188679
28	42000	853,8555004	28,30188679
29	43500	882,1573872	28,30188679
30	45000	910,459274	28,30188679
31	46500	938,7611608	28,30188679
32	48000	967,0630476	28,30188679
33	49500	995,3649344	28,30188679
34	51000	1023,666821	28,30188679
35	52500	1051,968708	28,30188679
36	54000	1080,270595	28,30188679
37	55500	1108,572482	28,30188679
38	57000	1136,874368	28,30188679
39	58500	1165,176255	28,30188679
40	60000	1193,478142	28,30188679
41	61500	1221,780029	28,30188679
42	63000	1250,081915	28,30188679
43	64500	1278,383802	28,30188679
44	66000	1306,685689	28,30188679
45	67500	1334,987576	28,30188679
46	69000	1363,289463	28,30188679
47	70500	1391,591349	28,30188679
48	72000	1419,893236	28,30188679
49	73500	1448,195123	28,30188679

50	75000	1476,49701	28,30188679
51	76500	1504,798897	28,30188679
52	78000	1533,100783	28,30188679
53	79500	1561,40267	28,30188679
54	81000	1589,704557	28,30188679
55	82500	1618,006444	28,30188679
56	84000	1646,308331	28,30188679
57	85500	1674,610217	28,30188679
58	87000	1702,912104	28,30188679
59	88500	1731,213991	28,30188679
60	90000	1759,515878	28,30188679
61	91500	1787,817765	28,30188679
62	93000	1816,119651	28,30188679
63	94500	1844,421538	28,30188679
64	96000	1865,226146	20,80460815
65	97500	1865,23	0,003853718
66	99000	1881,36	16,13
67	100500	1932,34	50,98
			SUM
			1932,34

Table 6 - Running time

The running time curves so comes:

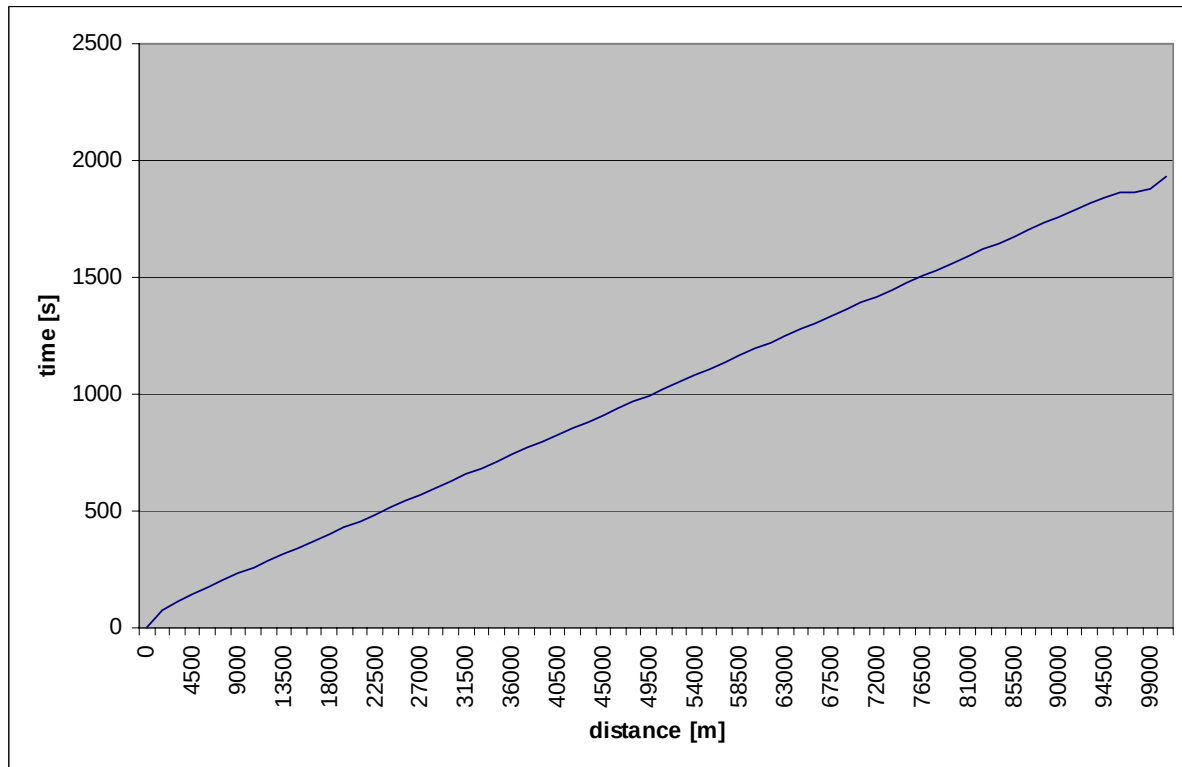


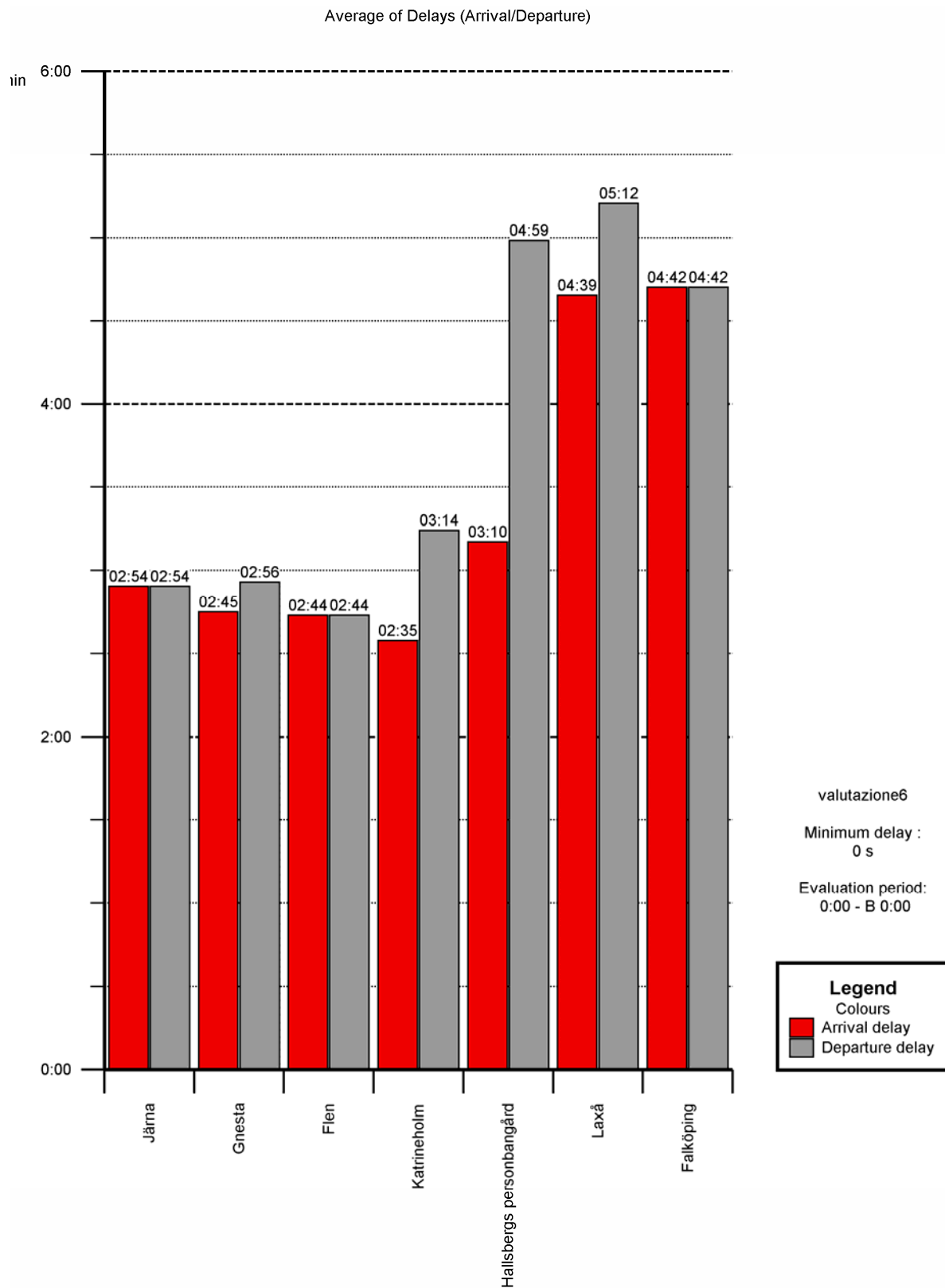
Figure 4 - Running time curve for x2

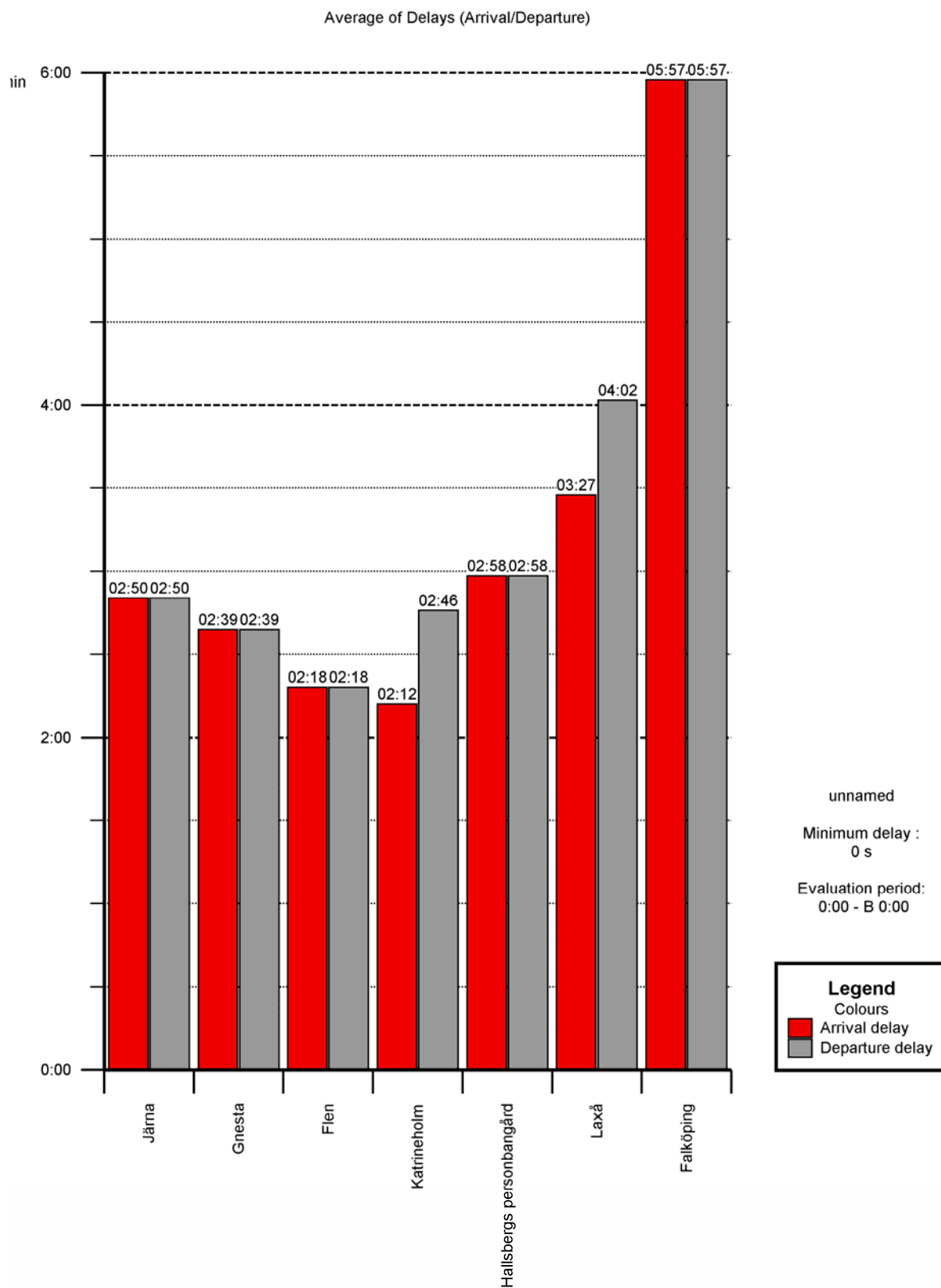
(B) Bar chart with delays for all the patterns simulated in the multiple simulation.

The bar charts from the evaluation manager are next addressed.
 Table 7 matches the name of the evaluation with the pattern which is referred.

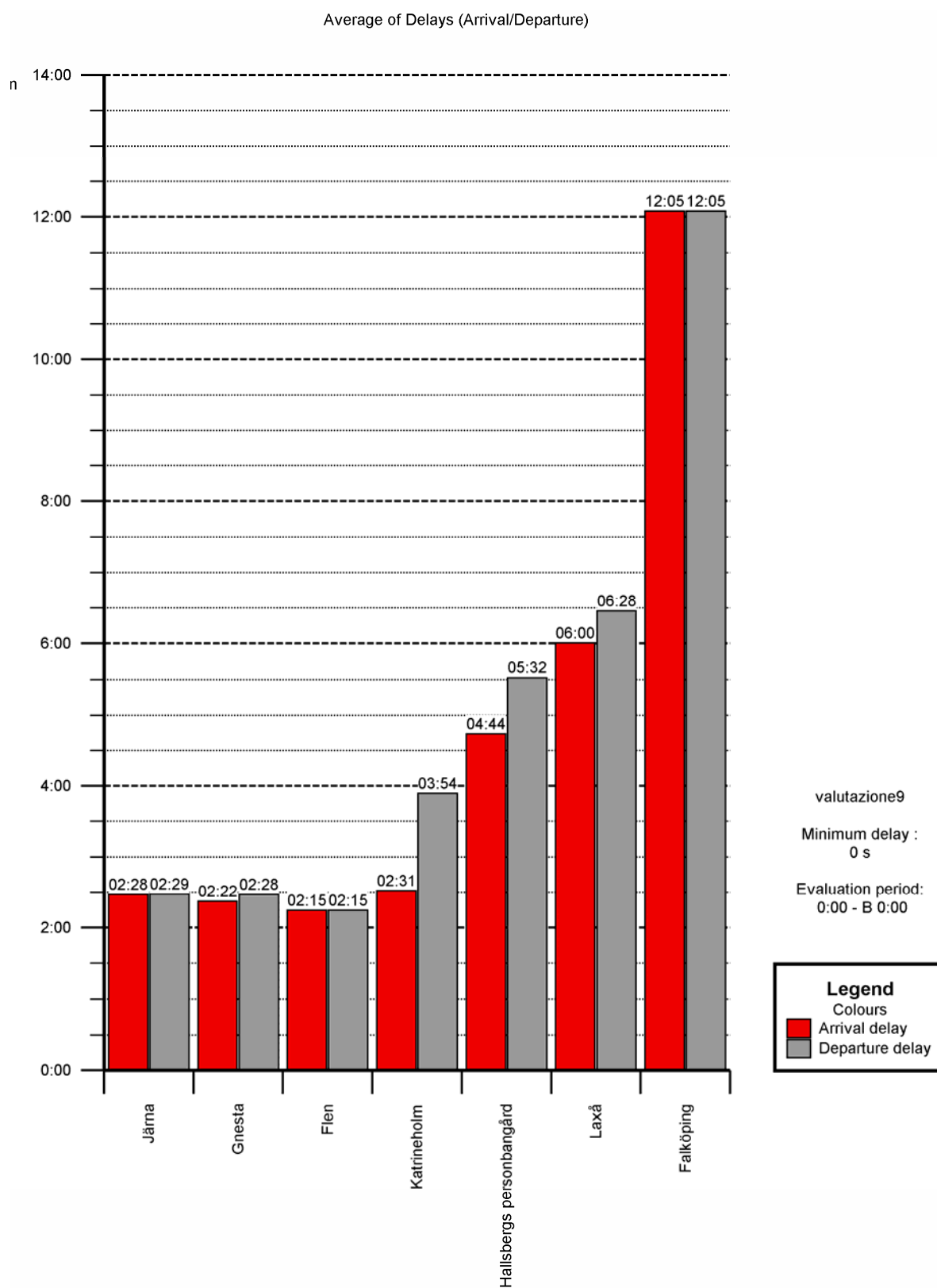
Chart name	Train pattern (1 hour)	Signalling system
Valutazione6	H/R/H/R/H/R	Fix blocks
Valutazione14	H/R/H/R/H/R	Moving blocks
Valutazione9	R/R/F/R	Fix blocks
Valutazione18	R/R/F/R	Moving blocks
Valutazione4	H/R/F/H/R/H/R	Fix blocks
Valutazione15	H/R/F/H/R/H/R	Moving blocks
Valutazione7	HHH/RRR/F	Fix blocks
Valutazione16	HHH/RRR/F	Moving blocks
Valutazione8	HHH/RRR	Fix blocks
Valutazione17	HHH/RRR	Moving blocks
Valutazione99	RRR/F	Fix blocks
Valutazione19	RRR/F	Moving blocks
Valutazione61	HR	Fix blocks
Valutazione261	HR	Moving blocks
Valutazione1	HHH...H	Fix blocks
Valutazione10	HHH...H	Moving blocks

Table 7 - Train pattern match with bar chart name

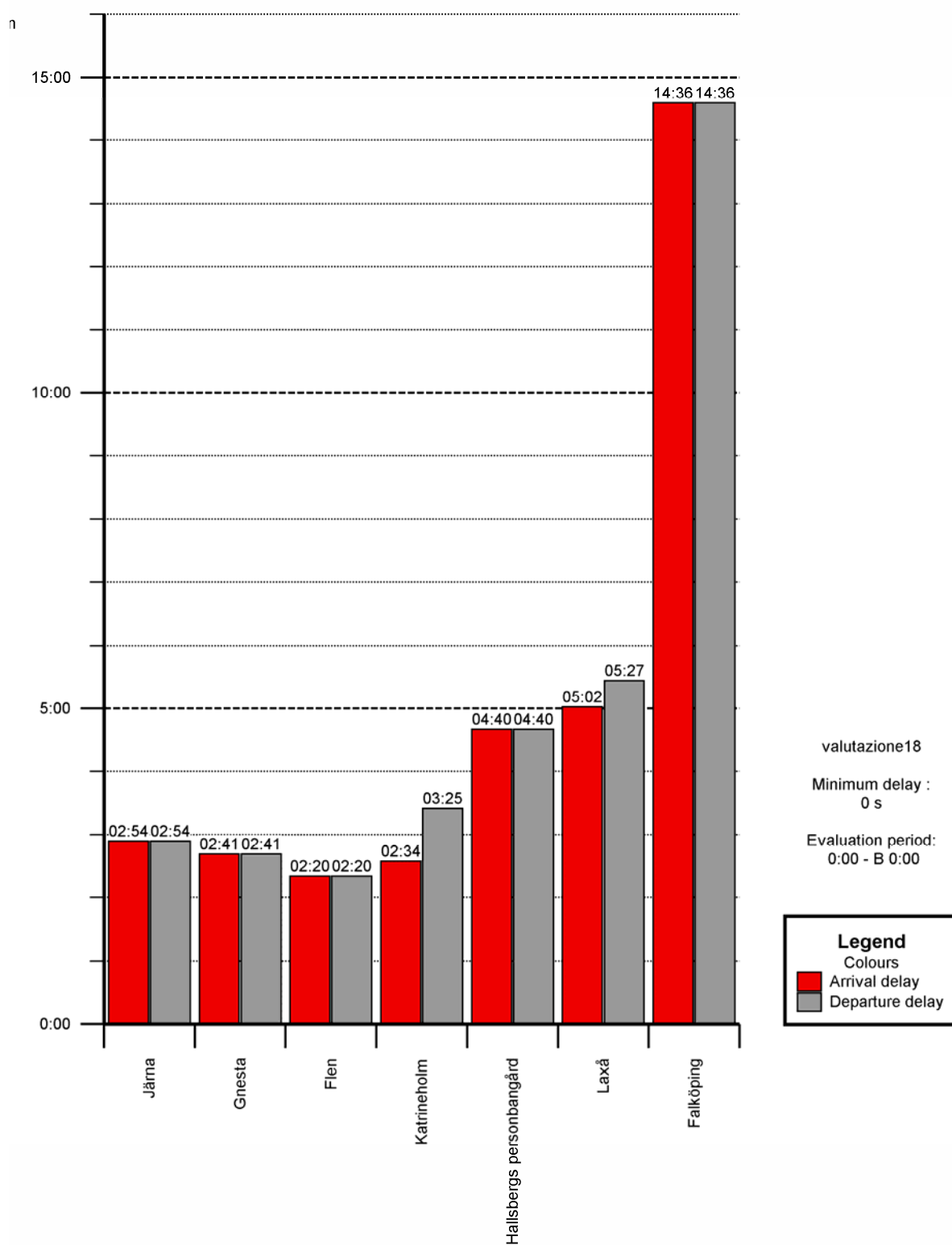


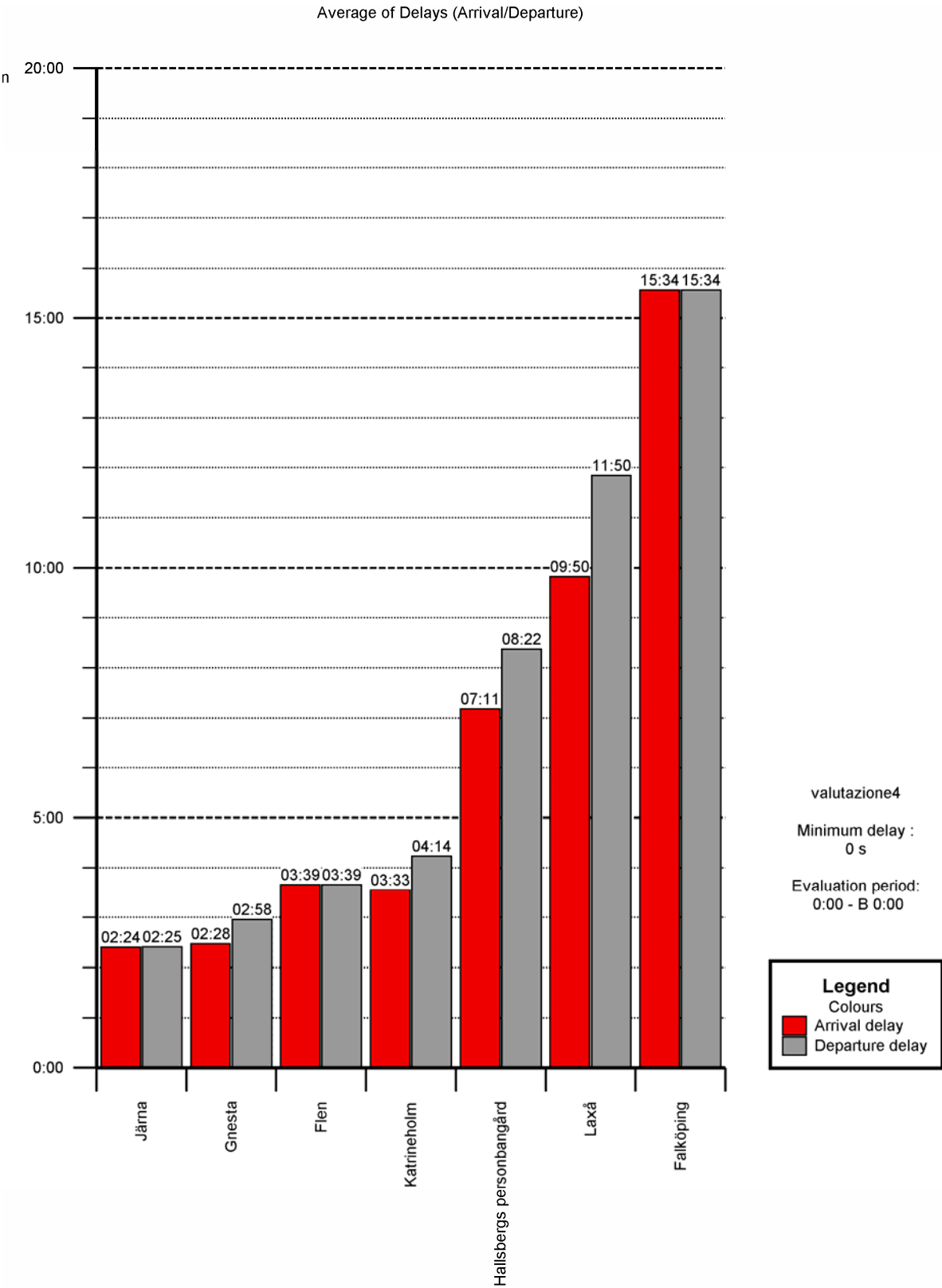


valutazione14

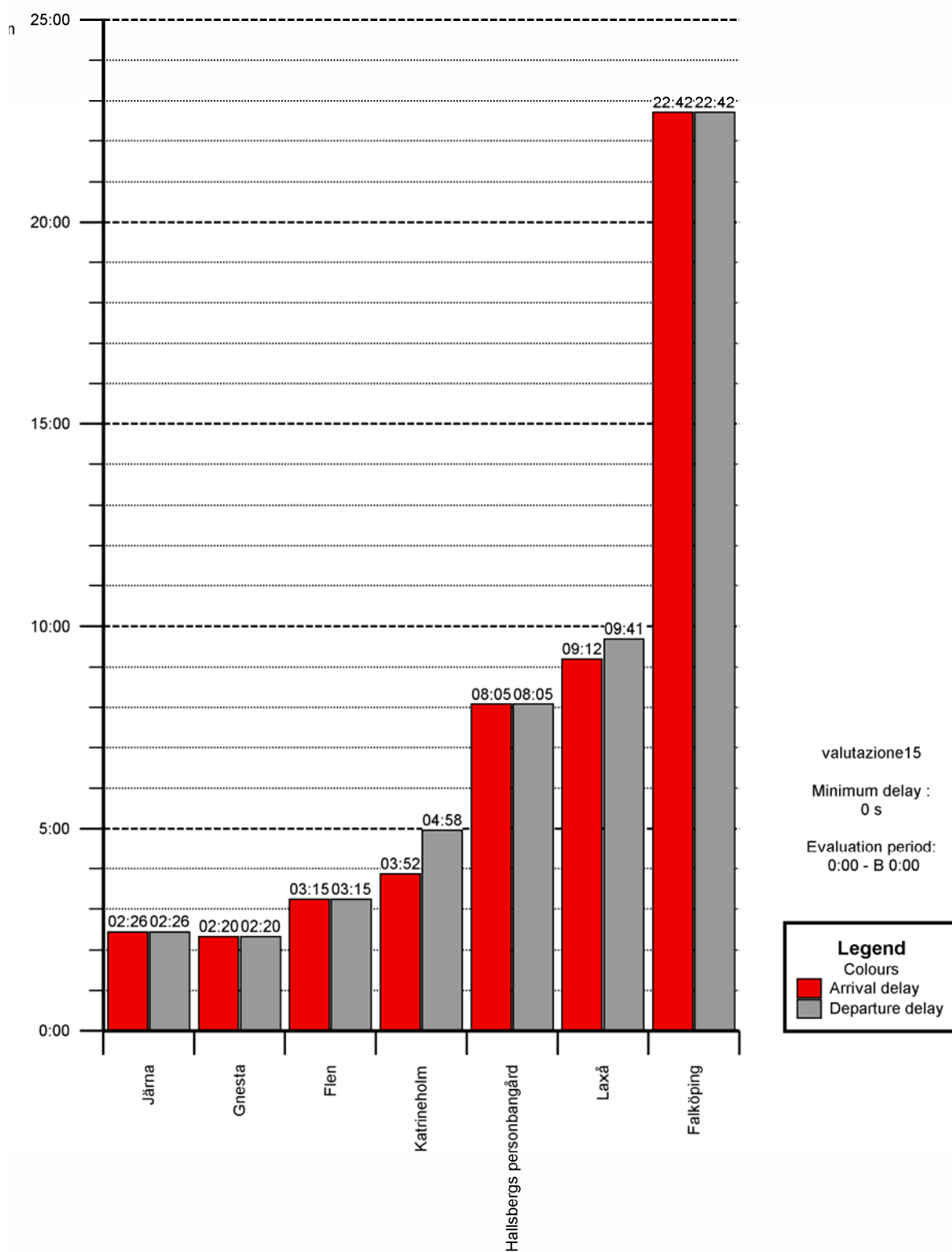


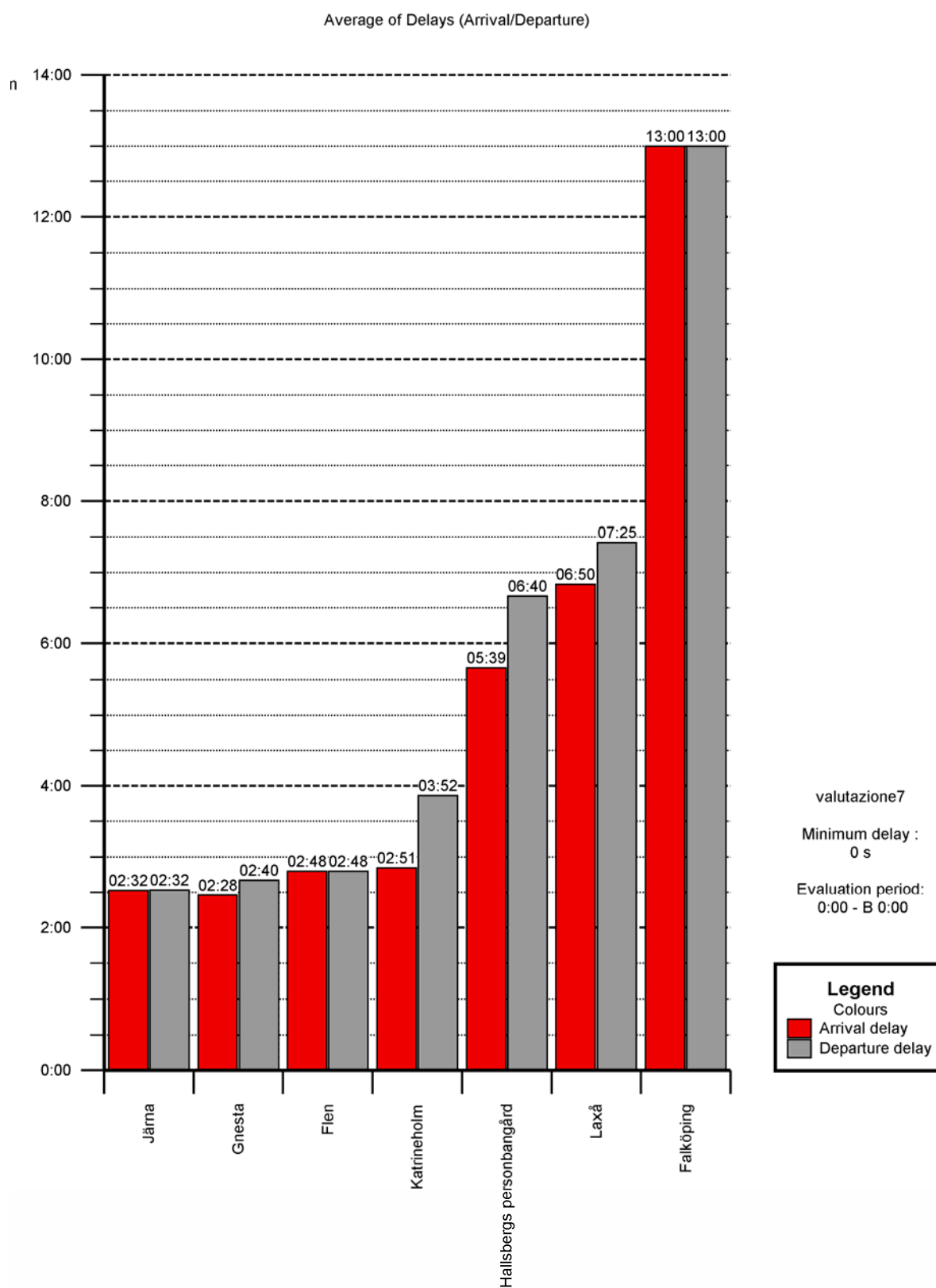
Average of Delays (Arrival/Departure)



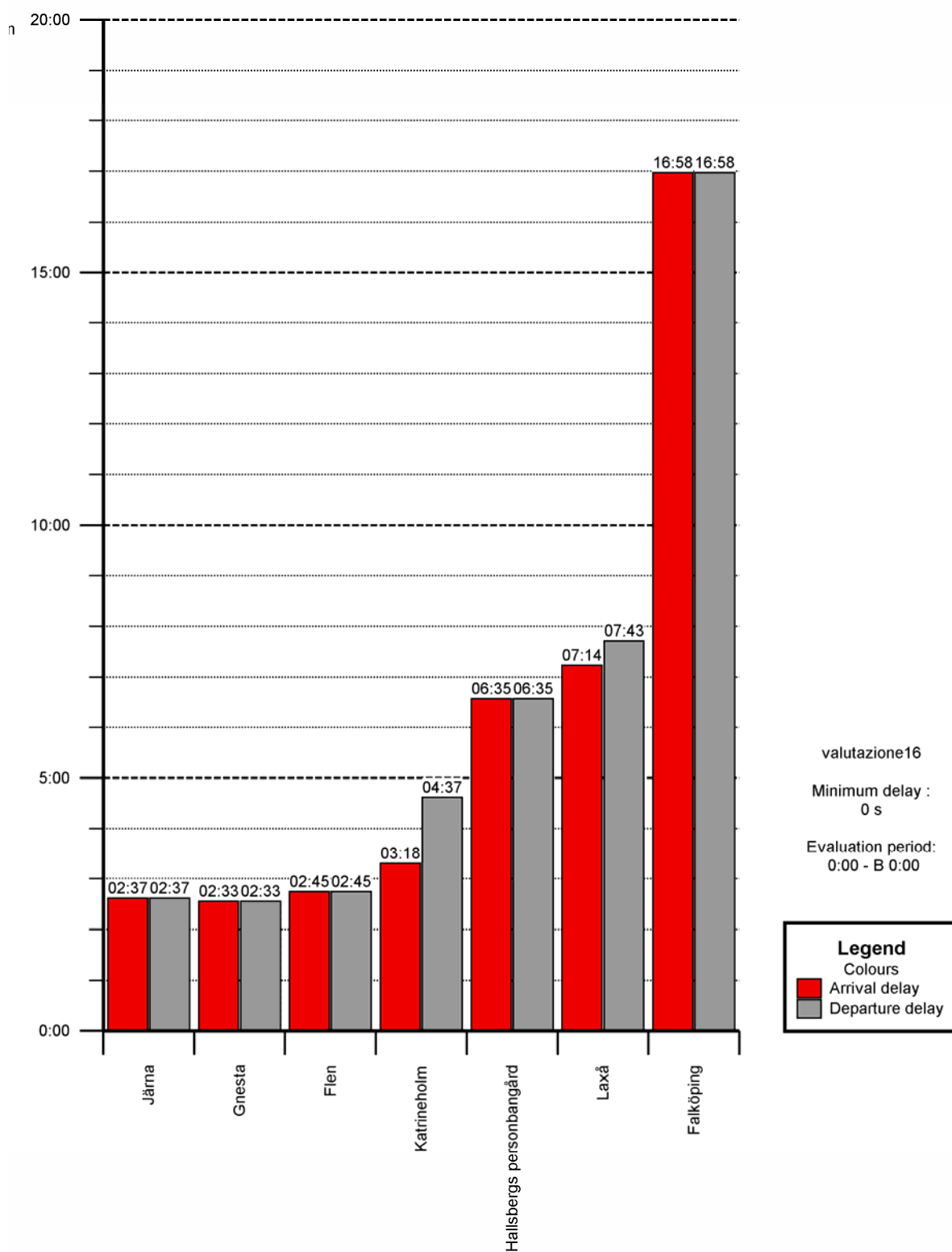


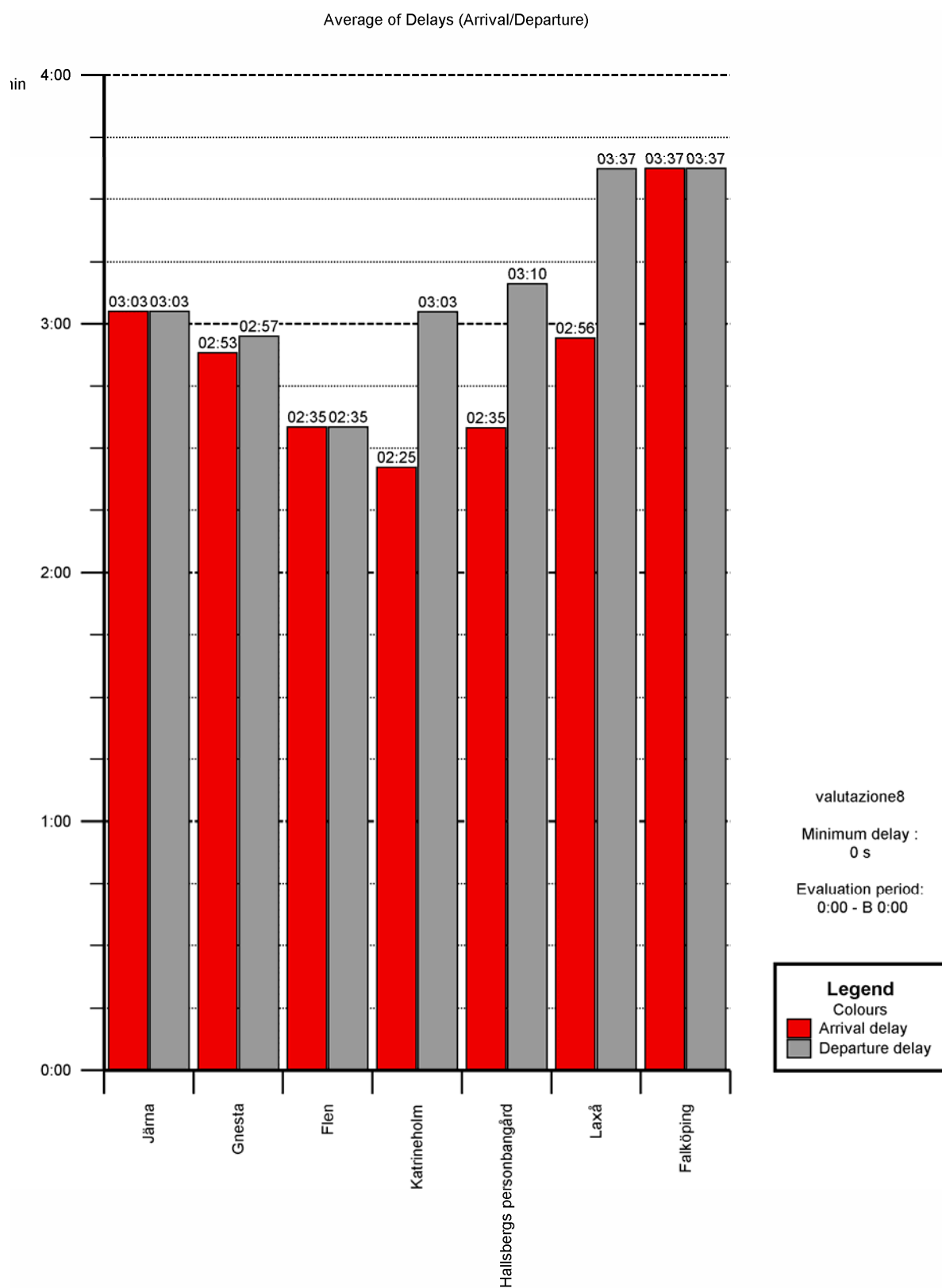
Average of Delays (Arrival/Departure)



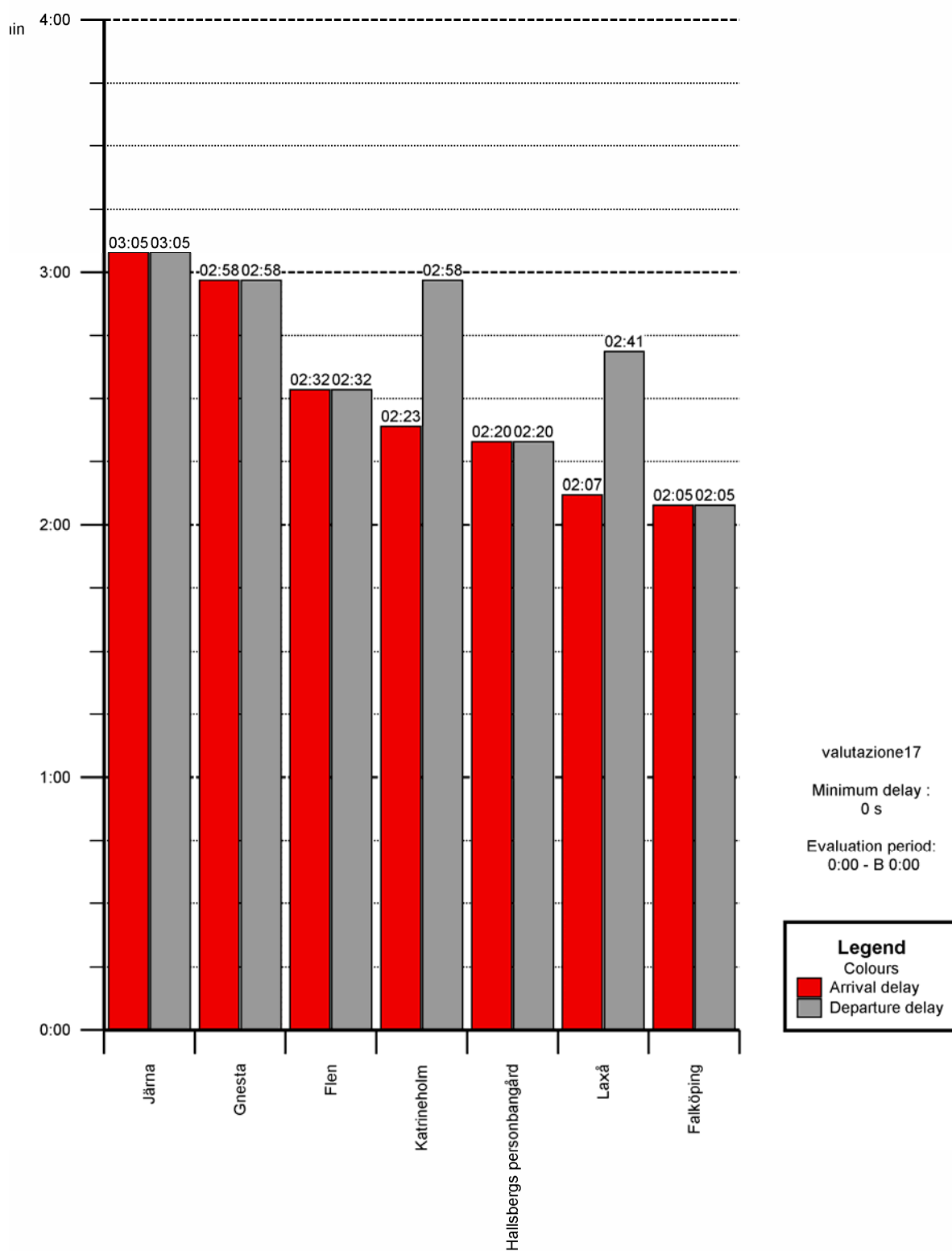


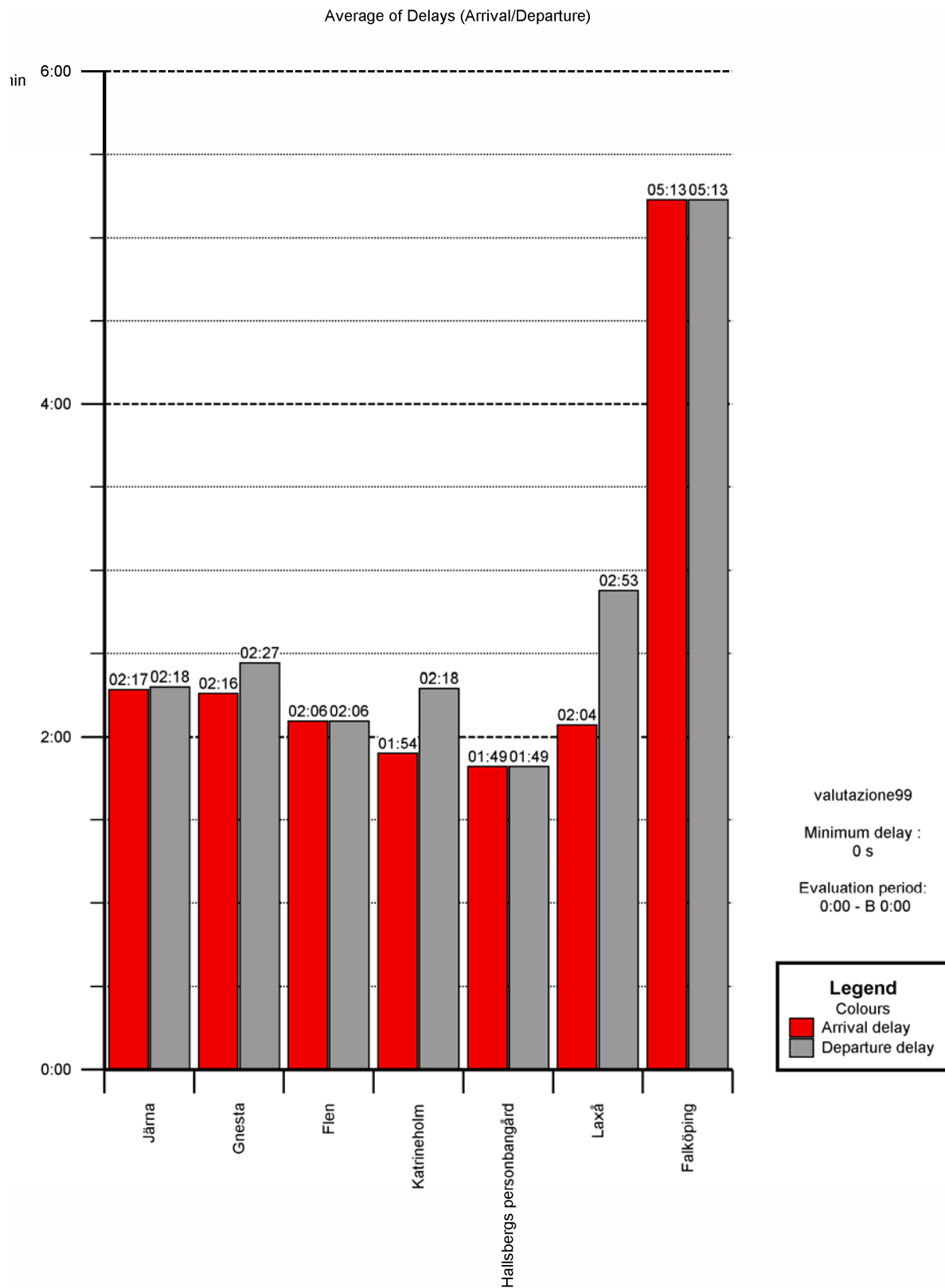
Average of Delays (Arrival/Departure)

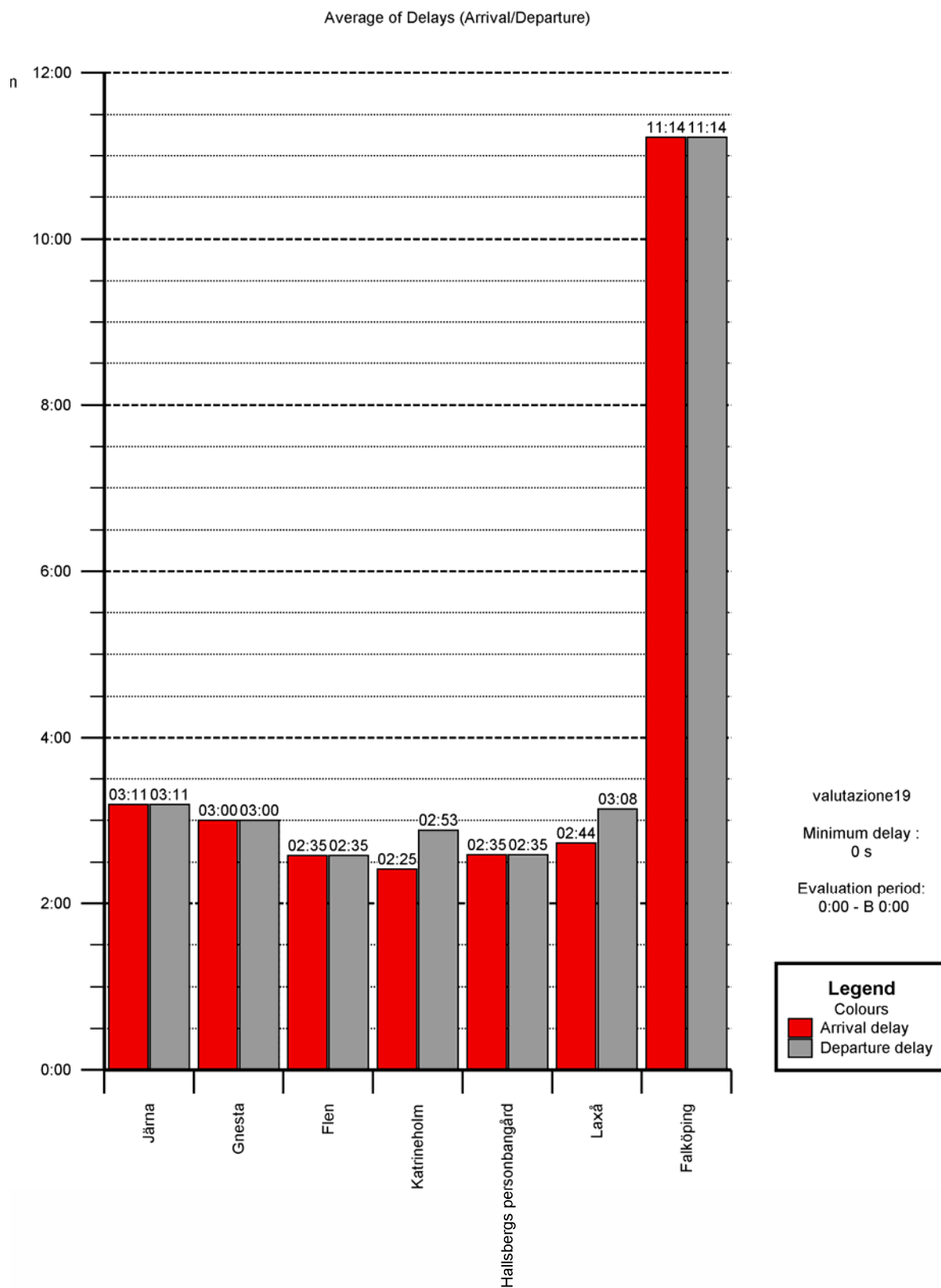


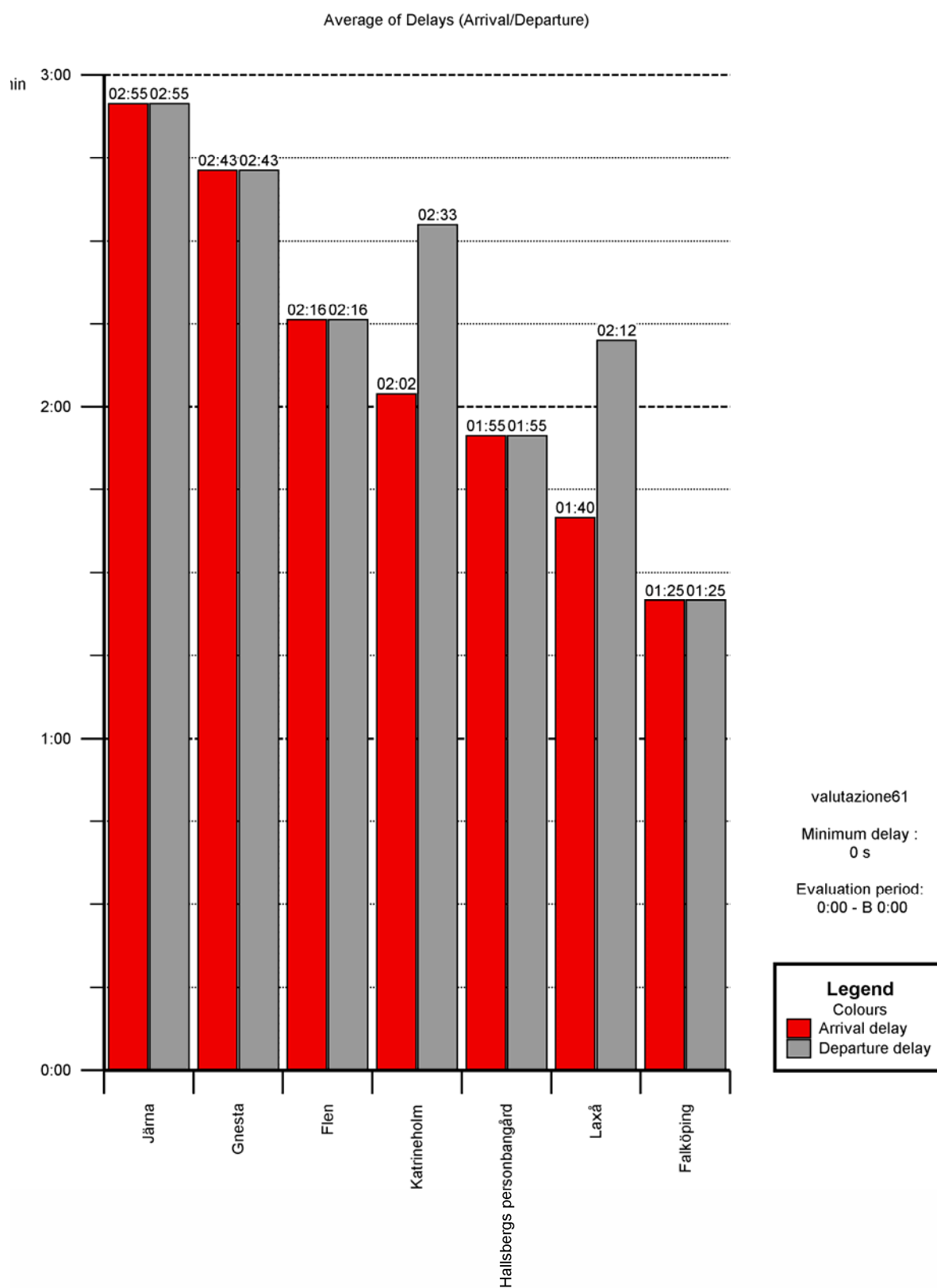


Average of Delays (Arrival/Departure)

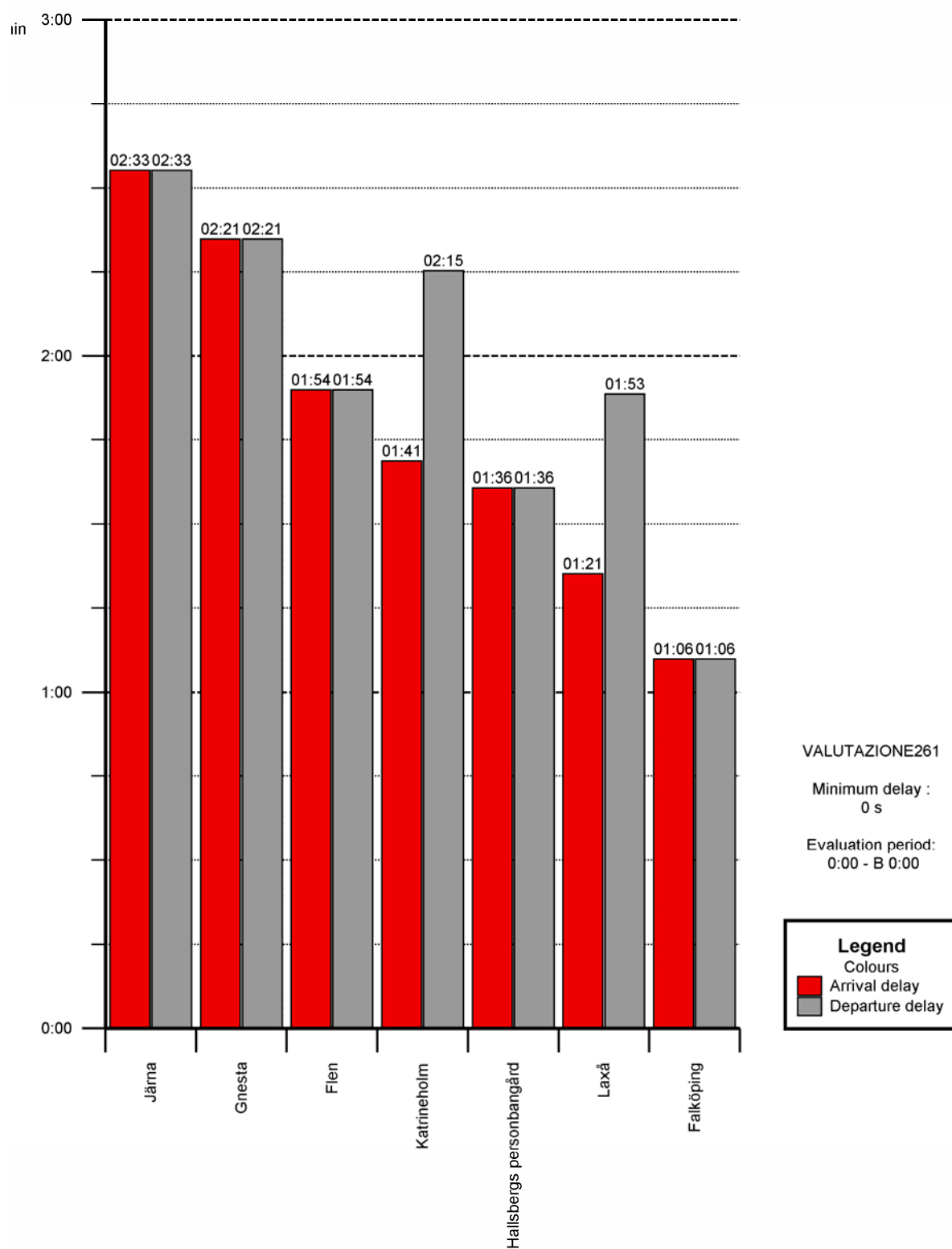


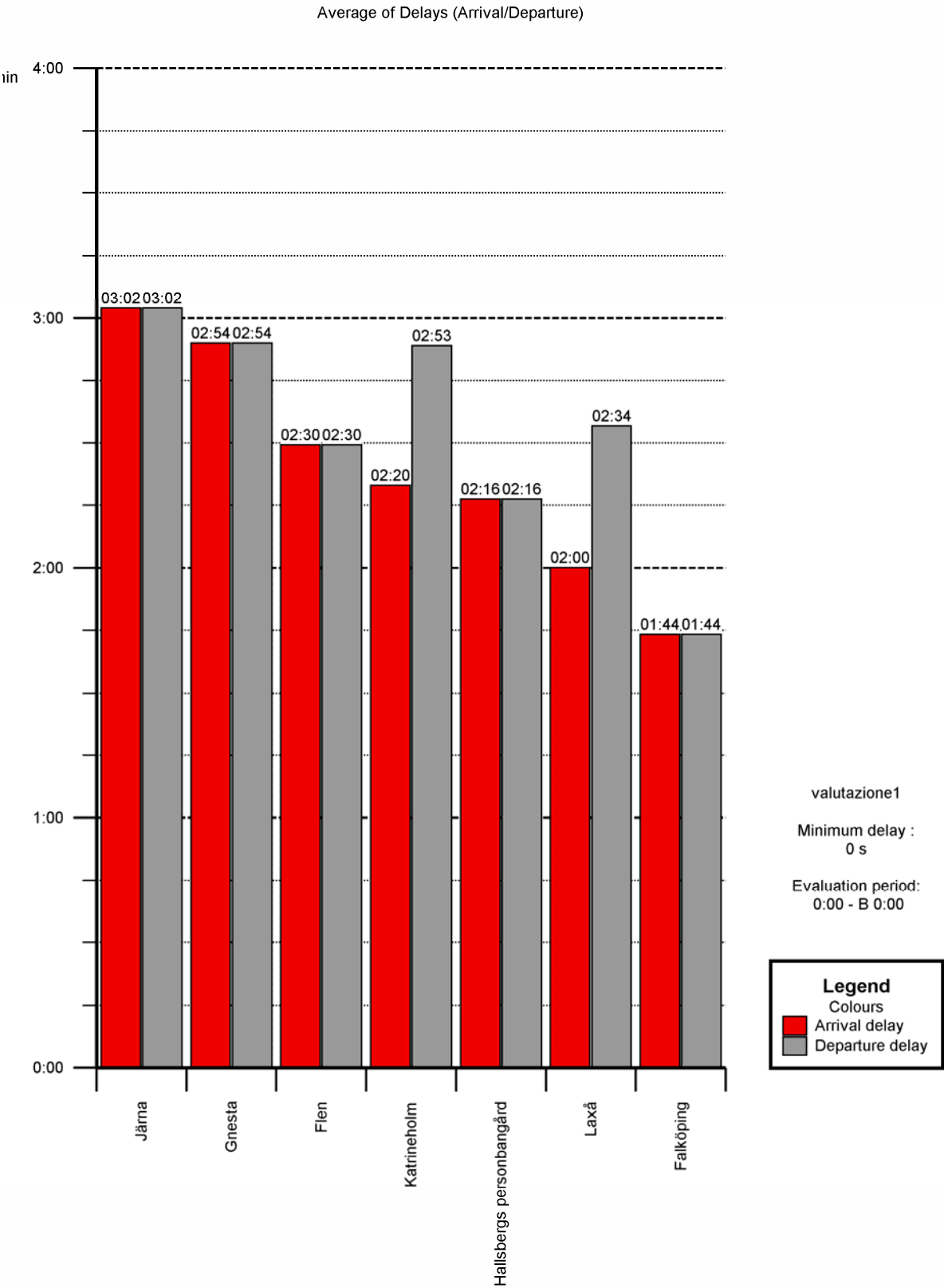


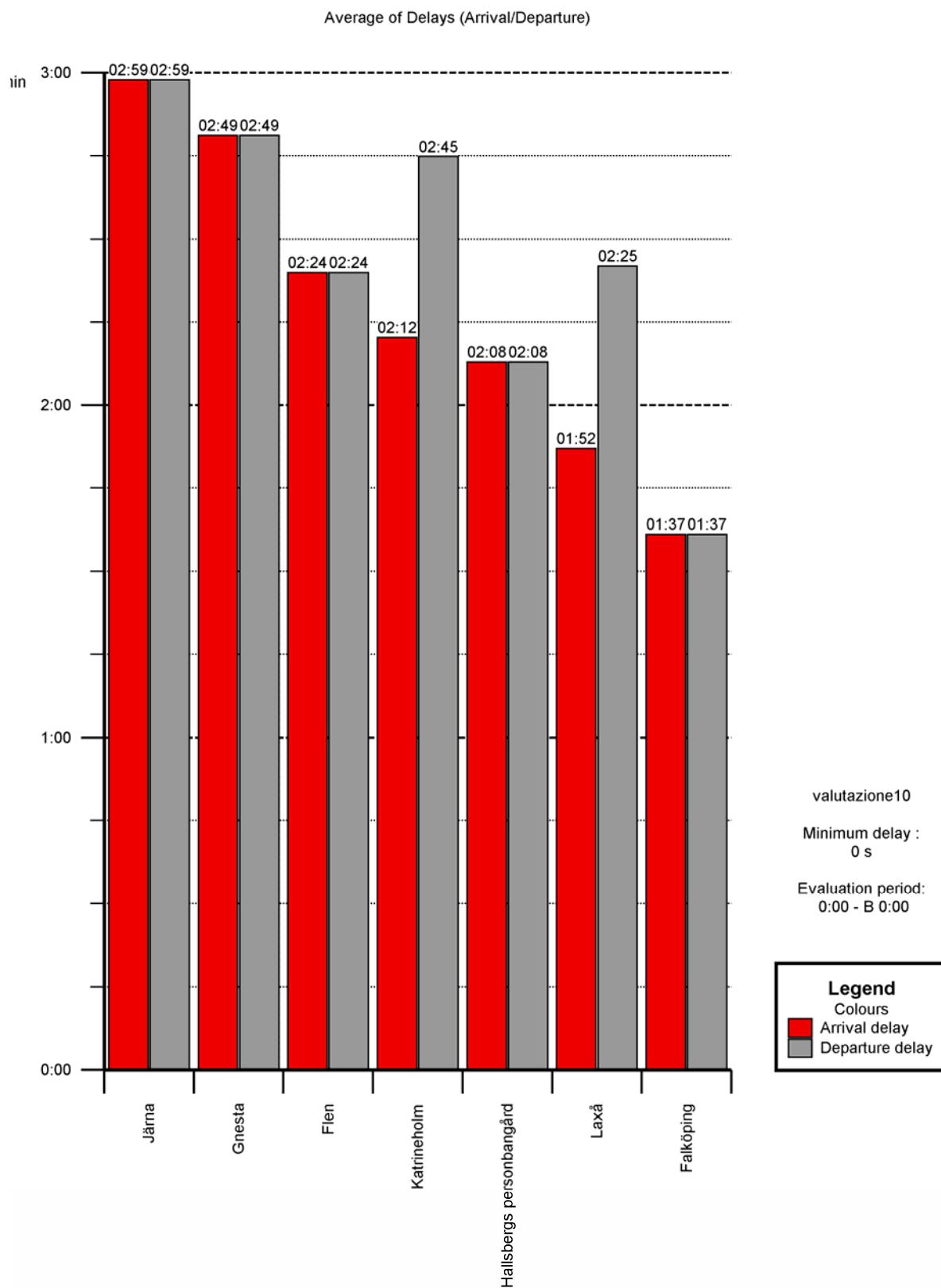




Average of Delays (Arrival/Departure)







(C) Station and line delays calculation

Next in table 27 and in table 28 are the values for the different patterns for the absolute dwell delay and delay between station respectively in fix and moving block operation.

The cells marked in yellow indicate the stations where dwell delays are applied.

pattern: H/R/H/R/H/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,54	152	2,54	152,4	0	0	0
Gnesta	2,45	147	2,56	153,6	6,6	17822	-5,4
Flen	2,44	146	2,44	146,4	0	45129	-7,2
Katrineholm	2,35	141	3,14	188,4	47,4	23133	-5,4
Hallsberg	3,1	186	4,59	275,4	89,4	65457	-2,4
Laxå	4,39	263	5,12	307,2	43,8	30107	-12
Falköping	4,42	265	4,42	265,2	0	114158	-42
pattern: R/R/F/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,28	137	2,29	137,4	0,6	0	0
Gnesta	2,22	133	2,28	136,8	3,6	17822	-4,2
Flen	2,15	129	2,15	129	0	45129	-7,8
Katrineholm	2,31	139	3,54	212,4	73,8	23133	9,6
Hallsberg	4,44	266	5,32	319,2	52,8	65457	54
Laxå	6	360	6,28	376,8	16,8	30107	40,8
Falköping	12,1	723	12,1	723	0	114158	346
pattern: H/R/F/H/R/H/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,24	134	2,25	135	0,6	0	0
Gnesta	2,28	137	2,58	154,8	18	17822	1,8
Flen	3,39	203	3,39	203,4	0	45129	48,6
Katrineholm	3,33	200	4,14	248,4	48,6	23133	-3,6
Hallsberg	7,11	427	8,22	493,2	66,6	65457	178
Laxå	9,5	570	11,5	690	120	30107	76,8

Falköping	15,3	920	15,3	920,4	0	114158	230
pattern: HHH/RRR/F							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Differnce [s]	Distance [m]	line delay [s]
Järna	2,32	139	2,32	139,2	0	0	0
Gnesta	2,28	137	2,4	144	7,2	17822	-2,4
Flen	2,48	149	2,48	148,8	0	45129	4,8
Katrineholm	2,51	151	3,52	211,2	60,6	23133	1,8
Hallsberg	5,39	323	6,4	384	60,6	65457	112
Laxå	6,5	390	7,25	435	45	30107	6
Falköping	13	780	13	780	0	114158	345
pattern: HHH/RRR							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Differnce [s]	Distance [m]	line delay [s]
Järna	3,03	182	3,03	181,8	0	0	0
Gnesta	2,53	152	2,57	154,2	2,4	17822	-30
Flen	2,35	141	2,35	141	0	45129	-13,2
Katrineholm	2,25	135	3,03	181,8	46,8	23133	-6
Hallsberg	2,35	141	3,1	186	45	65457	-40,8
Laxå	2,56	154	3,37	202,2	48,6	30107	-32,4
Falköping	3,37	202	3,37	202,2	0	114158	0
pattern: RRR/F							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Differnce [s]	Distance [m]	line delay [s]
Järna	2,17	130	2,18	130,8	0,6	0	0
Gnesta	2,16	130	2,27	136,2	6,6	17822	-1,2
Flen	2,06	124	2,06	123,6	0	45129	-12,6
Katrineholm	1,54	92,4	2,18	130,8	38,4	23133	-31,2
Hallsberg	1,49	89,4	1,49	89,4	0	65457	-41,4
Laxå	2,04	122	2,53	151,8	29,4	30107	33
Falköping	5,13	308	5,13	307,8	0	114158	156
pattern: H R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Differnce [s]	Distance [m]	line delay [s]
Järna	2,55	153	2,55	153	0	0	0

Appendix

Gnesta	2,43	146	2,43	145,8	0	17822	-7,2
Flen	2,16	130	2,16	129,6	0	45129	-16,2
Katrineholm	2,02	121	2,33	139,8	18,6	23133	-8,4
Hallsberg	1,55	93	1,55	93	0	65457	-46,8
Laxå	1,4	84	2,12	127,2	43,2	30107	-9
Falköping	1,25	75	1,25	75	0	114158	-52,2
pattern: HHH...H							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	3,02	181	3,02	181,2	0	0	0
Gnesta	2,54	152	2,54	152,4	0	17822	-28,8
Flen	2,3	138	2,3	138	0	45129	-14,4
Katrineholm	2,2	132	2,53	151,8	19,8	23133	-6
Hallsberg	2,16	130	2,16	129,6	0	65457	-22,2
Laxå	2	120	2,34	140,4	20,4	30107	-9,6
Falköping	1,44	86,4	1,44	86,4	0	114158	-54

Table 8 - Absolute dwell and line between station delays for the different patterns in fix block operation

pattern: H/R/H/R/H/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,5	150	2,5	150	0	0	0
Gnesta	2,39	143	2,39	143	0	17822	-6,6
Flen	2,18	131	2,18	131	0	45129	-13
Katrineholm	2,12	127	2,46	148	20,4	23133	-3,6
Hallsberg	2,58	155	2,58	155	0	65457	7,2
Laxå	3,27	196	4,02	241	45	30107	41,4
Falköping	5,57	334	5,57	334	0	1E+05	93
pattern: R/R/F/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,54	152	2,54	152	0	0	0
Gnesta	2,41	145	2,41	145	0	17822	-7,8
Flen	2,2	132	2,2	132	0	45129	-13
Katrineholm	2,34	140	3,25	195	54,6	23133	8,4
Hallsberg	4,4	264	4,4	264	0	65457	69
Laxå	5,02	301	5,27	316	15	30107	37,2
Falköping	14,4	862	14,4	862	0	1E+05	545

pattern: H/R/F/H/R/H/R							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,26	136	2,26	136	0	0	0
Gnesta	2,2	132	2,2	132	0	17822	-3,6
Flen	3,15	189	3,15	189	0	45129	57
Katrineholm	3,52	211	4,58	275	63,6	23133	22,2
Hallsberg	8,05	483	8,05	483	0	65457	208
Laxå	9,12	547	9,41	565	17,4	30107	64,2
Falköping	22,4	1345	22,4	1345	0	1E+05	781
pattern: HHH/RRR/F							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,37	142	2,37	142	0	0	0
Gnesta	2,33	140	2,33	140	0	17822	-2,4
Flen	2,45	147	2,45	147	0	45129	7,2
Katrineholm	3,18	191	4,37	262	71,4	23133	43,8
Hallsberg	6,35	381	6,35	381	0	65457	119
Laxå	7,14	428	7,43	446	17,4	30107	47,4
Falköping	16,6	995	16,6	995	0	1E+05	549
pattern: HHH/RRR							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	3,05	183	3,05	183	0	0	0
Gnesta	2,58	155	2,58	155	0	17822	-28
Flen	2,32	139	2,32	139	0	45129	-16
Katrineholm	2,23	134	2,58	155	21	23133	-5,4
Hallsberg	2,2	132	2,2	132	0	65457	-23
Laxå	2,07	124	2,41	145	20,4	30107	-7,8
Falköping	2,05	123	2,05	123	0	1E+05	-22
pattern: RRR/F							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	3,11	187	3,11	187	0	0	0
Gnesta	3	180	3	180	0	17822	-6,6
Flen	2,35	141	2,35	141	0	45129	-39
Katrineholm	2,25	135	2,53	152	16,8	23133	-6
Hallsberg	2,35	141	2,35	141	0	65457	-11
Laxå	2,44	146	3,08	185	38,4	30107	5,4
Falköping	11,1	668	11,1	668	0	1E+05	484
pattern: H R							

Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,33	140	2,33	140	0	0	0
Gnesta	2,21	133	2,21	133	0	17822	-7,2
Flen	1,54	92,4	1,54	92,4	0	45129	-40
Katrineholm	1,41	84,6	2,15	129	44,4	23133	-7,8
Hallsberg	1,36	81,6	1,36	81,6	0	65457	-47
Laxå	1,21	72,6	1,53	91,8	19,2	30107	-9
Falköping	1,06	63,6	1,06	63,6	0	1E+05	-28
pattern: HHH...H							
Station	Arriv. delay [min]	Arriv. delay [s]	Dep. Delay [min]	Dep. Delay [s]	Difference [s]	Distance [m]	line delay [s]
Järna	2,59	155	2,59	155	0	0	0
Gnesta	2,49	149	2,49	149	0	17822	-6
Flen	2,24	134	2,24	134	0	45129	-15
Katrineholm	2,12	127	2,45	147	19,8	23133	-7,2
Hallsberg	2,08	125	2,08	125	0	65457	-22
Laxå	1,52	91,2	2,25	135	43,8	30107	-34
Falköping	1,37	82,2	1,37	82,2	0	1E+05	-53

Table 9 - Absolute dwell and line between station delays for different patterns in moving block operation

(D) Glossary of Terms

Some of the terms that more recur in the work are here addressed with explanations.

AUTOMATIC TRAIN PROTECTION	A safety system that enforces either compliance with or observation of speed restrictions and signal aspect by trains.
BALISE	A passive transponder mounted on the track which can communicate with a train pass over it.
BALISE GROUP	One or more balises which are treated as having the same reference location on the track.
BALISE TRANSMISSION MODULE	On board equipment for intermitted transmission between track and train. It shall be able to receive telegrams from a balise.
BLOCK	A method of controlling the separation between trains by dividin the line unto sections with, normally, no more than one train in each section. The block can either be a fixed block or a moving block.
BRAKING CURVE	A graphical representation of a train in relation to the braking characteristics of the train. The graph normally shows train speed varying against either distance or time.
BRAKING DISTANCE EMERGENCY	The distance in which a train is capable of stopping in an emergency. Dependent upon train speed, train type, braking characteristics, train weight and gradient.
CLEAR (A SIGNAL)	To change a signal aspect from its most restrictive aspect to a less restrictive aspect.
CONFLICTING MOVEMENTS	Movements that would require trains to occupy the same portion of track over all or part of their length.
CONTROL CENTRE	A signal box covering a large area, usually incorporating other operational functions.
CURRENT POSITION	The position of a train at a certain moment measured using defined system co-ordinates.
DANGER (ASPECT)	An indication given by a signal to stop.
DRIVING ON SIGHT	The driver driving at a speed that allows him to stop the train to avoid obstacles on the track.

DYNAMIC SPEED PROFILE	The speed/distance curve that a train may follow without violating the static speed profile and/or the end of movement authority. This curve depends on the braking characteristics of the train and the train length.
ENTRANCE SIGNAL	A main signal, intended for trains entering a station.
EUROBALISE	The group of technical solutions for use in ERTMS/ETCS installation.
EUROLOOP	The group of technical solutions for loops for use in an ERTMS/ETCS installation.
EURORADIO	The functions required of a radio network coupled with the message protocols that provide an acceptably safe communications channel between track side and train borne equipment's.
EXIT SIGNAL	A main signal that is intended for trains leaving a station.
FIXED BALISE	A balise that contains data which does not vary according to the route set or the signal aspect displayed.
INFILL LOOP	A loop that is installed a rear a signal where it is not essential for train safety, but avoids unnecessary delay by transmitting in fill information advising the train at once when the signal clears.
MOVEMENT AUTHORITY	Permission for a train to run to a specific location within the constraints of the infrastructure.
MOVING BLOCK	A block whose length is defined by characteristics of the train occupying the section track.
RADIO BLOCK CENTRE	A centralised safety unit working with an interlocking(s) to establish and control train separation. Receives location information via radio from trains and sends train movement authority via radio to trains.
ROUTE	The path along a section of track between one "block" and the next. Track section prepared for train operation.
SECTION	A part of the movement authority corresponding to one or more signalling block.
TELEGRAM	A telegram contains one header and a identified and coherent set of packets. A message maybe comprised of one or several telegrams.
TRACKSIDE EQUIPMENT	The equipment with the aim of exchanging information with the vehicle for safely supervising train circulation.

TRAIN BORNE	The ERTMS/ETCS equipment carried on the train.
TRAIN BORNE EQUIPMENT	The equipment with the aim of supervising vehicle operation according to the information received from infrastructure installations, from other non ERTMS/ETCS on-board equipment from the driver and from the track side signalling system.

Table 10 - Glossary of terms

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