ERTMS implementation on existing lines

Impacts assessment and performances in future scenarios

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SUMMARY

ABBREVIATIONS	
ACC-M	Centralized Control Interlocking System Multistations [*Apparato di Controllo Centralizato-Multistazione*]
AV/AC	High Speed/High Capacity [*Alta Velocità/Alta Capacità*]
BAcc	Code current automatic block *[Blocco automatico a correnti codificate]*
DD	*Direttissima* Rome-Florence
EOA	End of Authority
ERTMS	European Railway Train Management System
ES	Eurostar
ETCS	European Train Control System
HS	High Speed
IC	Intercity
LL	Slow line Rome-Florence
MA	Moving Authority
RBC	Radio Block Center
RSC	Repetition of signals on-Board [*Ripetizione Segnali in Cabina*]
SCMT	Train Running Control System [*Sistema Controllo Marcia Treni*]
SS	Subsection
SSB	Board Sub-system [*Sottosistema di Bordo]*
SST	Ground Sub-system [*Sottosistema di Terra*]

1 INTRODUCTION

ERTMS represents nowadays the boundary of the future signalization in railway context. With the European directives, it is duty of the member states to provide to their national networks the implementation of these new technologies with the aim of making easier the interoperability among different countries.

The passage from national railway situations to new interoperable ones, that necessarily have to be planned taking into account the needs of each country, is never so easy, as it comes to collide with own traditions and cultures. However, the final agreement among countries on how the future European railway networks should be compliant has led to the definition of ERTMS, a system that will progressively bring to a unique standard of European railways.

Italy in this field represents surely an excellent reality, since the implementation of the new system started already from ‘90s when the need of new High Speed lines allowed to have a white paper to implement the ERTMS. It was in fact the opportunity to design new lines, starting from zero, that permitted Italian RFI to provide them with the new signalling system.

However, in the Italian context the *Direttissima* (Roma – Firenze) HS line still represents a weak point. The reason is nothing else that the historical period in which the line was born. In ‘70s the line was designed in order to guarantee a speed of 250 km/h (considered *High speed* from European standards) and the ERTMS was still far from its ideation. After 40 years, it is unavoidably needed a process of modernization that will adapt it to the HS Italian standard which is just the ERTMS.

This situation represents something new in the Italian panorama, because of the use that has been made of the *Direttissima* line until now. In fact, promiscuous services run on it, especially in the extreme sections, and this means, as better explained later, that ERTMS will not have to be matter of only HS trains, as up to now is in the Italian network.

In addition, the upgrading process has obviously a glaring difference from the opportunity to start from zero: the activities that will bring to the new configuration can not be carried out stopping the current services, that represent ones of the most active in the Italian network.

1.1 OBJECTIVE

As the peculiarity of the *Direttissima* line makes the ERTMS implementation more complex, but also more interesting, this work will surely focus on what ERTMS means and implies in this context.

With this work the author would like to highlight the consequences of the implementation of ERTMS in an operating line. These are often wrongly evaluated, especially about potentiality actual improvements. However, at the same time the thesis has the purpose of underlining the great opportunities coming from new technologies, whose innovative principles can really revolutionize the railway panorama.

1.2 COMPOSITION

The thesis will be parted into two main sections. In the opening one, theoretical considerations will be proposed, in order to understand the general functions of the ERTMS, its requirements and the differences among the three levels, even if it is expected that only level 2 will be implemented. In addition, recalls of line potentiality will be necessary in order to understand the actual consequences coming from the upgrading process.

In this phase a comparison between present and post-upgrading situations will be proposed. The comparison will threat mainly the physical configurations, represented mainly by the signalization schemes and then block sections and signal positions. They are in fact necessary input data to understand if and how potentiality could be affected by the implementation of a new signalling system.

In the second half of the work it will be described a solution to schedule mixed traffic on the *Direttissima* line, exploiting the potentialities of ERTMS technologies. The supposed scenarios have been then simulated on Opentrack platform, whose results are finally shown at the end of the thesis.

2 HISTORY

The line *Direttissima* that links the cities of Rome and Florence detains a unique record in railway field. It has been in fact the first *High Speed* line all over the Europe. Its history started around '50s when Italian governments started to consider inadequate the old line (nowadays the so-called LL *Linea Lenta).* After a first period of analysis in 1970 the first stone was put close to the Paglia River where now the longest viaduct extends.

The works lasted about 22 years but already in 1976 the first section (between Orvieto Nord and Città della Piave – 21.7 Km) was opened. In few months, other legs started to be active until 1977 when an official ceremony inaugurated the *Direttissima* line between Settebagni and Città della Pieve.

The actual end of the works is dated on 26th of May 1992, after 22 years from the first stone.

As said this was a real Italian primate since for the first time in Europe a train could run at a speed of 200/250 km/h and so be considered an *High Speed Train.*

2.1 CURRENT CHARACTERISTICS OF THE LINE

The line, that has surely been subjected to some maintenance interventions, has kept its original configuration. Its extension amounts up to 253.6 Km. It is important to remind that the term *Direttissima* (DD) refers to the line that links Settebagni and Rovezzano. The legs between Settebagni and Roma Termini and between Rovezzano and Firenze S.M. Novella are overlapping with the *Linea Lenta (LL)* and are not considered parts of the DD line.

The line is an HS line, double track, electrified in direct current 3kV, equipped with traditional signalization and repetition on board of the signals with 9 codes (RSC). SCMT (Sistema Controllo Marcia Treni) provides train separation in order to guarantee safety conditions.

No level crossings and intersections are present along the whole line. The interaxle spacing between the two tracks is 4 metres, and every track can be used in both directions. Nearly every 16 Km a double crossover allows trains to pass from a track to the other one.

Minimum radius of the curves is 3000 metres and the maximum slope 0.8%. The maximum design speed is 250 Km/h, which requires braking distances around 5400 metres as reference value. The signalling system has been drawn according to these distances.

The *Direttissima* line constitutes together with the LL line a unique managed system of four tracks in order to guarantee a greater potentiality and flexibility of the circulation. Ten interconnections exist between the two lines (*Bivi*). All the service points (crossovers, junctions, sidings) are managed by electromechanical interlocking ACEI (Apparato Centrale Elettrico ad Itinerari).

2.1.1 Services on the line

The line was initially designed to be run by *Settebello* (ETR 300) trains, at speeds around 180 Km/h. With the technological progress an increasing of the speeds has been registered up to the current 250 Km/h of modern trains that nowadays provide the HS services between Rome and Firenze.

However, extreme sections of the DD line, present promiscuous services. *Eurostar* trains are not the only ones running in the sections between Settebagni and Orte and between Arezzo and Firenze. Regional and Intercity services are scheduled, mostly in the peak hours, as well as Cargo trains (mostly during soft hours).

In particular, as evident from the following table that shows trains running through Settebagni station in a normal working day (26th May), a mixed traffic characterizes the line in the section between this place and Orte. *ES* trains surely represents the majority of the trains but also some regional services run on the line.

Table 1 - Number of trains passing Settebagni station. Even track.

	Even Track				
Hour Gap	**ES**	**IC**	**REG**	**Cargo**	**Total**
05:06	1	0	2	0	3
06:07	5	1	7	0	13
07:08	7	1	8	0	16
08:09	9	0	6	0	15
09:10	8	0	5	0	13
10:11	8	0	4	0	12
11:12	6	1	6	0	13
12:13	5	1	5	2	13
13:14	4	0	5	1	10
14:15	7	0	5	0	12
15:16	6	2	5	1	14
16:17	10	1	6	2	19
17:18	9	0	8	0	17
18:19	9	1	7	0	17
19:20	7	1	7	0	15
20:21	4	1	6	1	12
21:22	2	0	3	1	6
22:23	0	1	3	3	7
23:00	0	1	1	2	4
00:01	0	0	0	3	3
01:05	0	0	0	0	0

After Orte station, the lines is crossed only by ES trains. The Allerona station's recording in the same day shows the exclusive presence of the HS trains on the line during normal circulation.

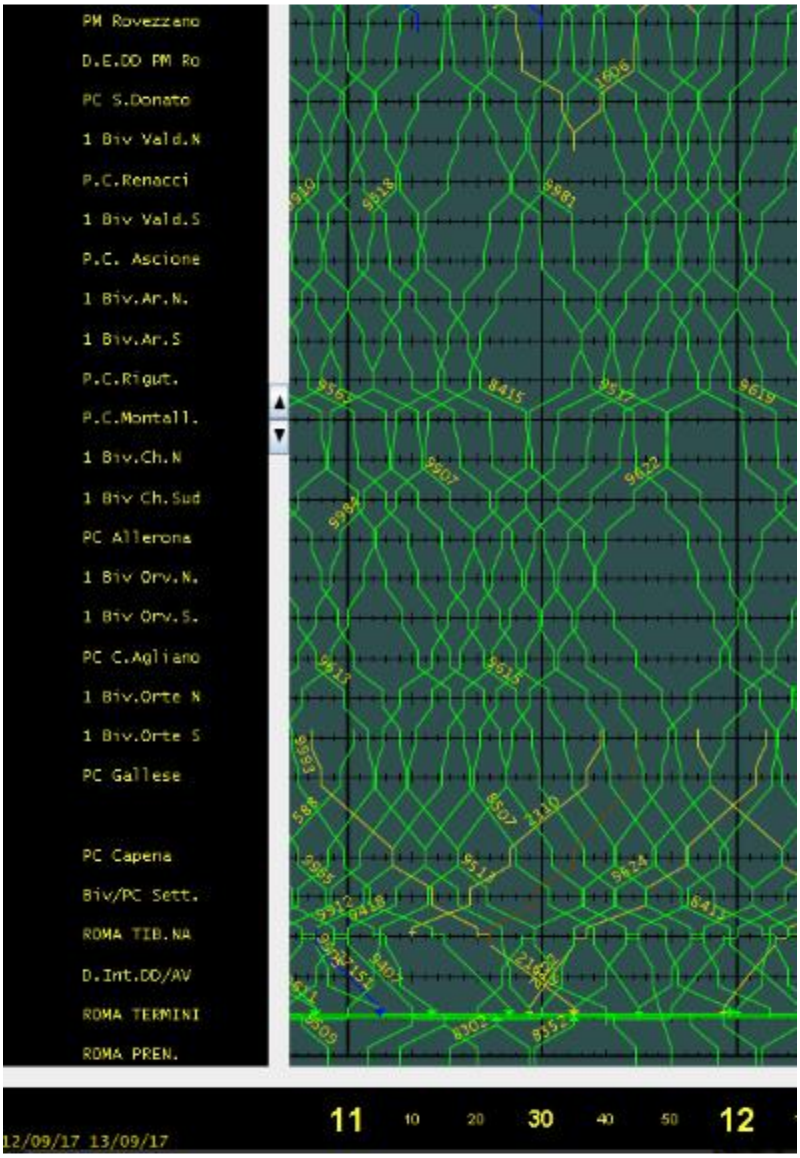
Table 2 - Number of trains passing Allerona station. Odd track.

	Even Track			Odd Track		
Time period	**ES**	**IC**	**TOT**	**ES**	**IC**	**TOT**
06:07	3		3		1	1
07:08	7		7	1	1	2
08:09	8		8	5		5
09:10	9		9	9		9
10:11	8		8	9		9
11:12	6		6	9		9
12:13	7		7	6		6
13:14	4		4	5		5
14:15	5		5	7		7
15:16	7		7	7		7
16:17	7		7	4		4
17:18	9		9	8		8
18:19	9		9	7		7
19:20	8		8	8		8
20:21	6		6	9		9
21:22	3		3	7		7
22:23	0		0	5		5

The timetable of the line allows to understand better how the traffic is organized and how much is the running time along the line. An important element of the line is that no passenger service is accomplished in the stations between Settebagni and Orte and Arezzo and Firenze. The stations play the only role of points of service and then no train stops between these places. The trains run without intermediate stops between the main nodes.

In the following picture an extract of the timetable, during the morning peak hour, is presented. By a quick analysis of the timetable it is easy to get the running times of the trains.

A *ES* service lasts about 1 hour and 2 minutes between Settebagni and Rovezzano while regional trains take about 20 minutes to run from Settebagni to Orte and then leave the *Direttissima*. On the other side, 10 minutes are required by trains that run on the LL from Valdarno to Rovezzano and about 20 minutes from Arezzo to Rovezzano too.



Picture 1 - Timetable from Settebagni to Rovezzano. 11:00/12:00

It is here presented an example of running times for different train categories and services.

Table 3 - Example of time schedule

	REG	ES	ES	REG	IC
	2304	**9504**	**9602**	**3168**	**580**
Settebagni	06:22:00	06:36:00	06:42:00		
Capena	06:29:00				
Gallese	06:40:00				
Bivio Orte N	06:42:00				
Agliano					
Allerona					
Montallese					
Rigutino					
Bivio Arezzo					07:36:30
Ascione					
Valdarno				07:41:00	
Rovezzano		07:38:00	07:44:00	07:50:00	07:54:30

2.2 UPGRADING INTERVENTIONS

After forty years of service, the line, that once represented an excellence in the railway panorama, is nowadays anymore a point of strength of the Italian railway network. Old technologies used are by now at the end of their economic life, new technologies have come to the light and new performances are required by a High Speed line. Even if the DD allows a good service between two fundamental poles like Rome and Florence, interventions for modernization and alignment to European parameters have been considered necessary.

For this reason, in 2014 the projects for the modernization of the line were assigned and completed in order to start the upgrade activities. Feasibilities studies allowed to individuate a plan to bring to AV/AC standards the current DD line, finalized to create conditions for:

- Qualitative and quantitative improvement of services, through the increasing of performance levels guaranteed by the system;
- Improvement of circulation management on the whole line AV Milan-Rome, both in normal and degraded situations, through modern management functionalities concentrated in a unique *Posto Centrale.*

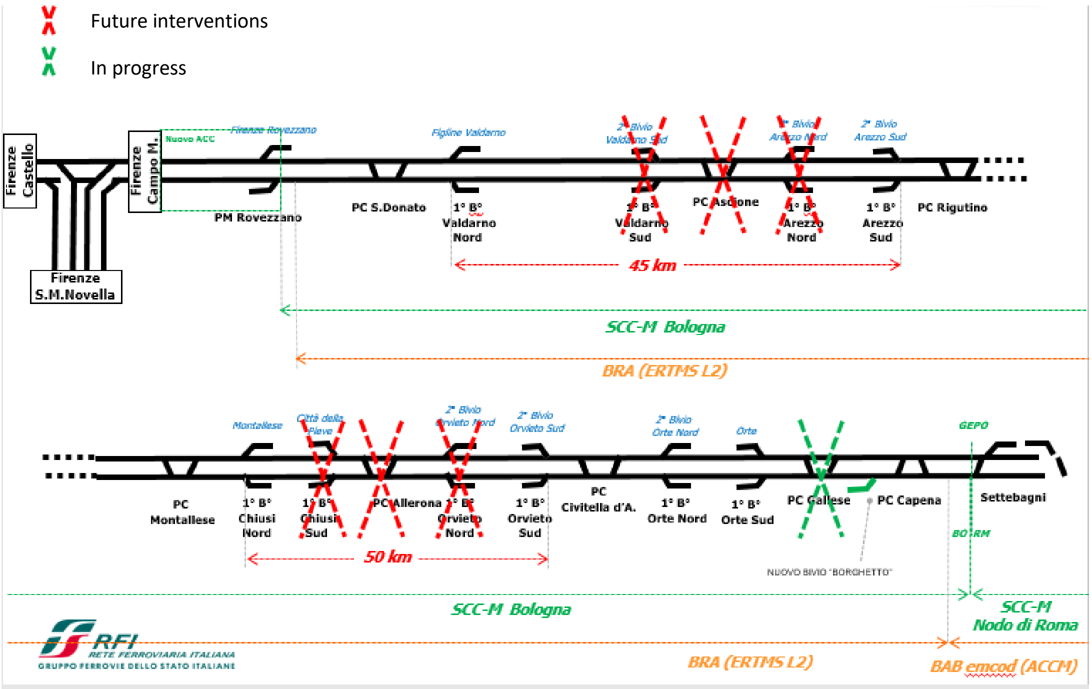
But which are the real designed interventions?

First of all, the activities will not affect the physical profile of the line. The vertical and horizontal alignments are not going to be changed. The improvements will concern the technological aspects of the line, mainly about signalling system.

How will the new line be different:

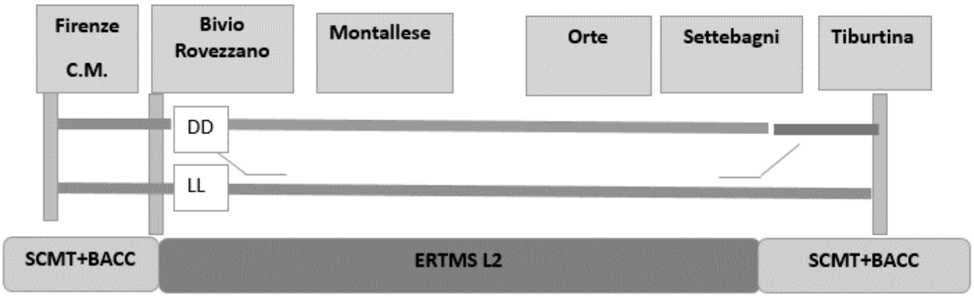
- Elimination of 4 out of 10 junctions between the DD and LL lines and of 3 crossover points. In particular the junctions of Valdarno Sud, Arezzo Nord, Chiusi Sud and Orvieto Nord will be closed as well as the crossover point of Ascione, Gallese and Allerona.
- All the old local interlockings (ACEI) will be decommissioned and the routes in all the service points of the whole section between Settebagni and Rovezzano will be managed by a modern multi-stations interlocking from a single *Posto Centrale* located in Bologna. The extreme legs (Settebagni-Roma and Rovezzano-Firenze will be under control of the SCC-M of the respective cities).

- The existing block system will be replaced by the new ERTMS technologies between Settebagni and Rovezzano. This means that only trains whose SSB is set with ETCS will be able to run on this line. This represents a completely new situation: up to now AV/AC lines equipped with ERTMS are crossed by only HS trains. In this new scenario regional trains that will have to continue running between Settebagni and Orte, for instance, will have to be equipped with a proper ERTMS SSB.



Picture 2 - Upgrading of Rome – Florence line

The SSB upgrade consists mainly in the equipment of the trains that will have to run on this line with the ERTMS L2 and not already equipped.



Picture 3 - ATC on the Rome - Florence line after the upgrading interventions

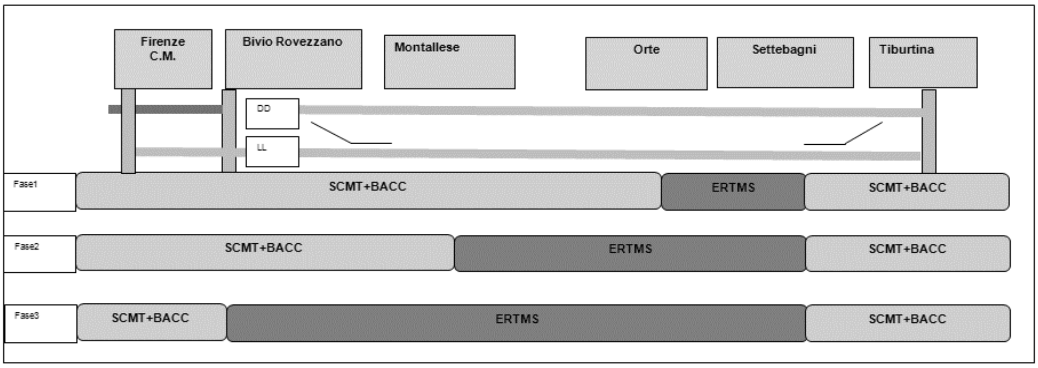
The section between Settebagni and Roma Termini will be affected by the interventions too. In particular the management of the service points in this part will be under the control of a new ACC-M located in Roma Termini which has in charge the management of the whole node of Roma.

At the same way in the other extreme section between Firenze Campo di Marte and Rovezzano, the service point of Rovezzano will be managed by a new ACC-M located in Firenze Campo di Marte which has in charge the management of the whole node of Firenze.

Finally, in the *Posto Centrale* in Bologna for the management of the whole section will be implemented a double emplacement for the operators.

The just mentioned interventions are pretty technological measures and hardly they can affect the potentiality of the line (exception made for some particular situations that will be later explained). The original design of the line already aimed to fully exploit the line at 250 km/h and nowadays the increasing of the speed on this line would require interventions on the electric side of the line itself. The 3kV DC voltage of the line in fact strongly influences the possibility to increase the performances in terms of speed. In the sections where the alignment allows a speed higher than 250 km/h it is necessary however to provide an upgrade of the contact line.

The peculiarity of the interventions stays behind the idea of proceeding in three phases in order to guarantee the continuous circulation of trains during the working activities without suspending the services. The phases will be organized as shown in the following picture.



Picture 4 - Temporal phases of the upgrading activities

3 ERTMS

This chapter is addressed to describe the ERTMS system in its entirety, in orer to understand the functional principles and overall concepts. However, it must be clear since the beginning that, from the technological point of view, only one of the three described levels will be implemented in the specific case (L2).

3.1 GENERAL OVERVIEW

The ERTMS has its origin at the end of the last century when the *European Rail Research Institute (ERRI)* set up a team of railway experts in order to give birth to the requirements of ETCS. The new framework was mainly characterized by a new on-board equipment based on open computer architecture (EUROCAB), a new discontinuous system for data transmission (EUROBALISE) and a new continuous transmission system (EURORADIO).

After some years of development, on the 25th April 2000, the final signature on ERTMS specification arrived. Only in recent years (2009) the adoption of the ERTMS Deployment plan made the ERTMS implementation mandatory on six European corridors.

But how really works the ERTMS?

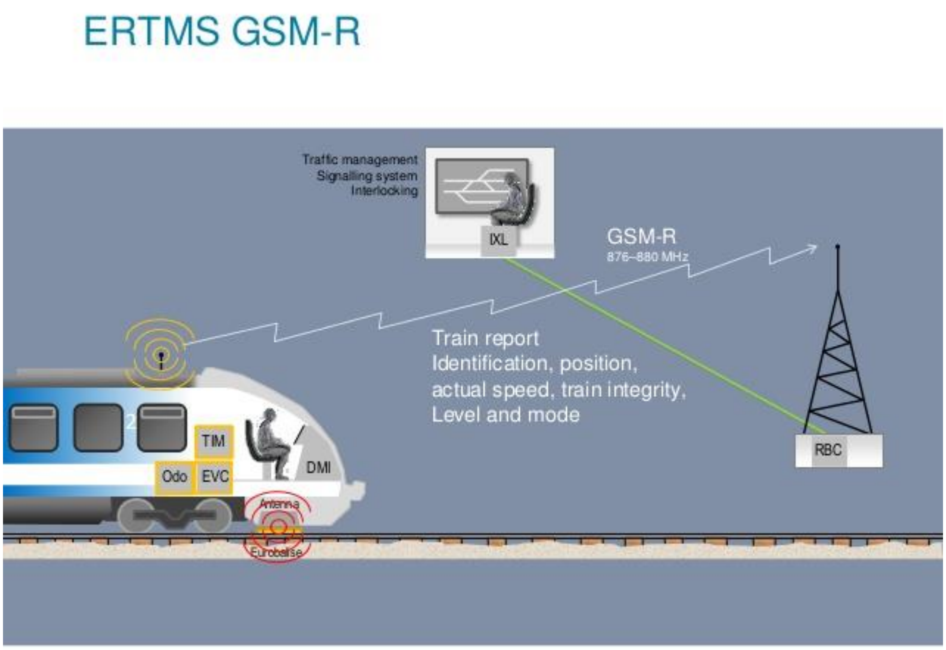
Basically, the system is intuitively easy: a ground system (SST) interacts with the on-board system and, accordingly to the level of the ERTMS of the line, it gives information on where and when to brake in order to guarantee a safe separation of the train.

The structures of the two systems is obviously less easy than their functions but they can be described as follows.

The SST is mainly composed by:

- RADIO BLOCK CENTER (RBC): It is the interoperable component that manages the functions of centralized block. It generates the information necessary to the train running sending them in form of Moving Authority (MA).
  The logic behind a MA is achieved by information that are received by the systems of national signalization concerning the integrity of trains and of the lines (electric loops), by Eurobalises and by the train itself (ERTMS L2). The RBC keeps under control each single train running under its jurisdiction through the identification of the SSB installed on them;
- Information Point (PI): this is mainly constituted by a group of two Eurobalises that can have different functions;
- Operator emplacements (both Central and Peripherical).
- Lateral signals that announce the start/end of a section equipped with ERTMS or that announce the place of a EOA.

The SSB refers mainly to the equipment present on board.



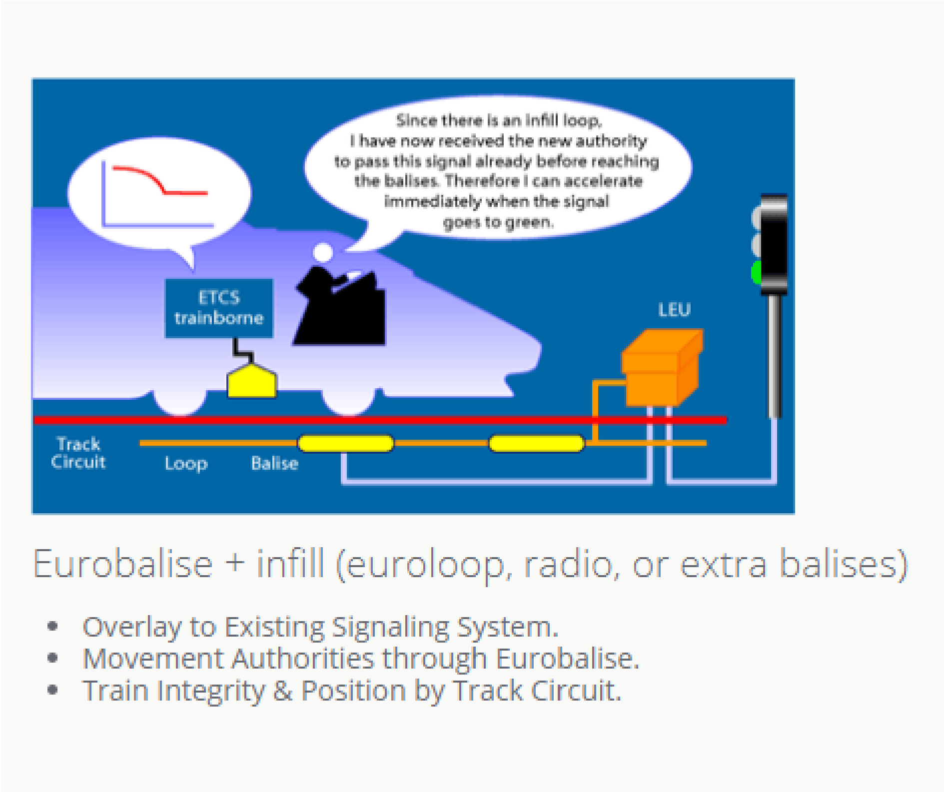
Picture 5 - ERTMS GSM-R general functioning

3.1.1 Level 1

The first level is characterized by a discontinuous system of interaction between the SST and the SSB: the train, running over the Eurobalises, receives information about the line (slopes, maximum speed, tunnel, etc.) and the distance from the point it has to stop at. The integrity check is carried out by traditional national systems such as electric loops that remain mandatory as well as lateral signals. The system can be considered very closed to the Italian SCMT that works in a very similar way. Once the train has received information about the EOA place, the SSB elaborates a braking curve that the train has to respect in order to stop in safety conditions.

Picture 6 - ERTMS L1: key functions

The presence of the *infill* solution (ERTMS L1+Infill) allows the train to be updated when the signal turns green after that it has received a stop command from overstepped balises . The infill information permits the train to cancel the stop command and so to start accelerating approaching the signal at the new free aspect.



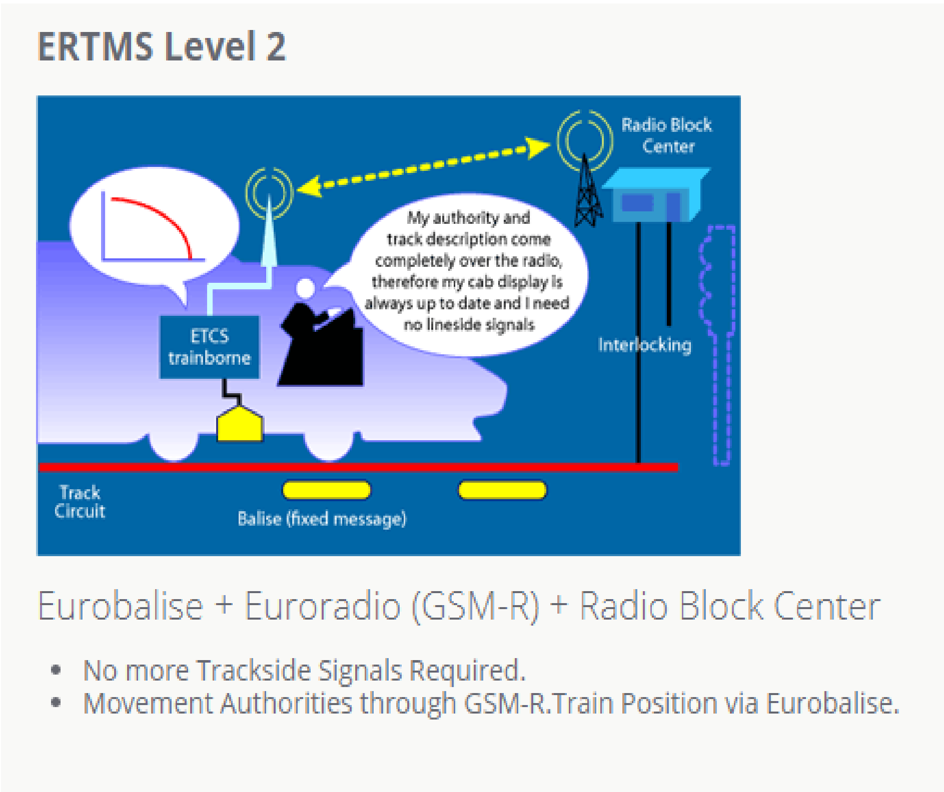
Picture 7 - ERTMS L1+Infill: key functions

3.1.2 Level 2

The ERTMS L2, used in the AV/AC Italian network (in few years adopted also in the DD line), has the great peculiarity to work without lateral signals.

Although the integrity check still requires old and traditional equipment (loops), the interaction between trains and ground is carried out by telecommunication systems, that in real time provides the train the information needed for a safe run and gives to the RBC all the characteristics of the train (speed, position, etc.). Eurobalises are present but anymore play a primary role. The information (especially movement authorities) are transmitted by GSM-R.

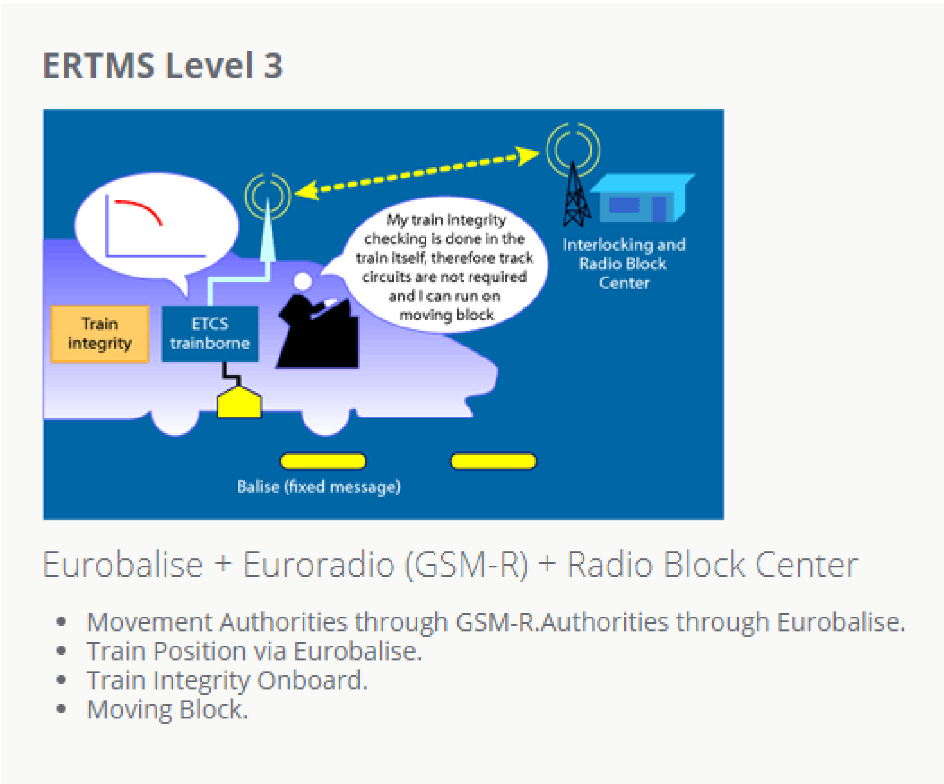
In such a situation, the block sections remain fixed and the logic of train separation remain the same of the traditional block systems: a block section can be occupied by only one train.



Picture 8 - ERTMS L2: key functions

3.1.3 Level 3

The third level of ERTMS is still under examination. The main problem that has to be overcome is represented by the train integrity check. Once that modern systems will be able to guarantee the train integrity check on board the L3 could be implemented. The main advantage coming from such a system is the opportunity to overpass the fixed block sections in favour of moving blocks. Track circuits will disappear, as well as lateral signals, and the train running will be constantly monitored by the RBC that will send Movement Authorities via GSM-R.



Picture 9 - ERTMS L3: key functions

3.1.4 ERTMS differences with traditional systems

Once the general functions of ERTMS have been explained, it could result interesting and useful to understand how the ERTMS works differently from current signalling/separation systems.

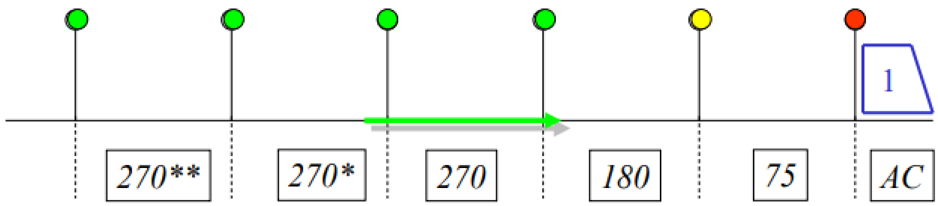
In the current state, the line is divided into block sections, delimitated by Main Signals. On the *Direttissima* two-aspects signals) are used, this means that every signal has a respective specific Advanced Signal at about 1500 metres before. In addition, the track circuit, realized by means the two rails, act like an antenna able to transmit coded information to trains, allowing the repetition of signals aspects on board. The 9-coded information transmitted allows the running at speed until 250 Km/h.

The sections are parted into subsections, corresponding to a track circuit that sends a specific code. The sight of the signals become in this way not essential. The driver receives an indication by the code and knows in advance how he/she will have to behave in order to guarantee a safety run. The main codes in a normal situation are the following six:

- 75: Next signal is Red. The train has to stop.
- 180: Next signal is Yellow. The train has at least 1350 metres free ahead.
- 180*: The maximum speed is 150 km/h because of works along the line.
- 270: The train has at least 2700 metres free ahead.
- 270*: The train has at least 4050 metres free ahead.
- 270**: The train has at least 5400 metres free ahead.

Two more codes (120, 120*) are used to give to the driver information about the speed in diverted routes.

What happens in a plain situation is graphically represented in the following picture.

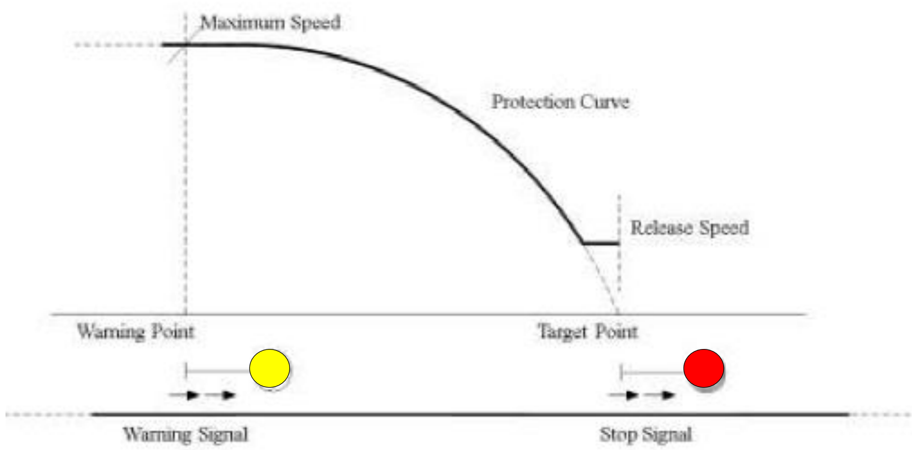


Picture 10 - 9 codes standard sequence

This system performs the automatic safe control of the train speed but only with respect of the ceiling speed representative of every code.

To make the system able to achieve a continuous speed control, in regard to the speed limits coming from both the line and the train itself, additionally, the SCMT system has been foreseen. The system, thanks to the presence of fixed balises that sends useful information, elaborates a braking curve (Position – Speed) that the train has to respect in order not to enter in emergency braking phase.

From a fixed informative point (balise) the train receives the information on the distance and the aspect of the following Main signal. If the signal requires the train to stop the on-board system, having train characteristic as input data, and knowing the train speed elaborates a speed profile in order to arrive at the critical point at the desired speed (release speed). Once the curve is computed, it is duty of the driver to respect the speed profile along the distance to the signal. If the driver fails, the automatic intervention of the system is triggered.



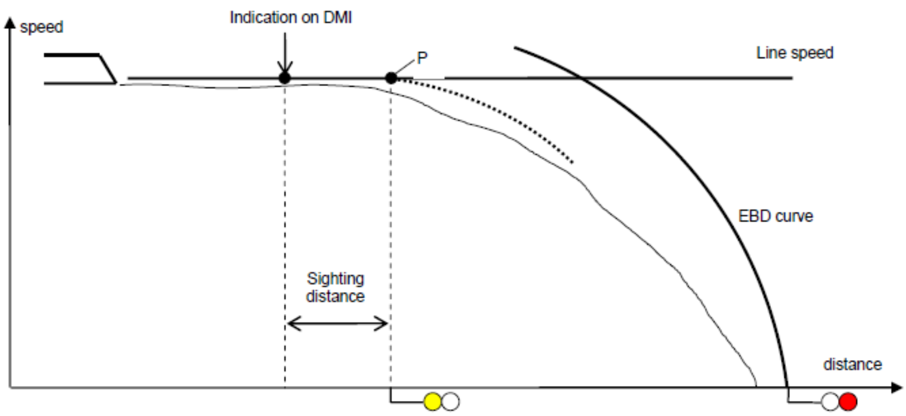
Picture 11 - Braking curve in conventional lines

The principles that hide behind the ERTMS are not so far from the logic of SCMT and, as a consequence, the safety level could be considered the same, but also there is a quite big functional difference between them, that is:

- in the SCMT system the computed braking curve is not shown to the driver who acts on the base of the same behavioural rules used in the lacking of the control system. This could lead him to behave cautiously, namely keeping a speed lower comparing the safe one calculated by the system, in order to avoid automatic intervention of the brake. This results in a performance reduction;

- In the ERTMS system the computed braking curve is shown to the driver who may keep the real speed of the train just a little bit lower than the permitted one, increasing the performance.

With the difference listed above and from technology point of view can be stated that ERTMS L1 is pretty the same of SCMT, whereas in L2 and L3 there is a very important difference. The information is in fact sent and received by the train continuously, even if no signals are present the idea is however the same: the RBC sends the position of the following EOA, and the curve is built on board from that point up to the position/speed of the train. The starting point of the braking curve can be seen as the yellow signal and the EOA as the red one. The following picture explains well this concept.



Picture 12 - Braking curve and speed profile

3.1.5 Braking curves

Braking curve is the instrument that has to ensure the safety condition. In Italian AV/AC the model that stays behind it comes from the specification of the SCMT[1] braking curves.

The model approximates the development of the real braking phase distinguishing two sub-phases:

- Transitory phase: the deceleration is considered null and represents the phase during which the depression in the general pipe is propagating along the whole train.
- Regime phase: the deceleration is considered constant until the achievement of the *Objective Speed.*

The core of the model is represented by the computation of the S_{EBI}, the distance necessary to end a braking phase in emergency conditions. This output,

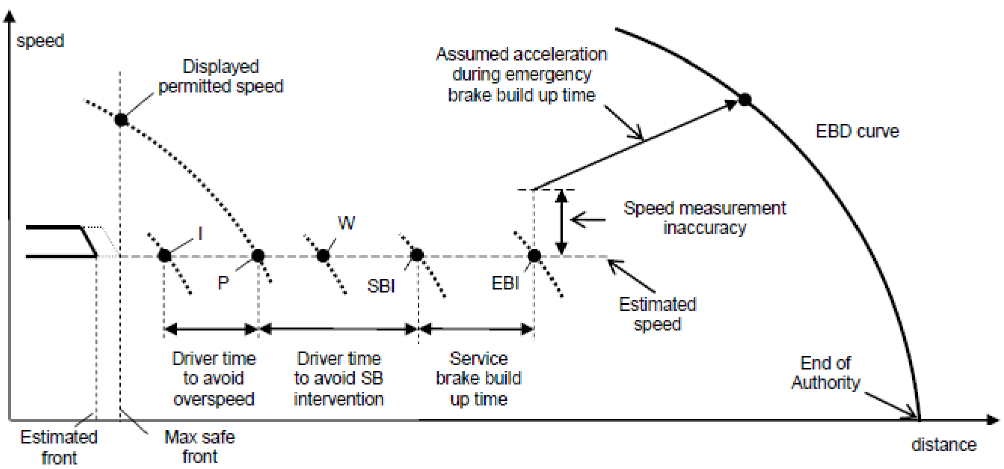
[1] *Modello di frenatura per SSB AV – RFI [Codifica: RFI TC.PATC SR AV 03 M01 A]*

outcome of the following formula is function of many parameters. Some of them come directly from the information received about the line, others are input data proper of the train that the driver has to insert at the moment of the start of the run.

$$S_{EBI}= \left(h + t_f\right) V_i + \frac{V_i^2 - V_O^2}{2\,(d_p + d_i)}$$

Where:

- h: delay time related to the SBB [0; 5];
- t_f: time during which the model is assumed to be null;
- V_i: Speed at the moment of the braking imposition by SSB;
- *Vo:* Objective speed;
- d_p: deceleration proper of the braking system;
- d_i: deceleration contribute by gradient.
-



Picture 13 - ERTMS relevant speed points

The ERTMS standard defines the EBD curve (Emergency braking distance) as a parabolic curve in function of the space. It is computed backward from the EOA. The model *draws* speed function of the space:

$$v(d) = \sqrt{v(d_0)^2 - 2 \cdot a \cdot (d - d_0)}$$
$$v(t) = v(t_0) - a \cdot (t - t_0)$$

Where d_0 represents the starting point of the braking phase.

Once the EBD is computed, the model provides together other 5 points in order to prevent the emergency situation. Every time the train approaches one of the point the driver receives a signal from the system. Among them it is the P point (*see picture 13*) to refer to the actual speed the drivers has to follow.

If the driver is not aware and does not follow the curve of the permitted speed, when the train gets to the EBI point the system takes control of the train and brakes the train through an emergency braking.

3.1.6 SCMT and ERTMS software and hardware's size

A **SCMT** system requires hardware and software devices that are on average forecasted per each kilometre of double track line as follows:

A. nr. 10 fixed balises and relative SCMT telegrams;

B. nr. 2 commutative balises and relative SCMT telegrams;

C. 4km cables

D. nr. 2 encoder;

E. nr. 2 boxes for BAcc;

F. nr. 2 electric circuits with code currents;

G. nr. 2 unbalanced detectors;

H. nr. 8 mechanic joints and relative diagnostic devices;

I. nr. 2 inductive boxes;

J. nr. 4 light signals;

K. nr. 8 billboards devices;

L. nr. 0.15 radio GSM-R places;

On the other side, **ERTMS** requires:

M. nr. 12 Fixed balises;

N. nr. 0,004 Radio Block Centre;

O. nr. 2 Track circuits with audio frequency or conventional track circuits or devices for *Blocco Conta assi;*

P. nr. 0,25 radio GSM-R places (the same of conventional lines with no signalling functions) and additional antennas for ETCS to have greater signal availability on lines with v>200km/h);

Q. nr. 4 Signage for Marker Board ETCS.

3.2 ERTMS IMPLEMENTATION BENEFITS IN POTENTIALITY TERMS

From the basic computations about line capacity, carried out on the study case of the *Direttissima* line, it has come out that ERTMS implementation does not necessarily mean increasing potentiality of a line. Being a system that makes use of the concept of fixed block sections (L1 and L2), it is still the profile of the block sections to determine the theoretical capacity of the whole line. The presence of a critical section is, also in this kind of separation system, a key factor in the performances of a network. However, in some situations the only introduction of ERTMS can improve the potentiality of a line.

First of all, let's consider a generic hypothetic scenario, where the line has the most simplistic configuration, with sections length constant and equal to 1350 metres. In the traditional system, track circuits send the information through 9 codes. The block section is 5400 metres long (4 subsections of 1350 m). The logic sequence in the case of not permissive signal is:

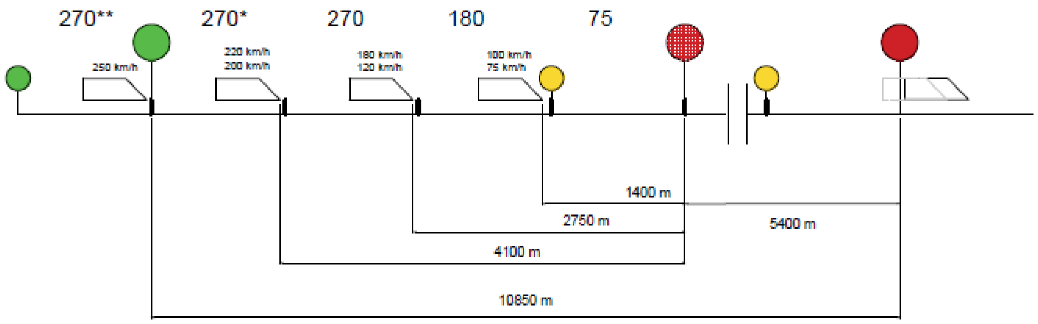
270** → 270* → 270 → 180 → 75

Let's assume some values for braking distances corresponding to different speeds, according to results of SCMT model computations in plain condition.

Table 4 - Braking distances according to SCMT model [RFI]

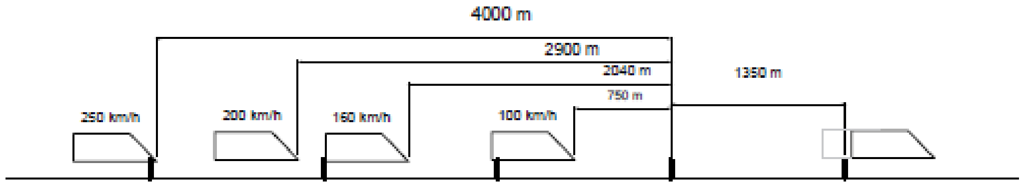
Speed [km/h]	Braking distance [m]
300	5620
250	4019
220	3300
200	2860
180	2500
160	2040
140	1500
120	1080
100	750
90	595
75	415
50	200

Since the codes from track circuit give only 3 values of free distances ahead -5400, 4050 and 2700 metres- trains running at different speeds should stay inside the section whose code allows the running without perturbation. This means that only 4 values of maximum speed can be sent to the train.



Picture 14 - Minimum spacing for unperturbated conditions in traditional system

In ERTMS context the situation is much different: the distance between two trains is determined by only the braking distance of the following train from the EOA before the leading train.



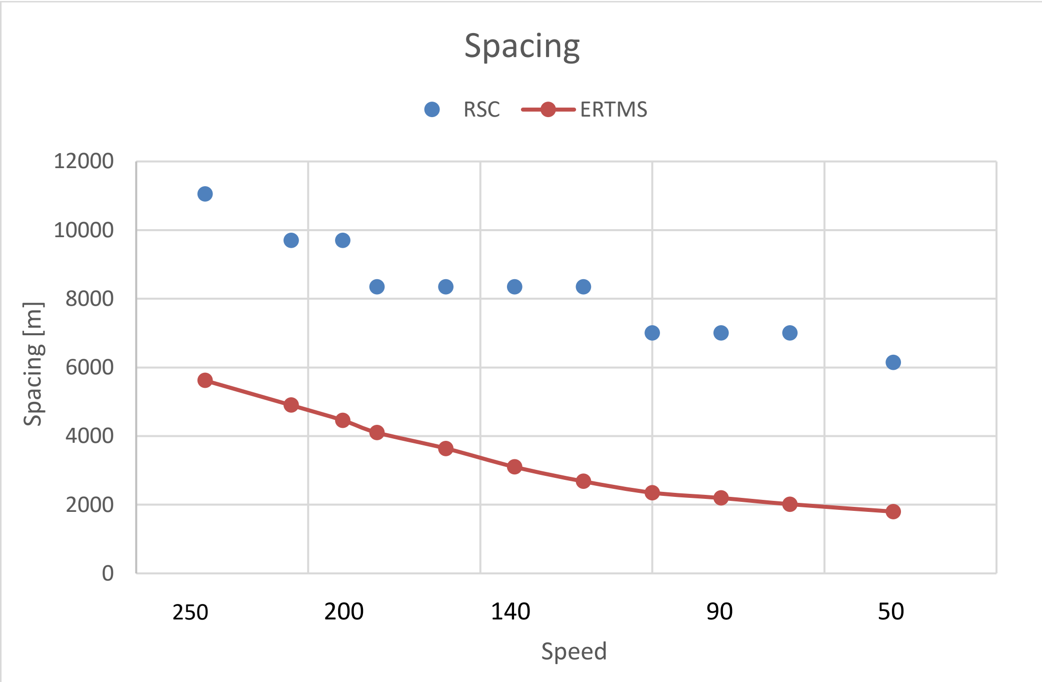
Picture 15 - Minimum spacing for unperturbated conditions ERTMS system

The gap between the two situations results to be very high, with about 4000/5000 metres of differences.

Table 5 - Comparison: minimum spacing in the two configurations

Speed [km/h]	Spacing RSC [m]	Spacing ERTMS [m]	Δ [m]
250	11050	5619	5431
220	9700	4900	4800
200	9700	4460	5240
180	8350	4100	4250
160	8350	3640	4710
140	8350	3100	5250
120	8350	2680	5670
100	7000	2350	4650
90	7000	2195	4805
75	7000	2015	4985
50	6150	1800	4350

From the picture, the result is quite easy to pick up. Spacing between trains for traditional systems with RSC is much more rigid whereas in ERTMS is possible to make trains closer with the decreasing of speeds. In the following chart this is clearer.



Picture 16 - Trend of minimum spacing in the configurations with speed increasing

The minimum spacing between trains running with RSC has a discrete behaviour, since trains receive only 4 values of maximum speeds. The graphical results of the previous line chart reflects in the following, where time headways are represented.

Picture 17 - Trend of minimum headway (s) with decreasing speed

The analysis of how the systems act in different speed scenarios must not be seen as something pretty theoretical. Very often in railway operations the line and the rolling stock have to face with degrading phenomena that impose restrictions to the speed of the trains.

Degrading situations are one of the most common phenomena in railway operations. During these, trains are often required to slow down or even, when the damage on the line is insuperable and where it is possible, exit from the line and enter in a parallel one (let’s imagine at DD and LL).

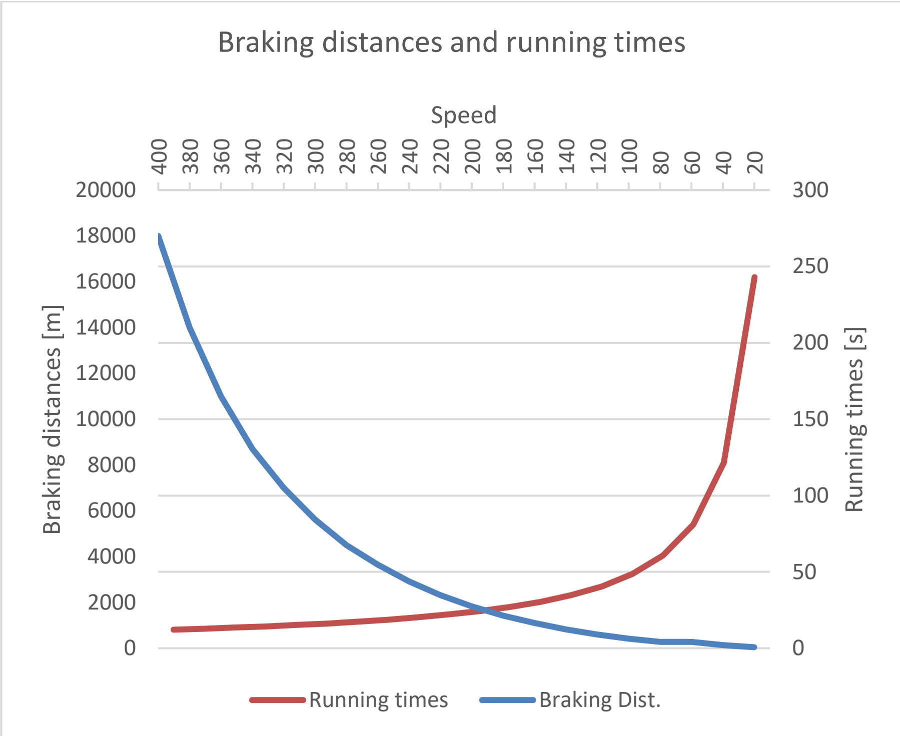
But what happens more frequently it is that trains have to decrease speed. In the previous lines the advantages of ERTMS have been highlighted.

Numerically speaking the difference between the two systems is very relevant. In addition, the lower is the allowed speed the higher is the gap. ERTMS headway function (of speed) remains quite plain whereas the RSC system results to be more affected by the lowering of the speeds. The reason is quite intuitive: shorter block sections are faster to be freed.

Table 6 - Minimum time headway in the two configurations

Speed [km/h]	Headway RSC [s]	Headway ERTMS [s]	Headway RSC [min]	Headway ERTMS [min]
250	140	81	2,3	1,3
220	159	80	2,6	1,3
200	175	80	2,9	1,3
180	167	82	2,8	1,4
160	188	82	3,1	1,4
140	215	80	3,6	1,3
120	210	80	3,5	1,3
100	252	85	4,2	1,4
90	280	88	4,7	1,5
75	336	97	5,6	1,6
50	443	130	7,4	2,2

As shown in picture 17 ERTMS curve concerning minimum headways according to different speeds maintain a quite flat trend, meaning that this does not vary consistently with the speed. The reason is easy: spacing with this kind of system depends strongly on braking distance. If it is true that braking distances decrease with the speed decreasing, it is at the same evident that lower speeds correspond to higher running times. The following chart puts in relation these two parameters.



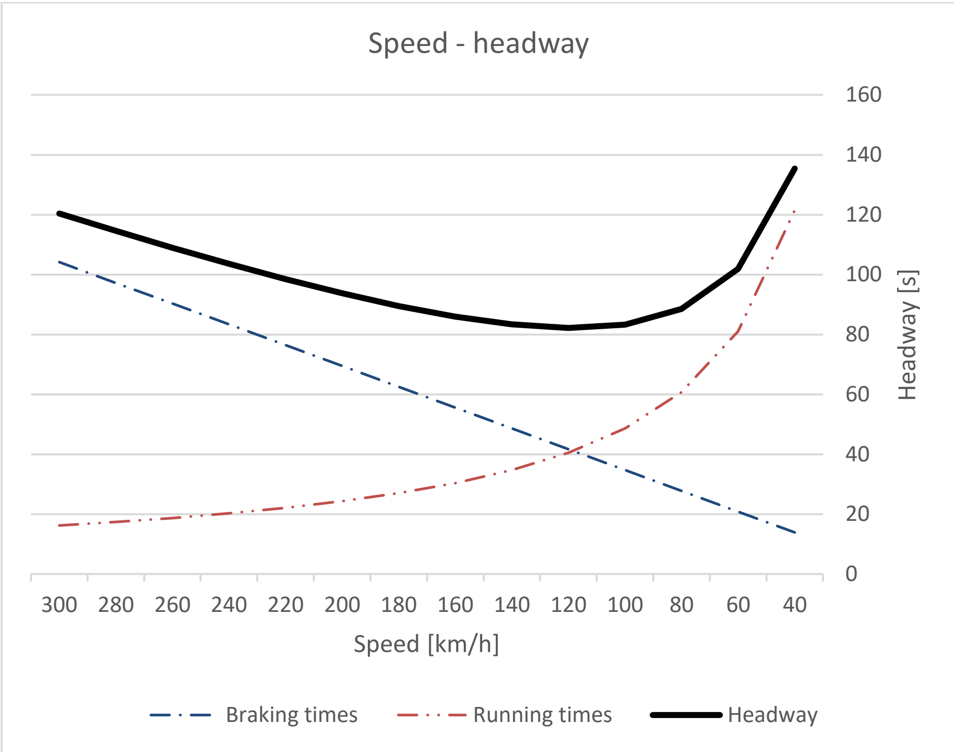
Picture 18 - Braking distances and running times with respect to speed

This leads to a pseudo-parabolic trend of the minimum time headway. This is in fact the result of the sum between two terms:

$$h = \frac{L_{sec}}{V} + T_{braking}$$

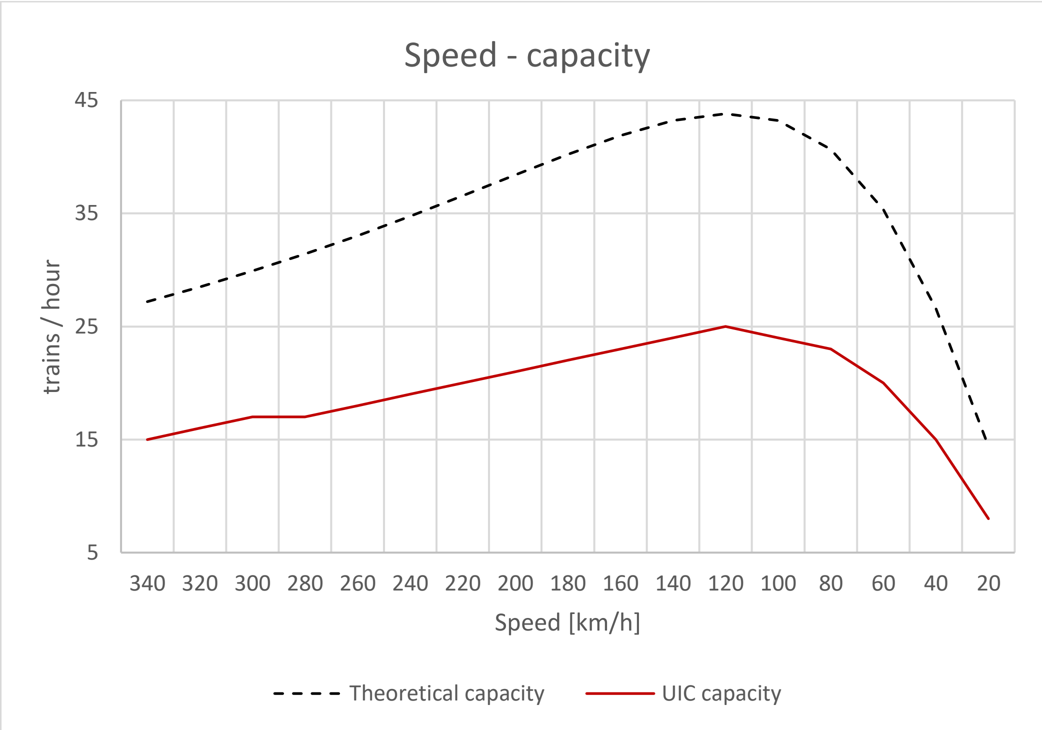
where the first one refers to the running time (hyperbolic decreasing trend), whereas the second one to the braking phase interval (that could be assumed equal to $\frac{V}{2a}$ from the uniformed deceleration motion relations – a linear increasing trend, see picture 19).

The minimum headway is then corresponding to a speed that is in the middle of the interval. In the specific case, for sections of 1350 metres, the minimum occupation time is achieved with speeds equal to 120 km/h.



Picture 19 - Headway trend with respect to speed

It is a logical consequence the reciprocal trend of the potentiality, both theoretical and by UIC method. They are graphically represented in the following diagram. At the speed of 120 km/h the system reaches the maximum value of global potentiality, equal to 25 trains/hour (theoretically 44 trains/h).



Picture 20 - Trend of theoretical and UIC-method capacity with respect to speed

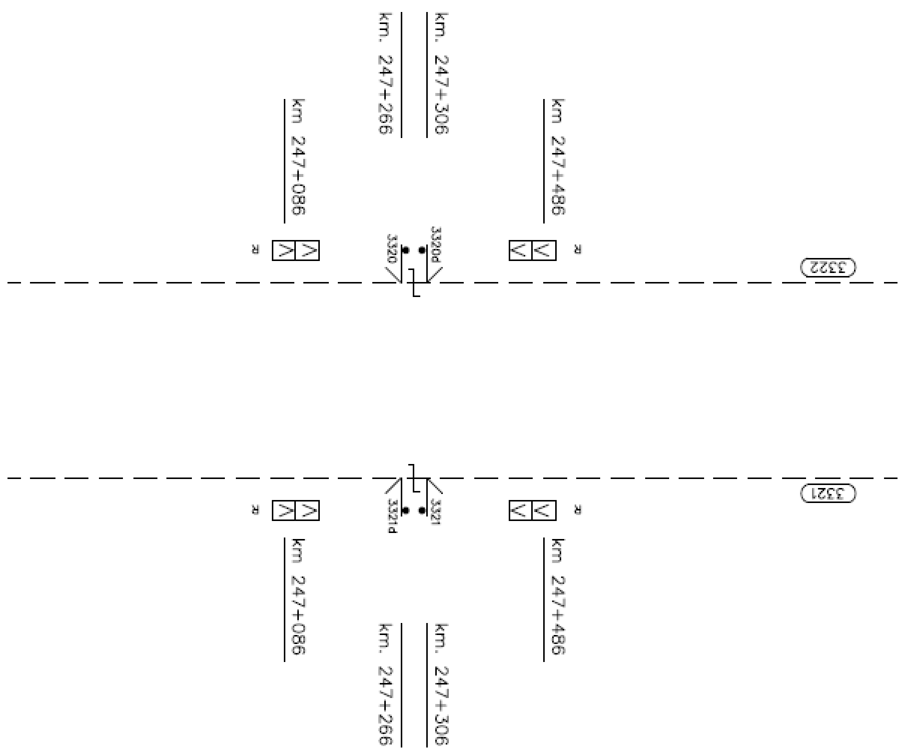
A second advantage is mostly evident in a comparison with a line where no RSC is available and the braking process only depends on the sight of the signals. If up to now the maximum speed of a train was strongly influenced by its braking capacity, in order to be able to stop in a specific distance (between advance and main signal), with the implementation of such a system the start of a braking phase is computed backward from the main signal. It is anymore the train to adapt to the line, but it is the system that adapts to the train. A vehicle with worse braking capability will be able to run faster in change of an advanced start of the braking phase.

It is clear that in order to achieve these kinds of advantages the rolling stocks should be equipped with a ERTMS SSB.

3.3 FOCUS ON THE *DIRETTISSIMA*

The interventions on the DD line foresee the ERTMS implementation along the whole section between Settebagni and Rovezzano. The level of the system is 2, so that to conform this line to the rest of the AV/AC network.

The design of the upgrade has led to the definition of 46 block sections with an average length of 2240 m, that play the separation functions. The block sections profile present as shown in the picture below.

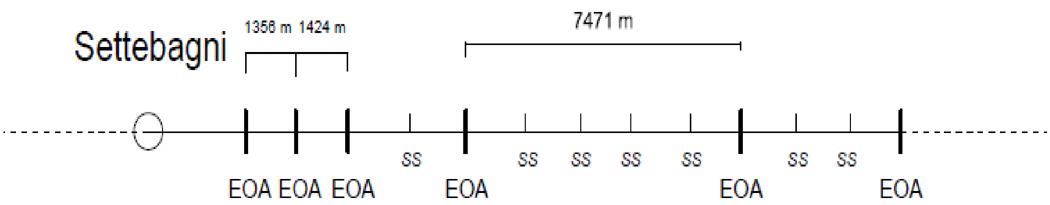


Picture 21 - Extract from block section profile of the upgraded line

Upper line refers to the even track (Settebagni – Rovezzano), whereas the lower to the odd track (Rovezzano – Settebagni). The design of the block sections results to be easier than the current configuration, being the presence of virtual signals for the two directions always coupled. With reference to picture 21, the marks at progressive 247+266 indicates the presence of a possible EOA for trains proceeding in even direction (both legal and illegal tracks). Just 40 metres downstream, the EOAs for the opposite direction are placed. The scheme is very easy and intuitive. The same results for the presence of the Eurobalises: they are located always about 180 metres in advance the related EOA (or sub-section virtual signal). In the example, Eurobalises for even direction are placed at mileage point 247+486, 180 metres far from the next EOAs.

It is important to notice that it can be possible that for one on the two direction the virtual signal indicates a possible EOA, while the virtual signal for the opposite direction (40 metres later or before) is a sub-section signal. In the picture above, both signals (marked with a *) have the function of EOA, but it is not rare to find situations where one is only a sub-section point (without *).

The idea of EOA and sub-section (SS) is better represented by the following picture.



Picture 22 - Scheme of the sections and sub-sections in ERTMS configuration

The difference between a sub-section and a section is given by the role they play. Separation between two trains is carried out only on the base of sections. However, in critical situations where long sections are designed, the need of parting them into more than one track circuit has led to the here-called sub sections. The key idea is always that in one section can be present only one train, even if this is long and parted in many sub-sections.

4 COMPARISON BETWEEN THE TWO SCENARIOS

4.1 CURRENT SITUATION

The line, as said before, is composed by three main legs. Two of them (Settebagni-Orte and Arezzo-Rovezzano) are characterized by mixed traffic (regional and high speed services) whereas the central part only by high speed services. This situation is going to remain the same also after the upgrading process, even if future plans could consider new scenarios. What is going to change is the block sections profile, since the physical signals will be replaced by virtual ones that will represent the possible EOA that the RBC will impose to the ERTMS trains.

The current situation is characterized by two-aspects signals that provide the separation among trains. For each *Main Signal* (1^{st} Category) there is and *Advance Signal* that announces the possible permissiveness of the following main one or its red aspect.

The pair track counts 46 Main Signals with an average distance from the respective Advance Signals of 1455 metres. Among the Main Signals this values amounts about 5000 metres (average section length – The max length amounts to 7697 m). The idea that stays behind the current configuration is mainly to be associated to the need of having a number of track circuits that do not exceed but also that guarantee distances not too high.

It is important to remind that the line is characterized by the RSC system in order to guarantee the running at high speeds (250 km/h). In a system like this, the general idea is to fix a distance of three or four loops of 1350 metres between two main signals. Lengths of the 180 loops stays around an average value of 1316 metres (max. of 2513 metres). In this way, for the longest sections four *Undersections* of one loop each are designed.

Once these main magnitudes have been analysed it is possible to individuate the section that most affects the potentiality of the line. Since the separation system is connected to fixed block sections, it is the longest one that finally impacts more the capacity of the line. The time needed to free this one is the time that provides the minimum headway.

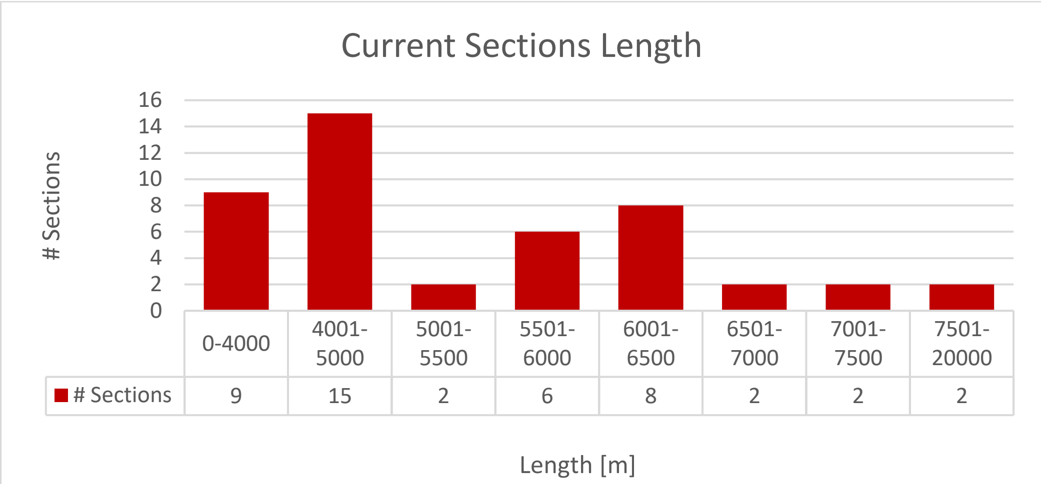
As said before, the longest section is 7697 metres long. However, this is located in the leg where only *Eurostar* trains run. It is in fact evident that the first leg (*Settebagni – Orte)* represents the more critical one. Here, promiscuous services run on the line and then create the most conflictual situation. In this part, a section of 6134 metres is individuated.

Computation on potentiality will be proposed in paragraph 4.5.

Table 7 - Current situation: block profile summary

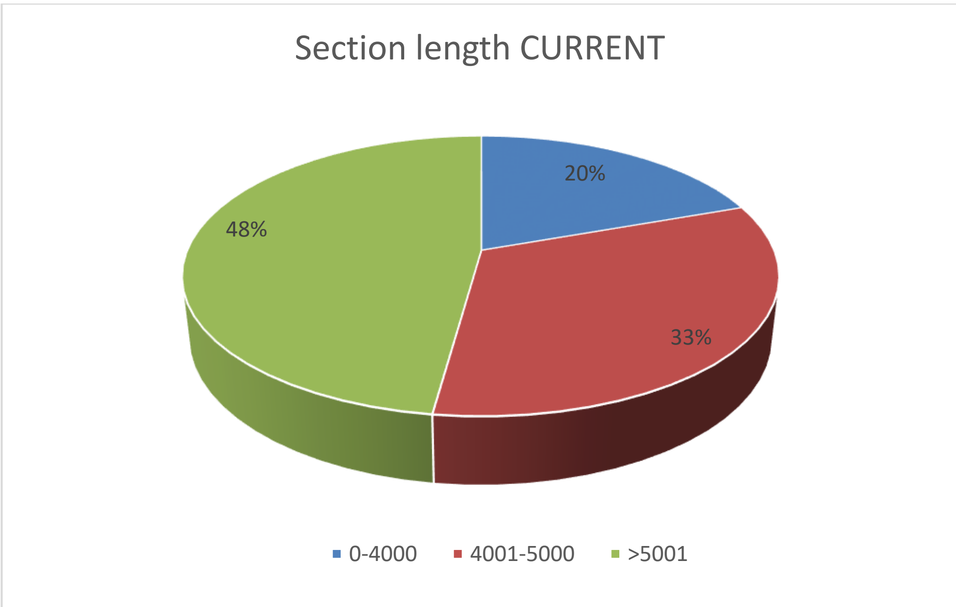
# Loops	Max Loop Length	Max Section Length	Avg Circuit Length	Avg Section Length
180	2513	7697	1316	4996

The distribution of sections length in the current configuration is reassumed in the following bar chart.



Picture 23 - Distribution of section lengths in current configuration

In percentage terms, the result is that about the half of the sections has a length greater than 5000 m, in line with the train separation system adapted to the high speeds.



Picture 24 - Distribution of sections lengths in current configuration

4.2 ERTMS PROFILE

Once that ERTMS basic functionalities have been explained (Paragraph 3), it is easy to understand the profile that will characterize the new *Direttissima* line: physical signals will be replaced by virtual ones. Furthermore, in the new configuration virtual signals (EoA) will be installed also in those locations where today points of code change are present (electric joints of track circuits without signals).

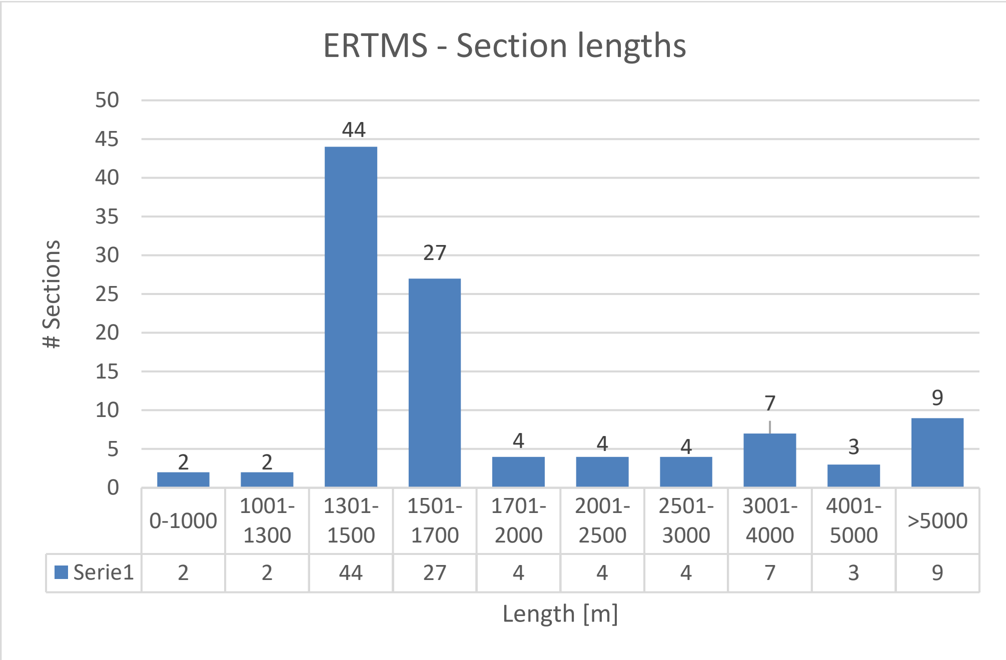
However, these will not always be positioned in the same place of the current entities (signals or track circuit joints) changing, in this way, the configuration of the block sections.

The new profile will be indeed characterized by only two entities: with the acronym EOA will be indicated the virtual signals that will provide the separation function among trains, whereas the SS abbreviation will refer to the subsections signals. It is important to remind that these ones will not play the role of block sections. For each of these entities a track circuit is placed and so the distances correspond to the lengths of the circuits themselves.

Table 8 - New (ERTMS) situation: block profile summary

# Loops	Avg Loop length	Max Loop length	Max Section length	Max SS Length
177	1305	1906	9356	1971

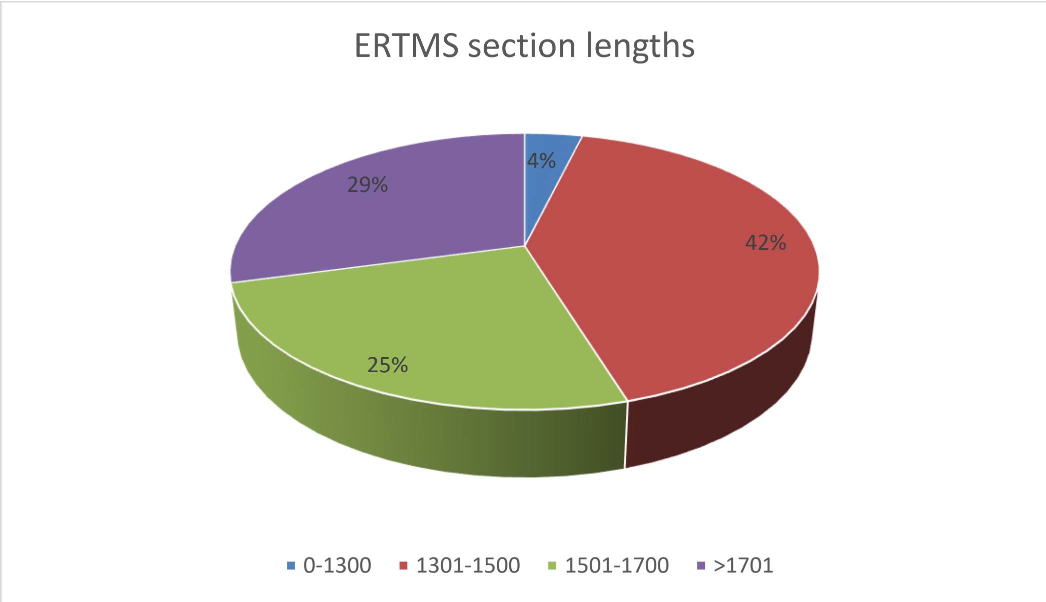
In the following bar chart the distribution of sections length is proposed. The evident decreasing length with respect to the traditional configuration is highlighted.



	0-1000	1001-1300	1301-1500	1501-1700	1701-2000	2001-2500	2501-3000	3001-4000	4001-5000	>5000
Serie1	2	2	44	27	4	4	4	7	3	9

Picture 25 - Distribution of section lengths in Upgraded configuration

The difference with the traditional system is very high. About the 40% of the sections have an extension between 1300 and 1500 metres. Only one third of the sections are longer than 1700 metres, whereas in current systems 20% of the sections are only shorter than 4000 metres.

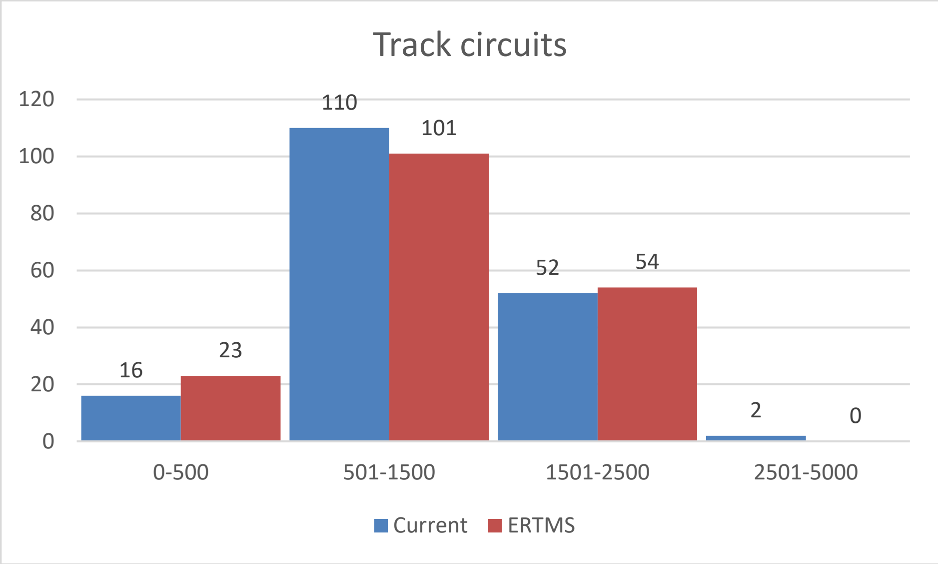


Picture 26 - Distribution of section lengths in Upgraded configuration

4.3 Results

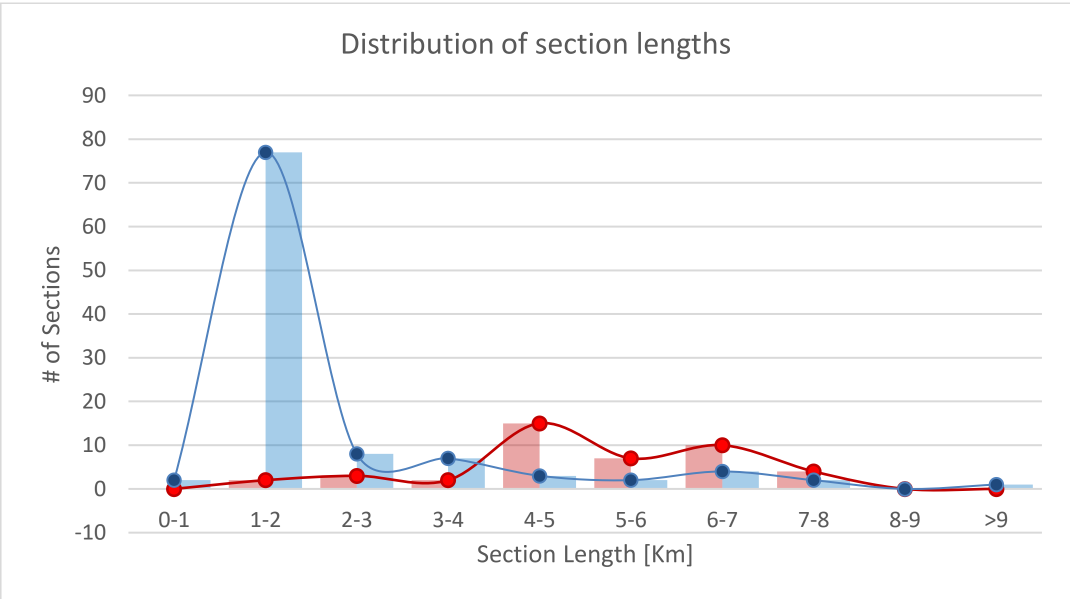
The difference between the two scenarios is very marked. If it is true that track circuits remain globally unchanged (see chart in picture 27), new block profile is totally changed.

Track circuits length do not variate much from the current situation, and this is due to the fact that these lengths are mostly linked to economic and safety reasons.



Picture 27 - Comparison between track circuits length in the two configurations

The number of sections as well as their length, on the contrary, result completely mutated from the two configurations. In the traditional system, sections extension rounds around the 5000 metres due to the 9 codes train separation system; in the ERTMS profile the majority of the sections stay below the threshold of the 1500 metres.



Picture 28 - Comparison between the distributions of section lengths

5 POTENTIALITY ANALYSIS

5.1 POTENTIALITY DEFINITION AND COMPUTATION METHOD

Before discussing how ERTMS can affect the potentiality of a line, it is necessary to clarify the concept behind this term. Potentiality, or capacity, in railway environment theoretically expresses the usual transportation definition of *maximum number of running movements in a specific time period that the elements of a network are able to process.* So it is quite easy to understand how it refers, considering a single track, as the maximum number of trains that can run on a line in a specific time period, without suffering of any perturbation.

Theoretically, this can be analytically reassumed as the reciprocal of the minimum time interval that has to exist between two running trains in order to guarantee safety condition. Until now, railway operations have been carried out only under block sections separation system.

For this reason computing the minimum time interval between two running trains corresponds to compute the time needed to free a block section plus an additional space that depends on the type of separation system (two or three aspects, with or without repetition on board of the signal information, etc.).

Once this time interval *to (occupation time)* is computed is easy to get the theoretical potentiality, equal to the reference time period (usually 1 hour), divided by the *occupation time.*

$$\mathrm{C} = \frac{1}{t_0\ [h/train]} = [\frac{t}{h}]$$

The so computed value will be used in this essay to express the *theoretical potentiality* of a line.

The term theoretical is necessary to understand the distinction with the practical capacity. In railway operations, differently from what happens in road transport, the separation system introduces some differences. Vehicles are not free to run wherever on the line, but have to respect limitations imposed by the block system.

In addition to this, railway circulation can not ignore concepts as regularity, punctuality and so on.

Practical capacity can be the reassumed as *the maximum number of trains which can run through network elements under specified levels of Operational Quality.*

Scholars that studied railway capacity managed to reproduce potentiality behaviour through different models, all expressing one crucial concept: the higher is the requested regularity, the lower is the theoretical capacity of the line. This because the higher is the number of running trains on a line the more likely is to have conflicts and then to loose regularity.

Among the different models that can be found in literature, the UIC one will be here used in order to assess the practical capacity of a line. This is a probabilistic method that, for a given exercise program, assesses how much is "*exploited*" the capacity of a line. If the outcome of the UIC model is a greater number of trains with respect to the actual situation, it means that line is able to process the given trains fluently and there is basically space for other services.

On the contrary, if the result of the UIC method is a number of trains per hour lower than the actual one it means that the line is probably not able to satisfy properly the schedule without any kind of conflict.

Numerical result of capacity according to UIC model, can be expressed in a quite simple relation.

$$C = \frac{T}{t_o + t_r + t_{zu}}$$

Where t_r and t_{zu} encloses the characteristics of required regularity and of the separation systems of the line.

It is then evident that practical capacity is always lower than the theoretical one, being the *occupation time* increased of two components t_r and t_{zu}.

While t_{zu} is easy to understand and compute, being equal to 0.25 * number of block sections within the critical section, the meaning of t_r is a bit more complex. This encloses the regularity concept and its value comes out from queue theory. The network is assimilated to a a service station that has its own utilization rate equal to:

$$\Psi = \frac{t_o}{t_o + t_r}$$

Wide test campaign from UIC members have try to identify values for maximum Ψ equal to:

- 0.6 for average operational condition – t_r equal to $0.6t_o$
- 0.75 for high traffic density condition – t_r equal to $0.75t_o$

In next lines both theoretical and practical potentiality will be computed as just explained.

It is important to underline that the potentiality is a concept that is strongly dependent on the subject to which is referred. It is in fact clear that the potentiality could be assessed for a whole line but also for a section of the line itself.

In the next paragraph the main focus on potentiality will be addressed to understand which is the maximum number of trains that can run on the *Direttissima* at the maximum speed (250 km/h), taking under consideration the whole line. In this sense the global potentiality of the line will be only influenced by the critical section that is the longest.

However, as also explained later, it is not wrong to look at how the potentiality can fluctuate along a whole line or can change according to the different speed values. This because even if it is true that potentiality increases together with the speed whenever the separation system is based on block sections, with an ERTMS scenario the direct proportionality is lost and potentiality has a parabolic trend with the speed.

5.2 ADVANTAGES ASSESSMENT IN REGIME SITUATION

5.2.1 Section: ORTE - AREZZO

In this paragraph, a study of the potentiality of the line before and after the upgrading process will be proposed. In order to get numerical results that can give an idea of the differences in terms of capacity the UIC method for capacity assessment has been used.

The method follows an analytical stochastic procedure that gives back the value of the capacity considering it as the ratio between the Time reference [T] and the headway. This value has to keep into account the stochasticity of the phenomenon as well as the physical characteristics of the lines (especially block sections).

The analysis has been carried out for two different situations: firstly the potentiality comparison has been focused on the second leg of the line (Orte – Rovezzano) where only *Eurostar* trains run; in a second moment the more interesting case of the first section (Settebagni – Orte) has been analysed. In this one the promiscuity of the services has led to a more complex computation even if the model results to be very easy and intuitive.

In both cases the model rotates around the concept of *occupation time,* meaning the time a train has to wait before leaving in order to never find a red signal. In case of omotachicity of the service this value is quite easy to compute: the only datum needed is the critical section (the section a train runs in the longest time). Since in this part the train are allowed to run at the maximum speed (250 Km/h for HS trains and 140 Km/h for regional ones), the critical section correspond to the longest one.

As said previously the two configurations differ not only for the signalization technologies but also for the profile of the block sections. This means that the critical section does not remain the same in the two cases.

Regarding the leg occupied by only *Eurostar* trains (Orte – Rovezzano), the critical section amounts to 7697 metres in the current situation and 9356 metres for the ERTMS one. To compute the *occupation time* some easy consideration must be carried out.

Let's before analyse the case of sections individuated by physical signals that can have two aspects. The critical section presents in this way.

In order the following train to have always green signals ahead the distance from the leader train must be equal to:

$$D = L_{train} + L_{section} + AdvanceSignalDistance + Visibility\ Distance$$

Assuming zero all the delays introduced by the system components.

In the specific case this distance amounts to:

$$D = 200\ m + 7697\ m + 1390\ m + 150\ m = 9437\ m$$

The *Occupation time* results to be in this case equal to:

$$t_O = \frac{9437\ m}{69.4 \frac{m}{s}} = 136\ s$$

In the ERTMS situation the computation requires a more detailed consideration. The question is: how far must be the following train from the one that precedes in order to never be in the condition to apply the brake? The ERTMS in fact works in such a way that a train receive constantly from the RBC the point where it has to stop, and it is a task of the on board system to compute constantly the Braking curve that allows to stop at a determined point.

For this reason it is easy to understand that a train starts to brake (like if it sees a yellow signal) whenever it is located in a point where the braking curve starts. In order to never decelerate it has to be always at a distance greater than the braking one from the received EOA (*see picture 13*).

In this way the distance from the train preceding at the same speed must always be at least equal to the length of the section (the critical section) plus a distance equal to the braking distance. In this computation this distance has been fixed as the distance that the SCMT model gives back for a train running at 250 km/h on a plain track that wants to stop completely. In order to have a security gap this distance has been set at 4000 metres.

By doing this the *Occupation time* for the ERTMS case is equal to:

$$t_O = \frac{(9356\ m + 4000\ m + 200\ m)}{69.4\ m/s} = 195\ s$$

Already from this first easy computation it is easy to understand that the implementation of the new technology does not mean necessarily an increasing on capacity. The need of such a long section (due to tunnel situation that in ‘70s did not have a strict regimentation like nowadays) leads to have values of capacity lower than the actual ones.

The final computation of capacity, as specified in the UIC model, requires the set of a Time reference (1 hour – Peak hour analysis) and of a schedule extracted from real Trenitalia programme.

CAPACITY COMPUTATION

Section: ORTE - AREZZO

CURRENT Scenario

DATA		
Headway	7,5	min
# of Trains	8	trains/h
Reference Time	1	h
Train Class	EUROSTAR	
# of block sections	1	

DATA		
Critical Section	7697 m - Montevarchi/Rovezz.	
Running Time	136	sec

Calculation Parameters – ACTUAL		
# of sequence in 1 h	7	
Minimum Headway	136	Sec
Elapsing Time	102	Sec
Additional Time	15	Sec
Potential Capacity	256	trains/d
Potential Capacity	**14**	**trains/h**

CAPACITY COMPUTATION

Section: ORTE - AREZZO

ERTMS Scenario

DATA		
Headway	7,5	min
# of Trains	8	trains/h
Reference Time	1	h
Train Class	EUROSTAR	
# of block sections	0	

DATA		
Critical Section	9356 m - SECTION 92	
Running Time	195	sec

Calculation Parameters – ERTMS		
# of sequence in 1 h	7	
Minimum Headway	195	Sec
Elapsing Time	146	Sec
Additional Time	0	Sec
Potential Capacity	192	trains/d
Potential Capacity	**10**	**trains/h**

5.2.2 Section: SETTEBAGNI – ORTE

Let's now analyse the section that intuitively creates more criticism to the line potentiality. It is in fact from Settebagni to Orte that the promiscuity of the traffic is present. This means that omotachicity is anymore guaranteed, trains run at different speeds and this means that slow trains *steals* capacity to the line and performance to faster trains.

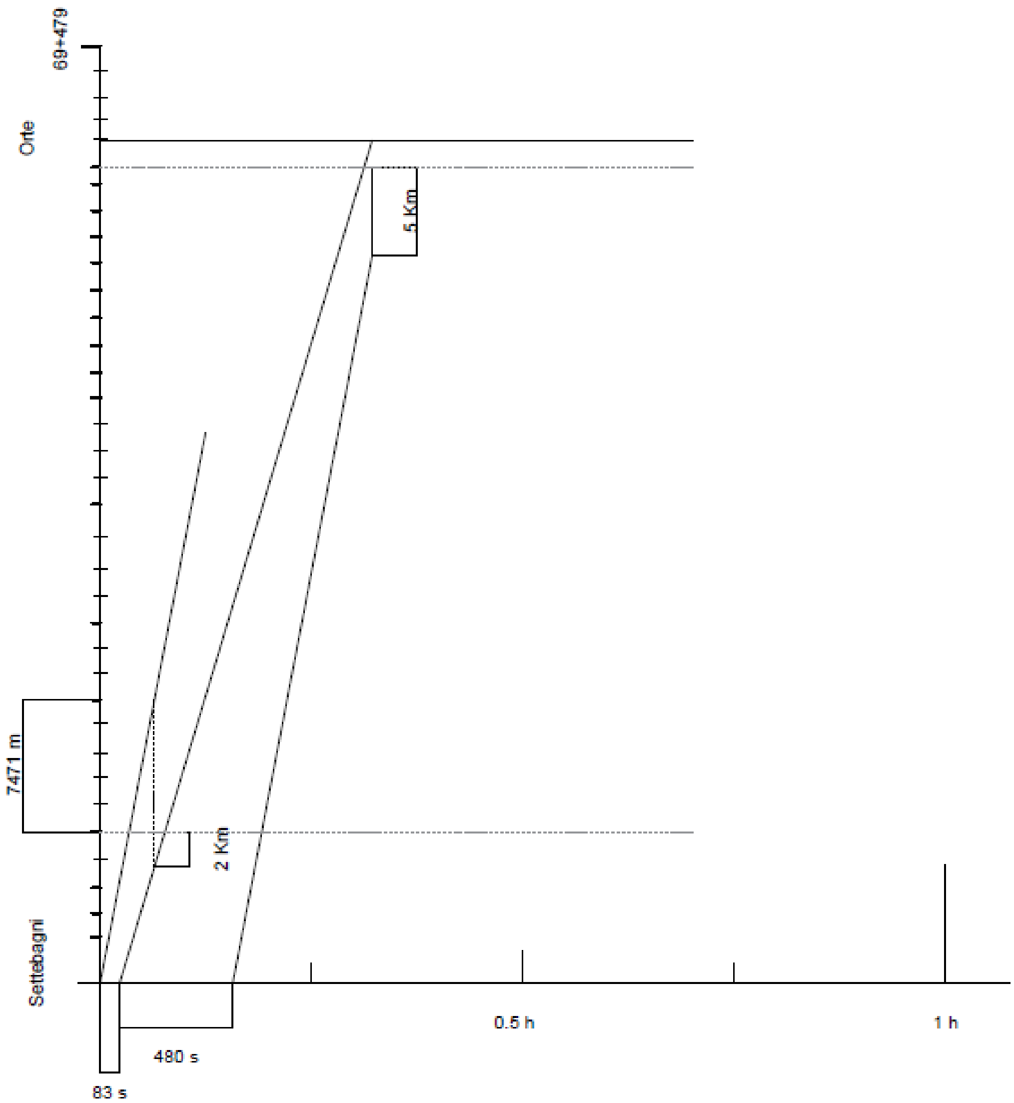
The circulation scheduled has been already shown in paragraph 2.1. However, the study of the potentiality has been carried out on the peak hour, when 9 *Eurostar* trains and 1 regional run along the line on the pair track.

The computation has followed the UIC method again, but differs from the previous situation for the presence of two categories of train, a slow one and a fast one. The computation of the t_{fm} changes since we introduce the concept of sequence of trains. Once a first schedule is in our hand it is necessary to understand how many times a fast train follows a slow one and vice versa. It is easy to understand indeed that each sequence has different *Occupation time*: a fast train that leaves after a slow one has to wait a time necessary in order to allow the leader train to be always at a distance sufficient to guarantee an undisturbed running. Vice versa a slower train that follows a faster one has only to wait a smaller time.

The two scenarios give again a result similar to the analysis carried out on the middle section. The current situation gives back better performances in terms of capacity: the current block profile allows to reduce occupation time and so the average headway.

Obviously, these results are only dependent on how the profile of the block sections has been designed. It is important to remind that modern projects have to respect modern rules and directives that probably at the time of the first realization of the DD did not exist.

For instance, tunnel regimentation has changed over the years in order to increase safety conditions: this reflects also on how a line can be parted in block section. If we analyse the profile of the upgraded line we discover that the section of 9356 metres, for instance, covers a section of tunnels and is the result of the need of assuring safety condition as the European laws state.



Picture 29 - Time/Space diagram: occupation time in mixed traffic conditions

CAPACITY COMPUTATION

Section: SETTEBAGNI ORTE

ERTMS Scenario

DATA		
Headway Class L	60	min
# of Trains L	1	trains/h
Headway Class V	6,7	min
# of Trains V	9	trains/h
# of Total Trains	10	trains/h
Reference Time	*1*	*h*

DATA: Settebagni - Orte		
Critical Section	SETTEBAGNI - ORTE	
Occupation Time L-L	215,0	sec
Occupation Time L-V	480	sec
Occupation Time V-L	83	sec
Occupation Time V-V	165,0	sec

Calculation Parameters - ERTMS		
# of sequence L-L in 1 h	0	
# of sequence L-V in 1 h	1	
# of sequence V-L in 1 h	1	
# of sequence V-V in 1 h	7	
Minimum Headway	191	sec
Elapsing Time	143	sec
Additional Time	0	sec
Potential Capacity	**10**	**trains/h**

t_{fm} con DB	187
Capacity con DB	10

CAPACITY COMPUTATION

Section: SETTEBAGNI ORTE

CURRENT Scenario

DATA		
Headway Class L	60	min
# of Trains L	1	trains/h
Headway Class V	6,7	min
# of Trains V	9	trains/h
# of Total Trains	10	trains/h
Reference Time	*1*	*h*

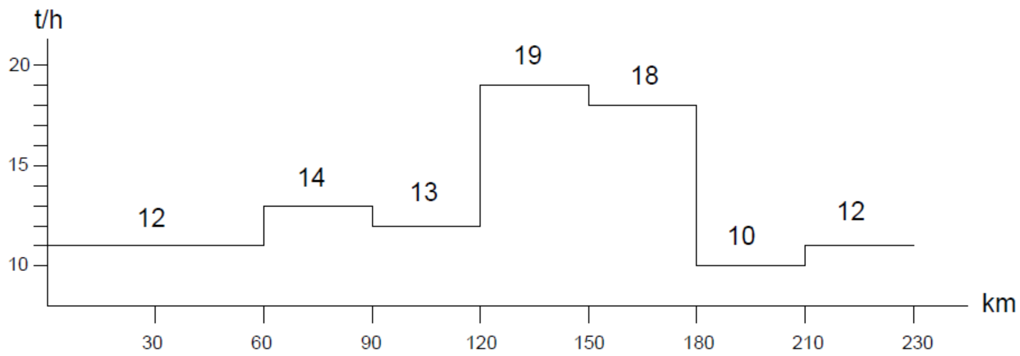
DATA: Settebagni - Orte		
Critical Section	SETTEBAGNI - ORTE	
Occupation Time L-L	175,0	sec
Occupation Time L-V	515	sec
Occupation Time V-L	88	sec
Occupation Time V-V	113,0	sec

Calculation Parameters - Current		
# of sequence L-L in 1 h	0	
# of sequence L-V in 1 h	1	
# of sequence V-L in 1 h	1	
# of sequence V-V in 1 h	7	
Minimum Headway	155	Sec
Elapsing Time	116	Sec
Additional Time	15	Sec
Potential Capacity	**12**	**trains/h**

tfm con DB	148
Capacity con DB	12

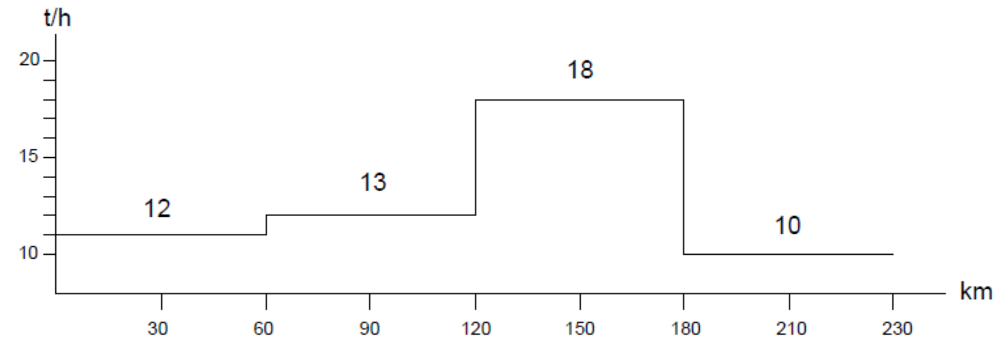
Referring to a real situation like the *Direttissima* one the advantage exists anyway. It is true that long sections will be present in the future line too, but these will represent extraordinary situations. So, if the theoretical potentiality of the line could not result improved if we consider the whole line itself, the overall reduction of the sections in ERTMS allows increasing potentialities in some legs of the line where with the traditional block system the sections are 4000/5000 metres long.

In this sense, it is possible to analyse how the potentiality of the line varies along the line, since sections length varies a lot in the about 240 kilometres of the line.



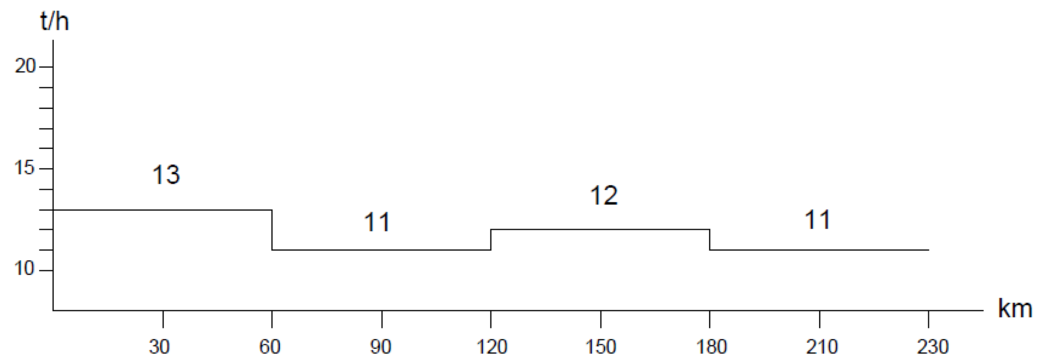
Picture 30 - Capacity fluctuations along DD: ERTMS profile [30 km partition]

Results in the above diagram come out from the same UIC procedures explained in paragraph 5.1. It is also necessary so specify that the diagram itself come out from the choice to consider legs of 30 kilometres. Any other space interval could lead to different diagrams. For instance, it is here presented the same diagram where sections of line 60 km long are considered.



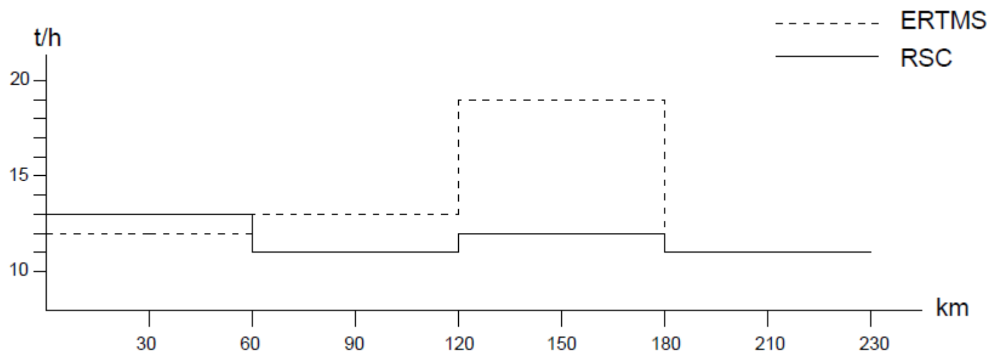
Picture 31 - Capacity fluctuations along DD: ERTMS profile [60 km partition]

It is in any case evident that the potentiality of the line does not remain the same at all, whatever it is the partition that it is considered. The difference with the RSC systems is in the opportunity to have sections where potentiality results much higher. With RSC, as shown in the next diagram, the capacity remains almost constant, with very small fluctuations.



Picture 32 - Capacity fluctuations along DD: current profile [30 km partition]

According to the theoretical definition of potentiality of a whole line, that depends on the critical section, the ERTMS does not imply an increasing of it. However, the opportunity to have a relevant amount of shorter sections reflects in local increasing of capacity.



Picture 33 - Comparison: capacity along the line in the ERTMS and RSC profile

6 FUTURE SCENARIOS

It is now clear that ERTMS is able to guarantee potentiality improvement wherever the length of the sections is kept low. As seen for the *Direttissima,* contrary to traditional systems, the ERTMS provides remarkable fluctuations of the capacity along a line.

The main weak points in potentiality terms are represented by tunnels, whose safety conditions have imposed the definition of long block sections in order to avoid the contemporaneous presence of two following trains inside the same tunnel.

In this way, one of the great advantage that ERTMS could bring to the network would be lost or strictly dimensioned. This is true even more so in Italian network where tunnels are often necessary. *Direttissima* case is an evident testimony of what just affirmed. Although the block profile of 1,350 metres could guarantee about 18 trains/h at 250 km/h (or even more at different speeds), the presence of tunnels and then of longer sections, impose a maximum of about 11/12 trains/h at 250 km/h.

6.1 CARGO SERVICES INTRODUCTION ON THE LINE

Future plans in Italian railway operations are addressed toward the utilization of the High Speed lines also by cargo trains. In last June 2017 first operation plans have been revealed: in 2019, after that the last six months of 2018 will be used for the experimentation of the system, six trains are going to run between Pomezia and Verona, 6 between Melzo and Pomezia and 6 between Novara and Pomezia. The total of 18 trains is going to grow up to 24 in 2021 and to 36 in 2023.

Running times are expected to be around 9 hours, and the estimated speed is not going to exceed the 120 km/h. In addition, as the director of *Interporto Servizi Cargo* has underlined during the conference, nowadays cargo operators are able to send only containers but not semitrailers due to gauge restriction along the historic line.

In particular, the so called mega-trailers, whose profile exceed the PC45 gauge, represent today the most used in Europe for cargo. This problem can be overpassed in short period only by via AV/AC lines.

It is then evident that the line has to be able to receive in the next years, different services without losing much in terms of potentiality. It is also obvious that for how the line is designed the promiscuity of services could hardly be well managed. Let's think about cargo services and high speed passengers trains that have to share the line, when the first ones run at speeds around 120/140 km/h.

7 MEASURES TO OVERCOME CONFLICTS

The objective of the following paragraphs is to expose a possible measure that could allow to exploit the maximum potentiality of the line along all the entire development, overpassing, as far as possible, the constraints due to the presence of tunnels and so of long block sections and of promiscuous services.

First of all it can be useful to remind what is the problem: the *Direttissima* line is going to be upgraded. After the implementation, the new signalling/separation system ERTMS will provide the train separation functions. A new block profile is designed, mainly characterized by short sections (average of 1400 metres).

However, due to tunnel normative restrictions, long sections are required in order to guarantee the presence of only one vehicle inside a tunnel (per direction). Long sections represent in this way bottlenecks to the line potentiality that, contrary to traditional systems, present positive values wherever sections present reduced length values.

The proposed solution is thought to provide benefits in case of mixed traffic with cargo services that in the future will unavoidably characterizes the line. It is clear that several years have to pass before a similar scenario will be actually occurring.

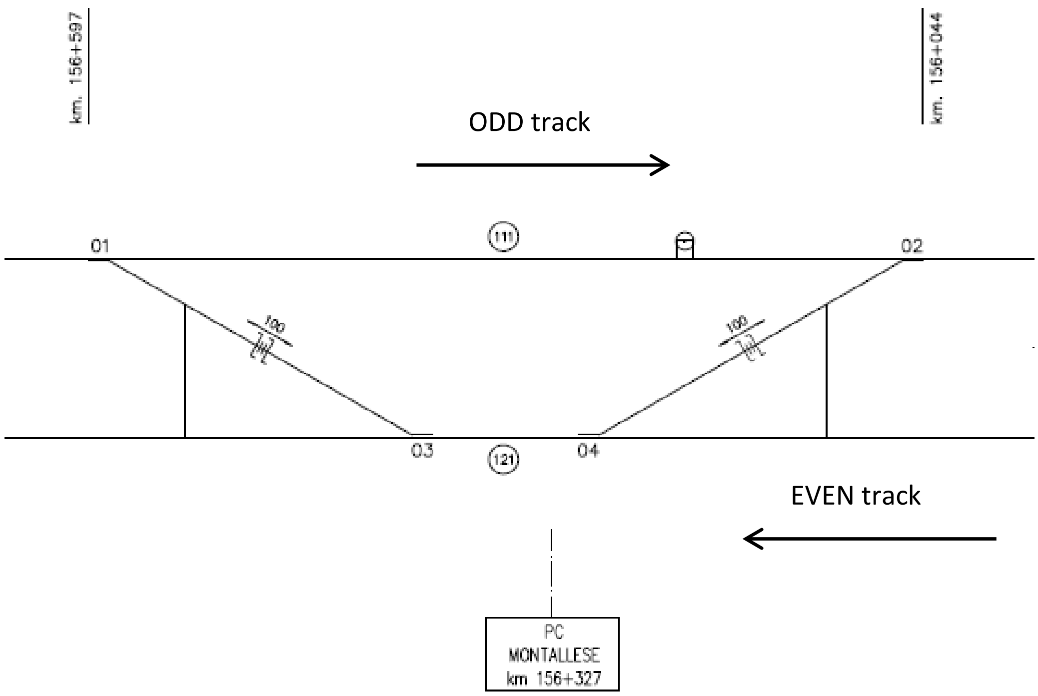
The idea is to implement new structural adjustments in order to avoid to affect passenger lines by the presence of new cargo services whose low speeds tend to cut the potentiality of the line. The solution would be then the creation of new service points. In a first scenario the idea is to allow the faster trains to carry out dynamic overpasses of the slow trains; in the second one with stopping tracks aside the line slow trains are imposed to stop in order to let the faster trains proceed without interferences.

7.1 DYNAMIC OVERPASSES

The solution is aimed to allow the overpassing of slower trains (cargo in the hypothetic scenario) by the passengers high speed trains without affecting their run.

In order to achieve such a result one of the possible solution could be sending the slow vehicles on the illegal track for a very short time interval and then back to the legal one just after the passengers train has accomplished the overpass.

It is clear that the infrastructure has to be capable to support these kinds of movements with crossovers along the line. The upgraded line is in this sense not sufficient. Only four crossovers are designed around kilometric progressives 37, 93, 156 and 183. In these situations, however, trains running on even track cannot run back to the legal track in a short time.

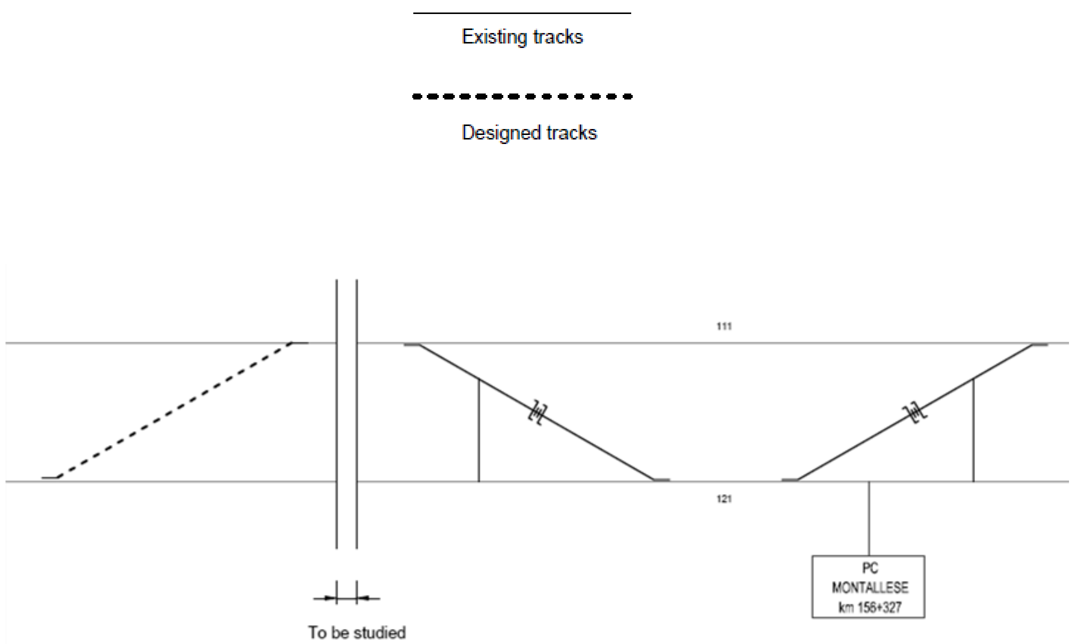


Picture 34 - Crossover of Montallese

In such a situation trains running on odd track could hypothetically change for a short time the track and then going back to theirs, but this cannot occur for trains running in the opposite direction on even tracks. For instance, with reference to the picture, *even* trains that change track at PC Montallese can only shift again at progressive 250 where the following crossover is present.

This is not sufficient for the proposed solution.

The idea is to provide the line an additional shift to allow trains running back to their original track within the time needed to carry out the overpass. This cannot be designed without keeping into account all the possible physical and logical constraints. The scheme is very simple and here presented.



Picture 35 - Scheme of the 1st proposal: crossover for dynamic overpass

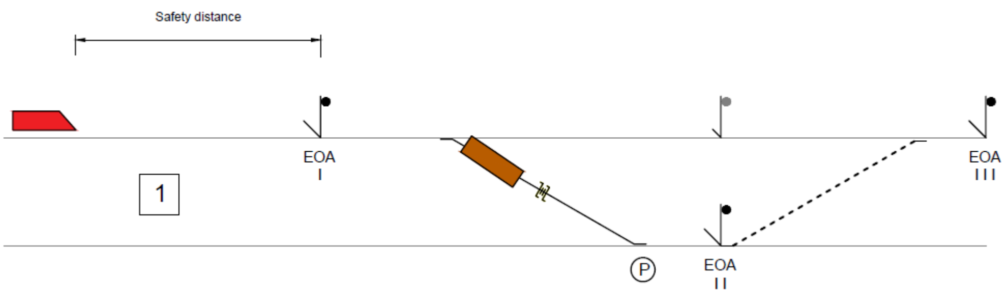
The location of the new switch must be carefully analysed considering the length of a hypothetical cargo train, the positions of the EOAs as well as constraints due to the fact that the occupation of the illegal train is a critical situation.

The opportunity to exploit the existing three communication points would be much preferable since every new adjustments would mean new economic efforts that should be kept at minimum.

The movements sequence is easy and graphically reassumed.

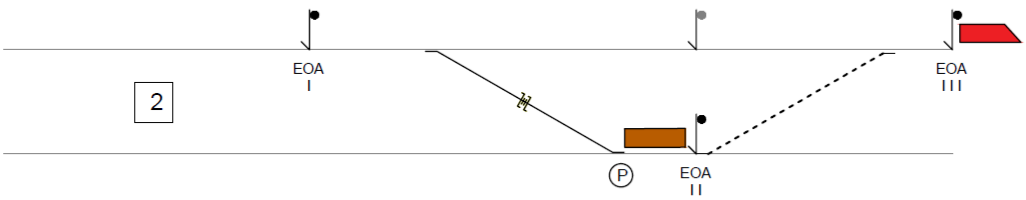
PHASE 1

The Cargo train (brown) takes the shift in order to pass on the illegal track. In this moment the following passenger train is at such a distance from EOA I that does not receive braking imposition.



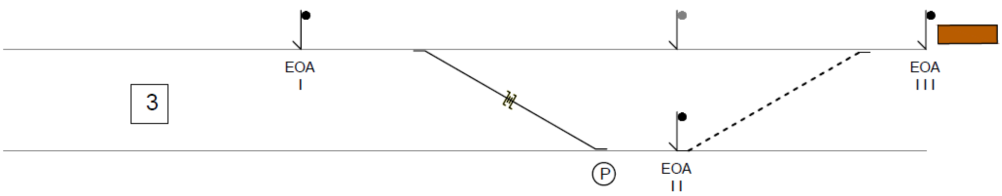
PHASE 2

Cargo train receives the restriction to stop at EOA II. During its braking phase the passenger train is running at maximum speed and carries out the overpass.



PHASE 3

Once the fast train has freed the block section between EOA II and III the Cargo train is allowed to leave the illegal track.

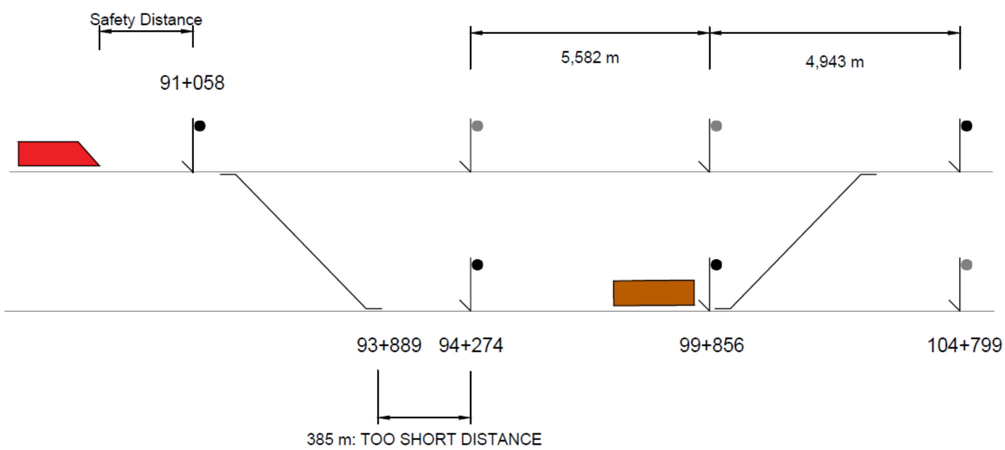


However, there are restrictive factors that can make unfeasible this kind of solution.

First constraints derive from the block section profile. It is not reasonable to pursue such a solution wherever sections are quite long. Let's think about a far position of EOA III. Cargo service has to stop at EOA II and wait that the faster train overcomes the EOA III. If sections are long, this time could amount to high values. This would lead to a durable encumbrance of the illegal train that affects the circulation in the opposite direction.

Moreover, the position of EOA II has to be far enough from point P in order to guarantee enough space to host a cargo train that normally is much longer than passengers one. At least 800 metres are needed.

These restrictions make not easy to exploit the existing crossovers on the line. It is the case of the PC of Cittadella d'Agliano. The crossover location hardly fits with the proposed solution in short times. The first EOA after the switch does not allow to host long train, since its distance from the end of the switch is of 385 metres.



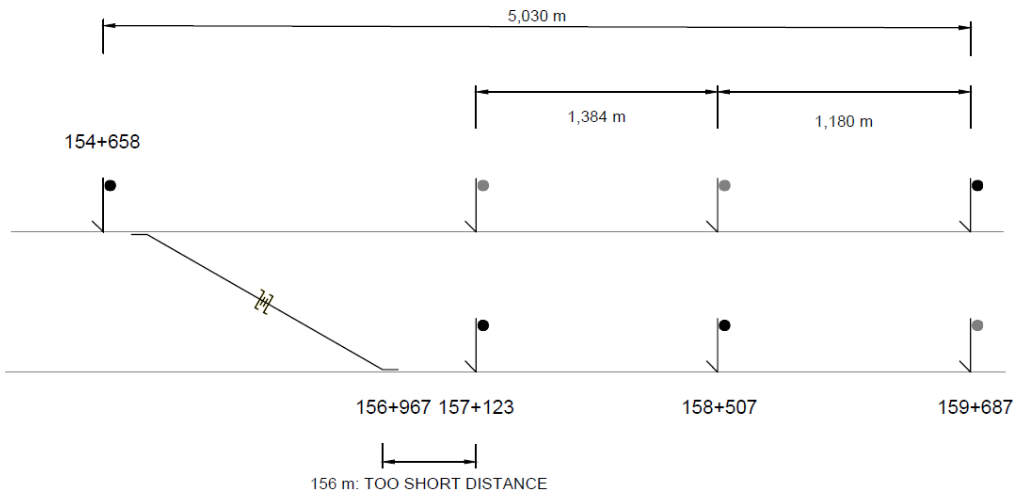
Picture 36 - Crossover at mileage 93: scheme

The freight train should in this case approach the EOA at progressive 99+856. In addition, before leaving the illegal train has to wait the faster to overpass the EOA at progressive 104+799.

Such a configuration would imply an interval of about 5 minutes of encumbrance of the illegal train.

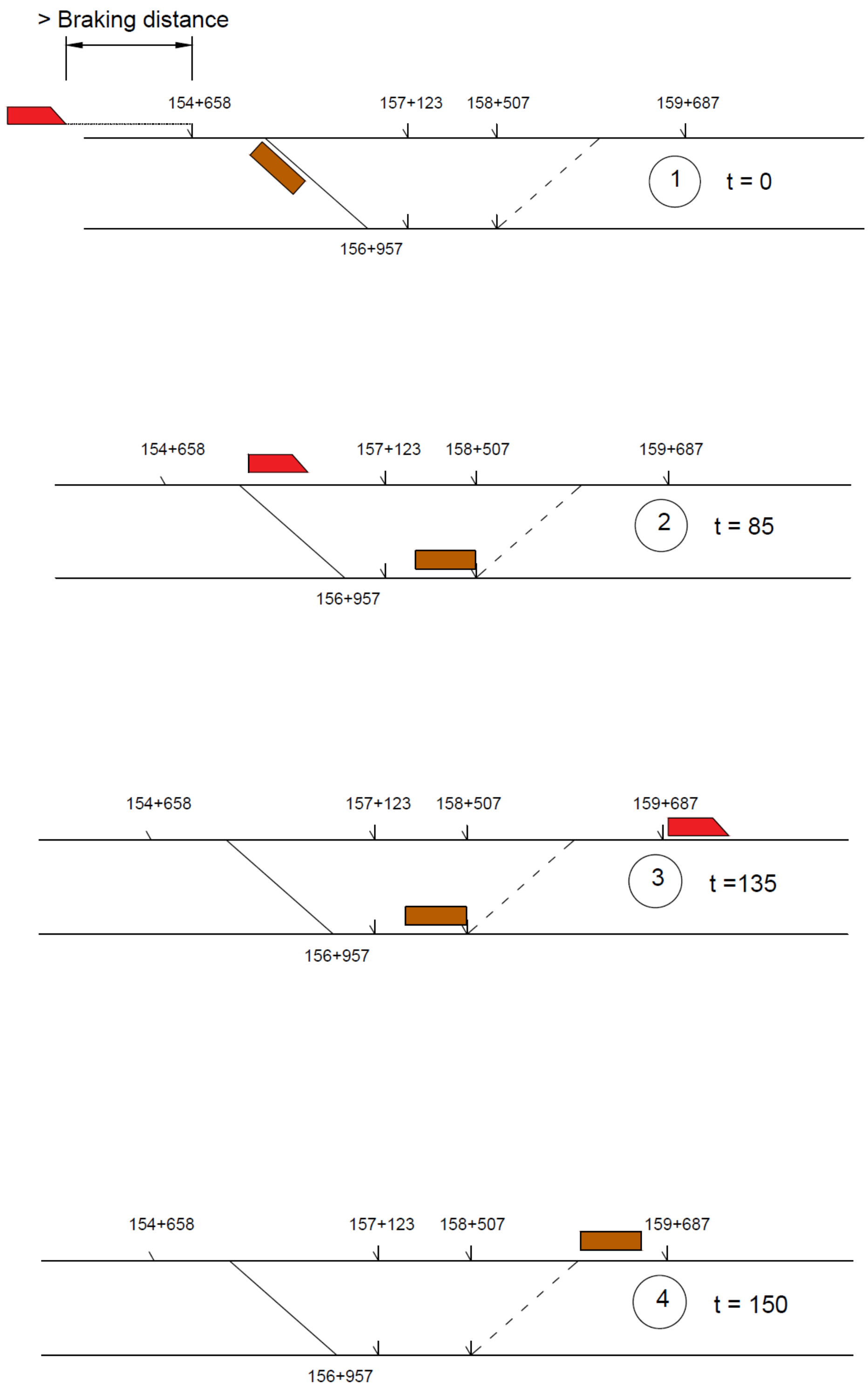
Adjustments of crossovers at progressive 156 and 183 could give back much better performances. In these part of the line sections maintain short extensions, allowing faster overpassing manoeuvre.

At progressive 156 the profile is as follows.



Picture 37 - Crossover at mileage 156: scheme

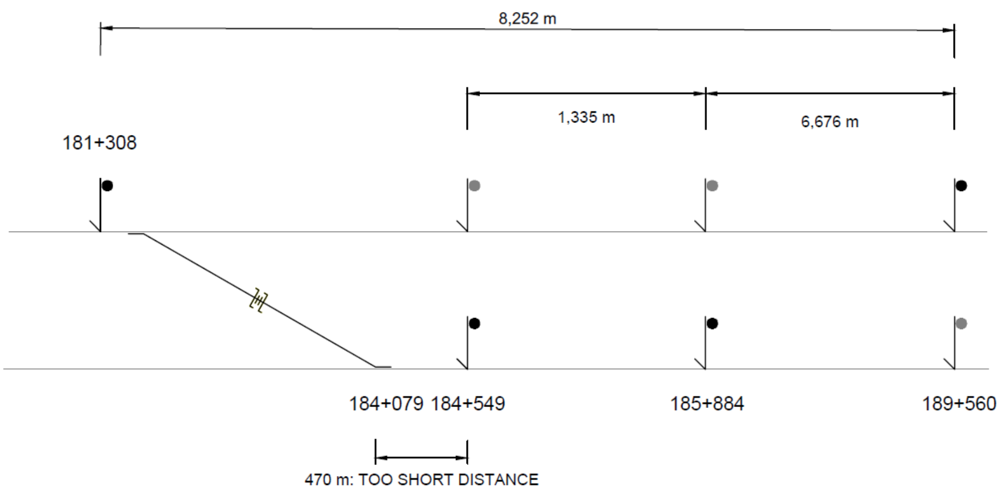
Distance between the end of the switch and the first following EOA is very low (150 m). However, the cargo train can proceed up to the EOA at progressive 158+507 and then waits there for the permissive authority. The waiting time would not be so much high.



Picture 38 - Simulation of dynamic overpass at mileage 156

In about 150 seconds, less than 3 minutes, a dynamic overpass can be accomplished by trains running on even track. Safety conditions are satisfied.

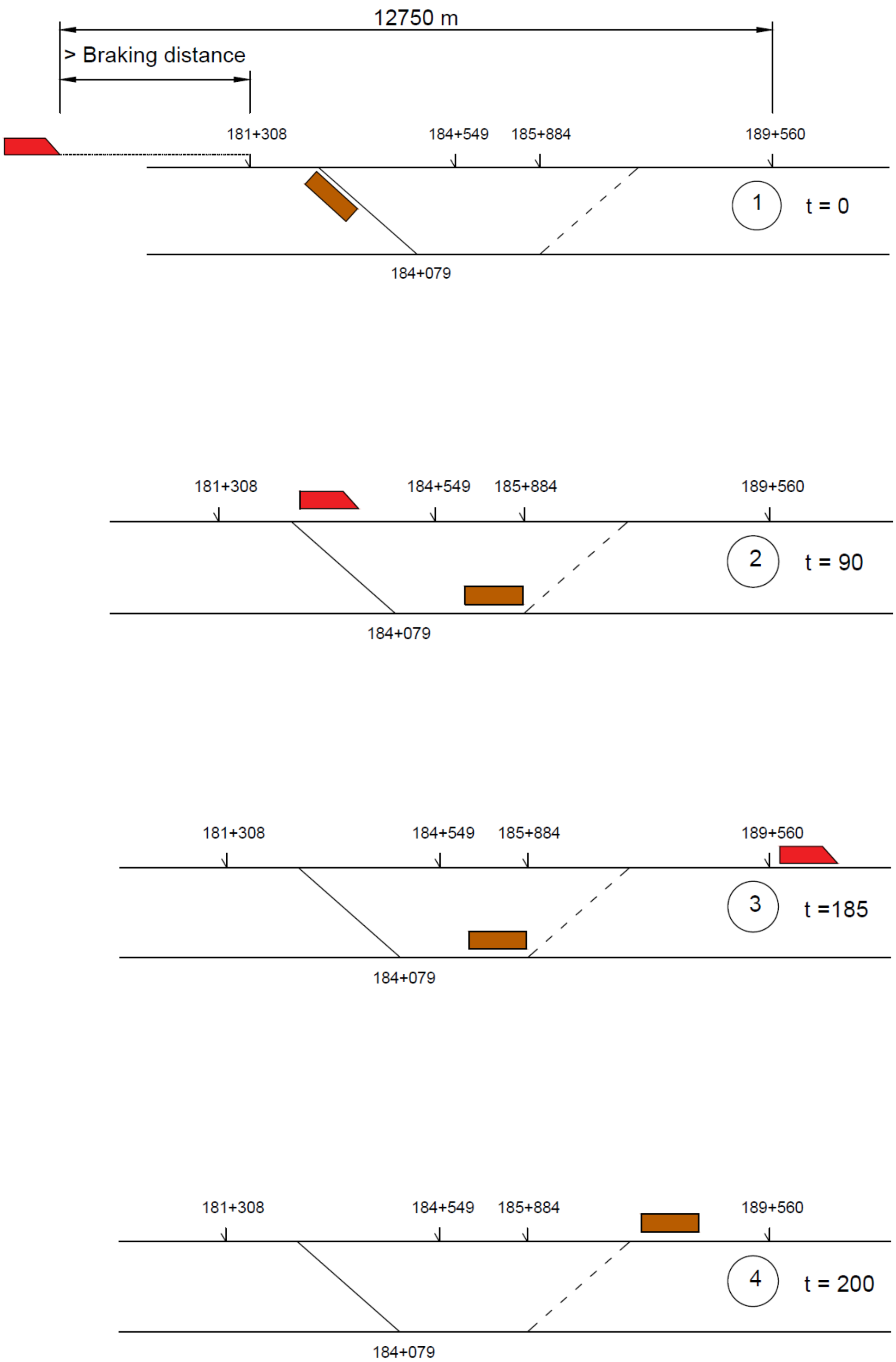
The second crossover, where a fast overpass is possible, is around the progressive 183. Here again the shortness of block sections allows a similar manoeuvre to the previously explained. The PC is designed as follows:



Picture 39 - Crossover at mileage 183: scheme

Also in this case there is a short distance between the end of the switch and the following EOA. Trains are required to stop at the successive (progressive 185+884) and wait there.

The passenger train has to run for about 185 seconds to pass the EOA at progressive 189+560.



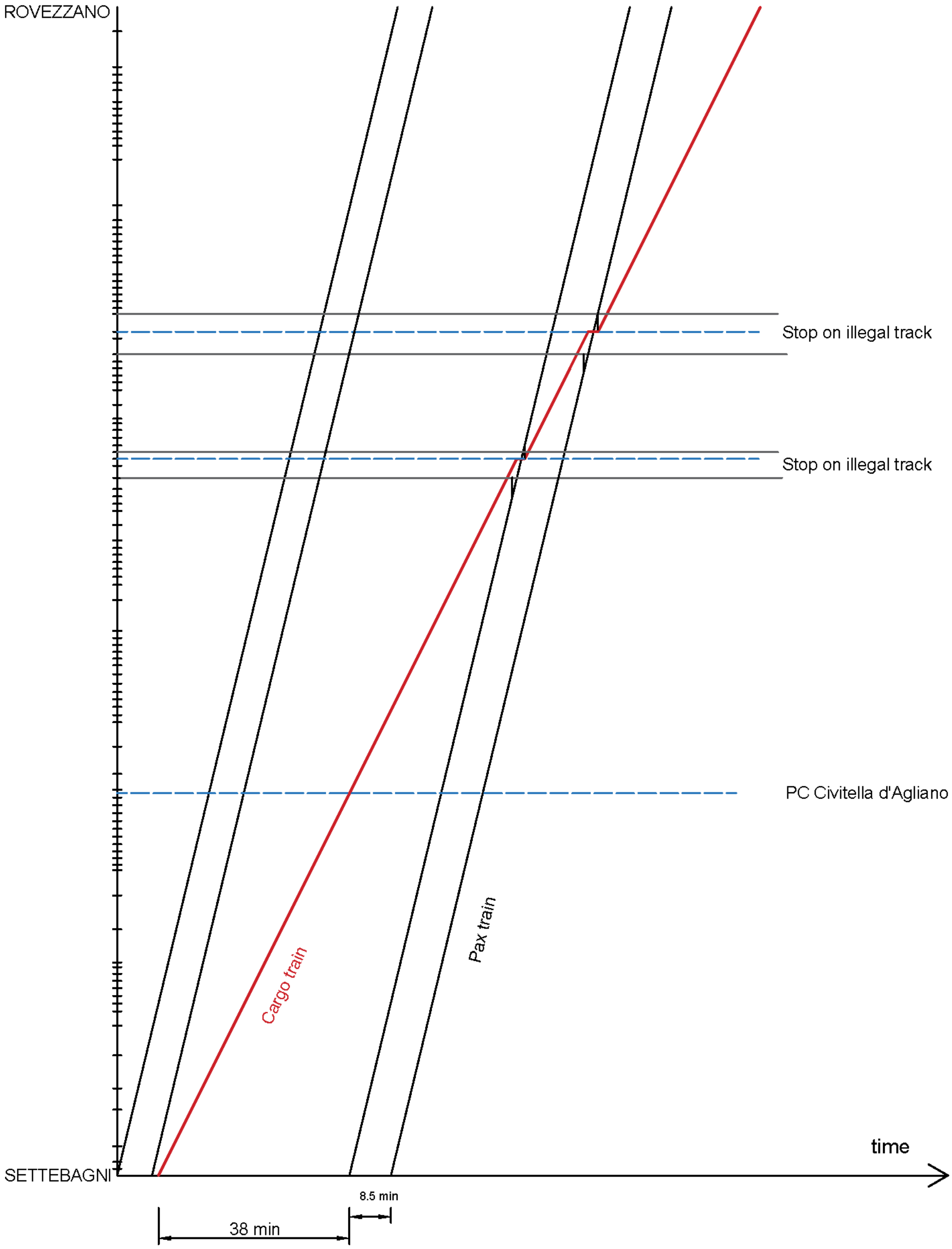
Picture 40 - Simulation of dynamic overpass at mileage 183

It has been then showed the possibility to provide the infrastructure tools in order to overcome the problem of mixed traffic on the line, in the hypothetical (but not so far) future where cargo services will be scheduled on the same line of passengers ones.

It is evident that, if implemented in all the 3 crossovers, the additional switch could allow the overpassing in three different points of the line.

On the other side, every adjustment of this kind requires an important economic effort. It should be understood how big would be the advantage of having an additional overpassing point with respect to the cost of implementation.

In the case of two (progressive 156 and 183) out of the three PCs the advantages would be graphically represented by the following time space chart.



Picture 41 - Overpassing points

The two additional trunks allow overpassing in two different points of the line. This would allow two passenger trains to leave from Rome much before they would do if no precedence could possible. In this way 4 passenger trains could run together with a cargo train in the same hour without having perturbations during their run.

Number of feasible overpassing points translate in number of trains that can overpass a freight vehicle. For this reason, it is evident that if PC at progressive 93 was treated in the same way, an additional passenger service could be inserted in the timetable.

However, as already said, the higher the number of precedence points, the higher would be the cost. In addition, it should be kept into account that the explained solution has been addressed to only even track and relative traffic. If the same occurs in the opposite direction it should be analysed if conflicts can exist.

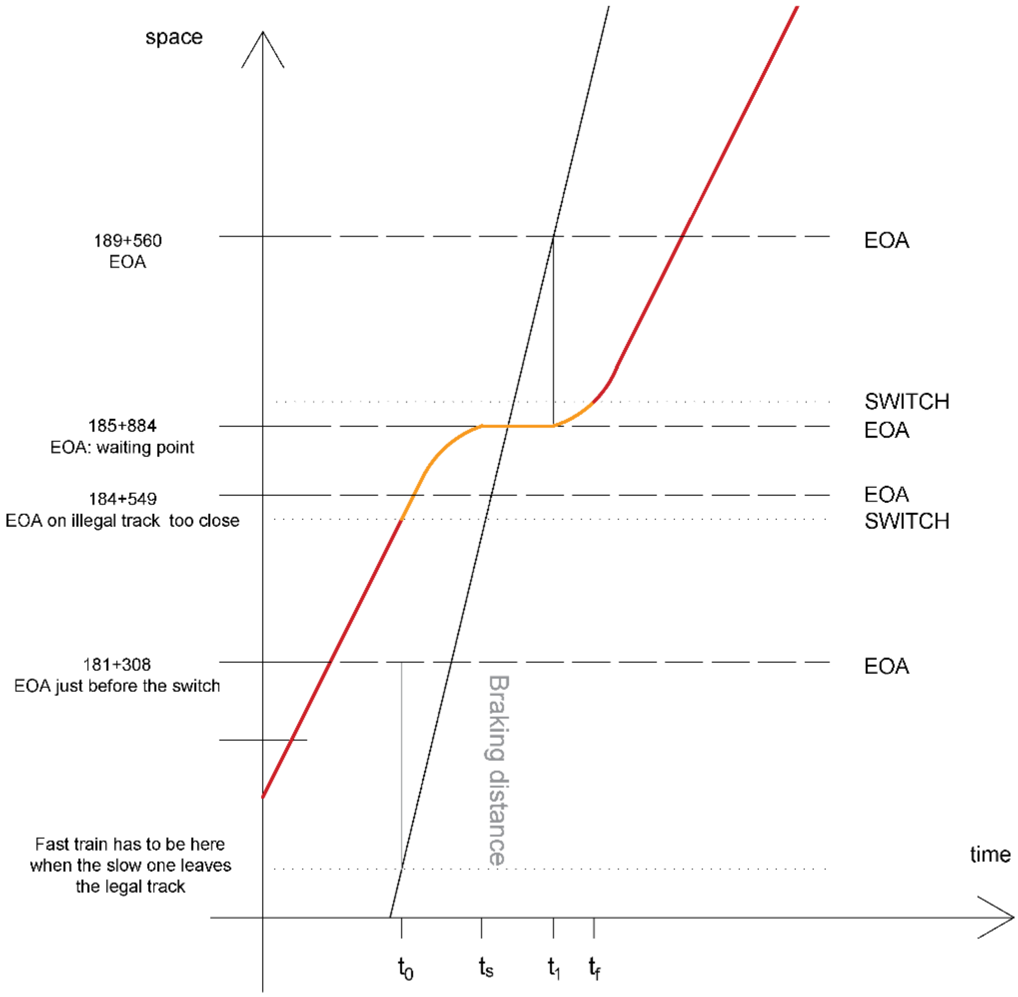
The proposed scenario fits in a realistic way a hypothetical timetable of the soft hours of the day where it is reasonable to programme a mixed traffic. Current timetables schedule few trains in some periods of the day:

- 3 from 06:00 to 07:00 and from 21:00 to 22:00;
- 4 from 13:00 to 14:00;
- 5 from 14:00 to 15:00.

In these time slots the introduction of one or more cargo services could be carried out without problems, according to the number of designed precedence points.

However, the idea of mixing traffic during peak hours remain quite an *utopia*.

The detail of the overpassing procedure is graphically presented in the following picture, where the PC at progressive 183 is schematized.



Picture 42 - Detail of a dynamic overpass in a time/space diagram

At time t_0 the cargo train takes the switch and leaves the legal track: the following passenger train has to be far enough from the right EOA in order not to receive stop message. Yellow segments represent the trajectory of the cargo train on the switch and the illegal track. At time t_s the slow train has approached the imposed EOA on the illegal track and stops, starting to wait the overpass of the passenger train. At t_1 the fast train frees the first EOA after the waiting point: in this moment the cargo train can leave the illegal train. At instant t_f the switch is freed and the train is on legal track again.

The proposed solution has concerned only even track. The same considerations could be addressed to solve the problem in the opposite direction. However, in this case, the configuration of communication points already allows dynamic overpasses in short times.

It is important to underline that the proposed solution is strongly facilitated by the upgrade to ERTMS scenario. The flexibility of this system allows to reduce the physical interventions to only the new shift. The opportunity to exploit the already designed EOAs positions is the key to limit the required new elements. If the line were equipped with traditional system new physical signals would be necessary and so a greater economic and maintenance effort.

7.2 OVERPASSING ALGORITHM

Such a manoeuvre is already feasible in the BAcc environment. However, with the traditional technologies it would be rather difficult to manage a dynamic overpass limiting the occupation of the illegal track.

In addition, it is almost unreasonable to think to manage such a situation in real time adapting to occasional perturbations on the line.

With the arrival of new technologies, like ERTMS, the idea of managing in real time conflicts between following trains appears much more feasible thanks to the continuous information exchange between board and ground systems. In this section, it is proposed a primordial algorithm that could manage the need of dynamic overpassing in real time in response to possible delays, able to adapt to every situation.

The situation can be reassumed in few steps:

- A slow train is running on a line;
- A faster train enters the line;
- An overpass, or precedence, is needed in order to avoid conflicts between the two trains;
- The slow trains approaches to movement point, if present, or to a crossover, as explained in the upper lines.
- Once the train has passed the cargo goes back on its way. If another train enters the line the procedure should be repeated.

The main objective is to be able to automatically carry out the actions of understanding if there is a potential conflict between two following trains, individuating the right crossover, and finally checking if conflicts with the opposite traffic can be avoided.

As the ERTMS is designed currently, such a solution is not implementable in the short period, but due to the high flexibility of the system it is neither too far for being designed.

The description of the scenario is the following:

The slow/cargo train is running on the line. In the moment of the entrance of a following faster train the RBC, that receives the positions of all the trains on the line by their continuous position-reporting, is informed of the presence of a faster train following the cargo. The first *test* is to verify if the overpass is really necessary. This can be easily understood comparing the space-time functions of the trains that RBC can easily compute. If these cross, for instance, the overpass is needed. To this, criteria of priority according to trains classes could be added.

Once this first test gives positive result, the second step is the individuation of right spot where the manoeuvre can be carried out. This action is always carried out by the RBC. The logical sequence is pretty simple even if its application could require a little effort. The idea is to scan the possible spots downstream and highlight the *most reasonable*. A crossover is to be considered the most reasonable when satisfy the constraints due to conflicts and limitation of the illegal track.

Constraints are mainly three:

- The time for cargo arrival must be greater than the minimum needed to prepare the itinerary and so compatible with interlocking times.
- The difference between the arrival of the following train and the leader one must be greater than a minimum value (at least 0. Otherwise, it would mean that the two trains would conflict).
- The difference between the arrival of the following train and the leader one should be the minimum acceptable, because the objective is to minimize occupation of illegal track: a long waiting by the cargo train would mean a long occupation of the illegal track.

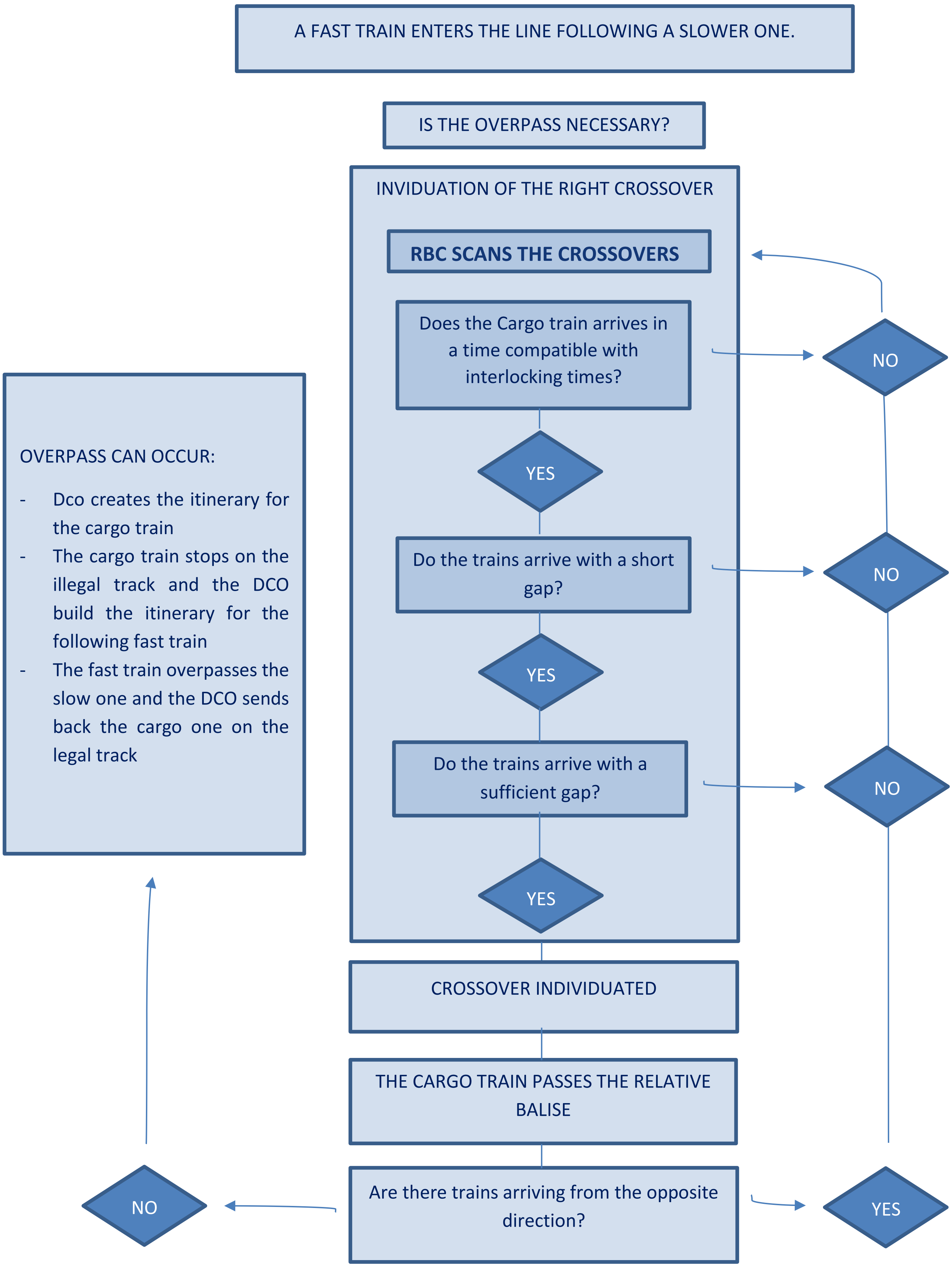
Since the ideal spot could not be located close to the running cargo train, it is not reasonable to create immediately the itinerary and block the circulation on the opposite direction.

The idea could be to set a balise at a certain distance before each switch. When the cargo train passes over that balise, the RBC should provide the third and final test: are there trains running in the opposite direction in the following X minutes? If no, it sends a message to the circulation manager that can build the itinerary safely. The cargo train then approaches to the crossover and stops on the illegal train. The circulation manager rebuilds the itinerary for the faster following train that carries out the overpass.

At this point the DCO can send the cargo train back to the legal track. The most delicate step is the final one. It could occur that a second faster train is approaching the crossover too. The RBC has the final task to compute if the time necessary to wait a second train is greater or lower than the time when the train running in the opposite direction is arriving.

Actually, in the current systems the RBC is not involved in logics of overpassing manoeuvres. It is in fact the SCC that accomplishes this task. In today's ERTMS the SCC would firstly elaborate optimal conditions of traffic and then transfer them to the ACC-M that realizes safely the proper paths. Finally, the RBC would intervene to command *safely* trains to run on the built paths.

However, in order to simplify the reasoning, the RBC is here assumed as a unique central *brain* able to carry out all the tasks. It cannot be excluded indeed that future technologies will provide a single machine able to develop all the mentioned functions.


A FAST TRAIN ENTERS THE LINE FOLLOWING A SLOWER ONE.
IS THE OVERPASS NECESSARY?
INVIDUATION OF THE RIGHT CROSSOVER
RBC SCANS THE CROSSOVERS
Does the Cargo train arrives in a time compatible with interlocking times?
NO
YES
Do the trains arrive with a short gap?
NO
YES
Do the trains arrive with a sufficient gap?
NO
YES
CROSSOVER INDIVIDUATED
THE CARGO TRAIN PASSES THE RELATIVE BALISE
Are there trains arriving from the opposite direction?
NO
YES
OVERPASS CAN OCCUR:
- Dco creates the itinerary for the cargo train
- The cargo train stops on the illegal track and the DCO build the itinerary for the following fast train
- The fast train overpasses the slow one and the DCO sends back the cargo one on the legal track

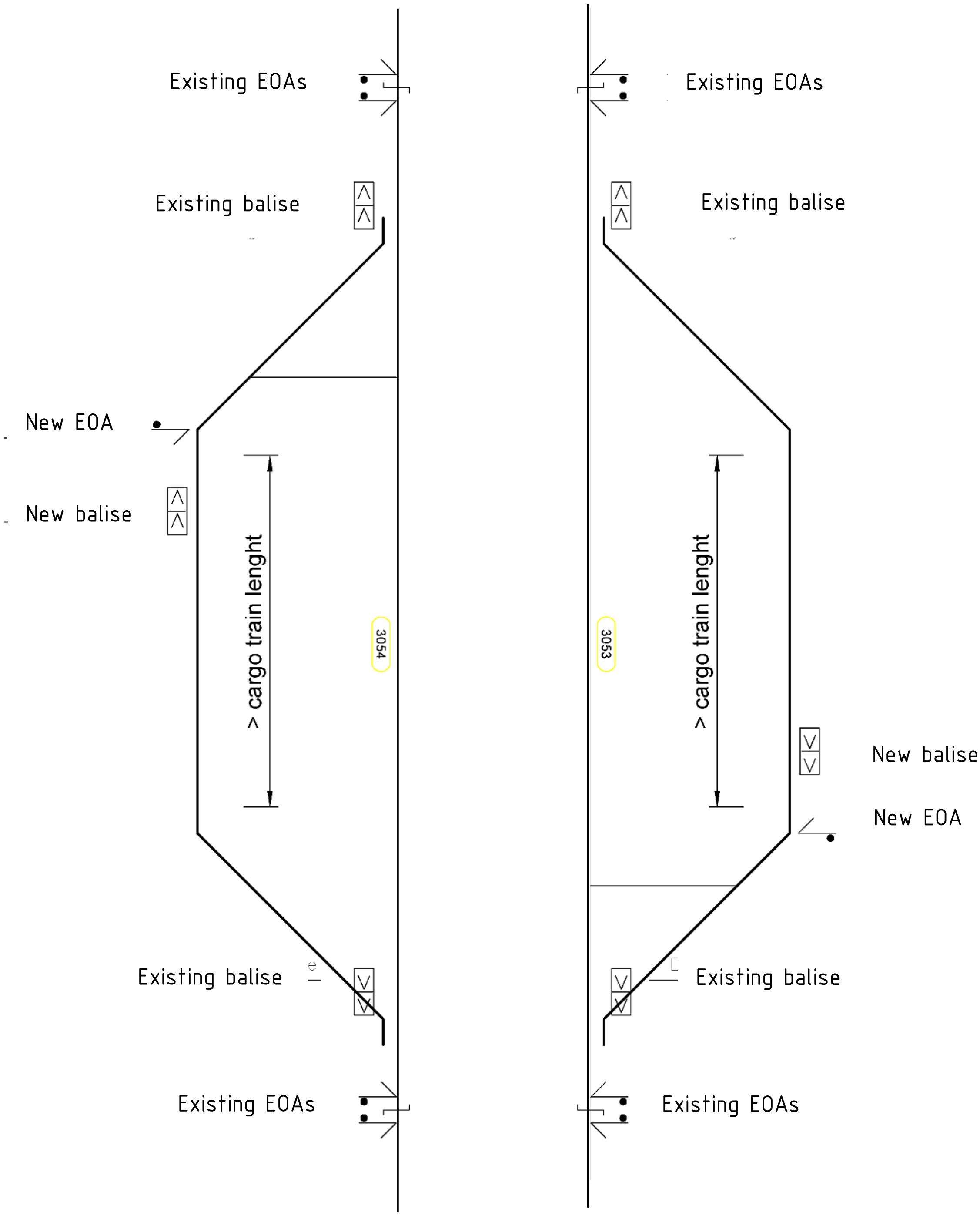
7.3 PRIORITY TRACKS

The second solution is represented by priority track aside the current line. A configuration of this type surely requires a bigger economic effort since it is not possible to exploit existing switches. In addition, such an adjustment requires that no physical constraints are present. The idea of implementing priority tracks in tunnels or along viaducts is not feasible so it is necessary understanding whether and where is possible to consider a similar solution.

Generally speaking, the layout would present as represented in following picture.

Priority tracks are designed aside the main tracks. The only new elements will be an additional balise with respective EOA on the priority track where the cargo train has to stop and wait the overpass by the fast train.

The main constraint is linked with the length of the priority track itself. This has to be long enough to host a freight train, that is generally much longer than a pax-train.



Picture 43 - Scheme of priority tracks

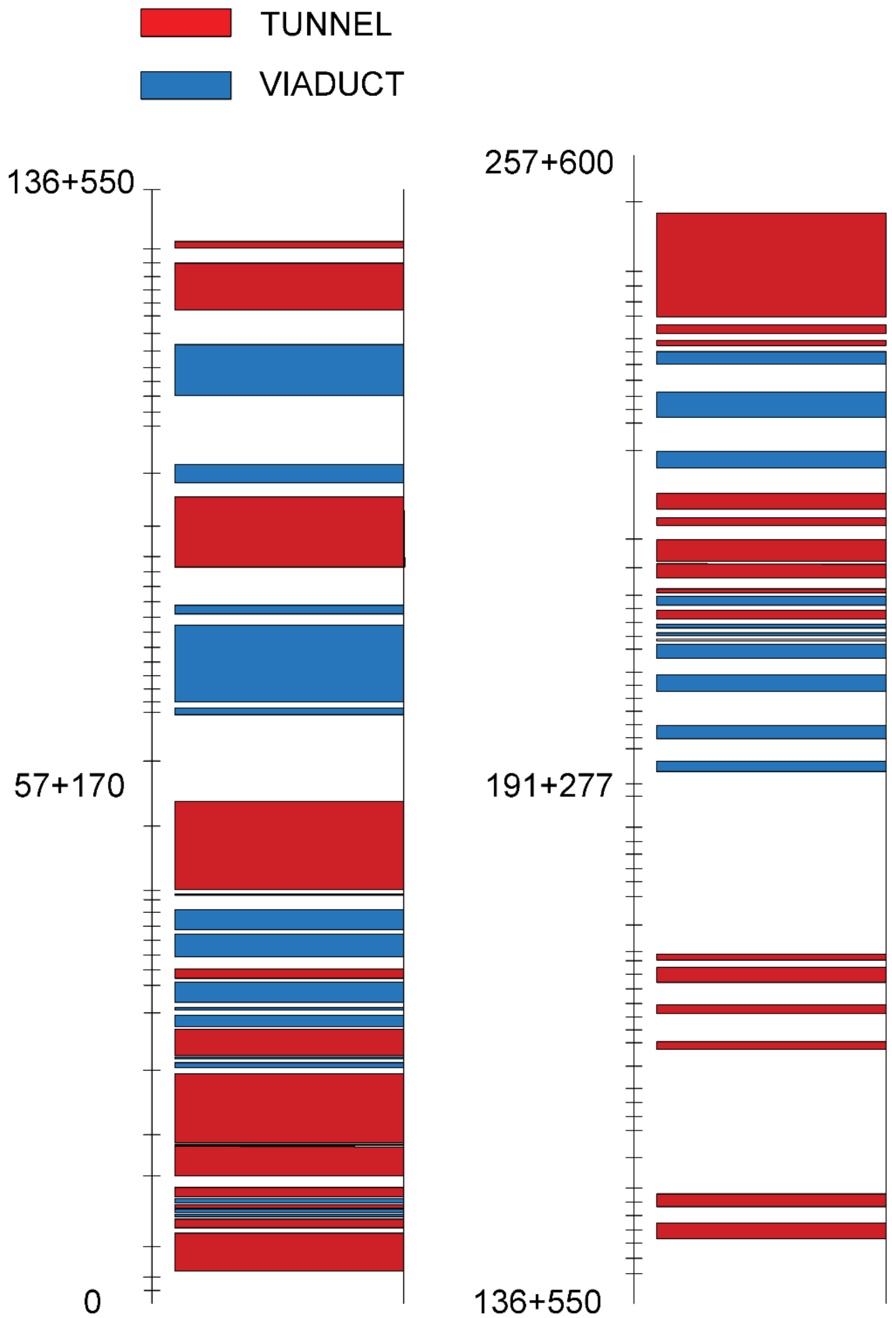
The steps that will characterize the overpassing manoeuvre are simple and here reassumed.

a) The cargo train receives the imposition to stop at the EOA on the priority track while the ACC assigns to the specific train the deviated itinerary.
b) The cargo train approaches to the EOA decreasing its speed until the release speed with the help of the new balise.
c) The cargo train stops and meanwhile the following train overpasses it on the legal track.
d) Once the first EOA has been overcome by the passenger train the cargo one can receive the permission to leave from the priority track.

The great advantage obviously comes from the opportunity to accomplish the overpass without the encumbrance of the opposite track and then to carry out the manoeuvre even with train running in the opposite direction.

However, space requirements make difficult to find a suitable location for the priority tracks.

The line is characterized by a very irregular altimetric profile, where tunnels and viaducts come in succession along the whole development.


TUNNEL
VIADUCT
136+550
57+170
0
257+600
191+277
136+550

From the picture it is easy to understand how difficult is to find sections free from tunnels and viaducts. Moreover, the presence of embankments and cuts make harder the implementation of additional tracks.

For this reason, the author believes that it is not reasonable to consider this type of solution. For such an economic effort, the consequent advantages should be more relevant. The implementation of priority tracks would surely provide easier overpassing among trains, but it should be considered the rareness of these situations. In the supposed -and quite realistic- scenario, number of cargo services cannot be greater that 1/2 trains per hour and these can be only scheduled in soft hours. The number of overpasses is the order of 1/2 too.

It is then evident than designing priority tracks that are forecasted to be used once or twice in a day could not be worth enough.

7.4 HYPOTHETICAL SCENARIOS

The proposed solution can help overcoming the problem of scheduling cargo services in the DD line. Obviously, the term *cargo* can be replaced by any service that implies lower speed or performances. The schedule of a regional service as well as any slow service can be obtained.

ERTMS functionalities allows in fact a more flexible and efficient response to situations of slowdowns.

In this last paragraph the author aims to show how the solutions of adjust the existing crossovers could lead to the scheduling of cargo (or in general, slow) services without losing anything in terms of performances and high speed passenger services.

In particular the scheduling is obtained in the early morning. Currently the schedule of passenger train is as follows.

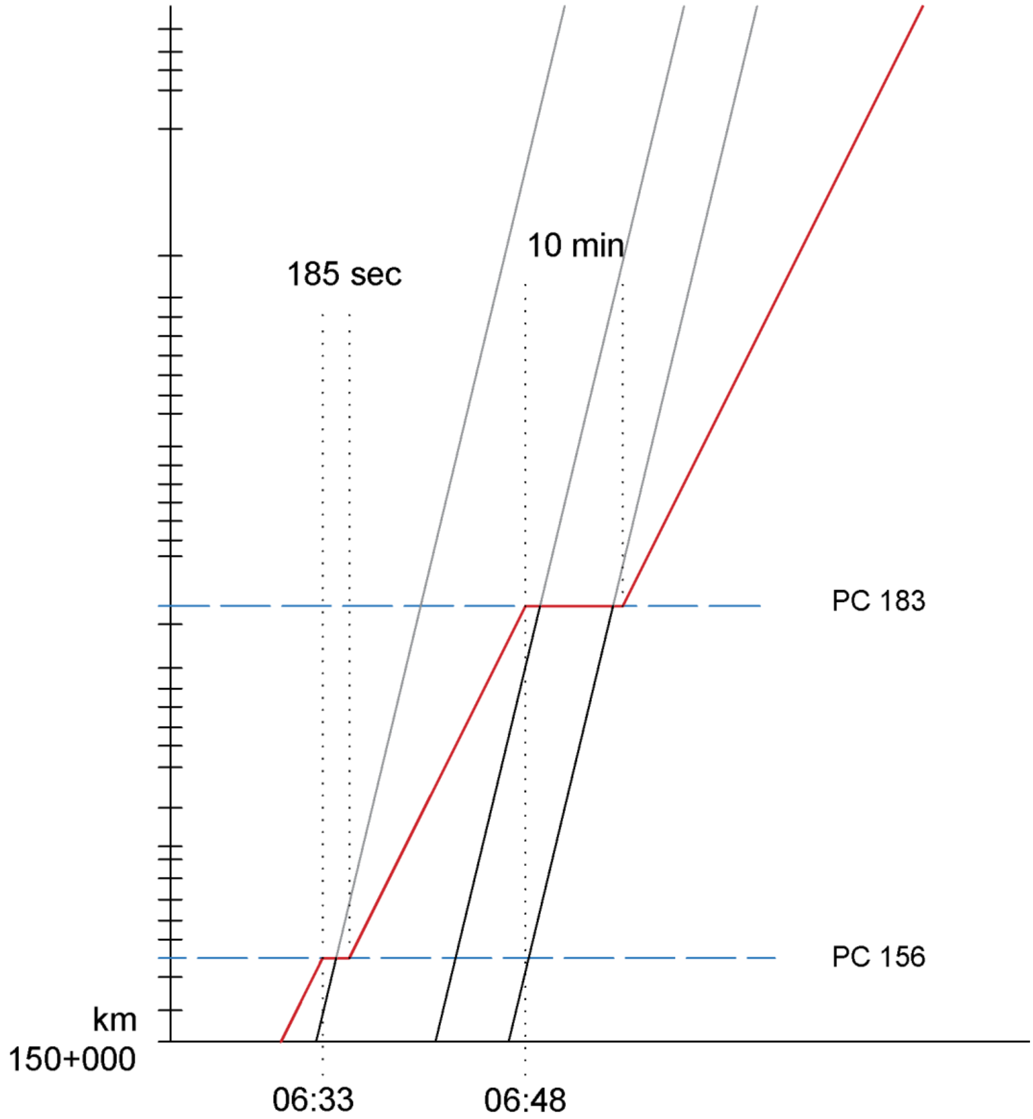
	A	B	C	D	E	F
	9900	9600	35642	9504	9602	8502
Settebagni	06:00:00	06:12:00	06:17:00	06:36:00	06:42:00	06:56:00
Rovezzano	07:03:00	07:15:00	07:33:00	07:38:00	07:44:00	07:59:00

6 high speed trains pass through Settebagni station from 06:00 to 07:00. In addition to them, and not reported in table, regional services run. However, this occupy the line for a very short period so that do not affect the proposed scenario.

The objective is to maintain the same number of passenger trains. In a first very simple scenario, only one new slow train is scheduled. The new schedule could appear as follows.

	*	A	B	C	D	E	F
	NEW	9900	9600	35642	9504	9602	8502
Sett.	05:20:00	06:00:00	06:07:00	06:12:00	06:40:00	06:50:00	06:58:00
Rov.	07:30:00	07:03:00	07:10:00	07:14:00	07:42:00	07:52:00	08:00:00

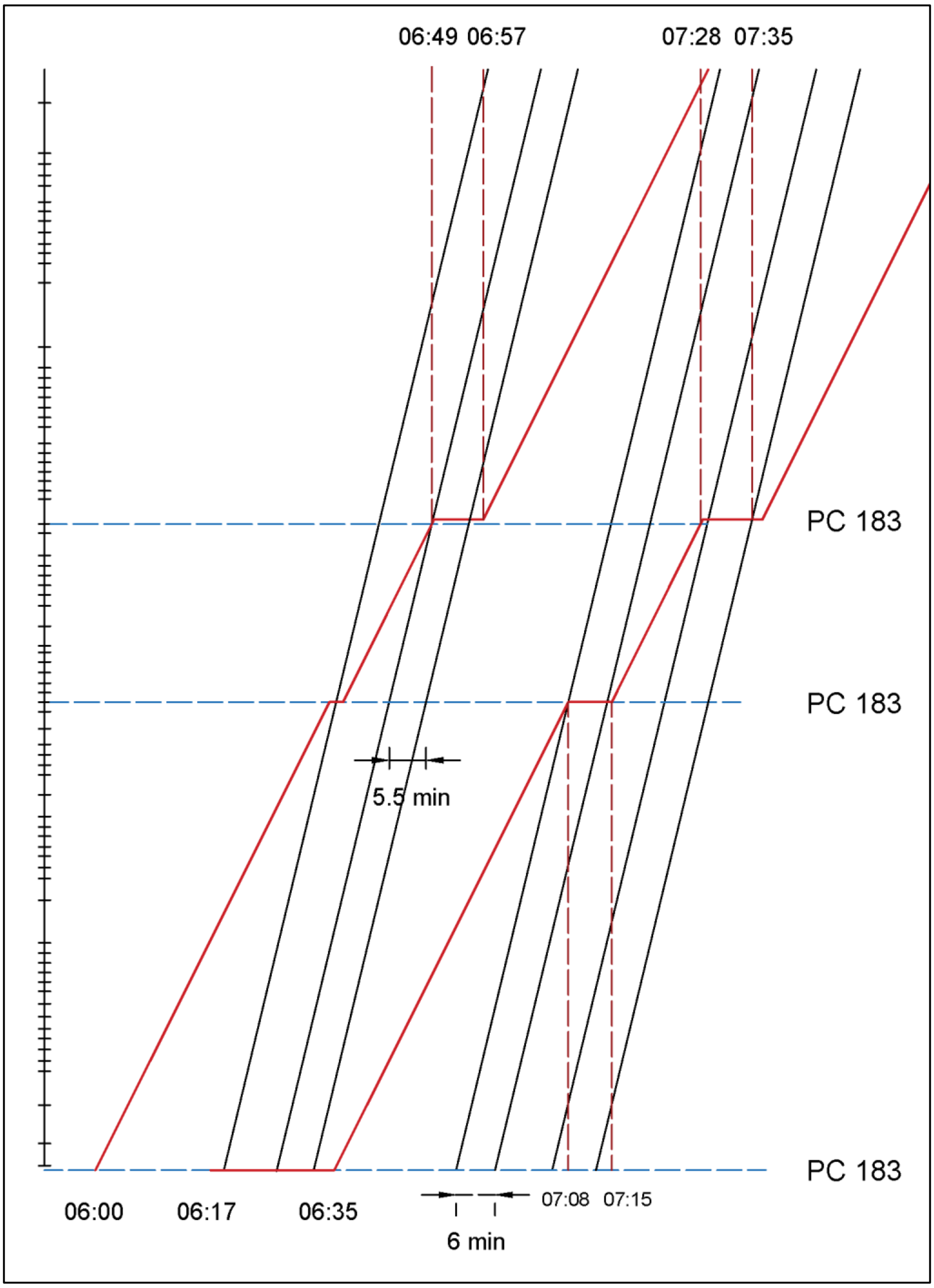
It is clear that the new service will have to be overpassed by at least train A, B and C. The detail of the overpassing is here represented.



Slow train arrives at PC 156 at 06:33 and waits for 185 seconds. One train overpasses it. At 06:48 the cargo service gets to PC 183 where waits for 10 minutes. In this cases train B and C have to pass. It is important to remind that in this phase of the day no trains run in odd direction in this section. First trains run from the North around 07:30. For this reason it is reasonable to leave the train on the illegal track.

The same could happen in the latest hours of the day but it is quite difficult to imagine during peak hours, when it is very hard to think a mixed traffic with current schedules of passenger services.

The possibility to redesign the original schedule could even allow to insert 2 additional services without affecting number of passenger services in the line. Here below an example is presented.



The proposed scenarios have the only task to show the possibility to introduce such innovations. It is clear that further studies can and should be carried out in order to find the optimized solution.

7.5 OPENTRACK SIMULATION

In this last paragraph it will be proposed the result of the simulation of an hypothetic scenario loaded in Opentrack simulator.

The aim of this activity is to show the feasibility of such a scenario where a cargo train is inserted in the morning schedule without affecting the circulation of passenger high speed trains.

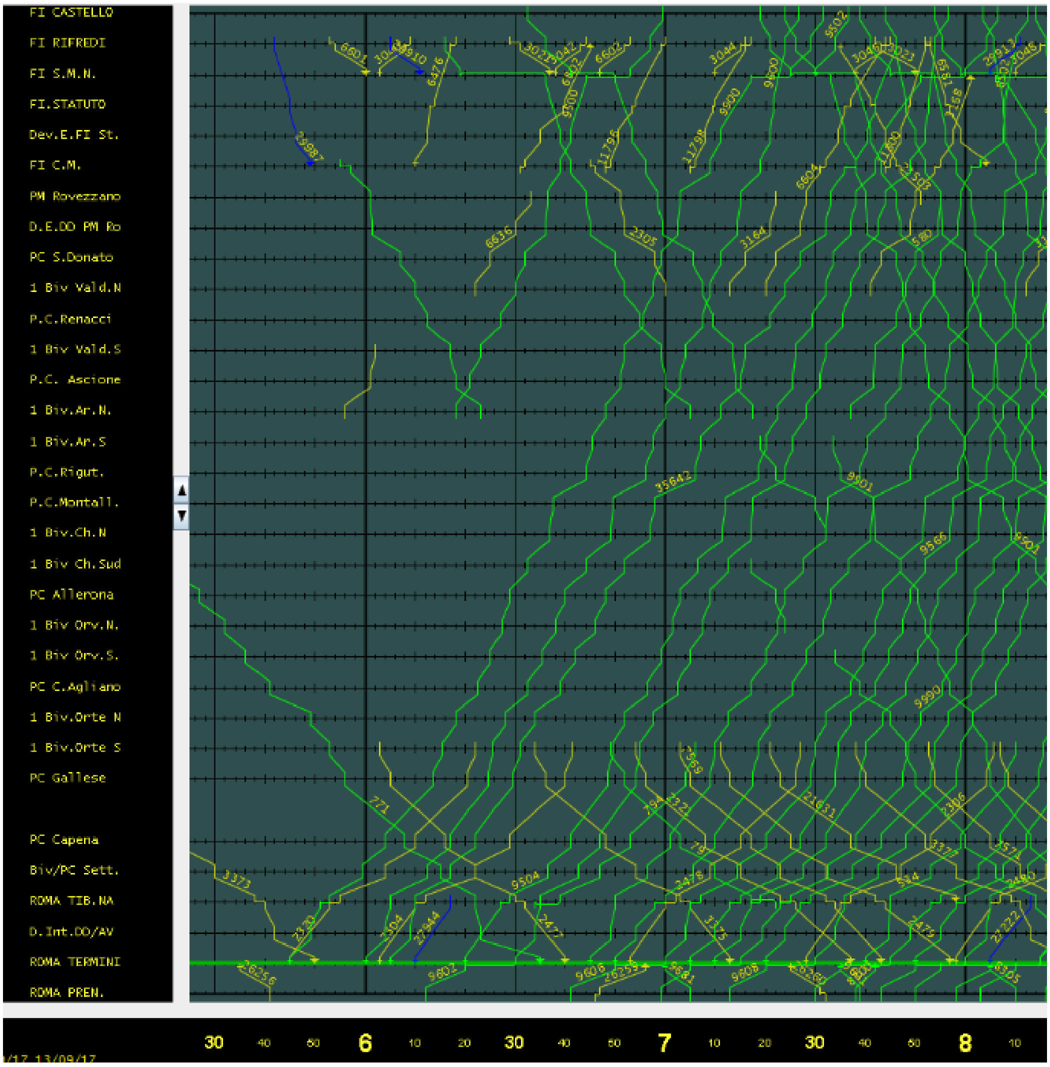
The first step of the simulation has been the representation of the infrastructure in terms of nodes and edges of both tracks of the line. However, for the odd track the full schematization of block sections has been avoided. The main traffic concerns the pair circulation and then it has been decided to *light* the simulation detail.

Sections for odd track have been detailed in the leg between Arezzo and Rovezzano since the traffic in this time period affects mostly this part of the line.

Mechanic characteristics of the two typologies of trains have been distinguished as well as physical attributes (length of the train over all). Passenger trains follow ETR500 characteristics, whereas the cargo train is set 600 metres long and its maximum speed at 120 km/h.

All the trains contained in the timetable shown in picture 36 in green have been put in the simulation, even if they did not affect the circulation or were useless to the final considerations. Yellow trains (that represents regional services) have been avoided since they run in the extreme legs of the network and they're impact is low and easily manageable.

The time period of the simulation starts at 5.20 with the departure of the cargo train and ends around 09:00.



Picture 44 - Space-Time diagram of a working day

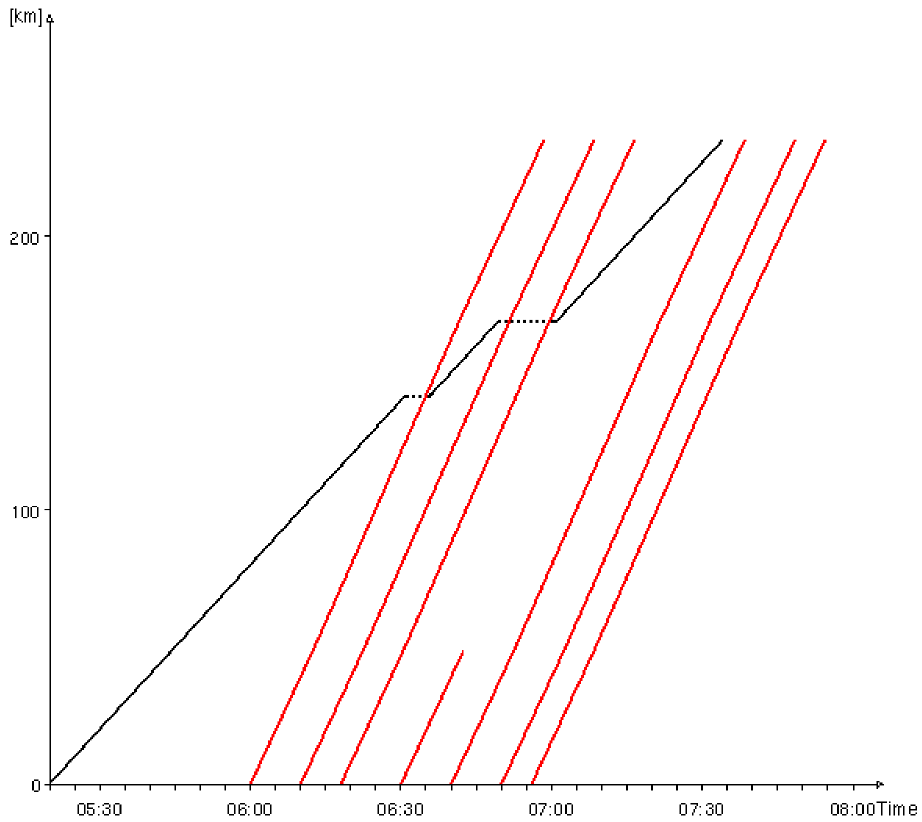
As said previously the current program foresees the following services:

	A	B	C	D	E	F
	9900	9600	35642	9504	9602	8502
Settebagni	06:00:00	06:12:00	06:17:00	06:36:00	06:42:00	06:56:00
Rovezzano	07:03:00	07:15:00	07:33:00	07:38:00	07:44:00	07:59:00

In the simulation the schedule changes a little the current schedule in order to avoid conflicts among trains.

	NEW	A	B	C	D	E	F
	CARGO	9900	9600	35642	9504	9602	8502
Sett	05:20:00	06:00:00	06:10*	06:17:00	06:30*	06:40:00	06:50:00

Stops at Orte

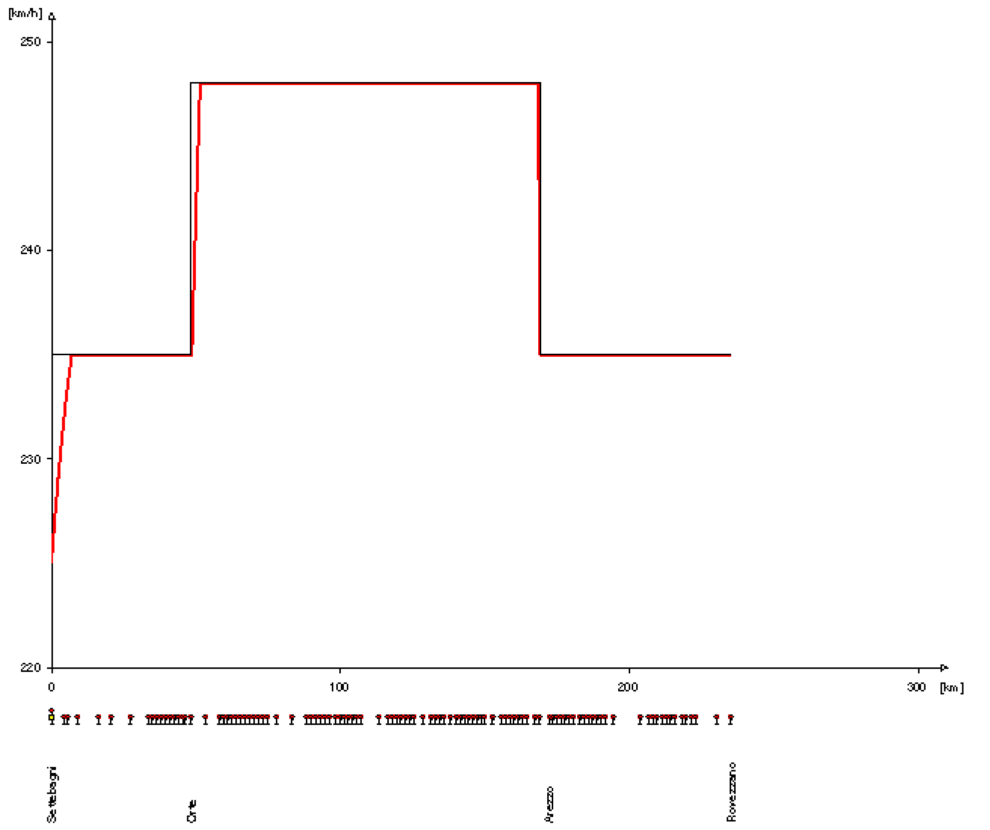


Picture 45 - Results of the simulation: time-space diagram

The time space diagram shows how the cargo trains perfectly fits the schedule without affecting the run of passenger trains. Absence of any train running in the opposite direction makes easier the application of the idea.

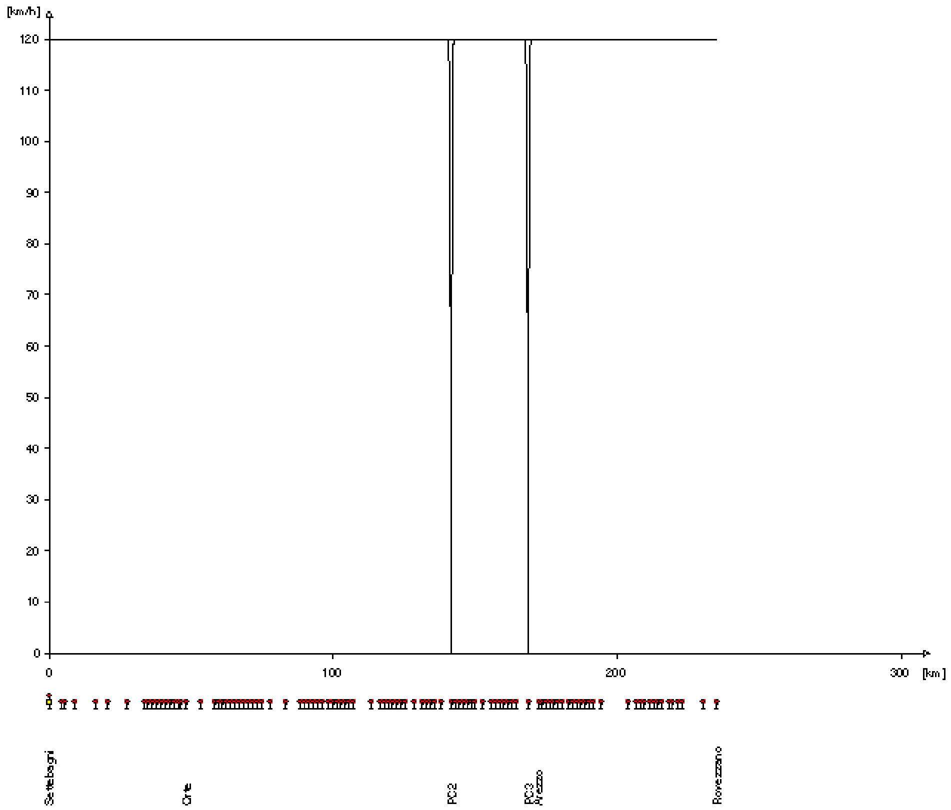
Concerning speed, the simulation has tried to keep it as close as possible to the reality, with running speed around 248 km/h in the middle section and about 235 km/h in the extreme legs between Settebagni-Orte and Arezzo-Rovezzano with entry speed around 220 km/h.

The space-speed diagram of passenger trains is the as follows.



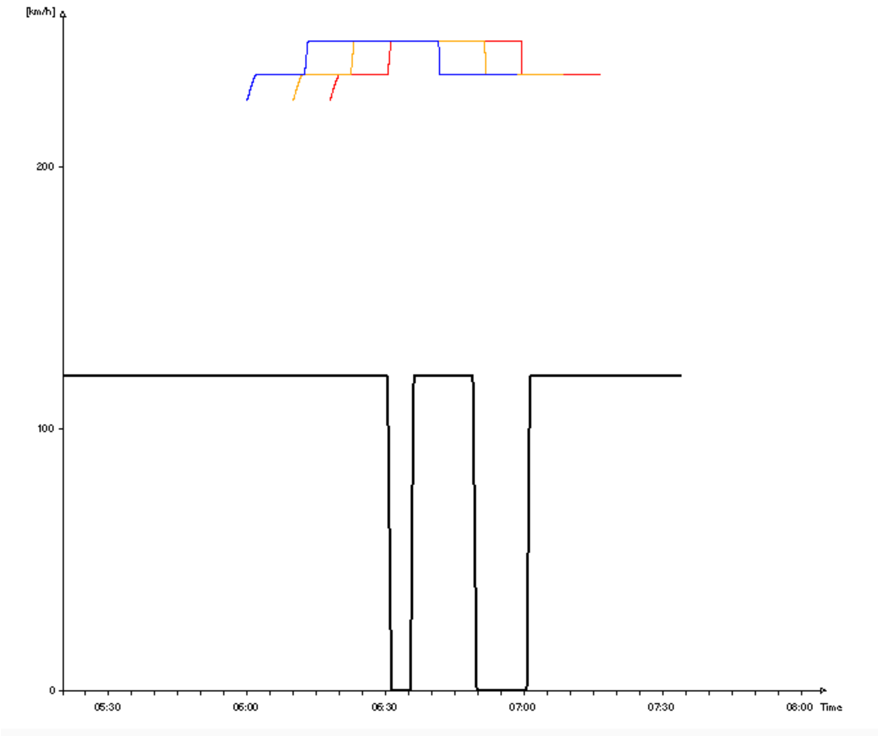
Picture 46 - Results of the simulation: Space-Speed diagram

About the freight service the speed obviously reduces to zero in the two new crossover in order to let the fast train to accomplish the overpassing.



Picture 47 - Results of the simulation: Space-Speed diagram [cargo]

The same diagram with time on x-axis allows to understand waiting times on the illegal track by the cargo train. Coloured lines represent the passenger trains speeds.



Picture 48 - Results of the simulation: Time-Speed diagram

The simulation highlighted the absolute feasibility of such a scenario as the run of the passenger trains does not feel the presence of a cargo train.

The flexibility and efficiency that ERTMS introduces allows to exploit the existing infrastructure allowing such a manoeuvre in safety conditions and in a very fast way. However, it is also reasonable to think to insert additional cargo services that can run for only a part of the DD line before moving on the historic lines.

With the introduction of simple adjustment this can happens in a relatively short period.

8 CONCLUSIONS

The scholarship activity, carried out in Italferr company, allowed to develop a deep knowledge about ERTMS, a technological innovative introduction in the railway panorama that allows, mostly in new lines, significant performances advantages in exchange of limited economic and maintenance efforts.

ERTMS represents the future of railway signalling. Its implementation does not introduce only a new way of giving information to train drivers, but changes at all the way to keep trains separated providing then safety conditions.

Until the possibility to count on level 3 systems will not come real, the level 2 is the goal new configurations should aim to. This system allows, as well as the third level, the removal of physical signals, provides information in real time and makes possible an efficient and flexible spacing system. In addition, technological progress enabled to centralize peripherical service points to unique Central places, through multi-stations interlocking systems (ACC-M), able to remotely control peripherical stations. ACEI are then replaced by the more modern ACC, whose digital electronic substitutes electromagnetic devices and allows, but not necessarily implies, the management of stations in a centralized way, in the so called *Posti Centrali*.

Generally, shorter block sections make feasible shorter spacing and headways that result strictly proportional to running speeds. From 9 codes systems, with fixed *steps* of information, spacing between trains starts to be thought in a flexible way able to adapt in every kind of situation.

In particular, in those cases where speeds are not so high (for instance regional services), potentiality of the lines registers significant improvement with respect to traditional systems[2].

[2] Computations refer to scenarios where block sections are 1,350 metres long.

However, even if the system is surely more flexible and efficient, it remains based on fixed block sections and it is then still strongly affected by bottleneck represented by critical sections.

Direttissima line is an example. It is true that on average length of block sections is reduced, leading to local increasing of potentiality but on the other side, the presence of long block sections (introduced to face tunnel restrictions), does not allow to register a global improvement in terms of capacity at maximum speed. This translates in the impossibility of reducing headways between successive departures.

Exploiting ERTMS features is without doubts evident wherever degrade conditions or slowdowns occur. Lower running speeds would not correspond to long times to free the sections (being these much shorter). Contrary, with traditional systems in case of degrade conditions and then slowdowns trains could take minutes to free sections about 5400 metres long.

Moreover, the future implementation of ERTMS could facilitate to overcome in short periods problems like the scheduling of slow services (mainly cargo) on the line *Direttissima*. In this work, a solution to this issue has been presented. The proposal is based on the exploitation of the three existing crossovers as designed after the upgrading interventions (at mileages 93, 156 and 183). The idea is to let faster trains overpass slower ones, without affecting speed performances, in order to schedule promiscuous services. Obviously, the solution is addressed to be exploited in soft hours, when trains coming from the opposite direction are few.

The dynamic of the manoeuvres is basically represented by a temporary occupation of the illegal track by the slow train that can restart its run once the high speed one has passed. It is easily intuitive that such an idea can be hardly applied in those hours when trains running from the opposite direction are frequent and an eventual occupation of the illegal track would affect their circulation.

It is then necessary, but not so complex, to optimize schedules in both directions in order to find the perfect coincidences among the services.

From the infrastructural point of view, existing crossovers do not allow the accomplishment of the overpassing manoeuvres for trains running in even direction (from Rome to Florence) in a limited time interval. The return to the legal track, with the current design of the crossovers, could occur only after distances of the order of 50 km, meaning too long occupation of the illegal track.

Through the insertion of three additional switches next to the existing ones it could be guaranteed the possibility to carry out quick overpassing manoeuvres for the even circulation as well as for the odd one. Such a solution would be much facilitated by the introduction of ERTMS, whose symmetric block profile in the two directions would not require additional physical implementation (signals, balises, circuits, etc.). Informative points and balises are in fact already installed. However, the real strength of ERTMS is its capability to manage in an almost autonomous way the overpassing manoeuvres, thanks to the great effectiveness of its components. The logic that stays behind the RBC interaction with the other components (trains, drivers, network) could be developed in such a way to make the system able to adapt in real time to the needs of the circulation.

Implementation costs would be only the ones relative to the switches. On the other side, advantages coming from the introduction of new services, cargo over all, are easily quantified by the fee operators would guarantee to the infrastructure manager. Additional advantages due to the possibility to manage degradative situations should also kept into account, even if hardly measurable.

However, deeper analysis about commercial and circulation issues could lead to more detailed and efficient results. The proposed solution can not disregard the technological upgrade of the rolling stock material, that are not able to run on the line without the ETCS. The upgrading process, although long and expensive, is the only goal to aim to.

In conclusion, the main result the author wants to highlight is that there is a great potential behind modern technologies that can be exploited to guarantee innovative and improved performances in terms of capacity of both new and existing lines.

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