Methodology for risk assessment at junctions between interconnected lines

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Abstract: The analysis of railway accidents in the last years in Italy and in other foreign countries shows as some of it occurrences on line, often happened in correspondence of junctions or interconnections between lines. In particular, the situation analysed in this work are the interferences generated in corrispondence of junctions between a main and a secodary line.

The case study is represented by the two lines system "Direttissima" (DD) and "Lenta" (LL) between Rome and Florence. In particular we have considerated a Signal Passed At Danger (SPAD) and its possible consequence: the interference with another train.

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1 Frame work

Railway operations are safety critical in many respects, and the safety of railway traffic is based upon a blend of safety management, rail traffic rules, technical safety equipment and human reliability. Human factors still plays a significant part in many railway accidents. With increasing train speed and traffic density a range of technical safety systems have been introduced in the various railway systems, but the safety of rail traffic is still to a high degree dependant upon reliable human operations.

Safety analysis – as an absence of danger or maximizing it using suitable measure - has become to assume importance in '70s by entrance of new technology (e.g. nuclear energy, etc.), which had new and high risk related to these new line production.

Safety analysis is based on a probabilistic model, called risk analisys. The risk evaluation is the first level of risk analysis, after that there is the acceptance of value.

Concerning acceptance analysis it's important underlining, from one hand, that risk evaluation demands examination about the occurrence possibility of an accident (hazard) and the gravity of consequences; on the other hand the acceptance risk involves scentific, legal ethical and social evaluation. Netherdeless it's obvious that acceptance risk it's not an absolute concept, but it's in evolution with technical control, law, information on health risk, etc, and it can change fastly with new alternative technical solution.

Risk analisys imply a study with trhee objectives:

- to identify the principal cause of the injury: the hazard;
- to determinate the risk rather the probability of the hazard
- to evalute the injury (personal injury, property damage, etc.).

The risk analisys has been develop a process composed by different phases correlated each others, with the principal aim to have an objective final report for risk assessment.

Starting point is the individuation of main system characteristic. This operation needs to "choice" only the basic components. For this reason it's important the well-knowing of the whole system.

After that, it has been individuated the core hazard, rather the probably cause and the related potential injuries.

The final phase is the accetpance of results. This is the hard phase of the whole process.

The acceptance of results is possible only through the comparison with historical data. The historical data need to calibrate the model too.

If the level risk will be not acceptable it's necessary to provide appropriated improvement to the system. It must be pay attention that the improvement doesn't create some new hazards. If they do, it will be necessary to reapplied the whole process.

All cause hazard must be analyzed and evaluate.

1.1 Hazard

Trains passing a signal displaying a stop aspect is a very dangerous occurrence with the risk of an immediate conflict with another train. Signal passed at danger (SPAD) occurrences have traditionally been relatively frequent incident. This is to be expected as a SPAD can be caused by a single failure of a driver who approaches hundreds of signalling points every day. Fortunately, it is only a small fraction of all SPAD occurrences that leads to real accidents, but when they occur they are often of a catastrophic nature.

A SPAD can occur due to several reasons:

1. Misjudging the effectiveness of the brakes under particular circumstances (leaf fall, snow etc).

2. Overspeeding in relation to braking performance and warning signal distance.
3. Broken driving sequence (i.e. the train stops to exchange passengers between the warning signal and the main signal and the driver forgets the signalling aspect during the stop due to distraction).
4. Misjudging of which signal applies to the train in question (i.e. the train proceeds based upon observation of a signal that was meant for another train).
5. Misunderstanding of signalling aspect.
6. Signal not seen due to bad visibility.
7. Complete oversight or disregard of a signal.
8. Driver is unconscious or falls asleep.

We can indetify those reason in five different components that concurr to generate hazard:

- Operational;
- Human behaviour
- Technical and infrastructural system;
- Rules and normative;
- Other external condition.

1.2 Injuries

A signal passed at danger can have different coseguences, two of these are:

- Open forcing of a point and derailment in corrispondece to a junction;
- Interference with another train.

These consequences are not the only ones that could happen, but are basic and direct. The injuries can be high and not marginal.
The SPAD is not the only cause, but the high speed is very important in incresing the probabilty of derailment. Also the junction position increases the probabilty of derailment.
Regarding interference it is important to determinate each couple of train that can be in conflict after one of these have passed a signal at danger.
Particular design of line or plan station (e.g. distance between signal and interference zone) can be very favourable to avoid or decrease the interference due to signal passed at danger.
Aim of the work is the risk assessment related to signal passed at danger in corrispondence of a juncion, and the focus is the interference with another train.
A signal passed at danger is not injourios by itself. It's necessary that other conditions happened to have injouriouses consequences. As above descript a SPAD is injurious if the two routes converge.
In this case the severity of injuries are very high.
Whereas historical ufficial data are lacking, and using the few publication available concernig the injoury analisys we can hypothesize the injury due to inteference produces high consequeces on circualtion and people healthness. At the moment it is not possible to quantify the severity but it's important to underline that the severity depends on speed. We can hipotyze two different severity classes one for "Direttissima" (high speed line) and the other for "Lenta" side.

1.3 Techincal and infrastructural system

1.3.1 Automatic train protection and control

Over the years various technical systems have been introduced to avoid SPADs or overspeeding occurrences due to train driver error. The functionality of some of these systems are briefly described in this section The systems may be divided into two main categories:

- Continuous systems (systems with line continuos transmission);
- Intermittent systems (systems with information transmission at certain locations, normally at signals or speed reduction locations).

Semi-continuous systems combining some of the advantages of continuous and intermittent systems also exist.

The continuous systems are the most powerful systems in terms of performance but are very costly, especially the track equipment. Continuous systems are used for high speed lines or lines where an increase in capacity is required. Some of the existing continuous systems are briefly mentioned below:

- cab signalling with overspeed detection (BACC/NS);
- cab signalling with fail-safe speed monitoring (ATB/NS);
- cab signalling with speed monitoring (TVM/SNCF, Eurotunnel);
- fail-safe speed control used with or without cab signalling (LZB/ÖBB, DB, RENFE).

Continous systems are so far not very widely used in terms of track coverage compared to the total rail network. They are mainly used for purpose built high speed lines or for lines with special high capacity requirements.

Intermittent systems are less effective since data are not refreshed in real time. Intermittent systems are cheaper and allow for a quicker and larger protection of risky equipment with the same amount of investment. Intermittent systems include two categories:

- signal warning or repetition on board;
- complete speed supervision.

The Italian State railways system is a continuos system. It is based on the overall rail track division in several blocks, most of them 1350 meters long. A signal generation system (BACC Codified Current Automatic Block) is placed at the beginning of each block. This system generates a numerical code, which defines the block status. The signal is transmitted by using a single block rails as transmission line.

Two sensors, installed under the train driver’s cab, detect the magnetic field generated by the current.

The control signals considered in this work are transmitted and detected by using a 9 Codes Continuous Transmission Mode. Table 1 shows these codes and their meaning.

Table 1: Nine code system

Code	Composition	Meaning
270**	270 f1+120 f2	Free running
270*	270 f1+75 f2	Stop signal at 5400 m
270	270 f1	Stop signal at 4050 m
180*	180 f1+75 f2	Speed reduction signal to 100/130 km/h at 2700 m or work in progress on the block – reduce the speed to 150 km/h.
180	180 f1	Notice of a stop signal or a speed reduction to 30/60 km/h at 2700 m
120**	120 f1+80	f2 Speed reduction signal to 130 km/h at 1350 m/h at 1350 m
120*	120 f1+75 f2	Speed reduction signal to 100 km/h at 1350 m

120	120 f1	Speed reduction signal to 30/60 km
75	75 f1	Stop

Frequencies f1 and f2 in Table I are related to two sinusoidal carriers at 50 Hz and 178 Hz transmitted along the block rails. The nine codes are generated modulating the carrier amplitude cyclically any minutes, e.g., code 270 is generating by setting to 0 the carrier amplitude 270 times in a minute shows a code obtained by superimposing the two 50 Hz and 178 Hz amplitude modulated carriers.

1.3.2 Train traffic control

The traffic control provide to control and reactive management of the train movements within a certain control zone. The operators performing this process are called 'dirigente centrale' (DC).
The overall goal of the DC's work is to make decisions for rearranging the productive resources and objects based on their assessment of deviations in order to avoid or minimise inconveniences or even incidents that may lead to economical damages or harm to humans. To react appropriately - especially in emergency cases - the DCs need to have in any moment an understanding of the dynamic system.
The DCs have the supervisory control of moving objects in their control zone. Yet, the direct responsibility and management of the different resources (e.g. humans, or machines) is assigned to other departments as defined in the organisational structure of the FS. Hence, the DCs have to collaborate and co-ordinate with colleagues of other departments, when they need to allocate productive resources, which end up in highly interactive processes
In some line the control system allows the operator (‘dirigente centrale operativo’ - DCO) to act directly on the line via switching junctions and setting protection signals of the stations. The station managers have been eliminated in most stations - this work is now covered by the DCO.

2 Analysis of junctions

Particular interst is rapresented from junctions, These are often passing station, sometimes transition from single to double track or branch lines.
In a lot of case connection is between the main line (high speed or high capacity line) covered by long-distance train with high speed and secondary line covered by local or freight train (with slower speed).
In particular, the situation analysed in this work are the interferences generated in corrispondence of junctions between a main and a secodary line.
The connection are built up by branching or by fly-over, Some examples are represented in figures from 1 to 3.
In particular in figure 1 is represented a generic junction with only one fly-over.
Otherwise in figure 2 is represented a generic junction with only two fly-over. The position of signals are also represented.

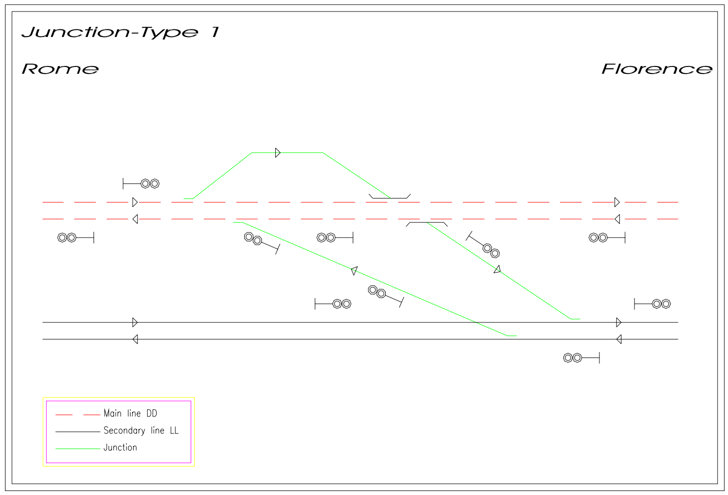

Figure 1: Generic interconnection with only one fly-over.

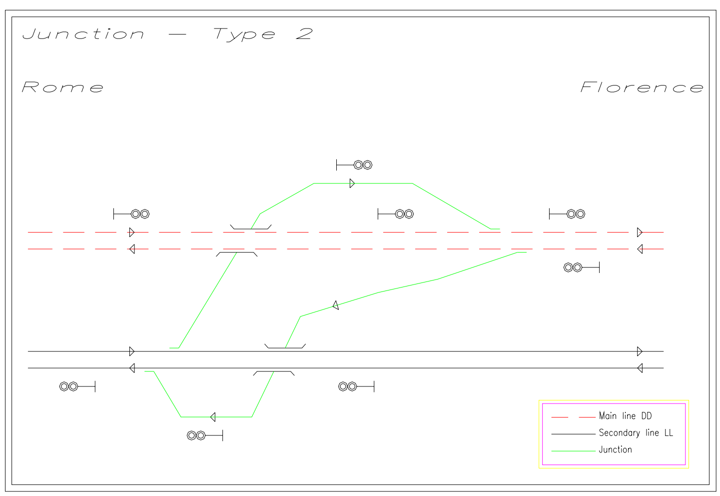

Figure 2: Generic interconnection with two fly-over.

Different situation are represented in figure 3 and 4.

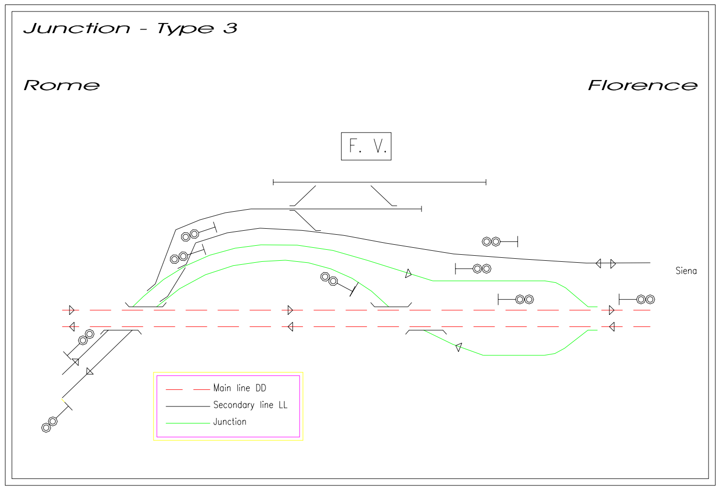

Figure 3: Generic interconnection in corrispondence to a branch line.

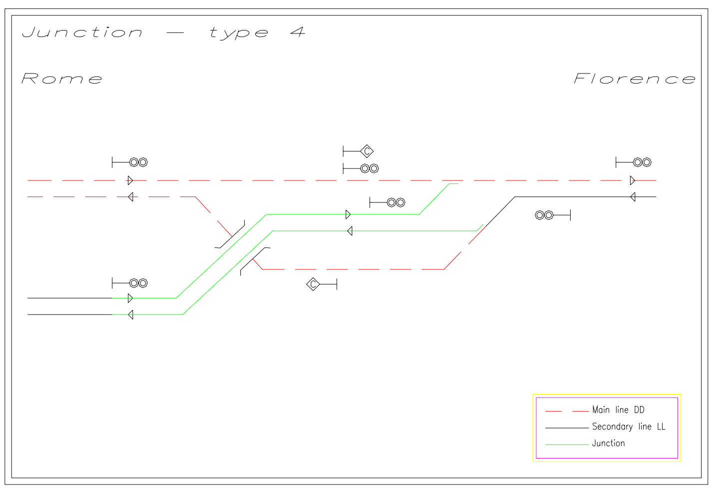

Figure 4: Generic interconnection with two fly-over

If a train pass a signal at danger can occupy a common zone with another train. In figure 5 are represented three possible interference zone. The zone A is in corrispondece of point on secondary line. The zone B is in corrispondence of crossing on secondary line. The zone C is in corrispondece of point on main line.

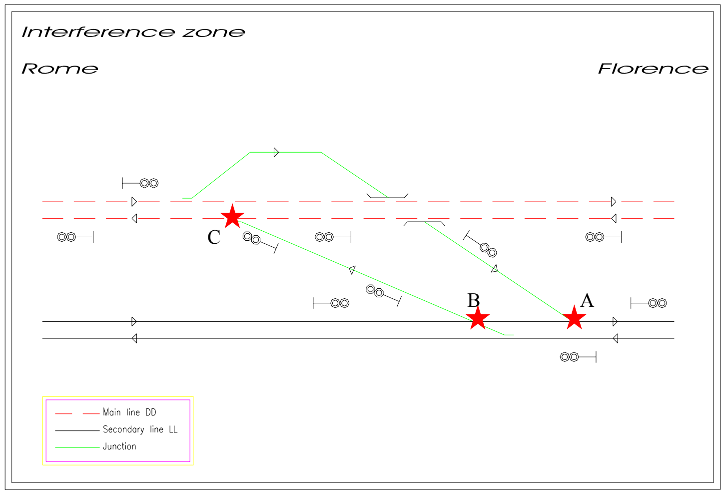

Figure 5: Different interference zone.

The interference can be generated from two different situation, relating from wich train is passing a signal at danger. In particular the train can be on branch or on line.
In figure 6 and 7 are represented these two different situation for the same inteference zone A.

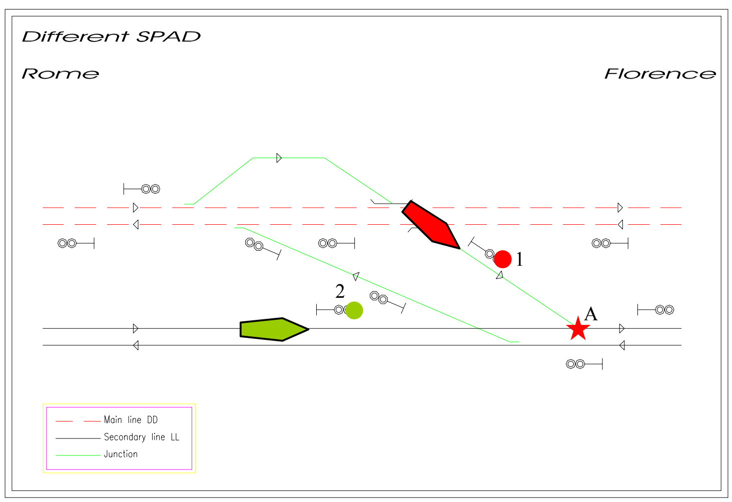

Figure 6: The train 1 on branch is passing the signal at danger.

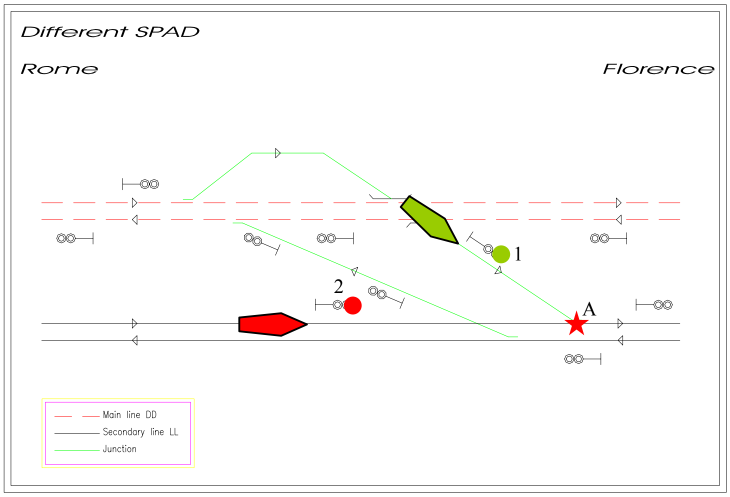

Figure 6: The train 2 on secondary line is passing the signal at danger.

3 Analytic model

The probability P of hazard injourious, depends on a SPAD. For this reason it's a combined probability of different factors: human behaviour, functional (reliability of system), infrastructural (distance between signal and junctions, etc) and operation.
The porpouse model – to evaluate the probability of the events - takes into consideration the follow elements:

- Speed (on line, on junctions);
- Circation time;
- Junctions position;
- Distance between signal and junctions (or interference zone);
- Train number;
- Signalling system.

The interferece probability is calculated as a combined probability of five terms

$$Pint = Si * Ci * Psc * Ssg * K \tag{1}$$

In wich:

$$Si = f(Ac, Rc, It) \tag{2}$$

$$Ci = f(V, d, a) \tag{3}$$

$$Psc = \prod_i \frac{\sum_j h_{ij} * n_j}{\sum_j n_j} \tag{4}$$

$$Ssg = \frac{n_1 * t_{1S}}{T} * \frac{n_2 * t_{2S}}{T} \tag{5}$$

$$K = \frac{n_1 * t_1}{T} * \frac{n_2 * t_2}{T} \tag{6}$$

The formula (1) represent the *probability of interference*. The other formulas are:

- (2) probability of human error;

- (3) coefficient of proximity;
- (4) factor of junctions;
- (5) factor of signalling (only if line is equipped by BACC);
- (6) factor of contemporaneity.

In wich the terms write above means:
Ac: Human behaviour
Rc: Circolation rules
It: Technical system (signalling system etc.)
d: distance between signale and collision point, distance for stopping, etc.
a: efficienty of brake system
hij: value 1 if train (passing a signal at danger) crossing junctions i converge over the other route train, otherwise 0
nj: number of train on generic routes j
Vl, Vd: speed on line or speed on junctions
ni: number of train in generic line i during time T
t_{1S}, t_{2S}: occupation time of the block interested from train circulation i
t_1, t_2: occupation time of the interference zone from generic train i

The *factor of signalling* is 1 if the line or the train are not equipped by BACC, otherwise it is valide the formula (5).

4 Model application

The model descript above is applied to the Rome – Florence Main line DD with purpose to evaluate the efficacy and the usefully.
For each zone of the junction, in wich it's possible to have the interference, it is determined the probability of both derailment and interference. The probability is calculated except from the probability of SPAD.
The main line "Direttissima" was the first high speed line in Europe, designed in the early 1960s, built up during the '70s, and starting operation in 1978. It has a speed limit of 250 km/h and 254 km lenght, from Settebagni (near Rome) to Rovezzano (near Florence).
Along the main line there are six interconnection points with the old parallel line at Orte, Orvieto, Chiusi, Arezzo, Valdarno and Rovezzano and some passing point too. In figure x is represented the "Direttissima" and the six interconnection. Each interconnection is composed by 2 junction (in nothern and southern direction) except for Rovezzano. The total number of junction is 11.
On figure 8 is represented the whole line Rome-Florence and the interconnection on it.

Figure 8: Main (DD) and secondary (LL) lines Rome – Florence (Courtesy of TAV S.P.A.)

The line passes through 3 Regions (Tuscany, Umbria, Lazio), 5 Provinces (FI, AR, TN, VT, RM) and 30 Municipalities and is 253.6 km long. It runs from the station of Settebagni (16 km from Rome) to the Rovezzano junction (4 km from Florence Campo di Marte). The traffic on the "Direttissima" includes mainly high speed train (Intercity and Eurostar), with some freight trains running on in out of peak hours.
Moreover, the whole tour tracks system concurs to allow the maintenance of single route sections without interrupt completely the traffic.The line is equipped with the BACC (Codified Current Automatic Block) signalling system.
In table 2 are represented the different tipology (single fly-over, double fly-over, other) of junction.

Table 2: Tipology of junction.

	Single fly-over	Double fly-over	Other
Orte sud	X		
Orte nord		X	
Orvieto sud	X		
Orvieto nord		X	
Chiusi sud	X		
Chiusi nord			X
Arezzo sud	X		
Arezzo nord	X		
Valdarno sud	X		
Valdarno nord	X		
Rovezzano			X

Interference index value on Rome-Florence junction are represented in table 3.
The index represent the probability interference value except from the probability of SPAD. The product of interference index and the probability of SPAD give the probability of interference.
Only the main line “Direttissima” is equipped by BACC, so the factor of signallig is considered only on “Direttissima” side. For this reason we have determine two different value probability of interference value. The *maximum* if both train are not equipped by BACC, and the *minimum* if both train are equipped by BACC. In the other case (only one train, on “Direttissima” or “Lenta” line are equipped by BACC) there have been intermediate value.

Table 3: Interference index.

	On “Lenta” side				On “Direttissima” side			
	A1	A2	B1	B2	C1 max	C1 min	C2 max	C2 min
Orte sud	3,82E-05	5,29E-05	1,88E-07	3,98E-07	1,35E-04	1,30E-08	1,73E-04	1,67E-08
Orte nord	4,60E-06	4,46E-06	-	-	1,49E-07	5,33E-12	2,39E-07	8,58E-12
Orvieto sud	1,43E-06	1,95E-06	3,85E-08	2,58E-07	8,17E-05	3,36E-09	1,29E-04	5,32E-09
Orvieto nord	9,91E-05	1,24E-04	-	-	1,06E-04	2,61E-09	1,53E-04	3,74E-09
Chiusi sud	2,39E-05	2,93E-05	5,73E-08	2,24E-07	2,64E-04	9,36E-09	3,58E-04	1,27E-08
Chiusi nord	6,50E-04	2,17E-04	6,35E-08	1,36E-06	1,87E-07	9,62E-12	3,05E-07	1,57E-11
Arezzo sud	1,00E-05	1,39E-05	1,48E-08	1,18E-07	1,75E-04	4,35E-09	2,48E-04	6,14E-09
Arezzo nord	1,16E-05	1,05E-05	1,73E-07	1,4E-07	4,42E-07	1,87E-10	7,11E-07	7,59E-11
Valdarno sud	2,54E-06	6,42E-06	1,39E-08	1,26E-07	-	-	-	-
Valdarno nord	3,12E-06	3,40E-06	2,72E-08	1,66E-07	3,29E-04	2,37E-08	5,56E-04	3,99E-08
Rovezzano	-	-	-	-	3,80E-04	6,33E-08	5,22E-04	8,70E-08

5 Summary and Outlook

The table 3 shows the different value of interfernce determin using the model developed.
As we expected the better situation is the presence of two fly-over, and the line (and all trains) equipped by BACC. Other parameters that influence the probablility of interference are the distance between signal and interference point. The value of interference index are comprised between 6,50 E-04 (Chiusi Nord on “Lenta” side) and 5,33 E-12 (Orte Nord on “Direttissima” side equipped by BACC).
Many countries have already adopted advanced method (e.g. Grait Britain). The absence of legislation in Italy has slackened off and penalize the development of methodology for risk analysis.
The futur development of the present work purpouse the increasing of study case of the model and the examination of different hazard in its globality. It’s necessary to concentrate the efforts espacially to determine the different level risk, and its level acceptance. Only after these operations it will be possible to identify the unaccetable risk level to minimize and wich are the best measure to reduce the risk