Malpensa Airport North Railway Link: impact of expected traffic onto the existing network

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ABSTRACT

This work presents an analysis about the performances of the lines and the nodes involved in the upgrade process of Malpensa International Airport accessibility. This study is developed throughout a new complete analysis model consisting of the rational integration of existing methods. The methodology proposed and applied for the evaluation of the railway infrastructural upgrade solutions for the development of the connections between Milan and its airport is conveniently developed and improved according to the study requirements. The evaluation of line and node capacity is carried out considering the actual and future layouts of the railway network at a regional level and the actual and planned services offered by the railway supplier. The results obtained recommend infrastructural upgrades in order to make available the matching network capacity. The analysis of the lines and the nodes involved in this process, as well as the effectiveness of the proposed infrastructural improvements, is strengthened by a scheduling analysis and the application of a simulation method.

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1 INTRODUCTION

The improvement of the railway connections between the city of Milan and its Malpensa International Airport is one of the key topics about European, national and regional transport planning process of the latest years. The will of the stakeholders is to upgrade the actual railway system increasing the number of services supplying the airport with the aim to extend its catchment area. The development of Malpensa Airport railway accessibility is declared as a priority for both the EU program *Connecting Europe Facility* and the national plan *Piano Nazionale degli Aeroporti (National Airport Plan)*. In both documents, it is highlighted the need to insert a core airport as Malpensa within the connecting system of TEN-T corridors. At regional level, the upgrade of railway connections from/to the airport is mentioned both in the document *PRS Piano Regionale di Sviluppo* (2013 – Regional Development Plan) and in the document *PRMT Piano Regionale Mobilità e Trasporti* (2016 – Regional Plan on Mobility and Transportation). A main step of this upgrade process has been already completed with the realization of the railway connection between Malpensa Terminal 1 and Terminal 2 in 2016: this work has permitted to extend significantly the potential catchment area (T2 yearly moves 6 million of passengers) finding in the railways a service economically advantageous with respect to other modes of transport.

Therefore, the remaining upgrade step is the realization of the T2 North Railway Link, that connects the airport and the Simplon line toward Gallarate and Sesto Calende. The development of the project has been entrusted to SEA[1] and FERROVIENORD[2] under the coordination of Lombardy Region. In the past fifteen years, different layout solutions were proposed, considering that there are three lines which may be potentially connected with

[1] SEA: Società Esercizi Aeroportuali; it is the group responsible of the management of Milan airports (Malpensa Airport and Linate Airport).

[2] FERROVIENORD: it is a society of FNM Group (Ferrovie Nord Milano) working as infrastructure manager of the railway network owned by the regional government.

the airport: the Simplon line, the line from/to Luino-Bellinzona and the line from/to Varese-Lugano.

The upgrade of the railway connections from/to Malpensa cannot be limited to the construction of the T2 North Link. In fact, it must be coupled with a wide evaluation of the operating conditions of a large part of the railway network around Milan, in order to understand whether other infrastructural developments are necessary to manage the increase of service that will be set at the opening of the new link. This evaluation has been entrusted to the Italian railway infrastructure manager RFI Rete Ferroviaria Italiana.

Therefore, the objective of this study is to assess whether the expected traffic derived by the introduction of a new system of services may be operated throughout the network on the existing infrastructure, or consequent upgrades are needed. This analysis focuses on the main line involved in the process of development of railway connections between Milan and Malpensa: the line Domodossola – Milano. The realization of the new link T2-Gallarate is part of a scheduled upgrade process of the existing infrastructure in the area, related to the improvement of regional railway services. This process needs a deep analysis of the lines and the nodes strictly connected to. With this aim, the methodology applied in the study is subdivided in steps. The first part regards the analysis of the 2020 system of services operating on the 2020 infrastructure (practically the existing supply and infrastructure, without considering significant scheduled upgrade projects on the relevant lines). After that, the paper focuses on the future infrastructural upgrade solutions subsequent to the introduction of the future 2026 railway supply, defined by the agreements between RFI and Lombardy Region. First, the analysis evaluates the upgrade projects already planned by the infrastructure manager; then, the study proposes new supplementary infrastructural solutions with the aim to present a complete future development scenario. The paper continues with a study about scheduling system of the relevant lines. At the end, a simulation method is applied with the aim to evaluate the solutions proposed during the study from an operational point of view. The steps of the analysis are synthetized in the scheme of Figure 1.

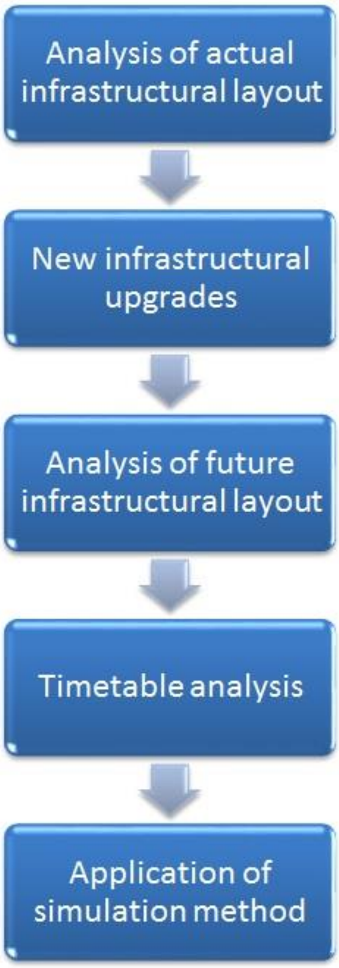

Figure 1: Schematization of the steps of the analysis methodology

This paper proposes a new analysis model representing the result of a rational integration of existing methods elaborated with an original approach. The application of the analysis methods permits to assess a railway infrastructure and its possible upgrades, with the aim to define the feasible operational model.

The methodology proposed may be considered as a general model for the evaluation of infrastructures characterized by similar conditions to that here analyzed with the aim to estimate the performances of lines and nodes consequent to expected traffic increase and infrastructural upgrades.

2 EVALUATION OF LINE CAPACITY AND NODE CAPACITY: METHODOLOGY REVIEW

Since many years, evaluating the capacity of an infrastructure is a central research topic in transportation engineering, because it allows describing numerically the performance of an infrastructure. In general, the capacity of a transportation infrastructure can be defined as the maximum number of Transport Units (TUs) that can run on network elements in a specific period. Given the dynamic features of vehicles, it is possible to define the minimum headway to ensure a safe braking without the following vehicle colliding with the first one. Higher speeds need a higher spacing between vehicles, whereas by adopting lower speeds, the number of vehicles crossing a defined section in a certain time interval decreases. So, there is a characteristic speed of circulation that maximizes the capacity of the infrastructure. This definition, used for example for road infrastructure, is not much useful in railways, where speed, running time and braking time are design data, connected with commercial requirements that define the various services. Nowadays, there are several methods for the evaluation of railway capacity based on theoretical concepts and different distributions of traffic volumes. In this area of interest, the research is in continuous development and traditional analytical methodologies are supported by simulation models.

Railway capacity is difficult to define and to compute. The most synthetic and completed definition is stated in the *UIC*[3] *Code 406* (2004),

"Railway infrastructure capacity depends on the way it is utilized. The basic parameters underpinning capacity are the infrastructure characteristics themselves and these include the signalling system, the transport schedule and the imposed punctuality level"

[3]*UIC : Union International des Chemins de Fer*

In general, railway capacity can be defined as the maximum number of trains that may be operated using concurrently a specific part of the infrastructure during a given period of time and with a fixed level of service. As in Figure 2, railway capacity is conditioned by technical parameters of the infrastructure (speed limits, typology and number of tracks, signalling and control systems parameters such as block section length), operational model (heterogeneity and succession of trains) and priority rules.

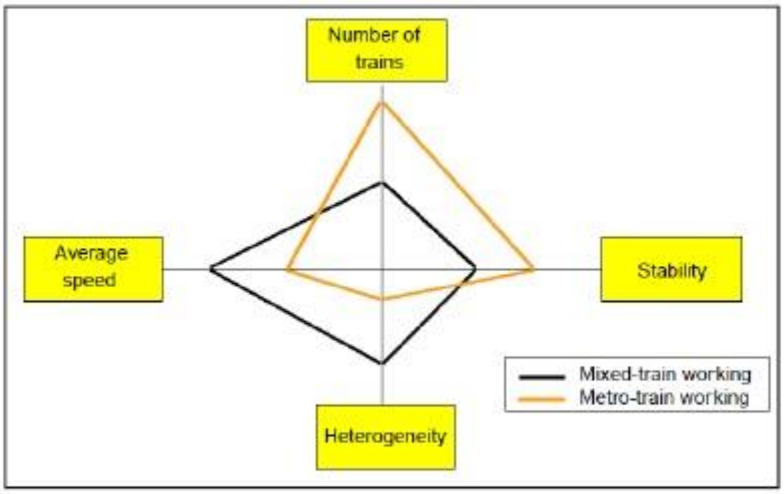

Figure 2: Capacity balance according to UIC Code 406

To distinguish correctly the two principal areas representing the railway transport system, it is necessary to consider independently line capacity and node capacity. In fact, different topological features and line and node operation produce the definition of different methods for the evaluation of capacity. In this chapter, we propose a general review of methodologies for the evaluation of railway capacity. This review is useful to correctly understand the methods of analysis chosen, enhanced and integrated in this study.

2.1 EVALUATION OF LINE CAPACITY

The definition of line capacity needs of preliminary considerations given by differences between theoretical capacity and practical capacity.

Theoretical Capacity is defined as the number of trains that could run over a route, during a specific time interval and it represents an upper limit for the capacity of a line. Practical Capacity represents the actual limit of the number of trains (usually considering the current train mix, priorities, etc.) that can be moved on a line to guarantee a reasonable level of regularity. It represents a more realistic measure of capacity, usually around 60%-75% of the theoretical one, as reported in Figure 3.

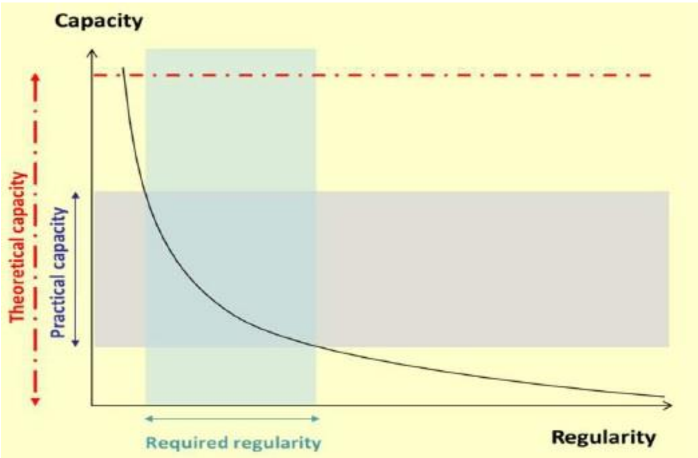

Figure 3: Link between capacity and regularity

Capacity as a concept is based on the definition of the minimum headway (time spacing) between two following trains compatible with the safe stop of the second train after a stop of the first one. Considering the worst case, the braking of the first train can be assumed instantaneous: that simplification is not excessive, as an extreme event that produces the derailment of a train usually makes the infrastructure unsafe for a following train from the very point where the derailment occurs. Spacing between two trains can therefore be calculated by the following formula:

$$\mathbf{d} = s_r + s_a + s_0 + L = v\,t_r + \frac{v^2}{2a} + s_0 + L$$

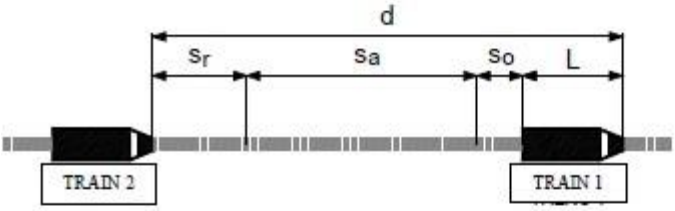

Figure 4: Minimum headway between following trains

in which s_r represents space run during reaction time t_r, s_a is the braking distance, s_0 is a safety margin, L is the length of the longest train, v the speed of the fastest train and a is the service acceleration.

Headway is given by $\Delta t = \frac{d}{v}$ and then capacity can be defined as $\mathbf{P} = \frac{1}{\Delta t} = \frac{1}{t_r + \frac{v}{2a} + \frac{s_0 + L}{v}}$.

So, capacity depends directly upon running speed: within lower speed range, capacity increases with speed increase. Within higher speed range, capacity decreases with speed increase.

Practical capacity considers a variety of train speeds and the actual performances of signalling systems. Signalling constitutes a spacing system with fixed block sections, detecting train position by means of specific devices such as track circuits or axle-counters. Reference values for the length of sections on the main Italian lines are included in the range 900÷2250 m[4]. According to the features of signalling system, we define a fixed spacing between two following trains as:

$$\boldsymbol{\lambda} + \boldsymbol{\delta} \geq \mathbf{v}\,t_r + \frac{v^2}{2a} + s_0$$

$$\mathbf{d} = \boldsymbol{\lambda} + \boldsymbol{\delta} + \mathbf{D} + s_0 + L$$

[4] Reference values for main lines of the Italian railway network (excluding High Speed AV/AC lines) adopting a technology called Automatic Block with interlocked sections (*Blocco Automatico a sezioni concatenate*)

in which d is not depending upon speed (in fact D is the length of a fixed block section), as reported in Figure 5.

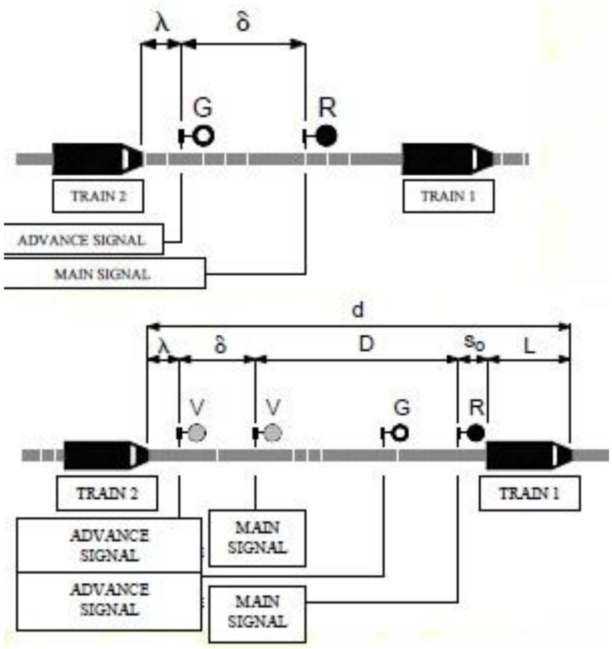

Figure 5: Fixed spacing between two following trains

As usually, capacity is $\mathbf{P} = \frac{1}{\Delta t} = \frac{v}{d}$. Line capacity is always defined as the capacity of the critical section (section with the longest running time).

Normally, spacing between trains is defined by fixed spacing requirements according to the technology adopted. Theoretical headway between trains is increased by a buffer time to avoid that possible delays of one train generate perturbations on the run of following trains. Italian infrastructure manager fixes a spacing requirement equal to *4*, *5* or *6* minutes according to the distance between main signals.

Capacity is dynamically and closely linked to the elements that make up the rail system. Its determination is affected by different parameters: infrastructural parameters, operational parameters and traffic effects.

Infrastructural parameters are:

- Number of tracks (single or double-track lines);
- Distance between two crossing or passing stations;
- Theoretical speed and project speed.

Operational parameters are:

- Operational model, intended as route paths occupied by trains on a time-space frame, in addition to technical specifications of temporal and spatial separations between trains, required for crossing and overtaking operations;
- Rolling stock features;
- Traffic typology (different performances reflect on allowed speed);
- Headway
- Total reference period (extension and location within day).

Traffic effects are:

- Generation and propagation of delays;
- Required and expected quality of service (requirements fixed in agreement between infrastructure manager and train operators that reflect on priority rules).

To calculate the line capacity of a railway infrastructure, different techniques and methodologies are used; these can be divided into three main categories:

- *Synthetic methods*: based upon deterministic expressions; in these methods, variables cannot change their state and they assume fixed values during the reference time. They are also called *static methods*.
- *Analytical methods*: based upon probabilistic expressions; they are also called *dynamical methods*;
- *Analogical methods*: they can be further divided into *asynchronous* methods (that provide the optimization of one or more variables) and *synchronous* methods (traffic simulation).

Following, we report a description of the main methodologies for each category described above.

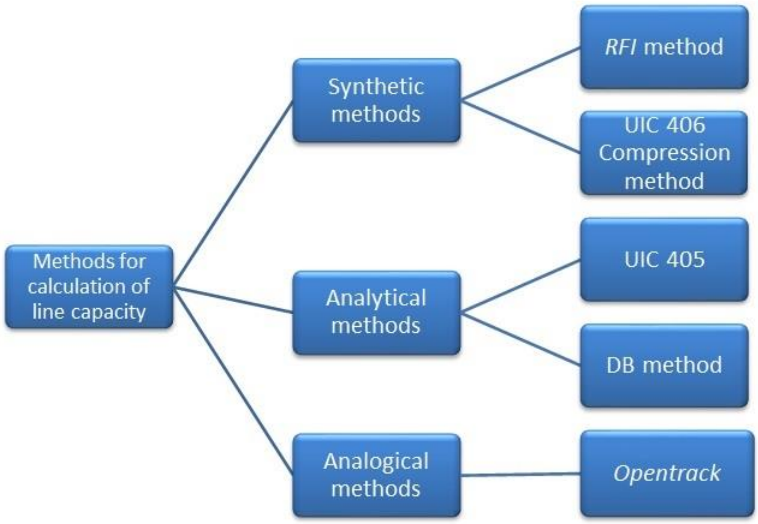

Figure 6: Schematization of main methods for calculation of line capacity

2.2 SYNTHETIC METHODS

These methods are based on deterministic expressions; the two methods here described are: *RFI method* and *UIC's Compression Method – 406*.

2.2.1 RFI method

This method was developed by the Italian railway infrastructure manager *Rete Ferroviaria Italiana* and defined in its internal guidelines. It treats values drawn up in a medium headway plus expansion margin and extra time. The margin is obtained by decreasing by 1/3 the hourly capacity and 2/3 the daily capacity; extra time is defined according to the number of stations along the analyzed line (0.25 min per station).

The method defines two different capacities: the theoretical (CT) capacity and the commercial (CM) capacity. Differentiating by multi-track and single line tracks, the formulas to calculate CT and CM capacity are:

$$\text{Daily Theoretical capacity for multi-track lines } CTG = \frac{N\,1320}{D_n}$$

$$\text{Daily Commercial capacity for multi-track lines } CMG = \frac{CTG}{K}$$

$$\text{Daily Theoretical capacity for single line tracks } CTG = \frac{1320}{T_d + \tau}$$

$$\text{Daily Commercial capacity for single line tracks } CMG = \frac{CTG}{K_1}$$

For multi-track lines, N represents the number of tracks while D_n indicates the line's headway defined as "normal" in the technical scenario. D_n depends on line characteristics and current traffic regime. Commercial capacity is lower than theoretical one due to a coefficient K which considers the variety of commercial speeds.

For single line tracks, T_d represents travel time of the relevant section at the speed of the slowest trains ("rank A[5]") and τ represents additional time for crossing maneuvers.

The formulas presented above are used for the calculation of daily theoretical and practical capacity; in the case of hourly capacity it is sufficient to substitute the coefficient *1320* (corresponding to *22* hours) with *60.*

Coefficients K and K_1 are reported in the following table.

Speed level	**1**	**2**	**3**	**4**	**5**
K	1.2	1.4	1.5	1.8	1.9
K₁	1.0	1.3	1.3	1.5	1.5

Table 1: Reducing coefficients according to speed levels

The advantage of this method is that it permits the determination of the value of capacity quickly; on the other hand, it presents several limitations, because it does not consider

[5] On the Italian network, line speed limits are differentiated according to the vehicles, which are admitted on a line according to up to four ranks. Typically, rank A, that sets the lower speeds, is reserved to freight trains and locos travelling alone, rank B to passenger trains, rank C to advanced passenger trains and rank P to tilting trains.

many aspects that affect line capacity. Among them, we can remark that with this method the effective difference between speeds of the different services is not considered; furthermore, this method is strictly connected with the definition of capacity according to the relevant section without any information about the other ones.

So, this method is useful for a brief and initial determination of the line capacity; in a second step the analysis with this method must be refined.

2.2.2 UIC's Compression Method – LEAFLET 406

The UIC Leaflet 406 (2004) states: *"capacity consumption shall be analysed within a line section through compressing timetable train paths in a pre-defined time window".* The methodology consists in different steps: the first one is to build up the infrastructure layout and the timetable of the line. Then the second one is the "compression" of the timetable in order to obtain the overall capacity consumption.

To understand the concept of *compression* we should consider that the calculation method suggested in UIC Code 406 is based on blocking time sequences.

Because of safety reasons, block sections remain occupied, depending on signalling systems (Figure 7), as long as a release point behind them becomes free, that is the section itself becomes available for further use by a following train.

For each block section, the occupation time, i.e. the time it is used by a single train and it is not available for other trains, is given by the sum of times for:

- route formation;
- clearance;
- visual distance/driver reaction;
- approach the section;
- track occupation

all depending on the timetable, infrastructure and vehicle characteristics.

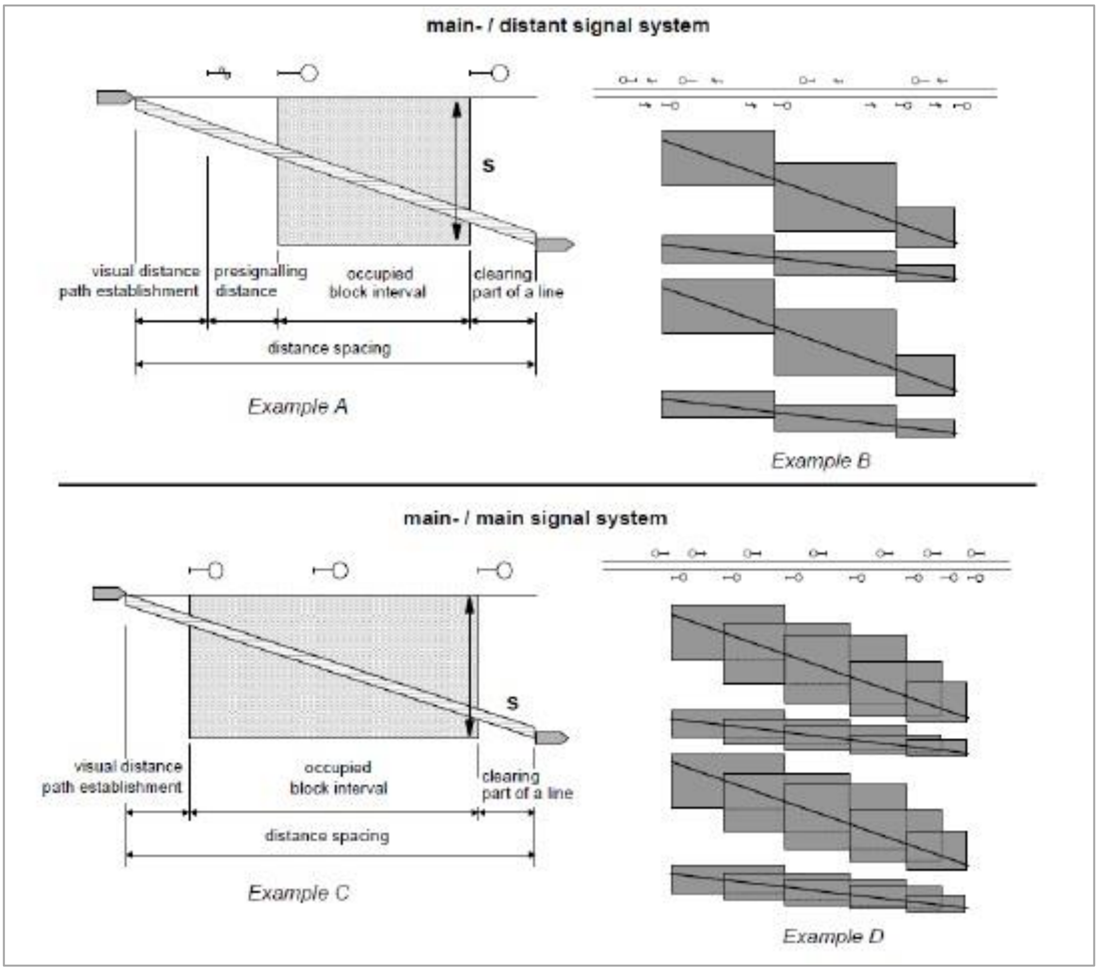

Figure 7: Example of occupation times in different signalling systems

For the estimation of the total capacity consumption it is necessary to consider time reserves for timetable stabilization (i.e. buffer time *B*) and for maintenance (i.e. *D*) besides the minimum occupation time *A* and supplement for single-track lines (i.e. crossing buffer C). The total consumption time *k* (Figure 8) can be calculated as:

$$\boldsymbol{k = A + B + C + D}$$

Given a reference time t_u (a chosen window time), the capacity consumption *K* [%] is defined as:

$$\boldsymbol{K = \frac{100\,k}{t_u}}$$

Unused capacity is given by part of slots not usable due to market requirements, while a second share of this represents still available capacity.

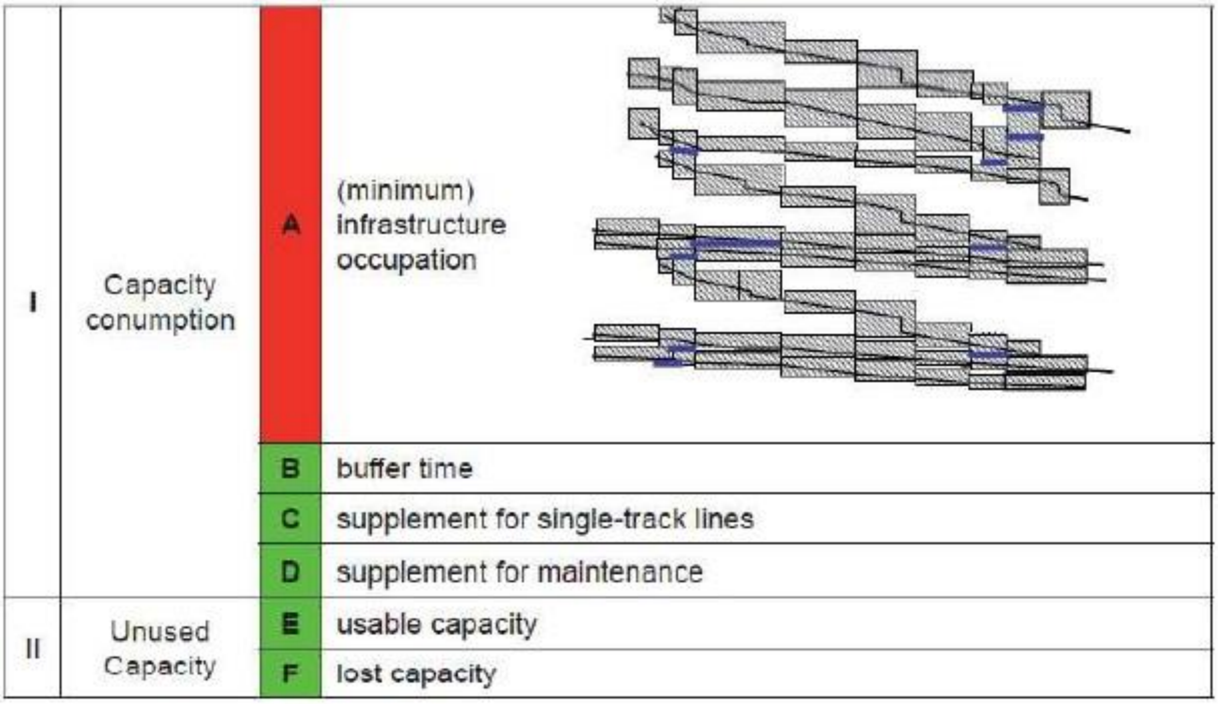

Figure 8: Determination of capacity consumption. Source: UIC Code 406 (2004)

This method is useful for the analysis of line sections and simple nodes; it was initially developed as graphic method but its application to complex railway networks (with speed variability) resulted difficult. Due to limitations of this methodology, other analytical methods based on it were implemented and developed. The analytical development of this graphic methodology represents nowadays the most powerful capacity evaluation for current and future railway lines; in fact, it is the most used method to obtain information about line capacity for infrastructures with expected increase of traffic.

2.3 ANALYTICAL METHODS

These methodologies are based on probabilistic expressions for the evaluation of circulation conditions on line. Analytical methods are deepened with respect of deterministic methods and they may be used not only for the evaluation of actual line capacity but also for future one. A limitation of this category of methods is that line capacity is calculated considering the critical section (the section with the longest running time) without considering the bordering sections. In fact, the output of the method represents the upper line capacity value. Furthermore, the utilization of analytical methodologies for complex lines characterized by speed variability is very difficult. At the end, these methods are used to obtain initial values of line capacity based on scheduled traffic operations. Following, two analytical methods are presented: *UIC method 405R* and *DB method.*

2.3.1 UIC Method 405R

This method was reported in the first edition (1978) of the calculation procedure in the UIC Fiche 405R. The expression of the capacity on a T-reference base, covering the whole day excluding the maintenance intervals, is:

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

Where:

- t_{fm} is the average minimum headway between trains;
- t_r is the elapsing time (an expansion margin linked with regularity);
- t_{zu} is an extra time considering the number of block sections on the concerned line's segment; this factor is calculated through the expression $t_{zu} = 0.25a$, where a is the number of intermediate block sections within relevant line's section.

Calculation of the key parameter t_r is based on queuing theory and it is aimed to define a level of service corresponding to the calculated capacity value. Considering the average amount of trains approaching the critical section $\frac{1}{t_{fm}+t_r}$ and the average amount of trains allowed running on the critical section $\frac{1}{t_{fm}}$, it is possible to calculate the utilization rate ψ as:

$$\boldsymbol{\psi} = \frac{\boldsymbol{t_{fm}}}{\boldsymbol{t_{fm} + t_r}}$$

Maximum values of utilization rate ψ are identified by UIC after wide test campaign as:

- *0.60* for average operational conditions (e.g. daily operations), corresponding to $t_r = 0.67\ t_{fm}$ (1.5 delayed trains);
- *0.75* for high traffic density conditions (e.g. short peak operations), corresponding to $t_r = 0.33\ t_{fm}$ (3.1 delayed trains).

For calculation of the average minimum headway t_{fm}, at first it is necessary to define the train succession cases, splitting the amount of trains into running time classes: in this way, a matrix called *[S]* is defined (summation is defined as *N-1* with *N* total amount of running trains). For each train succession case, an occupation time is associated defining another matrix called *[O]*. Considering the occupation times per train successions given by matrix *[S x O]* and its summation equal to the total infrastructure occupation time T_{ot}, we obtain that:

$$\boldsymbol{t_{fm}} = \frac{\boldsymbol{T_{ot}}}{\boldsymbol{N - 1}}$$

This method was later updated by UIC Leaflets 4052I (1983) and 406R (2004).

2.3.2 DB Method

This probabilistic method was developed by the German Federal Railways (DB) for the quantification of the capacity of railway lines. It is based on principles similar to the UIC method described above; main peculiarities of this methodology are:

- a simplified minimum headway calculation;
- more articulated link with regularity.

The expression of the capacity for the full day (excluded maintenance intervals) is in this case:

$$\boldsymbol{P} = \frac{\boldsymbol{T}}{\boldsymbol{t_{fm}(1+q)}}$$

In which:

- t_{fm} is the average value of the minimum headways between two following trains;
- q is the buffer time, which takes into account the timetable situation and the desired quality to be calculated by setting two parameters (degree of fluidity and transfer factor).

For the calculation of average minimum headway t_{fm}, the method defines trains succession cases as only two categories of trains:

- N_v is the amount of rapid trains;
- N_l is the amount of slow trains.

Occupation times of succession cases is defined as:

- t_{vv} is the average minimum headway for rapid-rapid trains succession;
- t_{vl} is the average minimum headway for rapid-slow trains succession;
- t_{lv} is the average minimum headway for slow-rapid trains succession;
- t_{ll} is the average minimum headway for slow-slow trains succession.

Calculation of average minimum headway between trains results as:

$$t_{fm} = \frac{t_{vv}N_v^2 + (t_{vl} + t_{lv})N_vN_l + t_{ll}N_l^2}{(N_v + N_l)^2}$$

Buffer parameter is calculated by the definition of two parameter: fluidity parameter *H* and transfer factor *U*. Fluidity parameter and transfer factor are related to primary delays generated in critical section: they are calculated according to following formulas:

$$H = \frac{P_f}{1440(W_e - \frac{W_e^2}{2})}$$

in which P_f is the global daily amount of tolerated primary delays generated in critical section and W_e is the probability of arrival of delayed trains and

$$U = \frac{t_{fm}}{P_m}$$

in which t_{fm} is the average minimum headway between trains and P_m is the average delay of trains approaching critical section.

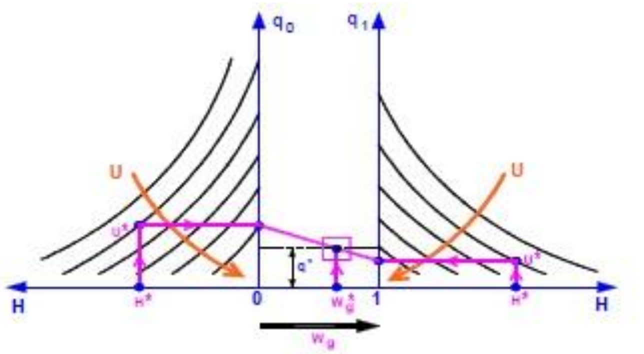

Figure 9: Parameters defining margins for regularity in DB method

By means of a pre-existing timetable it is possible to obtain buffer time *q* after the calculation of probability of homogeneity of successive trains W_g (Figure 9).

This method results as a simplification of UIC 405 method considering that only two trains categories are used for calculation of average minimum headway. DB method is linked with the concept of regularity by a transparent pseudo-random approach that considers both primary and secondary delays.

2.4 ANALOGICAL METHODS

Nowadays, several analogical simulation methods have found their natural application development in commercial tools. These instruments can simulate the rail traffic by generating graphs dynamically defined through equations in a defined timetable. It is possible to distinguish these simulation methods according to input and output data for the determination of rail capacity. Input parameters are classified into infrastructure, network parameters and effects of the operation. Output data can be theoretical capacity, commercial capacity, used capacity and residual capacity. Furthermore, these software environments have been classified based on main functions performed: simulation, optimization of timetables, railway capacity, infrastructure, facilities management, shifts, economic evaluation and sensitivity analysis. One of the most famous railway simulation software is *Opentrack*: this software was developed by the Institute for Transport Planning and System ETH in Zurich. It is able to simulate a complex network including lines and stations and it produces as outputs the graphic timetable and the average delays generated. The software reproduces in detail the signalling system and the topological characteristics of the network and considers dynamic characteristics of the vehicles. Performances of the network are evaluated by statistics on the circulation conditions generated by timetable perturbations. Imposed perturbations (e.g. failures of the systems, secondary delays) are determined on the basis of historic delays collected in a significant period.

2.5 COMPARISON BETWEEN METHODS FOR LINE CAPACITY CALCULATION

Line capacity and utilization rate can be determined by different methodologies as explained above. The choice of the appropriate method for the evaluation of line capacity depends on the accuracy that it is necessary to obtain as a result. Certainly, simulation methods allow obtaining results with an optimal degree of accuracy evaluating what effectively happens on the line. However, their application on complex network results heavy and strictly linked with scheduled timetable; for this reason, a critical aspect for reliability of output is the possible introduction of arbitrariness if timetable is unknown. Therefore, it is more recommendable to adopt analytical methods with an easier application for a first evaluation of traffic infrastructure conditions.

The decision to adopt deterministic or probabilistic methods depends on infrastructure characteristics and traffic typology. Application of probabilistic methods is appropriate in the case of railway infrastructure characterized by traffic with restricted speed variability and few services categories. Deterministic methods allow analyzing with precision complex railway network on which a complex timetable is operated, to assess the utilization degree of the single elements of a whole network.

For this reason, the methodology adopted in this study for the main network analysis is the compression method in its analytical formulation; other methods are then applied to check and refine the results obtained.

2.6 EVALUATION OF NODE CAPACITY

Methods for the evaluation of line capacity cannot be adopted to analyze a complex node: in fact, the circulation of trains within a station is extremely different with respect to line circulation. In a node, passengers boarding/alighting operations and possible loading/unloading operations of freight implicate a different circulation of trains within station and, for this reason, specific methods for the evaluation of node capacity are necessary. Performance of a railway node can be described by means of static capacity and dynamic capacity values and it strictly depends on node layout. Static capacity condition is simply defined as existence of tracks available for the acceptance of trains in station and it is related to stop times. For what concern the dynamic capacity inside a station, conditions are defined by compatibility or incompatibility between enter/exit routes and it is related to interdiction times.

The fundamental conditions the train dispatcher or the interlocking system has to check before a train is allowed to use a route are:

- Existence, obtained when switches defining the route are blocked in the correct position;
- Freedom of tracks composing the route;
- Prevention of movements an all the interfering routes.

Only at this point the signal commanding the route can be set free, and it ensures that all the conditions checked before are maintained as long as the train has travelled the whole route.

Node analysis takes into account all these conditions and convert them into infrastructure capacity. As well as for line capacity methods, it is necessary to define input data in common to all methodologies presented in technical literature. Factors affecting node capacity are:

- Topology: station layout identifies the number and the topology of entering/exiting lines, the position of primary movement tracks and secondary maneuvers tracks, the connection of arriving and departing tracks with lines, depot and yards. This information and other are reported in a schematization document produced by infrastructure manager.

- Technological system: it identifies the typology of interlocking system of the station and the use of elastic or rigid release of routes, i.e. whether the route is totally unavailable for other movements as long as the train has travelled along all of it, or part of it returns available as soon as the train has released some sections of it.
- Speed restrictions inside the station: speed of trains in the node is different according to typology of routes; typically, correct ("straight") layout of a route is run along with speed greater than deviated layout route. Speed is important for the calculation of blocking time of a route and then interdiction time.
- Utilization schedule of the station: it identifies the number of circulations inside a station in a reference time interval (normally peak period). Maneuver routes are typically for nodes linked with depot and yards; these kinds of routes are scheduled in time intervals that not interfere with arriving/departing routes of passengers/freight trains. Generally, maneuver routes are not considered in node capacity methodologies or else they are precisely scheduled and dealt with as they were trains.
- Traffic composition: different typologies of trains according to service and speed variability imply operational rules to solve conflicts.
- Stopping times: they are different according to typologies of service and therefore they determine capacity and utilization degree of the node.
- Speed restrictions due to maintenance and tracks out of service: ordinary or extraordinary maintenance can influence availability of parts of node area.

From these input data, it is possible to proceed with node analysis by means of different methodologies. As for line capacity, methods for the evaluation of node utilization can be classified in:

- Combinatorial and probabilistic methods;
- Analytical methods;

- Simulation methods.

Following, a general presentation of these methods is reported.

2.7 COMBINATORIAL AND PROBABILISTIC METHODS

Methodologies of this category (called also *static methods*) allow analyzing simple and complex node by computing as output a numerical index for the evaluation of capacity. These methods are based on the determination of synthetic indicators, as for example the *average number of compatible routes* n_m (that can be realized in full safety): this index can be calculated considering the combination of compatible routes deriving from the routes matrix. The exact calculation of n_m considers the n-tuple of compatible routes; normally, an empirical calculation is used for determination of this index. This way results faster than exact calculation: the hypothesis is that each route is used by a single train during the reference time, so the amount of trains corresponds to number of routes. By routes matrix, n_m results as the ratio between total number cells of matrix and cells with incompatibilities between routes:

$$\boldsymbol{n_m = \frac{N^2}{\sum_I n_i n_j}}$$

In which N represents the global amount of trains $N = \sum n_i = \sum n_j$.

Values of n_m calculated by empirical way are lower than exactly calculated method. In fact, empirical calculation considers only couples of routes without taking into account possible weight of n-tuple of higher order. Deviations between n_m values calculated with the two methods are around 20-50%.

The main methods are Potthoff method (developed in the 60s at the University of Dresden) and n-tuples saturation method. These two methods have in common the initial construction of the routes matrix reporting all possible relations of compatibility/incompatibilities between possible couples of routes. The difference is given by the determination of n_m value.

Limitations of these methodologies are linked with probabilistic hypothesis about arrival and departure of trains to/from the station. Hypothesis are not realistic in case of analysis of long-time interval (e.g. a complete day) while they can be assumed realistic for short-time period analysis (e.g. peak-hour).

2.8 ANALYTICAL METHODS

This category of methods is normally used for the determination of preliminary solutions. They are based on the mathematical computation of temporal diagrams reporting the real occupation of node entities, considering the arrival, stopping and departure times for each train. Studying these diagrams, it is possible to determine theoretical and practical capacity values. The first analytical methods reported in technical literature omitted the random component of circulation; in this way, it is possible to simply compare the value related to circulation duration with the effective availability of the station.

Several examples of descriptive analytical methodologies developed during the year are reported in technical literature. In 1979, Corazza and Florio [1] introduced random aspects of railway circulation for the formulation of an analytical theory able to determine capacity and operational regularity of a station. In 1984, Florio and Malavasi [2] presented an analytical method to apply in a complex node for the determination of capacity introducing part of delays analysis. In 1999, Canciani [3] proposed a queuing theory application method for the study of junction stations characterized by many arrival lines and only one departing line. This method verifies the availability of a node in comparison with the distribution of arrivals (three different distributions: deterministic, exponential and Erlang distribution were applied). In 2001, Antognoli, Corazza and Guida [4] analyzed Ciampino railway station near Rome and compared results obtained with Potthoff method, Corazza – Musso method and an experimental method characterized by detailed observation of node operations and circulation. In 2002, De Vita, Giovine and Ricci [5] compare different methodologies applied to Tarvisio Boscoverde railway station. The first method used in the study is characterized by construction of histograms of arrival frequency of n-tuples of trains with values from 2 to 7 and relative cumulative curves. Defined a reference value for percentage of arrival trains without delay; it is possible to build a curve defining the utilization of the node. The second method is an evolution of Gantt chart in which activities are the trains' stop in the station and duration of activities are the scheduled stopping times of trains. The third method used is Potthoff method. The three methodologies produce results compared to real values observed for the analyzed station. In 2007, Ciuffini [6] proposed a method for the analysis of an elementary terminus station with the hypothesis of uniform headways among trains and a possible development of compression's method for the analysis of a line.

These calculation methodologies can be used for determination of system constraints, but they are very sensitive to input data, so results obtained can be different according to the method used. This fact can be a limit for their application.

2.9 SIMULATION METHODS

Development of computer-science has permitted the development of simulation methodologies for the analysis of railway nodes by means of dedicated software. This software reproduces numerically and continuously the entire circulation process in the station, considering also random aspects linked with circulation. In this way it is possible to verify and validate a scheduled timetable. Input data of these methods are information linked with realistic and detailed representation of station, expected timetable and possible irregularities. Precision and reliability of outputs are connected with quantity of information introduced in the software.

As for calculation of line capacity, the railway simulation software *Opentrack* is largely utilized for the analysis of node capacity considering its possibility to define station areas.

Cappelli, Ricci and Staffini in the 1996 [7] developed a simulation software to reproduce the working state of a station with a defined operational plan permitting to determine optimal circulation under perturbed conditions.

Crotti, Deflorio, Elia and Ioncoli in 2005 [8] developed a simulation model using programming code Visual Basic for Application. This model is able to analyze a complex station generating as output the utilization rate for stops, movements, maneuvers and interdictions.

Nowadays, simulation methodologies represent an optimal support tool for railway planning. Limitations in the application of these methods derive from the high number of input parameters for the description of station and operational plan. Furthermore, results obtained by simulation are complex and they are usually synthetized by indicators similar to that obtained with analytical methods.

3 LINE CAPACITY AND NODE CAPACITY: ANALYSIS METHODOLOGY

The determination of capacity parameters for the elements composing the railway system is fundamental for all planning activities. Generally, in a railway network, the lines have a capacity greater than the nodes that may represent bottlenecks or congestion points. However, one or more sections of a given railway line with congestion phenomena can affect the potentiality of railway nodes along the line, with possible issues for passengers or freight circulation. Therefore, the estimation of capacity of the railway network is important to evaluate if the actual rail infrastructure with its own characteristics is able to absorb the expected traffic, with or without significant impacts on regularity. In terms of planning activities, an accurate capacity assessment can assist policy makers in taking better decisions for investments for new infrastructures, setting coherently the relevant priorities and contributing to minimize the overall cost for users.

This analysis focuses on the railway lines Domodossola – Milano and Seregno – Bergamo: both are involved in projects for the development of connections from/to Malpensa International Airport. The objective of this analysis is to estimate the utilization rate of the sections composing the lines and the utilization rate of the main stations of the lines assuming first the actual characteristics of infrastructure and railway supply and then the future infrastructure with the new system of services (2026 railway supply). The results obtained by the analysis are used to evaluate the impacts of the introduction of new services on the existing infrastructure to determine if upgrades on it are necessary. The methods used for this study are: an analytical method derived from UIC's Compression Method for line capacity and the well-known Potthoff method for node performances.

3.1 UIC's COMPRESSION METHOD

As explained in the previous chapter, UIC's Compression Method is a methodology for the evaluation of capacity based on the determination of blocking time of trains. Estimation of capacity values can be by means of a graphic procedure as shown in Figure 10. It consists in the compression of a reference timetable, by determining the time needed to deploy it with the minimum scheduled headway between all train paths (spacing requirement). The total occupation time of all running trains represents the global utilization time of the line; utilization rate of the line is the ratio between the time to deploy the compressed timetable and the reference time. This value has a link with the level of saturation of the line by considering range of values obtained by practical considerations about operation and traffic management. Part of the unused capacity represents usable capacity for the introduction of additional trains.

This methodology is particularly appropriate for the analysis of line sections and simple nodes; its application to complex network and timetable characterized by speed variability is limited. For this reason, an analytical methodology derived by graphic procedure has been developed in literature. This one represents the most reliable procedure for the evaluation of utilization rate of a line, and it represents the most used method to determine consequences derived by the increase of traffic and infrastructural upgrades.

Figure 10: Graphic procedure for timetable compression

3.2 ANALYTICAL METHOD DERIVED BY UIC'S COMPRESSION METHOD

For the analysis of the lines, an analytical methodology based on UIC's Compression Method has been developed in this study for the estimation of the utilization rate. The method is variable according to the layout of the line: single-track or double-track.

Input data of this method are the infrastructural characteristics, which significantly influence scheduled operation of the line.

Output is given according to the following input parameters:

- Reference time *T*, typically coincident with peak hours, considering that – by definition – in this time interval services have higher frequency;
- Typology and speed of the trains, given by graphic timetable; these parameters are useful to divide trains in speed classes;
- Service frequencies, for each typology and origin-destination;
- Operational systems existing along the line that are necessary to obtain spacing information between trains.

3.2.1 Common Elements of the Methodology

The first step of this methodology is the subdivision of a given railway network in homogeneous sections with uniform number of tracks and spacing requirement. Moreover, sections are defined by subdividing the network into segments without junctions or priority; therefore, along each segment train succession cannot vary. The next step is the calculation of the reference travel time for each typology of departing trains: for each section individuated in the previous step, travel time is calculated according to train speed. Each travel time considers also the scheduled stopping time of the trains at the stations. At the end of the process, trains speed classes depend on the obtained values of travel time (e.g. long haul, regional, suburban, freight trains). Train frequency is necessary for the determination of number of rides per hour for each O/D connection in the reference period. Frequency may also be different according to peak and off-peak hours and in-flow direction and counter-flow direction. Then, the next step is to build a table with in row the speed class travel times and in column the reference travel time values (possible "candidates" to reference travel times). For each *i-j* cell of the table, the difference (in absolute value) between speed class travel time i and reference travel time j is calculated. After that, differences obtained in each cell are multiplied by number of trains, speed class by speed class, and then the values are summed per column. The minimum sum identifies the reference travel time of the section. The value of the sum obtained identifies the time lost for speed variability. This table is repeated for each section individuated in the first step. Considering the number of trains, the spacing requirement characterizing each segment and the time lost for speed variability, it is possible to calculate the utilization rate. For each section, the utilization rate is separately computed according to peak and off-peak hour.

3.2.2 Methodology for Double-Track Layout Lines

Based on the method reported above, it is possible to calculate the utilization rate of the segments with double-track layout. The global utilization of the segment is calculated as:

$$\boldsymbol{number\ of\ TRAINS * scheduled\ SPACING + TIME\ \ LOST\ for\ SPEED\ VARIABILITY}$$

Utilization rate *U is* given by the ratio between total utilization and reference time:

$$\boldsymbol{U = \frac{Total\ Utilization}{Reference\ time}}$$

For input data on scheduled spacing requirement, it considers the sum of actual blocking time according to technologies used in the blocking system plus a buffer time to preserve regularity and to avoid propagation of delays. This input data can be acquired by infrastructure manager's documents reporting characteristics and technologies of each line.

Following, an example of application of the method is reported for a line segment with double-track layout.

Line: Milano - Domodossola

Section: Gallarate – Busto Arsizio

Layout: Double-track

Spacing requirement: 5′

Number of trains associated to each travel time per speed class:

- 3′→1 train (long haul passenger train);
- 4′→5 trains (regional and freight trains);
- 5′→4 trains (suburban trains).

		Reference travel times			**Nr. trains**	**Reference travel times**		
		3'	**4'**	**5'**		**3'**	**4'**	**5'**
Travel time per speed class	**3'**	0	1	2	1	0	1	2
	4'	1	0	1	5	5	0	5
	5'	2	1	0	4	8	4	0
					Total delta	13	**5**	7

Table 2: Example of table for individuation of reference travel time and time lost for speed variability

After these operations, the results indicate that the reference travel time that minimizes the differences is **4′**. The time lost for speed variability is equal to **5′**. So, global utilization and utilization rate of the section are equal to:

$$Total\ Utilization = 10 * 5' + 5' = 55' \ (1)$$

$$Utilization\ rate\ U = \frac{55'}{60'} 100 = 91.67\ \% \ (2)$$

Figure 11 resumes the steps of the methodology described for the calculation of the utilization rate of a segment.

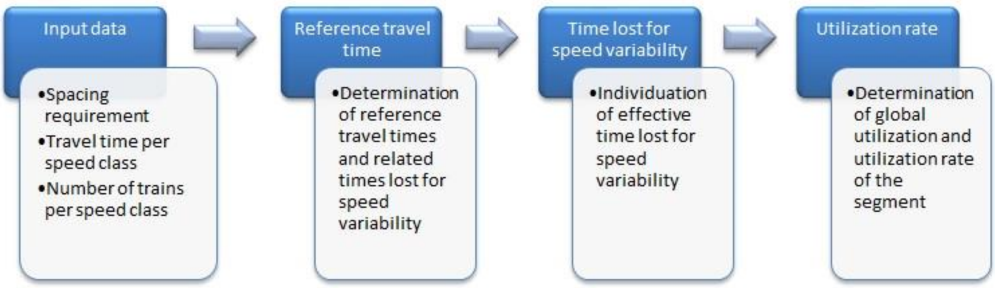

Figure 11: Schematization of methodology steps for the calculation of utilization rate of a segment

3.2.3 Methodology for Single-Track Layout Lines

For a line with a single-track layout, the calculation of utilization of a given railway segment follows the previous explained steps and remembering that it is necessary to consider simultaneously the trains in the two directions. In this case, the blocking time of the segment is calculated as the travel time of the section and possible additional times due to the presence of low speed switches or departure-after-arrival technical times for each typology of running trains. By (1) and (2) formulas, it is possible to calculate the used time and the utilization rate.

3.3 METHODOLOGY FOR THE ANALISYS OF COMPLEX NODES

Performances of a station are mainly depending on its layout that defines operational constraints and capacity parameters. The objective of the analysis on a complex node is to understand if it is able to satisfy an expected railway traffic, independently upon duration of train stops. Analyzing the capacity of a station to satisfy a defined circulation plan, a quantitative traffic assessment becomes necessary. Considering the simplest possible layout, with two tracks crossing each other, the common crossing area can be used by a single train at a time. This situation involves potential constraints for traffic along the two lines and potential conflicts with a train delayed by another one. These issues increase their complexity when station dimensions increase. An effective solution can be represented by a methodological approach based on matrices that describe the operation in the station. For the analysis of an existing station in the current situation, it is necessary to check if its layout is compatible with the programmed railway traffic. For the capacity design of a new station, traffic is not observable and only hypothesis can define the operation: so, it is necessary to check the temporal congruity with train movements and related delays under a fixed time interval.

3.3.1 General Capacity Check Condition

Considering the layout of a simple crossing station as in Figure 12 with bold lines representing main tracks and dotted lines representing tracks dedicated to trains stop only, capacity is potentially influenced by intersection points of lines leading to the station. Key capacity issues may be solved with the check of compatibility between traffic density and station layout, qualified by an assigned operational plan in a defined reference period and the quantification of capacity margin to increase railway traffic. The solution of this problem originates from the meeting of reciprocally influencing components:

- Station layout;

- Operational rules, defining all the regular and safe procedures of the station according to rulebooks and signalling systems;
- Operational plan, representing by timetable (amount and typologies of trains, origin and destination, arrival and departure, delays or anticipated arrivals);
- Reference period.

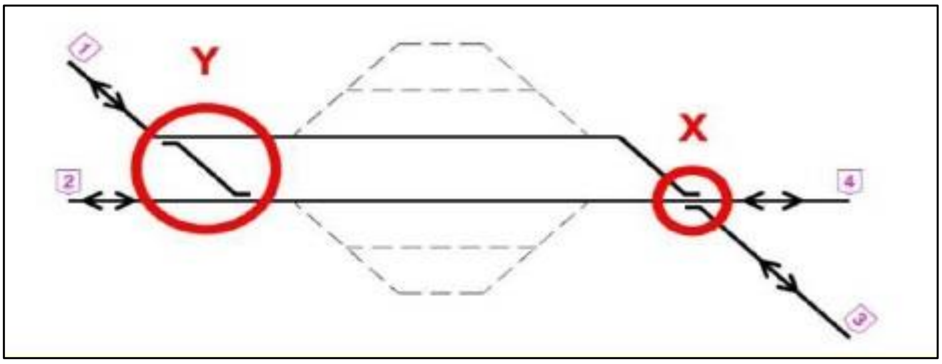

Figure 12: Simple crossing station layout

The elementary critical node *X*, representing the intersection point between the line identified as 1-3 with the line 2-4, must be run by only one train at a time. This fact involves that the reference time T must be shared between the traffic flows of the two lines. Hence the elementary node *X* represents a conflict point that reduces the capacity of both lines.

In general, reference time T is divided into three parts:

- Times required to cross intersection defined as occupation time ($\Sigma t = B$);
- Waiting times or delays ($\Sigma t = R$);
- Times available for additional trains.

The congruity condition of traffic and station's layout is analytical expressed as:

$$T \geq B + R$$

In which equality condition corresponds to saturation of the node (no times available for traffic increases).

3.3.2 Evaluation of a Simple Node

An elementary node is the intersection point of two crossing lines, as in Figure 13. The signalling system ensures the safe operation with the interdiction of a line during the occupation of another one. The interdiction situation includes a train stopped by the closed signal, waiting a time variable from zero to the total occupation time of the train crossing the node (depending upon its arrival time). The extension of interdiction starts with signal showing permissive aspect and ends with train's rear passing critical section. Considering n_1 trains/T on line 1 with occupation time t_1 and n_2 trains/T on line 2 with occupation time t_2, average delays suffered by trains running on lines are:

- $t_2/2$ on line 1;
- $t_1/2$ on line 2.

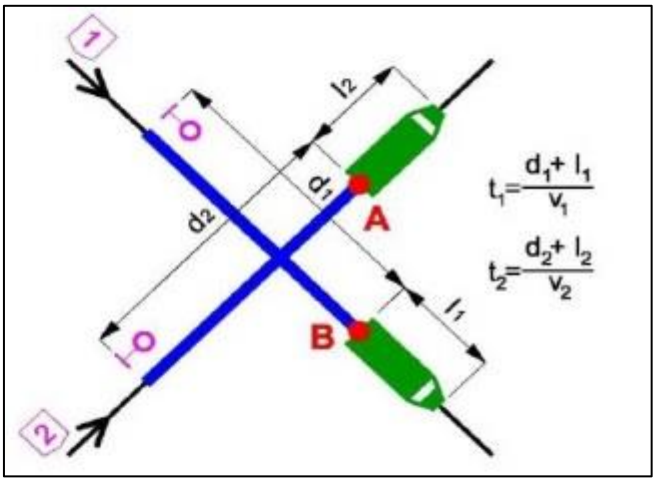

Figure 13: Elementary node: crossing lines

With the hypothesis of constant density of arrivals probability (realistic for short periods as rush hour) in reference time T, the probability to meet a not permissive signal on line 1 is equal to:

$$p_1 = n_2 \frac{1}{T} t_2$$

Global delay suffered by n_1 trains on line 1 is equal to:

$$R_1 = n_1 n_2 \frac{{t_2}^2}{2T}$$

So, with the extension of the concept to line 2, congruity condition is equal to:

$$\boldsymbol{T \geq n_1 t_1 + n_2 t_2 + n_1 n_2 \frac{{t_1}^2 + {t_2}^2}{2T}}$$

Representing regular traffic condition.

3.3.3 Evaluation of a Complex Node: Potthoff Methodology

Analytical methodologies for the analysis of simple station layout as in the previous paragraph appear non-transferable directly to the analysis of complex stations. In a simple station represented as an elementary node, the operation may be in two ways only, with or without an interdicted train, and the crossing movement is the only one permitted by the layout. In a complex station, it is possible to expect a multiplicity of movements and possible conflicts involving more trains at the same time. For the checking process of operational plan of a complex station, it is necessary to evaluate the use of a method permitting to individuate in a complete way all the possibilities of circulation inside the station area. On this basis, it is possible to evaluate if methods developed for the analysis of a simple station may be extended to complex ones.

Preliminary to the explanation of the methodology used for the analysis of stations, it is necessary to focus on differences between complex station and complex node. A complex station is the area composed by all tracks and track devices (switches, junctions, etc.) that perform the assigned functions under a single operational jurisdiction. Instead, a complex node is a specific part of a complex station resulting as a group of simple nodes; performances of a complex node influence directly the capacity of the station.

For the analysis of complex stations of the lines evaluated in this study, it is used the Potthoff method. This methodology is well consolidated in technical literature and it is based on a synthetic-combinatorial approach that uses graph theory and matrix calculation. The condition compatibility/incompatibility of the routes permits to synthetize circulation parameters by means of weight average calculation. With this method, it is possible to evaluate the average number of compatible train routes, the average occupation time of the node and delays generated by circulation process. Considering the global occupation time B, delays R and reference time T, the general capacity check condition for the complex node is, as previously:

$$\boldsymbol{T \geq B + R}$$

Deepening, parameters for temporal congruity check of a complex node are:

- n_m is the average number of compatible train routes;
- t_m is the average occupation time of the node by the n_m group of trains;
- T is the reference time;
- SR is the delay generated by the circulation of N trains;
- N is the total number of trains circulating in the node during the time T.

According to definitions introduced above, the circulation process of the node may be synthetized as a series of N/n_m events for each of the n_m trains that run at the same time with an occupation time equal to t_m. This synthesis of operational process permits to define the global average occupation time of the node as:

$$\boldsymbol{B = \frac{N}{n_m} t_m}$$

Delays must be globally evaluated as results of real incompatibilities but also taking into account the effect produced on the elementary node. Total delay results as the sum of delay generated by each simple node, giving the possibility to have a complete evaluation of capacity of complex node. So, congruity check condition for regular traffic can be defined as:

$$\boldsymbol{T \geq \frac{N}{n_m} t_m + \frac{\sum R}{n_m}}$$

First parameter to calculate is the number of compatible trains' routes n_m. This calculation starts with the preliminary definition of route matrix for the complex station or node analyzed. Route matrix or compatibilities/incompatibilities matrix reports the presence of conflicts between two defined station routes according to a specific codification, as in Figure 14. Route identification follows the different typologies of train movements:

- Entering route: from main protection signal to main departure signal;
- Exiting route: from main departure signal to last station switch;
- Maneuver route: route for operations within the station area (normally not considered in capacity analysis, except for specific situations).

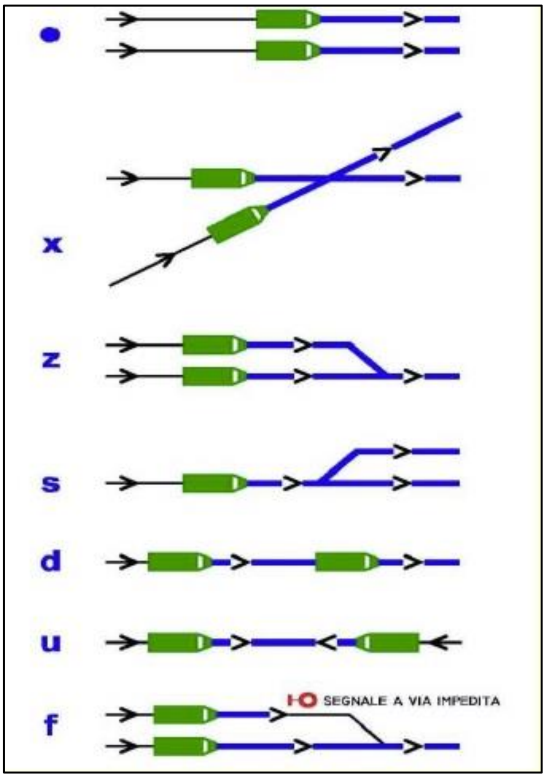

Figure 14: Compatibility/Incompatibility typologies

Then, routes are determined according to the positions of all station switches for the evaluation of reciprocal compatibility. For full comparison of routes, logic structure of the matrix proposes in rows and in columns the station routes and in the cells compatibility/incompatibility symbols according to codification. To make route matrix compatible with the calculation process, another matrix is computed, with *0* for compatibility and *1* for incompatibility. Starting by this matrix and assigning number of trains for each station route according to their frequency, it is possible to calculate n_m

parameter. Potthoff method proposes an empirical calculation based on the hypothesis that a single train uses each route during *T*. In this way the amount of trains corresponds to number of routes: each row and each column of the matrix are reported many times as trains running on each route (e.g. cell of matrix corresponding to routes used respectively by 3 and 4 trains contains the value 3x4=12 times). The total number of trains considered in the process is $\boldsymbol{N = \sum_I n_i = \sum_I n_j}$. The empirical expression fulfilling this condition is:

$$\boldsymbol{n_m = \frac{N^2}{\sum_I n_i n_j}}$$

Summation of denominator is extended only to cells with incompatibilities, including those of the main diagonal ($i = j$). The value obtained with this empirical approach results lower than the value obtained with the exact calculation method called "n-tuples saturation method". Differences between values are due to the fact that empirical calculation used by Potthoff method considers only couple of routes without the evaluation of the weight of n-tuples of higher order. Deviations between n_m values calculated by combinatorial and empirical methods are included in the range 20%-50%. The exact calculation method provides a value of n_m that considers the possibility to manage and plan the circulation of the station reaching the saturation condition; its dissertation rapidly increases its complexity according to dimensions of the station. So, for its simplicity and its cohesion with real typical operational conditions of a station, it is often preferable to adopt empirical calculation of n_m by Potthoff method.

After the evaluation of the average number of compatible routes of a complex node by means of the computation of route matrix, it is necessary to evaluate the average occupation time t_m of the complex node. This calculation, based on infrastructure and rolling stock features, is done by building another matrix, called interdiction time matrix. For each station route, occupation or blocking time is calculated. According to the typology of the route, in this study blocking time is evaluated as follows:

- For entering routes with train stopping for passengers boarding/alighting operations, blocking time is calculated as the time to run a distance equal to two sections before the main departure signal plus the visibility distance (200 m) plus the length of the train;
- For transit routes (for example long-haul trains stopping only in main stations or freight trains), blocking time is calculated as the time to run a distance equal to three sections before the main departure signal plus the visibility distance plus the length of the train;
- For exiting route, blocking time is calculated as the time to run a distance equal to one section after the main departure signal plus the length of the train.

Calculation of blocking time is done according to the specific block system of the line. In the cases considered in this study, the block system is BAcc, or Automatic Block system with codified currents with 4 or 9 codes[6]. Considering an arrival route, cab signal repetition system displays in succession to the driver code *180* (for direct route) or *120* (for deviated route) and code *75*. In this way, drivers can reduce the speed in time to ensure a safe stopping maneuver. Considering a transit route, train run must not be perturbed by the presence of previous trains. In this way, three block sections must be free to ensure a correct spacing for unperturbed conditions, with cab signalling system showing the code *270*. Furthermore, considering that code *180* must have a length requirement greater than 2700m according to infrastructure manager regulations, in presence of block sections with reduced length (900÷1060 m) an additional section for reshowing of code *180* is considered in calculation of blocking time for arrival and transit routes. Each blocking time increases in calculations with a 30 s additional technical time for the stations routes. Length of the trains is considered according to their typology: for regional services (both fast and slow categories) length is normally equal to 200 m, for AV/AC high speed services length is

[6] BAcc *Blocco Automatico a correnti codificate*: it is an automatic block system characterized by permanently energized track circuits. Codified currents in rail transmit information on board: in this way it is possible to implement a cab signalling system that ensures safe conditions making train driving independent upon visibility conditions. Cab system can be built on 4 or 9 codes. Main codes are: AC *Assenza Codice* meaning no code, 75 meaning that next signal has restrictive aspect, 180 meaning that next signal has permissive aspect with advice that signal following the next one has restrictive aspect, 120 meaning a speed restriction for deviated routes (30 km/h, 60 km/h or 100 km/h) and 270 meaning that next signal has permissive aspect.

approximately 350 m and for freight trains length may be assumed equal to 750 m, according to European railway standard. After these considerations, the average occupation time of the node t_m may be evaluated by:

$$\boldsymbol{t_m} = \frac{\sum_I \boldsymbol{n_i n_j t_{ij}}}{\sum_I \boldsymbol{n_i n_j}}$$

In which t_{ij} represents the interdiction time of route i against route j. As for the calculation of n_m, summation is extended to all incompatibilities I.

At the end, delays generated by the conflicts between trains running on station routes must be evaluated. Considering that self-incompatibilities (a) and diverging incompatibilities (s) do not generate delays, these ones are not taken into account in the calculation. Potthoff method employs the formulation of simple node with related hypothesis for the evaluation of delay; so, for each incompatibility ij:

$$\boldsymbol{R_{ij}} = \frac{\boldsymbol{n_i n_j t_{ij}^2}}{\boldsymbol{2T}}$$

Concluding, general check condition for a complex node must be written as:

$$\boldsymbol{T} \geq \frac{\sum_I \boldsymbol{n_i n_j t_{ij}}}{\boldsymbol{N}} + \frac{\sum_L \boldsymbol{R_{ij}} \sum_I \boldsymbol{n_i n_j}}{\boldsymbol{N^2}}$$

Remembering that I represents the set of incompatible couples of routes and L represents the set of incompatible couples of routes excluding incompatibilities of category *(a)* and *(s).* In this way, it is possible to calculate regular and global utilization rates by the following formulations:

$$\boldsymbol{U_{REG}} = \frac{\boldsymbol{B}}{\boldsymbol{T}}$$

$$\boldsymbol{U_{GLOB}} = \frac{\boldsymbol{B} + \frac{\sum_L \boldsymbol{R_{ij}}}{\boldsymbol{n_m}}}{\boldsymbol{T}}$$

Potthoff individuates as threshold for the utilization rate of a complex node the value of 75% for peak hour and 60% for off-peak hour.

For complex stations, the study is normally implemented identifying as first all the complex nodes and then applying the analysis method to the single one in order to obtain a specific focus on the station areas with possible criticalities. Figure 15 resumes the main steps of Potthoff methodology for the estimation of utilization rate of a complex node.

Figure 15: Schematization of steps to implement Potthoff methodology

4 THE ACTUAL INFRASTRUCTURAL LAYOUT AND RAILWAY SUPPLY MODEL

In this chapter, the paper reports a description of the actual infrastructural layout of the lines considered in this study and the related regional railway supply currently operated in Lombardy.

The railway lines analyzed are two: the line Domodossola-Milano and the line Seregno-Bergamo. The line Domodossola-Milano is strictly involved in the scheduled upgrade projects for the development of connections between Milan and Malpensa Airport. The line Seregno-Bergamo is partially involved in these projects due to the possible introduction of a new service connecting Bergamo with Malpensa.

The regional supply model is presented considering the passenger services and the freight services actually operated according to the agreements between the railway infrastructure manager and the regional government.

4.1 THE ACTUAL REGIONAL RAILWAY NETWORK

The railway network of Lombardy has an extension of about 2000 km with a total number of 421 stations. Considering the global extension of the network:

- About 320 km with 120 stations constitute the regional railway network actually in concession to Ferrovienord S.p.A.;
- The remaining part belongs to the national railway network managed by RFI S.p.A.

In Figure 16, a representation of the railway network of Lombardy Region.

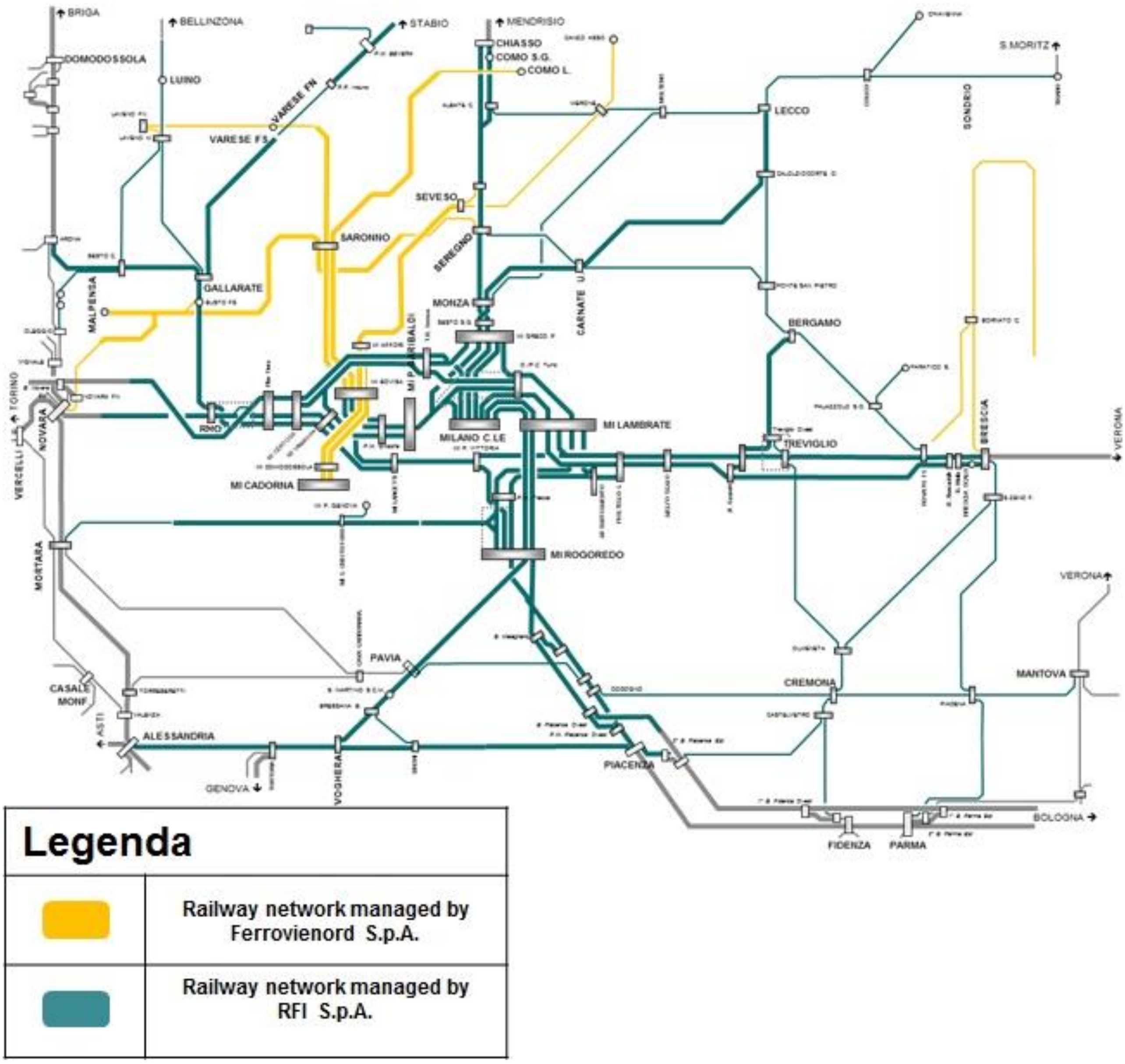

Figure 16: Schematization of Lombardy railway network – Actual layout

The regional lines belonging to the national railway network under the management of RFI are classified in:

- **Fundamental lines**, with an extension of 571 km;
- **Complementary lines**, with an extension of 954 km;
- **Node lines**, with an extension of 211 km,

The railway node of Milan belongs to the national railway network. It is marked by the station of Rho at west, by the stations of Gallarate, Monza and Seregno at north and by the stations of Milano Rogoredo and Milano Porta Romana at south.

The main stations of the node are:

- Milano Centrale: it is the railway hub of the city, a terminus station with seven lines merging to (“Malpensa”, ”Viaggiatori”, ”Chiasso”, ”Circolazione Locomotive”, ”Venezia”, ”Bologna” and ”Genova”);
- Milano Porta Garibaldi: it is the main station of the city for commuter traffic, including both deadlock and passing tracks. Lines “Novara” and “Cintura” merge into the station from west: the first one permits the connections with the station of Milano Certosa, while the second one permits the connections with the station of Milano Bovisa. The lines coming from Milano Greco Pirelli and Milano Lambrate stations merge from east throughout the “Mirabello” junction;
- Milano Certosa: it is the origin of the railway corridor “Passante di Milano” and the line “Cintura”; it is also connected with the station of Milano Bovisa FN (FNM line);
- Milano Lambrate: it is the fourth biggest station of the city of Milan, connected with Milano Centrale station throughout the lines “Venezia”, “Bologna” and “Genova” and with Milano Greco Pirelli station throughout the line “Merci”;
- Milano Rogoredo: it includes deadlock tracks dedicated to suburban services and eight passing tracks; it is the junction station for the lines Lodi-Piacenza-Bologna and Pavia-Arquata-Genova.

In Figure 17, the schematization with the lines of Milan railway node according to the classification reported above.

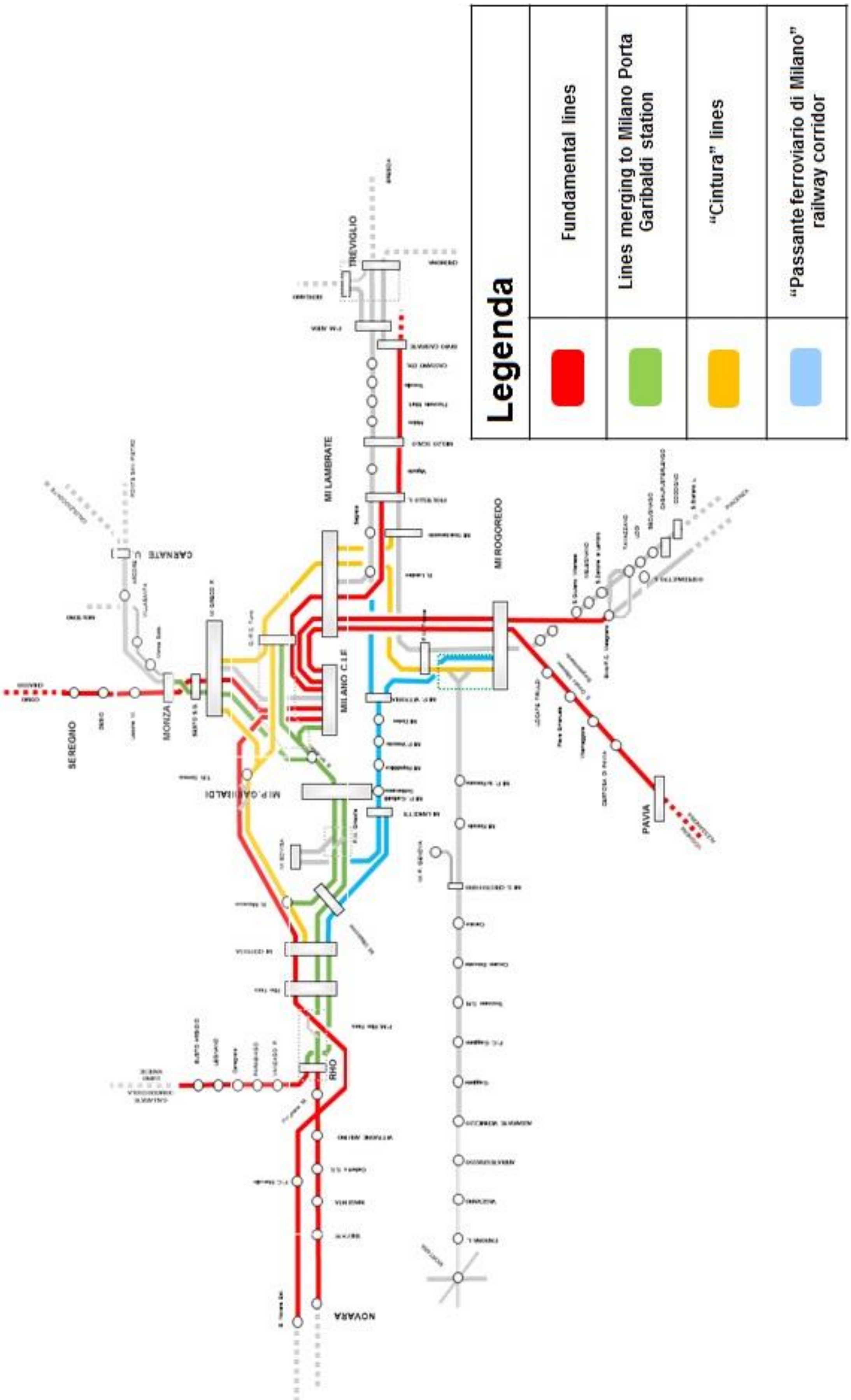

Figure 17: Lines of Milan railway node

4.2 THE DOMODOSSOLA-MILANO LINE

4.2.1 Description of the line

The RFI line Domodossola-Milano is one of the main Italian and international lines as well as one of the main congested lines for passenger and freight traffic. The line is a portion of the international Simplon line connecting Milan with the city of Domodossola and successively with the city of Brig, in Switzerland. From there, it is possible to have connections with Paris (via Lausanne), Genève and Bruxelles (via Basel and Luxembourg).
The first part Milano-Rho was introduced in 1858 and then the line was extended in successive sections up to Gallarate (1860), Sesto Calende (1865), Arona (1868) and finally Domodossola (1905). The electrification of the line (3 kV D.C.) was started in 1905.
Actually, the line has a double-track layout for all its extension. In Figures 18 and 19 the map of the line and its schematization reporting the main stations.

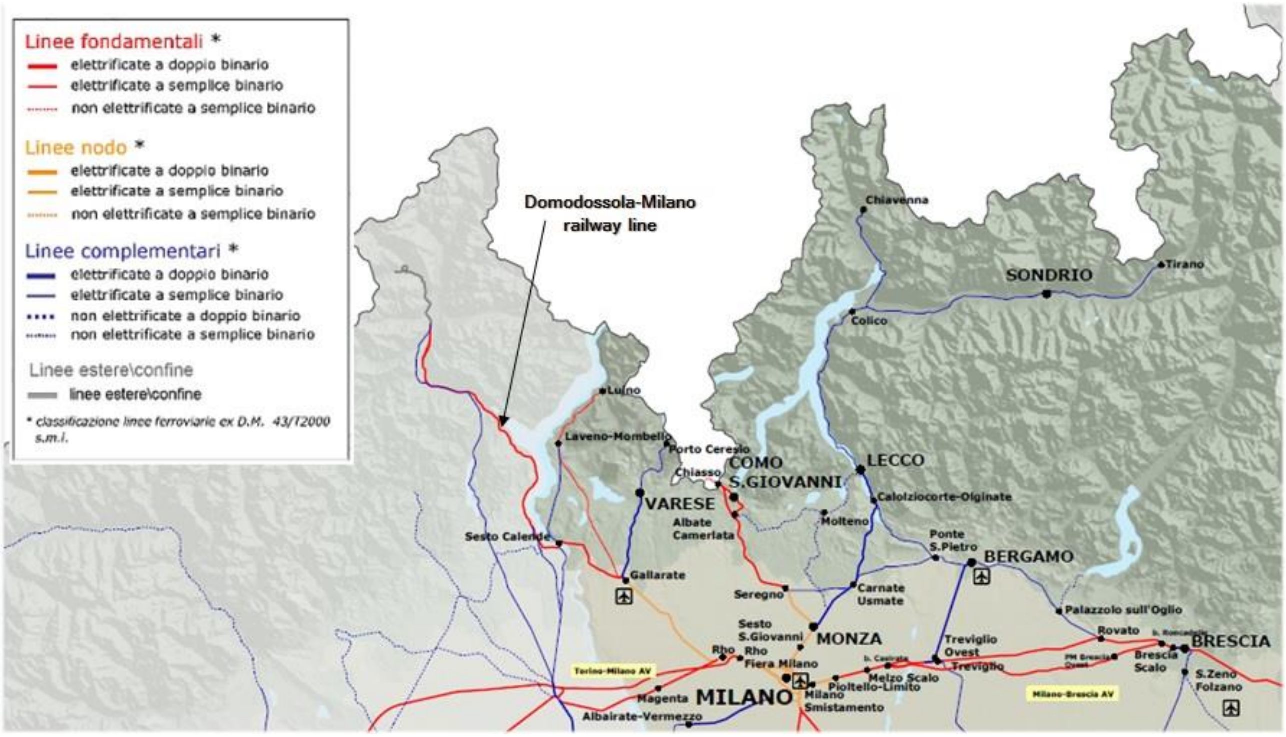

Figure 18: Domodossola-Milano railway line

As showed by Figure 19, in correspondence of the junction station of Rho, the line splits in two different branches called “Novara” and “Varese” lines. On the “Novara” line are normally running “fast” trains with origin/destination Milano Porta Garibaldi and by trains from/to “Linea Cintura”. On the “Varese” line are running suburban services from/to the railway corridor “Passante di Milano”. “Fast” services from/to Milano C.le run the line “Viaggiatori” that merges to the line “Novara” in correspondence of Rho Fiera station.

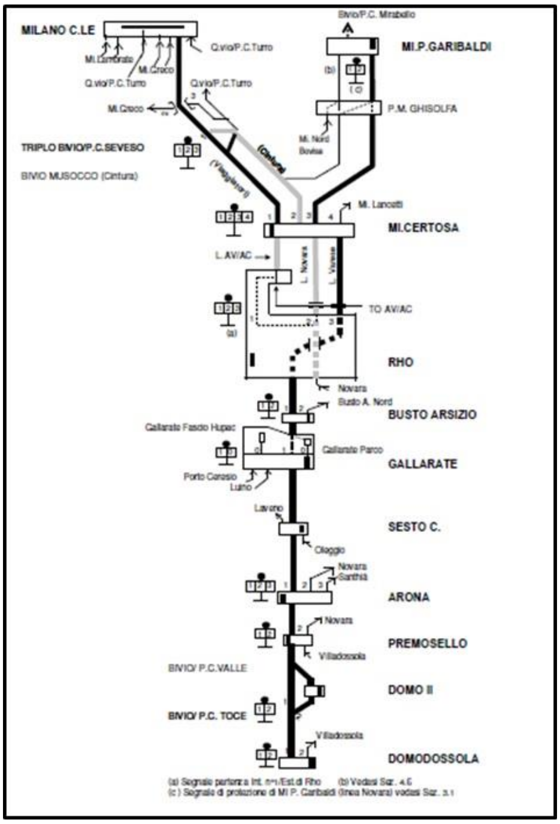

Figure 19: Schematization of the line Domodossola-Milano

The main sections of the line involved in the upgrade projects are Sesto Calende-Gallarate and Gallarate-Rho. The first section is involved in the project of realization of the new connection T2-Gallarate while the second one is involved in the projects for the realization of a new 4-track layout.

4.2.2 Sesto Calende-Gallarate section

This section has a length of about 17 km, and it includes the following service points:

- Sesto Calende: station;
- Vergiate: stop;
- Somma Lombardo: station;
- Casorate Sempione: stop;
- Gallarate: station.

Figure 20 shows a schematization of the line section between Sesto Calende and Gallarate stations. Figure 21 focuses on the line speed of the section and on information about block sections and related kilometer points.

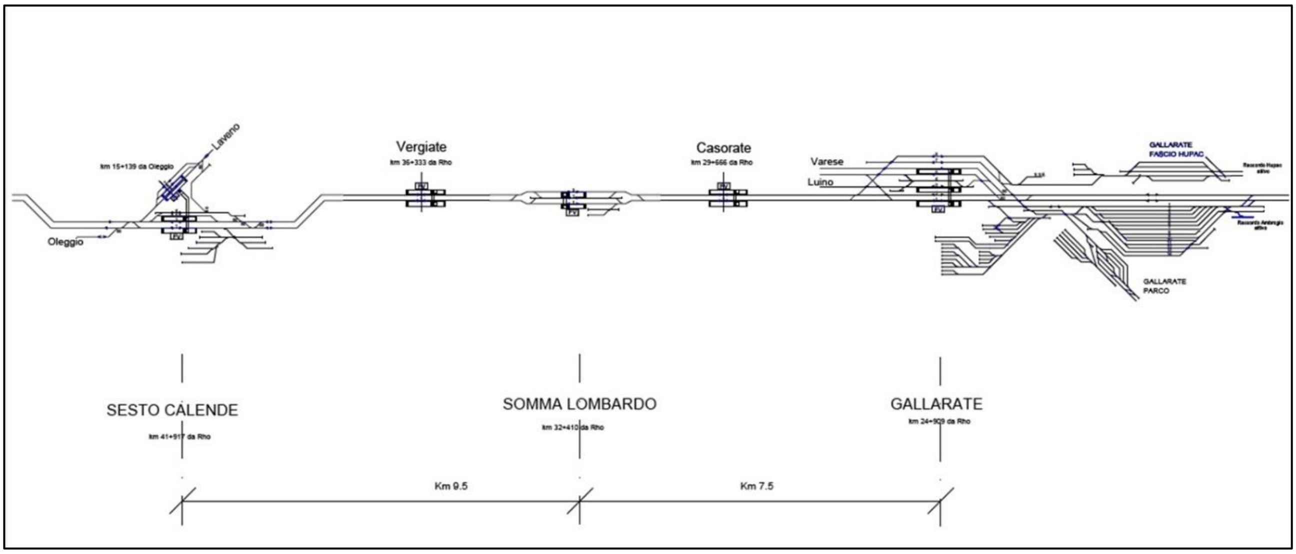

Figure 20: Layout of the section Sesto Calende-Gallarate

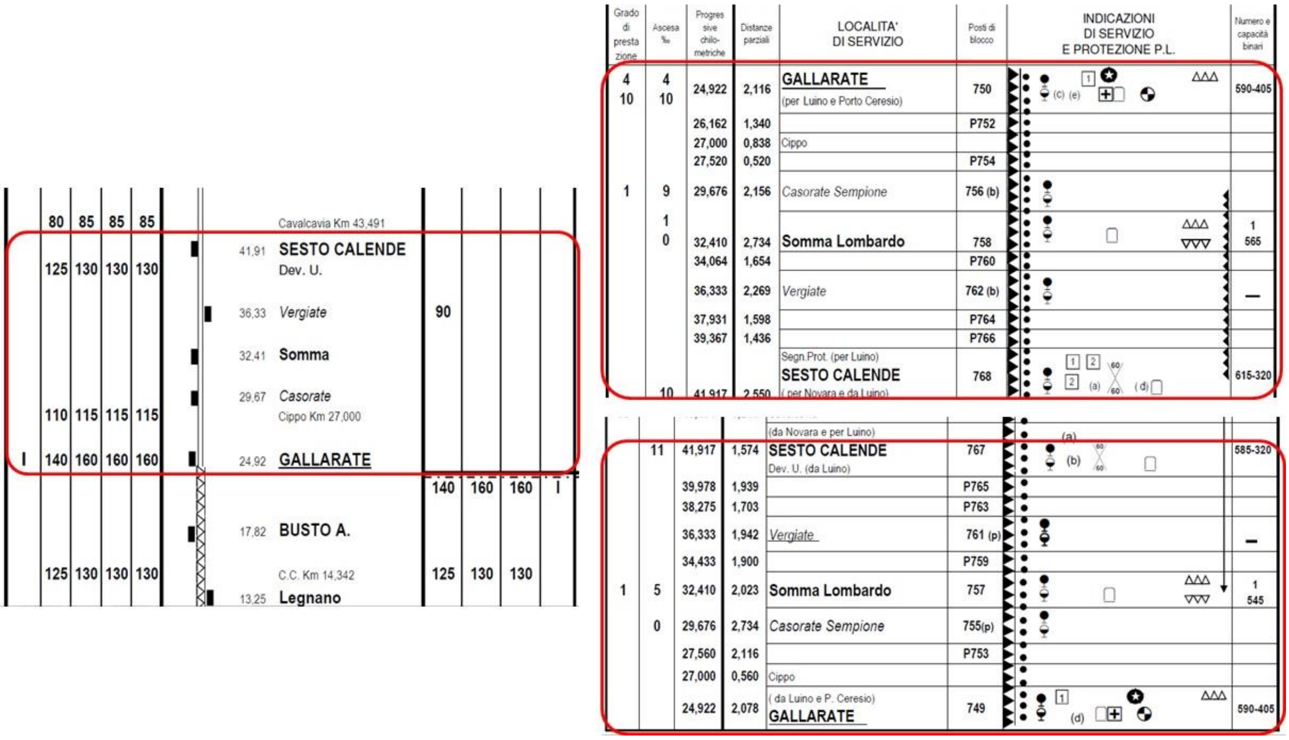

Figure 21: Line speed and block sections - Sesto C.-Gallarate

4.2.3 Gallarate-Rho section

This section has a length of about 25 km and includes the following service points:

- Gallarate: station;
- Busto Arsizio: station;
- Legnano: station;
- Canegrate: stop;
- Parabiago: station;
- Vanzago/Pogliano: station;
- Rho: station.

Figure 22 shows a schematization of the line section between Gallarate and Rho stations. Figure 23 focuses on the line speed of the section and on information about block sections and related kilometer points.

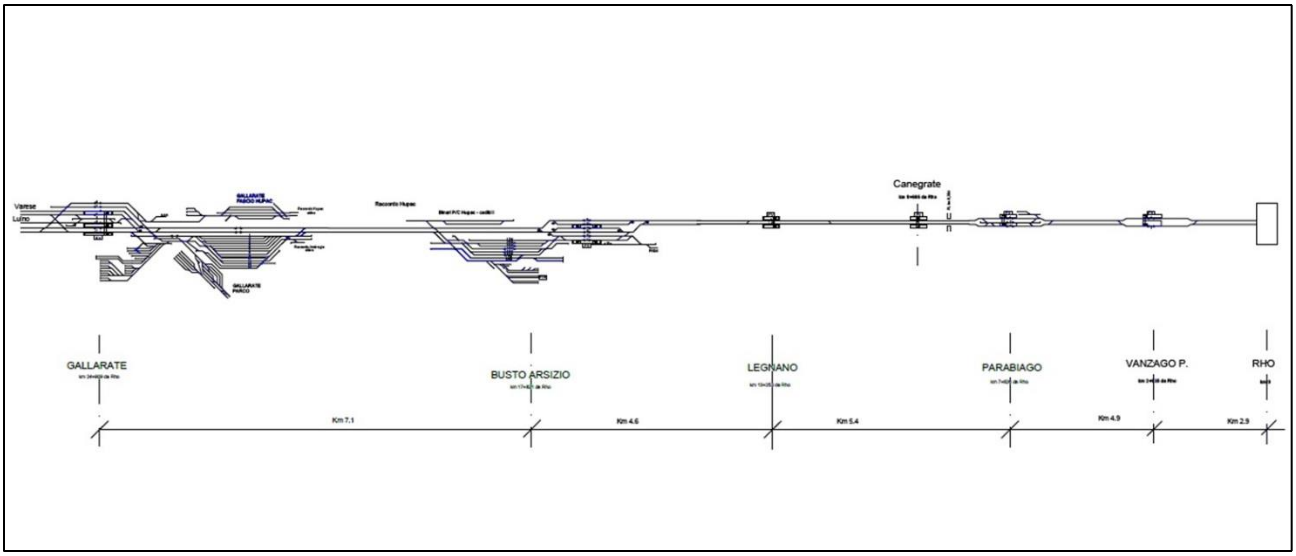

Figure 22: Layout of the section Gallarate-Rho

Grado di frenatura	Velocità max Km/h DIRETTA A	B	C	P	Grado di frenatura	Velocità max Km/h DIRAMATA A	B	C	P	Prog. Chilom.	LOCALITA' DI SERVIZIO	Velocità max Km/h DESTRA/ILLEGALE A	B	C	Grado di frenatura
Ia	120 140	130 160	— 160	— 160						16,34 / 12,62	RHO Dev. U	120 140	130 160	— 160	Ia
										2,93	Vanzago				
										7,82	Parabiago				
										10,25	Canegrate				
	125	130	130	130							Dev. I	125	130	130	
										13,25	Legnano				
	140	160	160	160							C.C. Km 14,342	140	160	160	
										17,82	Busto A.				
III	110	115	115	115						24,92	GALLARATE	90	—	—	III

Grado di prestazione	Ascese ‰	Progressive chilometriche	Distanze parziali	LOCALITA' DI SERVIZIO	Posti di blocco	INDICAZIONI DI SERVIZIO E PROTEZIONE P.L.	Numero e capacità binari
1	0	24,922	1,249	(da Luino e Porto Ceresio) GALLARATE	749	(a) 1 (b)	590-405
		21,922	3,000		P747		
		20,936	0,986		P745		
		17,821	3,115	BUSTO ARSIZIO (per Busto A. Nord)	743	1 (c)	620-300
		16,020	1,801		P741		
		14,342	1,678	C.C.			
		13,253	1,089	Legnano Dev. U.	739(p)	(b)	—
		11,600	1,653		P737		
		11,540	0,060	R.T.B.		Collegato con segn. part.za Parabiago	
		10,259	1,281	Canegrate			
		10,089	0,170		P735		
		8,384	1,705	P.L.		Segn. prot. Parabiago	
		7,826	0,558	Parabiago	733		1 445
		6,370	1,456		P731		
		5,013	1,357		P729		
		2,935	2,078	Vanzago- Pogliano	727		—
		1,820	1,115		P725		
	3	12,628 / 16,348	3,015	(da Torino) Dev. I. RHO		3 60 (e)	565-270

Grado di prestazione	Ascese ‰	Progressive chilometriche	Distanze parziali	LOCALITA' DI SERVIZIO	Posti di blocco	INDICAZIONI DI SERVIZIO E PROTEZIONE P.L.	Numero e capacità binari
4	0 5	12,628	—	RHO Dev. U (per Novara)	722	2 (a) 60 G 40 9	570-270
		0,795	1,985		P724		
	6	2,935	2,140	Vanzago-Pogliano	726		—
		4,466	1,531		P728		
		4,230	0,236	R.T.B.		Collegato con segn. part.za Parabiago	
		5,816	1,596		P730		
		7,826	2,010	Parabiago	732		1 445
		8,384	0,558	P.L.		Segn. part. Parabiago	
		9,498	1,114		P734		
		10,259	0,761	Canegrate			
		10,862	0,603		P736		
		13,253	2,391	Dev.I Legnano	738(p)		—
		14,342	1,089	C.C			
		15,265	0,923		P740		
		17,821	2,556	(da Busto A. Nord) BUSTO ARSIZIO	742	(b)	620-300
		19,802	1,981		P744		
		20,896	1,094		P746		
10	4 10	24,922	4,026	GALLARATE (per Luino e Porto Ceresio)	750	1 (d) (c) 40 8.5	575-390

Figure 23: Line speed and block sections - Gallarate-Rho

4.3 THE SEREGNO-BERGAMO LINE

The line Seregno-Bergamo, managed by RFI, has a length of about 40 km. The line was originally designed with the aim to connect the city of Bergamo with the international Gotthard line after the decision to not extend the line Lecco-Chiavenna through the Splügen and the successive connection with the Switzerland. The first section Bergamo-Ponte San Pietro originated in 1863 and then the decision to extend the line via Seregno followed, after several projects. The section Seregno-Carnate originated in 1888 and then the section Carnate-Ponte San Pietro in 1889. In 2017 a new stop was introduced: Bergamo Ospedale.

The line has a single-track layout and it is electrified at 3 kV D.C. The section Seregno-Carnate includes the stops of Macherio-Sovico and Lesmo; the section Carnate-Bergamo includes the stops of Paderno-Robbiate, Calusco, Terno, Ponte San Pietro and Bergamo Ospedale. The line includes three bridges; the most famous is the "San Michele" bridge over the Adda River. In Figure 24 is reported the map of the line and in Figure 25 the schematization of the line.

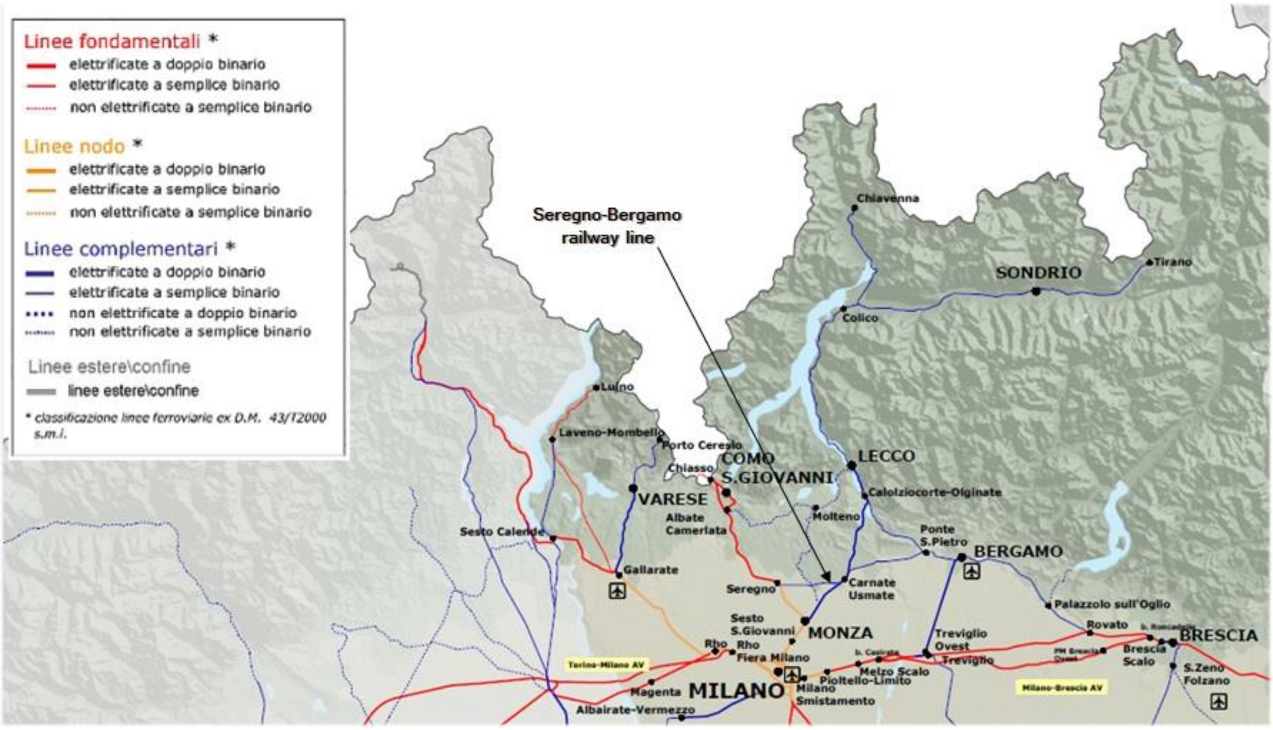

Figure 24: Seregno-Bergamo railway line

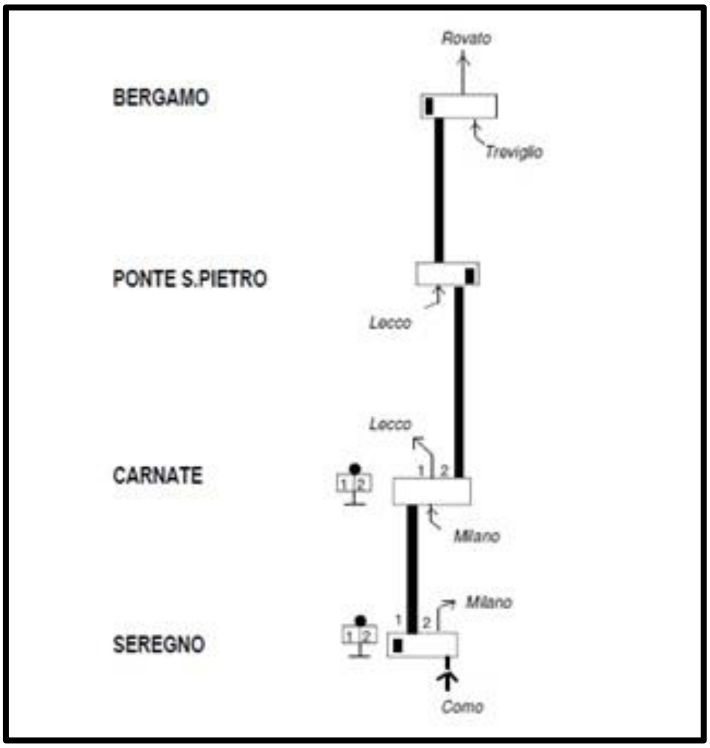

Figure 25: Schematization of Seregno-Bergamo line

Seregno is a junction station connecting the RFI lines Milano-Chiasso and Seregno-Bergamo with the FNM line Seregno-Saronno. Carnate is another junction station in correspondence of the RFI lines Milano-Monza-Lecco and Seregno-Bergamo. In correspondence of the station of Ponte San Pietro, there is the junction between the lines Lecco-Bergamo and Seregno-Bergamo.

In Figure 26, the layout of the section between Seregno and Ponte S. Pietro stations.

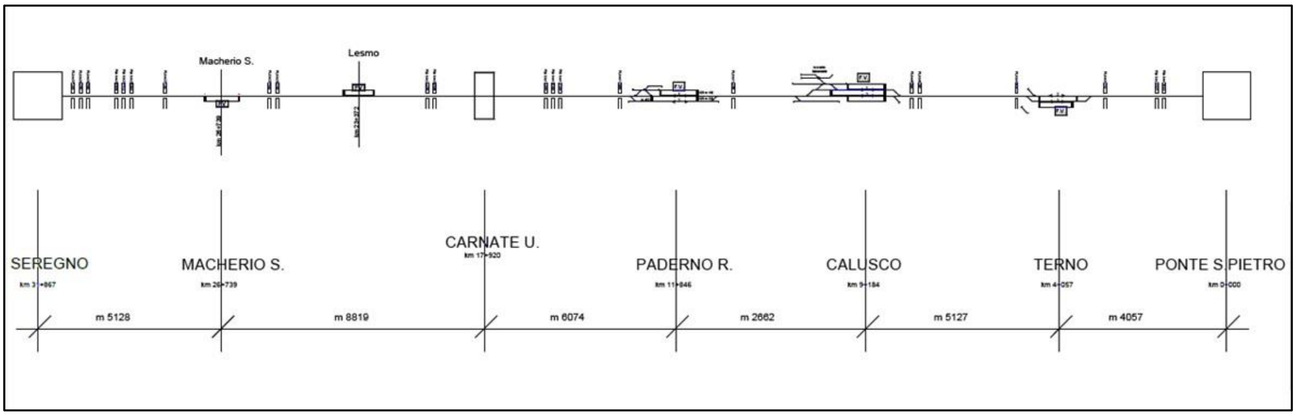

Figure 26: Layout of the section Seregno-Ponte S. Pietro

In Figure 27, it is reported the schematization with information about line speed according to the train category, block sections and related kilometer points.

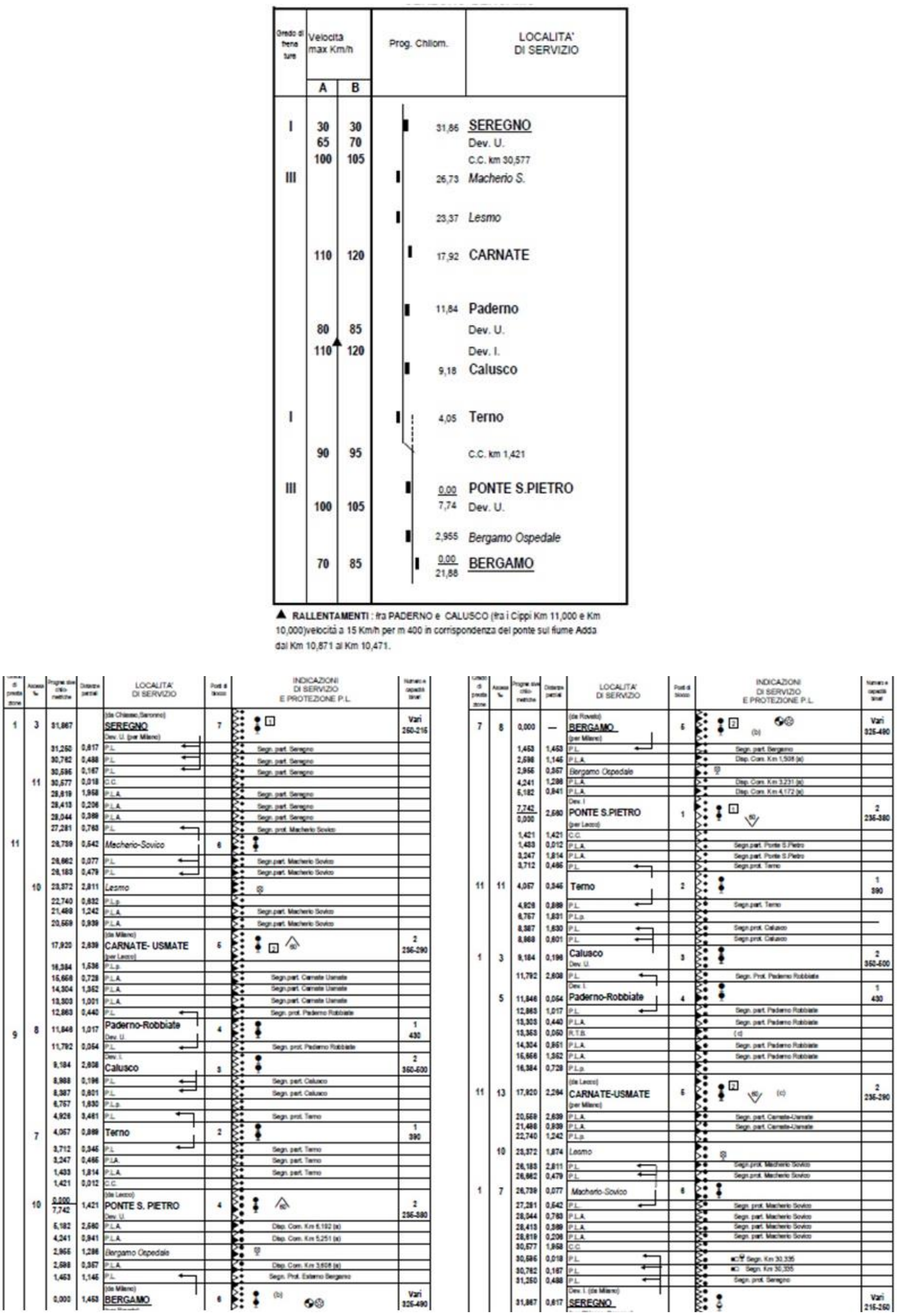

Figure 27: Line speed and block sections kilometer points - Seregno-Bergamo line

4.4 ACTUAL RAILWAY SUPPLY MODEL

4.4.1 "Accordo Quadro per i servizi di trasporto pubblico locale"

A Transport System can be defined as a set of entities and of relationships between them, from which the mobility demand as well as the related supply of transport services (addressed to satisfy that demand) have their origin. Therefore, a transport company (public or private) according to the needs expressed by local public entities must supply these services.

In Italy, the railway supply is stipulated by means of an agreement between the infrastructure manager Rete Ferroviaria Italiana RFI S.p.A. and the regional government called *Accordo Quadro per servizi di trasporto pubblico locale.* This document presents a series of attachments (in Italian "Allegati") with the main information about the railway supply:

- "Allegato A": it reports the characteristic parameters of the infrastructural capacity; it synthetizes all the services supplied, the characteristics of vehicle fleet, the frequency and the number of trains per hour per day for each service;
- "Allegato B": it reports the minimum services that the infrastructure manager must supply to all railway companies with assigned train paths;
- "Allegato C": it reports the average tolls imposed by the agreement;
- "Allegato D": it reports the guide lines for the upgrade of "Allegato A" with future scenarios;
- "Allegato E": it individuates the additional structures (e.g. depots) and services for the production of the assigned capacity;
- "Allegato F": it reports the average reference commercial speed of the services.

4.4.2 Classification of passenger services

Services are classified in different categories according to the commercial needs, the area supplied and the commercial speed. In Italy, the passenger services are classified in:

- High speed services AV/AC with different commercial denomination (TRENITALIA "Frecciarossa" and "Frecciargento" and ITALO) connecting the main cities throughout the Italian AV/AC network with high commercial speed;
- Long-haul services ("Frecciabianca", "Intercity" and "IntercityNotte") circulating on the historical railway network and connecting the medium-big Italian cities with a good commercial speed;
- Regional and local services supplying the urban and suburban areas of the Italian provinces; they are characterized by medium-low commercial speed stopping in all the stations;
- Euro City and Euro Night services EC/EN carrying out international railway connections with France, Switzerland, Austria and Germany.

4.4.3 Actual regional railway supply model

In Lombardy, regional services are classified in:

1. **Suburban services "S"** with high and constant intervals (30′-15′), stopping in all the stations of the urban area (supplying the railway corridor "Passante ferroviario di Milano") and connecting the hinterland with the city center;
2. **Secondary Regional services "R"** with intervals of 60′-30′, connecting the province (stopping in all the stations out of the hinterland) with the city center (Milano P. Garibaldi and Milano Greco Pirelli);
3. **Primary Regional services RegioExpress "RE[7]" and fast Regional services "RV"** with intervals of 60′-30′, high commercial speed with a low number of stops and

[7] RegioExpress: this train category indicated as RE is used in Lombardy by regional railway company TRENORD and it identifies regional trains which stop only in main stations at regional level. This designation corresponds to Fast Regional trains RV of the Italian Train Operator TRENITALIA

connecting main provincial cities with Milan (arriving at Milano Centrale or Milano Porta Garibaldi);

4. **Regional services "Rspot"** consisting of additional trains in peak hour to strengthen the supply.

The figures 28, 29 and 30 (reported in "Allegato A" of *Accordo Quadro* document) present the actual railway supply for the railway node of Milan, for the railway corridor "Passante di Milano" and for the section Rho-Gallarate.

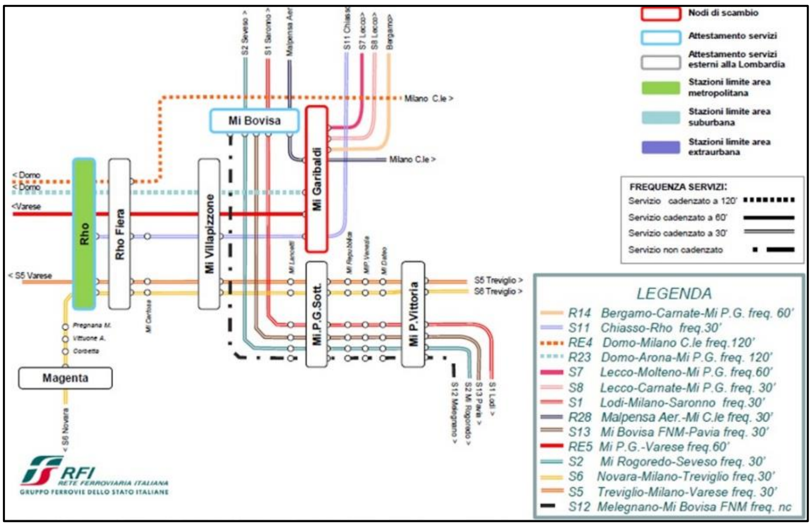

Figure 28: Actual system of services - railway node of Milan – 1

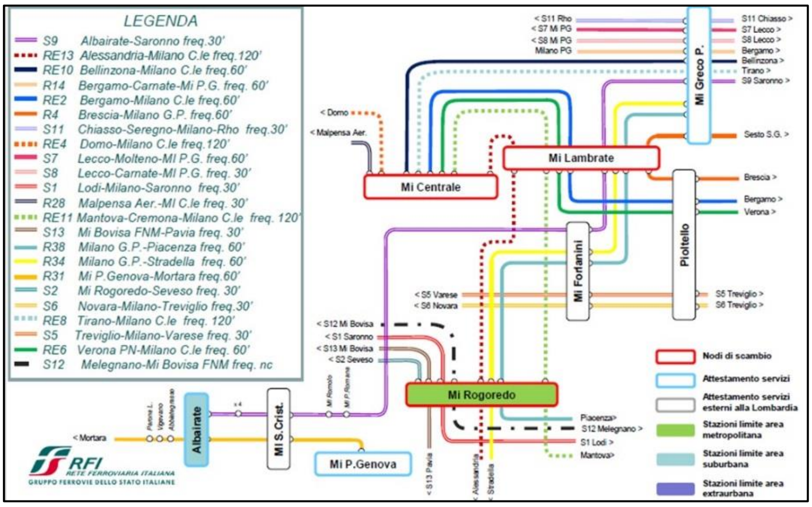

Figure 29: Actual system of services - railway node of Milan - 2

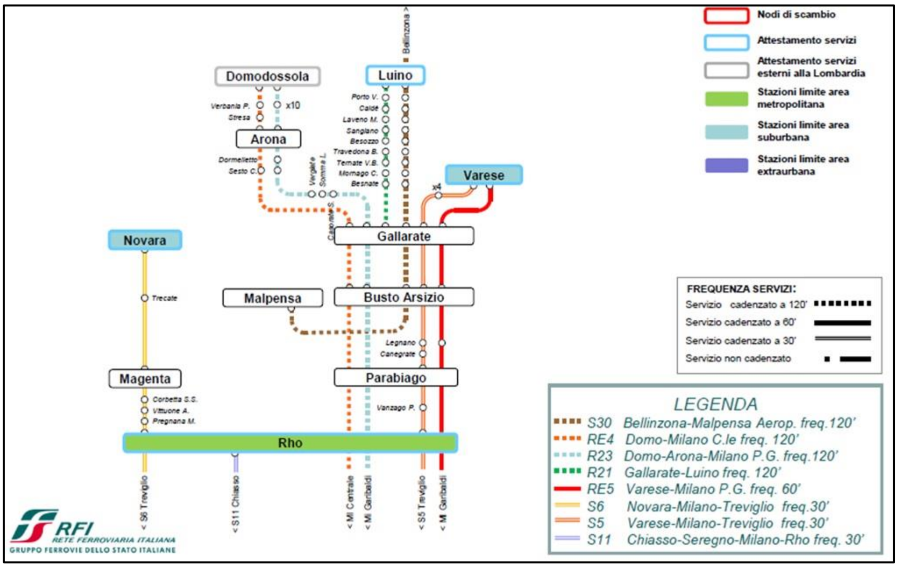

Figure 30: Actual system of services - Rho-Gallarate section

The actual railway supply has to consider also the international services from/to Milano Centrale, in particular, SBB EC services Milano Centrale – Domodossola – Genève/Basel (intervals: 60’ in peak periods and 120’ off-peak) and Milano Centrale – Domodossola – Frankfurt (one train per day per direction).

Service S30 Bellinzona-Malpensa Airport is not actually implemented. The realization of the line segment Arcisate-Stabio implies the realization of a suburban service called S40 Albate-Mendrisio-Varese-Malpensa Airport with 60’ intervals.

The intervals of services RE4 Milano Centrale-Domodossola are actually 60’ in peak periods; the interval of services R23 and R21 is 60’ daily.

The section Rho-Gallarate is involved by freight traffic represented by services from/to:

- Domo II-Gallarate (from/to intermodal terminals HUPAC and Ambrogio);
- Luino-Sesto Calende-Gallarate;
- Luino-Ternate-Gallarate;
- Domo II-Milano Lambrate;
- Busto Arsizio-Milano Lambrate.

The localities reported above could be not the origin or the final destination of the freight trains (the path reported is only that interesting the study network). Other freight services are in operation among Novara, Trecate and Milano Lambrate. Normally, the frequency of these trains is in rides per hour.

For the Seregno-Bergamo line, the actual railway supply is synthetized in Figure 31 (reported in “Allegato A” of *Accordo Quadro* document).

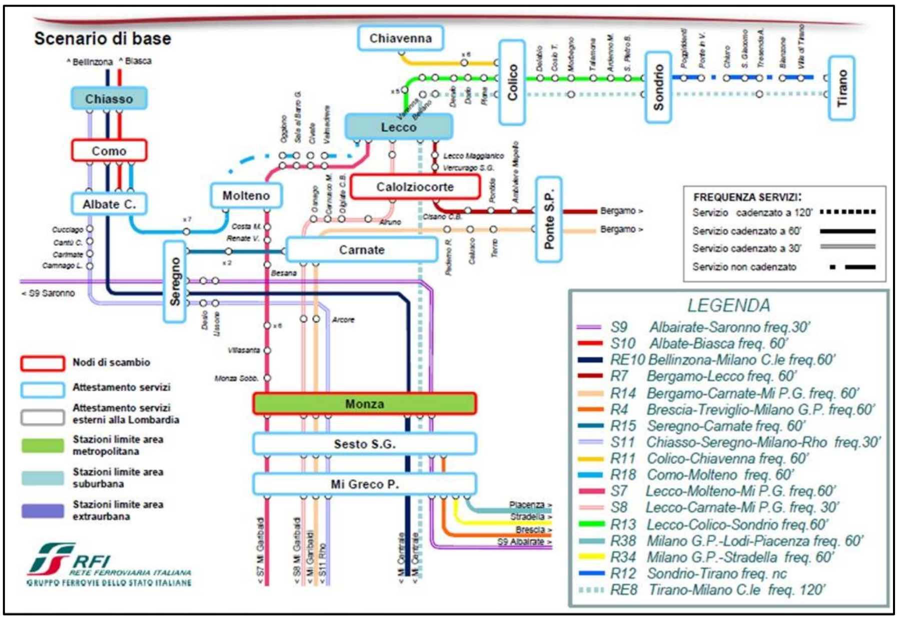

Figure 31: Actual system of services - Lombardy north area

The services directly affecting the traffic in the Seregno station are:

- EC Milano – Chiasso – (Switzerland) (intervals: 60’ peak – 120’ off-peak);
- S9 Albairate – Saronno;
- RE10 Bellinzona – Milano Centrale;
- R15 Seregno – Carnate;
- S11 Chiasso-Seregno-Milano Porta Garibaldi-Rho;

The services of study interest for the line Seregno-Bergamo are:

- R7 Bergamo-Lecco;
- R14 Bergamo-Carnate Usmate-Milano Porta Garibaldi;
- R15 Seregno-Carnate.

Freight services (not reported in Figure 31) interesting for the study are:

- Chiasso-Milano Lambrate;

- Chiasso-Carimate/Desio;
- Chiasso-Lecco Maggianico.

5 THE FUTURE INFRASTRUCTURAL LAYOUT

This chapter is dedicated to the description of the future infrastructural upgrade projects related to the improvement of the regional railway supply model. These projects are already planned, and they are mentioned in the agreements between the infrastructure manager and the regional government. The Thesis focuses on the line segments Rho-Gallarate-Malpensa and Seregno-Bergamo.

5.1 RHO-GALLARATE-MALPENSA: INFRASTRUCTURAL UPGRADES

According to "Allegato D" of *Accordo Quadro* document, the 2026 regime scenario for the development of the regional railway supply model is depending on the realization of the following upgrade projects:

- **New 4-track layout of the segment Rho-Parabiago on the Domodossola-Milano line**, with the aim to increase the infrastructure capacity and the regularity of the system;
- **PRG[8] of Rho station**, with the aim to eliminate conflicts among station routes;
- **Realization of a new railway stop supplying the town of Nerviano,** along the line Domodossola-Milano at the km point 5+500 from Rho station between Vanzago and Parabiago. The station plan presents four tracks with only the "slow" line tracks equipped with platforms of length 250 m;
- **T2-Gallarate North Railway Link**, with the aim to improve the railway accessibility of Malpensa and to develop the connection between the city of Milan and the airport enlarging its catchment area;

[8] PRG: Piano Regolatore Generale di stazione

- **ACC-M Gallarate-Sesto Calende**, consisting of the substitution of actual station and line technological plants with a new interlocking system, which permits the automatic remote management by the control room of Milano Greco Pirelli. Spacing of the trains is reduced from present 6 minutes to 5 minutes.

5.1.1 Rho-Parabiago segment

A new layout with 4-line tracks has been proposed and designed by the infrastructure manager with the aim to increase the capacity. The capacity increase is realized with the specialization of the line: two tracks reserved for "slow" suburban services stopping in all the stations and two tracks reserved for "fast" trains stopping only in the main stations. The specialization of the line permits to reduce the time lost for speed variability among different services and then to take advantage of infrastructure resources. Moreover, the project plans the introduction of a new railway stop supplying the station of Nerviano. The upgrade has been planned to improve the line up to the station of Parabiago with a subsequent development of a new station layout. Spacing of the trains is regulated by signalling system implemented by sections with a length of 900÷1060 m (4 min headway). This solution is evaluated in a specific scenario, in which the analysis methodology is applied to evaluate the benefits of this upgrade. The infrastructural upgrade permits the improvement of the future regional supply with the introduction of new services.

5.1.2 PRG of Rho station

The upgrade consists of the modification of railway equipment layout with the aim to separate traffic flows from Milano Certosa station to Gallarate/Domodossola and Novara avoiding interferences. Following the line upgrade, the project plans the separation of "slow" and "fast" services to Gallarate. In particular, crossing interferences between flows actually characterizing the Gallarate/Novara side of the station are solvable with the realization of a new overpass for one of the tracks of "Novara" line. In Figure 32, a schematization of the new station layout.

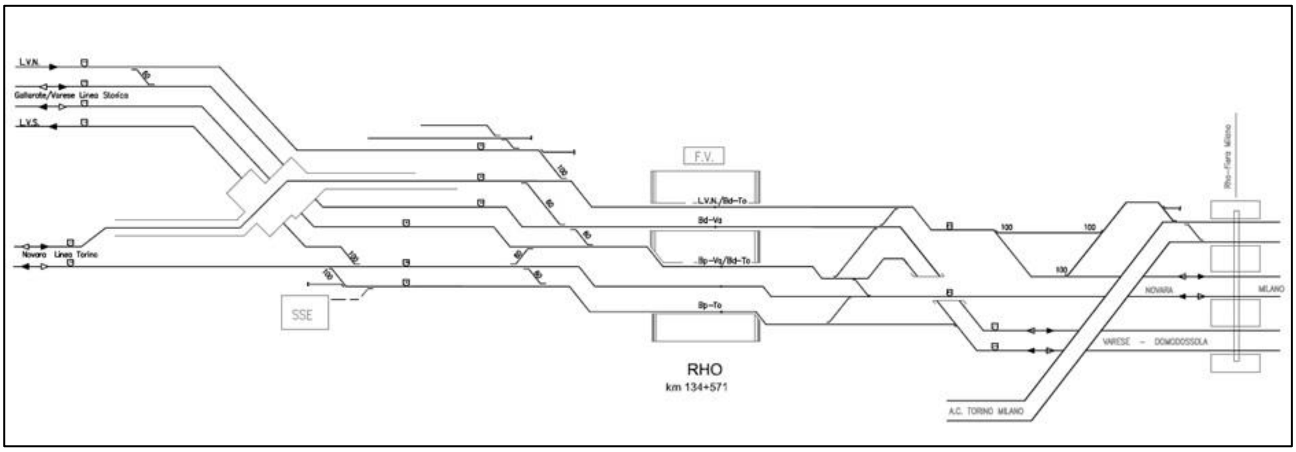

Figure 32: PRG of Rho station

5.1.3 T2-Gallarate North Railway Link

The improvement of the railway supply and the accessibility to Malpensa International Airport passes through the realization of this infrastructure. The definitive project plans the connection between the FNM line supplying Terminal 1 and Terminal 2 of Malpensa with the Simplon line (managed by RFI) completing the north accessibility to the airport.
The new line sections have a length of 4.6 km to Gallarate plus 1.1 km of the link to Casorate Sempione.
The new link originates in correspondence of the actual tracks of the Malpensa Terminal 2 station at the km point 52+073 continuing with the same alignment of the station tracks. After the north root of the station, the line continues with its double-track layout up to the km point 55+441, where is the new Cardano junction. The line tracks remain in direct route to Gallarate, while the deviated route tracks continue to Casorate Sempione with a max permitted speed of 60 km/h. The link with the RFI Simplon line is located in correspondence of the new Casorate junction. The connection with the Simplon line on Gallarate side is by an underpass interchange: the actual tracks are broad with respect to their position making possible the connection of the new tracks in central position between

the existing ones. This solution involves also the alignment of the road "SS 33 del Sempione". In Figure 33 the alignment of the new link, in Figure 34 the schematization of the new junction points.

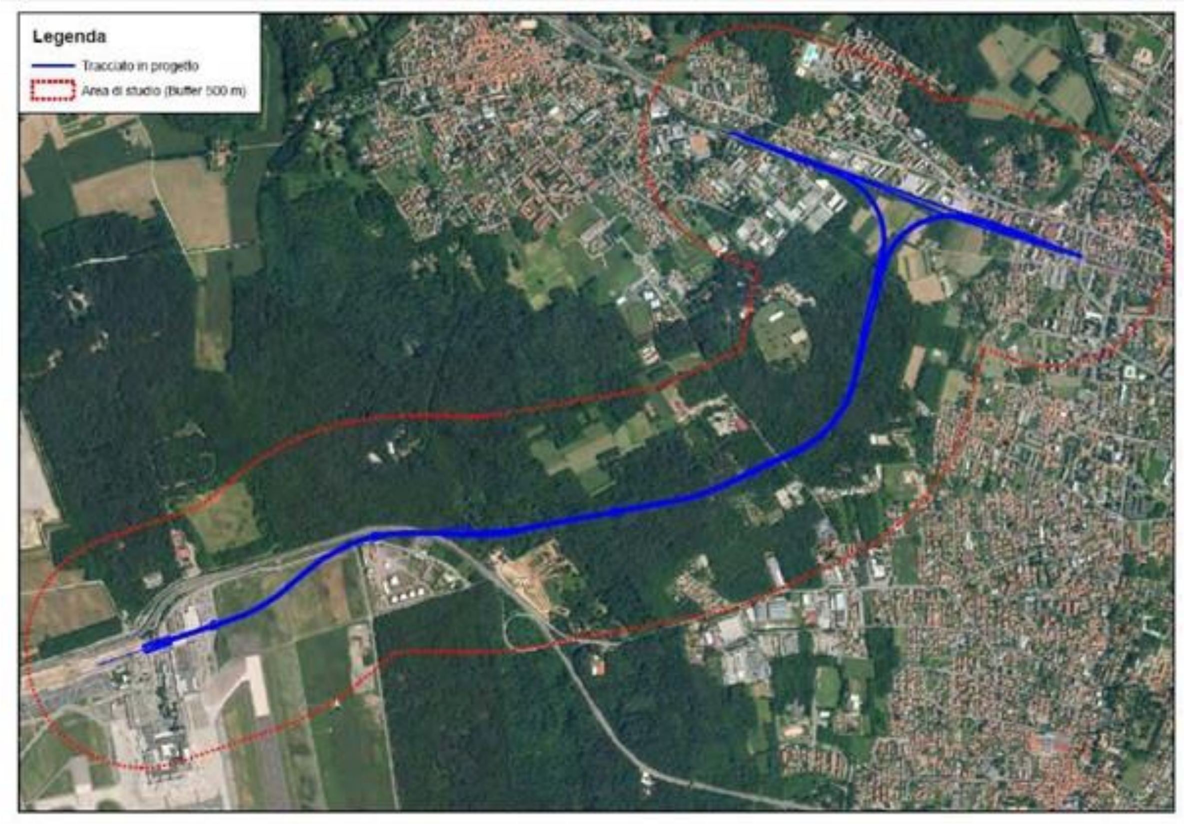

Figure 33: Alignment of the new link T2-Gallarate

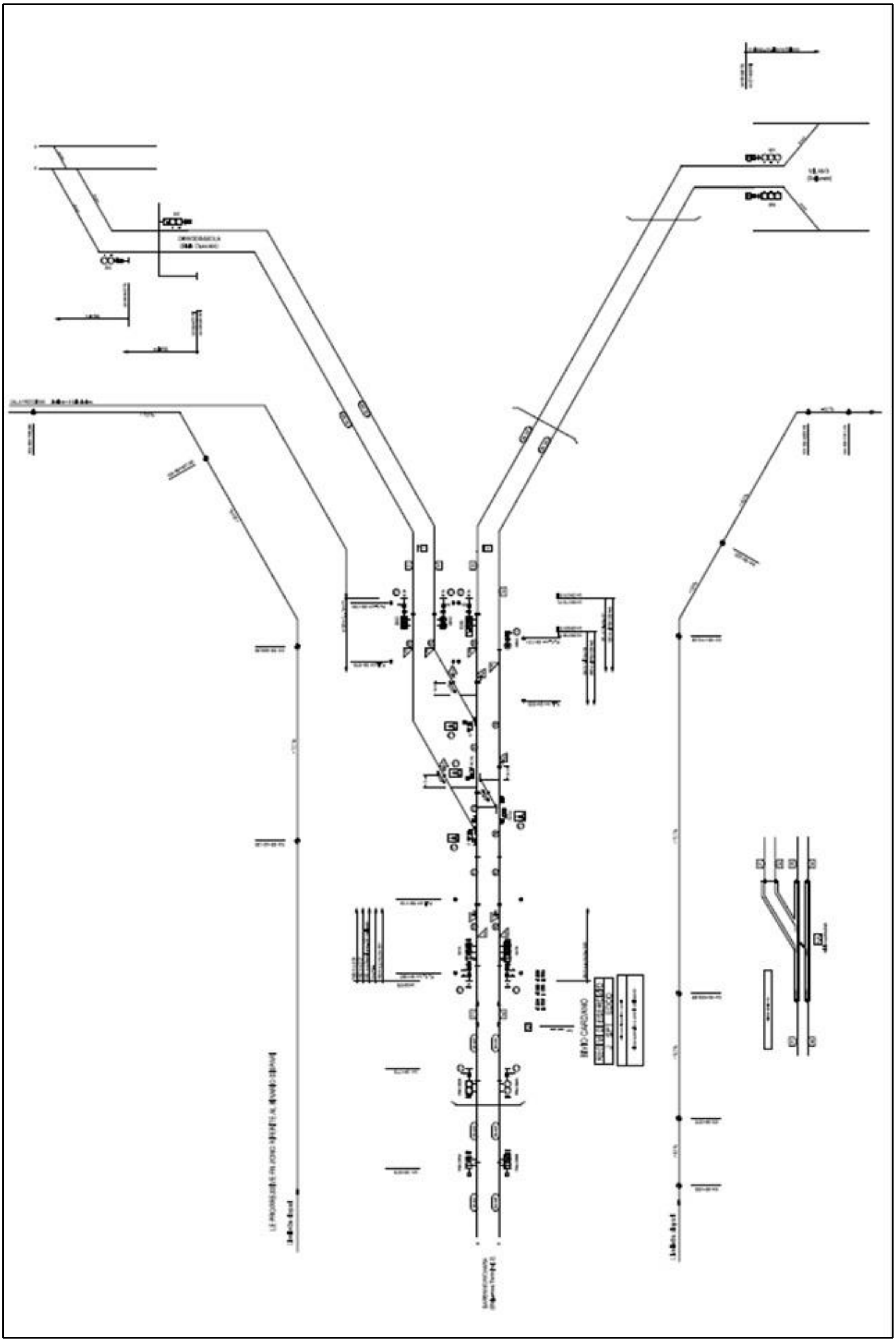

Figure 34: T2-Gallarate link layout

5.1.4 Design phases of the infrastructural upgrade of Rho-Gallarate segment

The infrastructural upgrades of the line Domodossola-Milano involve the segments Parabiago-Rho and Gallarate-Busto Arsizio. The section Gallarate-Rho is under saturation in peak hour and the situation does not permit the introduction of new services from/to Malpensa Airport.

The preliminary project, presented in 2003, had the objective to increase the line capacity and it plans the realization of a third track between the stations of Gallarate and Rho, parallel to the existing line. This upgrade has the objective to increase the capacity with a minimum impact on the urban areas. From an operational point of view, this solution permits to introduce an additional 30% of train paths. The main issue is the utilization of the new track: considering an asymmetric flow of trains between the morning and the evening peak hour of a typical weekday, the third track operates to Milan in the morning peak period and vice-versa in the evening peak.

To solve the operational issues on the use of the third track, the final project presented in 2009 plans the realization of two new tracks between the stations of Rho and Parabiago (a global 4-tracks layout). The connection between Milan and Malpensa is by the realization of a junction called "Raccordo Y". This junction aims to complete the accessibility to Malpensa connecting the RFI line Gallarate-Rho with the FNM line Novara-Saronno.

The final project, approved by *CIPE*[9] in 2010, successively integrated and modified with recommended provisions. The upgrade project plans the introduction of a new stop in Nerviano and a new layout for the stations of Rho, Gallarate, Busto Arsizio and Parabiago; Vanzago and Legnano become stops. Moreover, the project plans a third track between the stations of Gallarate and Busto Arsizio. In Figure 35, a schematization of the line section layout reported in this project.

[9] CIPE: Comitato Interministeriale per la Programmazione Economica

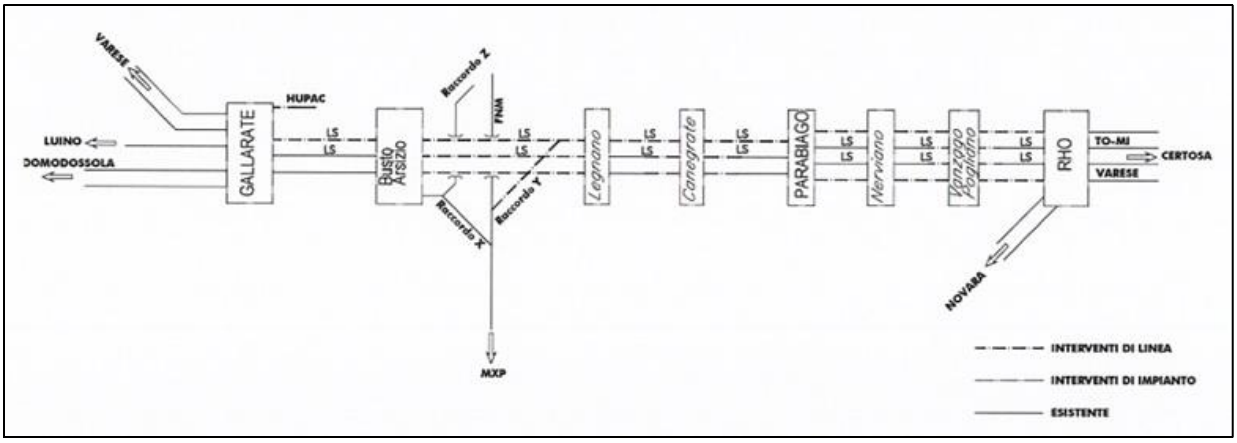

Figure 35: Layout of the line section in 2009 final project

In 2012, a judgment of Lombardy *TAR*[10] accepts an appeal against the upgrade of the line between Parabiago and Rho. This decision involved the cancellation of *CIPE* deliberation stopping the upgrade final project of the line.

In 2014, the organism *CSLP*[11] declared that the upgrade of section Rho-Parabiago must be re-designed with integrations about the consensus of citizens of the towns involved in the infrastructural upgrades and about environmental impacts.

Since 2014, the project is completely stranded. This impasse implies a slowdown of the upgrade process of Gallarate station considered a primary node by *PRMT* for railway traffic. Moreover, this situation implies a postponement of the introduction of new suburban services supplying the area in object.

The realization of T2-Gallarate North Link is not profitable without the upgrade of the Gallarate-Rho section considering that this line segment represents a bottleneck for the development of the connections between Milan and Malpensa Airport.

Actually, the project impasse seems to be finished with a re-evaluation of the infrastructural layouts planned in 2009 final project. In this contest, the upgrade solutions are the realization of the new 4-tracks layout between Rho and Parabiago and the realization of the new link T2-Gallarate. The projects abandoned the junction "Raccordo Y" between Busto Arsizio, Legnano, and the third track between Busto Arsizio and

[10] *TAR*: Tribunale Amministrativo Regionale
[11] *CSLP*: Consiglio Superiore dei Lavori Pubblici

Gallarate. The upgrade of the station layouts proposed in 2009 final projects includes all the possible interventions are subsequent to the line segment upgrade.

Figure 36 reports the main steps of the project process for Gallarate-Rho section upgrades.

Figure 36: Design phases of the infrastructural upgrades of the Rho-Gallarate segment

5.2 SEREGNO-BERGAMO: INFRASTRUCTURAL UPGRADES

As in the previous case, “Allegato D” of *Accordo Quadro* document reports the infrastructural upgrades necessary for the improvement of the railway supply. The only upgrade projects of study interest is the realization of a **new double-track line layout in the segment Montello-Bergamo-Ponte San Pietro.** The aim is to increase the infrastructural capacity with the possibility to increase the number of services and to speed the existing ones.

6 FUTURE RAILWAY SUPPLY MODEL

This chapter presents the development of the future railway supply. Obviously, all the modifications here reported must be put in relation with the infrastructural upgrades mentioned in the previous chapter. As in the previous case, the paper focuses on the services operating on the line segment Rho-Gallarate-Malpensa and Seregno-Bergamo.

6.1 POSSIBLE IMPROVEMENT OF THE REGIONAL RAILWAY SUPPLY

The development of the regional railway supply is reported in "Allegato D" of *Accordo Quadro* document. In this part, all the future scenarios subsequent to infrastructural upgrades are described.

6.1.1 Rho-Gallarate-Malpensa: possible supply development

The future services considered in this study are included in 2026 railway supply in its regime phase. With respect to the actual one, the future supply plans the introduction of new suburban services:

- **S14 Milano Rogoredo - Milano Passante - Magenta** (daily interval: 30');
- **S15 Milano Rogoredo - Milano Passante - Parabiago** (daily interval: 30');
- **S16 Abbiategrasso - Milano Lambrate - Parabiago** (daily interval: 30');
- **S12 Melegnano - Milano Passante - Cormano** (systematization of the 30' interval in peak periods).

Moreover, the future supply plans the following service extension:

- **S11: extension up to Parabiago with daily interval 30'**.

The suburban services S14 and S15 are mainly involved in the improvement of the supply given by the corridor "Passante Ferroviario di Milano". The introduction of these new services, together with the introduction and the modification of other ones (new service S12 Melegnano - Milano Passante - Cormano with interval 30′ and extension of the services S2 and S13) permits to reach the following objectives:

- To ensure a supply composed by 16 trains/h in the corridor Milano Lancetti - Milano Porta Vittoria with an average headway of 4′ increasing the number of passengers/h to 20.000÷25.000 per direction;
- To obtain an average interval of 15′ for all the lines merging to the corridor "Milano Passante";
- To increase the possibility of interchange among suburban, regional and long-haul services.

For what concern the development of the connection between the city of Milan and Malpensa Airport, new future planned services are:

- **RE MXP Milano Centrale – Milano Porta Garibaldi – Rho – Gallarate – Malpensa** (daily interval 30′) in substitution of actual RE MXP Milano Centrale - Milano Porta Garibaldi - Milano Bovisa FN - Malpensa (via FNM line);
- **Modification of the actual service S5 Treviglio – Milano Passante – Varese in Treviglio – Milano Passante – Rho – Gallarate – Malpensa** (daily interval 30′).

The introduction of these new services is subsequent to the realization of the new link T2-Gallarate. These services represent the possibility to improve Malpensa railway accessibility, with the possibility to enlarge the railway catchment area of the airport.

The actual railway supply offers two different express services connecting Milan with Malpensa Airport:

- RE Milano Cadorna FN - Malpensa T2 (via FNM line), with interval 30′;
- RE Milano Centrale - Milano Bovisa FN - Malpensa T2, with interval 30′.

The first service is completely on FNM network, while the second one is on RFI network between Milano Centrale and Milano Porta Garibaldi continuing on FNM network from Milano Bovisa FN. The solution adopted for the planning of the future supply here reported, is to maintain the MXP service Milano Cadorna FN - Malpensa T2 with interval 30′ and to modify the actual MXP service from Milano Centrale with a new path via Rho - Gallarate with interval 30′. The choice of Milano Centrale station as city terminal to ensure the interchange and correspondences with all the services leading to (regional, IC and high-speed services). The original solution plans a MXP service from Milano Centrale routed on “Linea Cintura” and continuing its run on “Linea Novara” to Rho. Certainly, the route via “Linea Cintura” is faster than the route to Milano Porta Garibaldi considering the passage in correspondence of the junction point “Bivio Mirabello” characterized by congestion and low maximum run speed. The travel times of the solution via “Cintura” are estimated in 32′ to Malpensa Terminal 2 and 36′ to Terminal 1 against the current travel time of 57′ (to Malpensa T2). This solution excludes completely Milano Porta Garibaldi station that represents an important interchange node with suburban services (“Passante Ferroviario di Milano” and services S7, S8, S11) and regional services. Moreover, the station supplies the CBD of Milan.

So, the solution here presented considers a service from Milano Centrale to Malpensa via Rho-Gallarate stopping in Milano Porta Garibaldi. This choice implies an increase in the travel time up to 53′ (considering the railway traffic and the presence of other trains).

Another important pro for the introduction of a service Milano Centrale - Malpensa via Rho-Gallarate is the possibility to supply the fair center of Rho-Pero through the station of Rho Fiera. Actually, the regional railway supply does not plan a direct service between Rho Fiera and Malpensa. The possibility of a “fast” service without changes between the fair center and the airport is an important opportunity to shift demand from road transport (shuttle services from/to Malpensa) to railway transport. In this way the importance of the station of Rho Fiera as “door” station increases with the possibility of interchange between Malpensa connections and “fast” services from/to the west area (Novara, Turin). The estimated travel time between Rho Fiera and Malpensa T2 is 30′.

Clearly, the introduction of this service is strictly connected to the realization of infrastructural upgrades of the section Rho-Gallarate. Moreover, it is necessary to ensure cost-effective fees with respect to the road services from Milano Centrale to increase the attractiveness of railway services.

Considering the local catchment area of the airport, the service modified is the suburban S5 Varese-Treviglio. The service path is deviated to Malpensa via T2-Gallarate link.

The actual service path is very long considering the extension from Treviglio to Varese via Milano Passante corridor. A good designed supply should plan two different services: one between Treviglio and Gallarate and another one connecting Gallarate and Varese. The actual infrastructural layout does not permit the introduction of new services.

So, with the future infrastructural upgrades is possible to ensure a development of services RE5 Milano Porto Garibaldi - Varese - Porto Ceresio with interval 30′. The service S40 ensures connection between Varese area and the airport. With this configuration, it is possible to extend the service from/to Malpensa. The intervals are the typical suburban ones (30′) with 18÷19 service hours covered. The line shows a potential catchment area about connections with Malpensa airport up to 615,000 users considering the North-West area of Milan supplied by the stations of Rho and Gallarate. Without any exact demand projection, it is possible to believe that the marginal costs derived by the extension of the service could be covered by the incomes derived by an increase of the demand.

The future system of services supplying the line segment Rho-Gallarate-Malpensa may be synthetized by the Figure 37. This schematization considers the upgrade of the segment Rho-Parabiago and the realization of T2-Gallarate link.

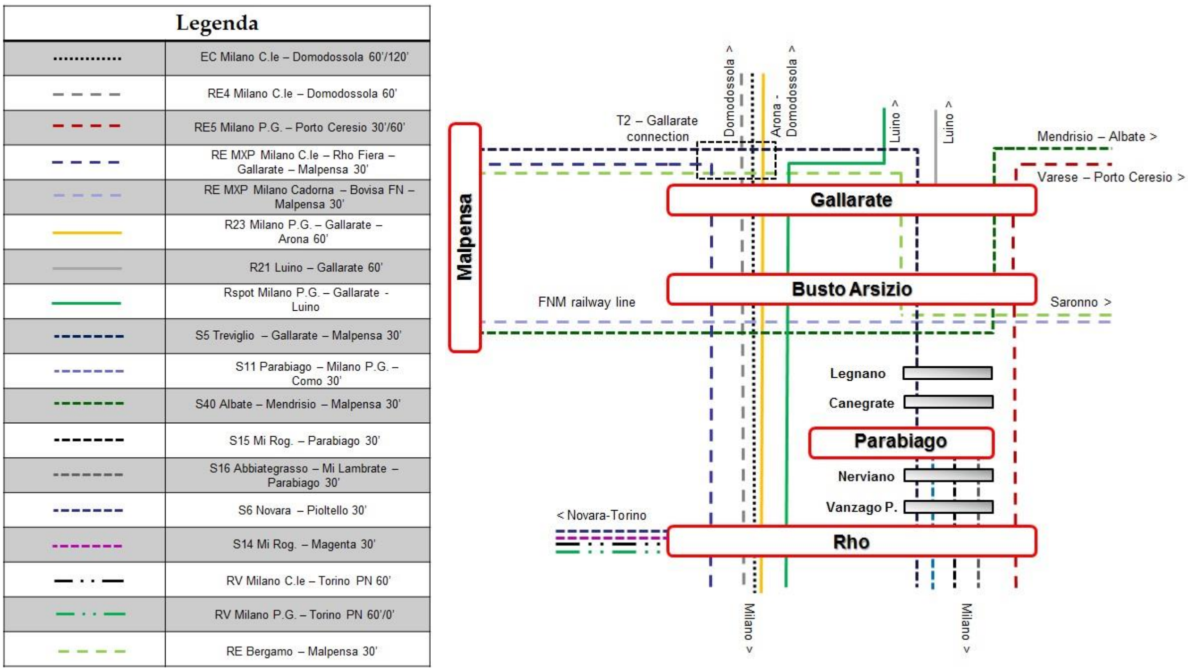

Figure 37: Schematization of the future railway supply model for the segment Rho-Gallarate-Malpensa

6.1.2 Seregno-Bergamo: possible supply development

The new services planned for the future regional railway supply are:

- **S18 Milano Porta Garibaldi - Carnate Usmate - Bergamo - Montello** in substitution of the regional service R14 Milano Porta Garibaldi - Bergamo;
- **R7 Bergamo - Lecco:** extension of the regional service up to **Montello**;
- New suburban service **Ponte San Pietro - Montello**;
- Hypothetic **regional service connecting Bergamo with Malpensa airport** with an interval of 30'.

Other modifications are the completion of the 60' interval of the service Milano Porta Garibaldi - Villapizzone - Pioltello - Bergamo and the transformation into suburban services of the regional services Bergamo - Brescia and Bergamo – Treviglio.

7 APPLICATION OF THE METHODOLOGY

For the analysis of the lines Domodossola-Milano and Seregno-Bergamo, we apply the methodology described in the previous chapter:

- Utilization rate values of line sections by the application of an **analytical method derived by the UIC's Compression method**;
- Utilization rate values of the main nodes of the lines by the application of the Potthoff method.

The methodology proposed is simulating scenarios characterized by different infrastructural and traffic frameworks. The study focuses on 2 scenarios differentiating the infrastructure layout and system of services:

- **Scenario 0: infrastructural layout and railway traffic model related to the activation of timetable 2020** (from December 2019 to December 2020);
- **Scenario 1: infrastructural layout and railway traffic model related to the realization of 2026 upgrade projects.**

Scenario 0 takes into account the infrastructure and the system of services as described by the paper in Chapter 4; in fact, no significant upgrade projects will affect the relevant lines by 2020. Scenario 1 takes into account the following scheduled infrastructural upgrades, as presented in Chapter 5: 4-track layout between Rho and Parabiago, PRG of Rho station and T2-Gallarate link for the line Domodossola-Milano; new double-track layout of the segment Ponte San Pietro-Bergamo-Montello for the line Seregno-Bergamo.

Each scenario presents the results obtained by the application of the methodology for the line capacity and the node performances.

7.1 CALCULATION IMPLEMENTATION AND REFERENCE VALUES

The classification of lines in sections correspond to the position of stations or crossing/priority maneuvers locations scheduled by the timetable. For this study, each "S" section has single-track layout and each "D" section is a double-track layout.

Input data for the analysis are:

- **Reference time interval**: peak hour or off-peak hour of a typical weekday;
- **Train classes** defined according to speed levels and typology of service; they are identified as:
    1. Level 1: High speed services, EC and Eurostar services;
    2. Level 2: Fast regional services, RegioExpress[12] services and IC services;
    3. Level 3: Regional services excluding some stops;
    4. Level 4: Regional services stopping in all stations and Suburban services;
    5. Level 5: Freight trains.
- **Frequency**: stated for peak or off-peak hour. In some cases, frequency could be different according to directions: so, in the analysis we identify a main and a secondary direction, coincident with the contrary direction. Therefore, the frequency is: 1) for main direction in peak period, 2) for main direction off-peak, 3) for secondary direction in peak period, 4) for secondary direction off-peak. In the analysis, some services are "spot", introduced to strengthen a given connection with high demand. Spot services have not a specific frequency: so, we assigned a hypothetic frequency of 120 minutes. Freight trains have not a given frequency and then we report only the number of rides per hour (peak and off-peak) for a typical weekday in the two directions. Peak and off-peak periods relate to passenger

[12] RegioExpress: this train category, indicated as RE, operated in Lombardy by the regional railway company TRENORD. It identifies regional trains, which stop only in main stations at regional level. This designation corresponds to Fast Regional trains RV of the Italian Train Operator TRENITALIA.

traffic; therefore, on lines with prevailing freight traffic, off-peak periods might have a higher traffic than peak periods.

- **Spacing requirements**: identified according to circulation rules characterizing the line, reported in the infrastructural manager documentation. Values are:
  - Reversible Automatic Block/Automatic Block system: 5/6 minutes;
  - ERTMS European Rail Traffic Management System: 5 minutes;
  - Manual Electric Block System: occupation time + 3 minutes;
  - Axle Counter Automatic Block System: occupation time + 2 minutes.

Input data are in a matrix called *incidence matrix,* reporting in rows all the sections identified by the subdivision of the line and in columns all the services involved in the O/D connections of study interest. Cells of the matrix report 1 if service *j* runs on section *i* or 0 if it does not run on. Occupation time of each section is on *Train Graph*[13], in which it is possible to find all the locations effectively passed through by the train. If a section is not run by any train of a given train class, the missed train class occupation time is equal to that of the closest class.

At the end, each section is linking with its own spacing requirement according to block technology of the line.

With the application of the methodology previously described, it is possible to obtain the time lost for speed variability, calculated for peak and off-peak periods for main direction. If the line is equipped with Reversible Automatic Block/Automatic Block or ERTMS, the utilization of a given section is equal to the product between the total number of running trains and the spacing requirement values, plus the time lost for speed variability.

If a line is equipped with Axle Counter, Automatic Block or Manual Electric Block, it is necessary to consider a total occupation time given by the sum of the products between travel time and number of running trains of each train class. Utilization of a given section with lines equipped with Manual Electric Block or Axle Counter Automatic Block differs for single-track or double-track layouts. For double-track layout, utilization results as the

[13] *Train Graph:* RFI system that displays minute by minute the scheduled position of a train in a time-distance chart.

total occupation time for the main direction divided by the number of intermediate crossing points or block posts[14] of the section plus the product between number of running trains of main direction and release time. For single-track layout, utilization results as the sum of occupation times of the two directions divided by the number of intermediate crossing points or block posts of the section plus the product between the total number of trains (for the two directions) and the release time. Utilization rate is the ratio between utilization and reference time interval. For the lines with double-track layout, the utilization rate obtained is different according to peak/off-peak periods and direction. For the lines with single-track layout, the utilization rate is one for the two directions and it is different according to peak/off-peak periods. The utilization rate value of the line is always the highest between the peak value and the off-peak one.

It is possible to define a range of utilization rate values to have a graphic representation of conditions of lines in terms of capacity. Different range are defined for double-track and single-track layouts.

Double-track layout		
Green	0÷83%	Unsaturated
Yellow	83÷100%	Partially saturated
Red	>100%	Saturated

Table 3: Range of Utilization rate values for double-track layout

Single-track layout		
Green	0÷91%	Unsaturated
Yellow	91÷100%	Partially saturated
Red	>100%	Saturated

Table 4: Range of Utilization rate values for single-track layout

[14] Block post: in Italian POSTO DI BLOCCO INTERMEDIO (PBI): it is an intermediate railway signal located between two stations with the aim of increasing capacity of the line dividing a section in two.

These ranges of values derive from different considerations about single-track and double-track layout. Saturation condition means that capacity of a given section is exhausted and there is not possibility to add trains. Transfer from unsaturated conditions to partially saturated conditions is different on the two layouts. For lines with double-track layout, utilization rate equal to 83% (or 10/12) corresponds to a value that permits to add a train in the half hour. For lines with single-track layout, this value corresponds to 91% (or 55/60). It derives from considerations about punctuality slots of the trains. Usually, on single-track lines run regional trains with a punctuality slot of 5 minutes (train considered on time when running with up to 5 minutes delay with respect to the scheduled timetable). Following a hypothetic hour with all trains running with 5 minutes delay, the next hour must not suffer by previous trains on delay.

In the next paragraphs, all the results obtained with the application of the methodology.

7.2 SCENARIO 0: RESULTS OBTAINED BY THE METHODOLOGY APPLICATION

This Scenario presents the situation given by the infrastructural layout and the railway supply model related to the activation of timetable 2020. Considering the lines Domodossola-Milano and Seregno-Bergamo for the development of railway connections with Malpensa International Airport, this Scenario represents the actual situation: in fact, no significant infrastructural upgrades or traffic modifications will affect these lines by 2020. Following, results obtained by the analysis of the lines.

7.2.1 Scenario 0: performances of the lines

The sections of the line Domodossola-Milano considered in this analysis are in Table 5.

ID	SECTION	D/S
1	Sesto Calende - Gallarate	D
2	Gallarate - Busto Arsizio	D
3	Busto Arsizio - Parabiago	D
4	Parabiago - Rho	D
5	Rho - Milano Certosa (Varese)	D
6	Rho - Milano Certosa (Novara)	D
7	Rho - Milano Certosa (AV/AC)	D
8	Milano Certosa - PM Ghisolfa (Novara)	D
9	Milano Certosa - Bivio Musocco (Cintura)	D
10	Milano Certosa - Milano Lancetti	D
11	Milano Certosa - Triplo Bivio Seveso (Viaggiatori)	D
12	Bivio Musocco - Triplo Bivio Seveso (Cintura)	D
13	Bivio Musocco - PM Ghisolfa (Cintura)	D
14	Triplo Bivio Seveso - Milano Centrale (Viaggiatori)	D
15	Bivio Mirabello - Quadrivio Turro	D
16	Quadrivio Turro - Milano Centrale (MXP)	D
17	PM Ghisolfa - Milano Porta Garibaldi (Novara)	D
18	PM Ghisolfa - Milano Porta Garibaldi (Cintura)	D
19	Bivio Mirabello - Milano Porta Garibaldi	D

Table 5: Analyzed sections of line Domodossola – Milano – Scenario 0

The analysis starts from the station of Sesto Calende and it continues southward with the sections up to the main stations in Milan. The choice to start from Sesto Calende and not from Domodossola is because all the future infrastructural upgrades for the development of connections with Malpensa Airport involve this specific part of the line.
The actual system of services employing the sections considered above is in Tables 6 and 7.

ID	Category	Name	Service	Frequency (min)		Peak type	Subject to overpass	Train class	Rides/h main dir.		Rides/h contrary dir.	
				Peak	Off-peak				Peak	Off-peak	Peak	Off-peak
1	AV	AV	AV Torino - Milano C.le TI	20	60	U	0	1	3	1	1	1
2	AV	AV	AV Torino - Milano C.le NTV	30	120	U	0	1	2	0.5	0.5	0
3	AV	AV	AV Torino - Milano P.G. - Roma TI	60	0	U	0	1	1	0	0	0
4	EC	EC	Milano - Domodossola	60	120	B	0	1	1	0.5	1	0.5
5	RV	RV	Torino P.N. - Milano C.le	60	60	U	0	2	1	1	1	1
6	RV	RV	Torino P.N. - Milano P.G.	60	0	B	0	2	1	0	1	0
7	RE	RE4	Milano C.le - Domodossola	60	120	B	0	2	1	0.5	1	0.5
8	RE	RE5	Milano P.G. - Gallarate - Varese - Porto Ceresio	30	60	B	0	2	2	1	2	1
9	RE	MPX	Milano C.le - Milano Bovisa FN - Malpensa	30	30	B	0	2	2	2	2	2
10	R	R23	Milano P.G. - Gallarate - Arona (prosegue su Domodossola)	60	60	B	0	3	1	1	1	1
11	R	Rspot	Milano P.G. - Gallarate - Luino	60	0	U	0	3	1	0	0	0

12	R	R14	Milano P.G. - Carnate - Bergamo	30	60	B	0	4	2	1	2	1
13	R	Rspot	Milano P.G. - Villapizzone - Treviglio - Bergamo	60	0	B	0	3	1	0	1	0
14	R	Rspot	Milano P.G. - Treviglio (prosegue come R6)	60	0	U	0	3	1	0	0	0
15	S	S5	Varese - Treviglio	30	30	B	0	4	2	2	2	2
16	S	S6	Novara - Pioltello	30	30	B	0	4	2	2	2	2
17	S	S7	Milano P.G. - Molteno - Lecco	60	60	B	0	4	1	1	1	1
18	S	S8	Milano P.G. - Carnate - Lecco	30	30	B	0	4	2	2	2	2
19	S	S11	Milano P.G. - Como	30	30	B	0	4	2	2	2	2
20	S	S11 pros.	Rho - Milano P.G.	60	60	B	0	4	1	1	1	1
21	S	S40	Albate-Mendrisio-Malpensa	60	60	B	0	3	1	1	1	1

Table 6: Actual Passenger system of services – Domodossola-Milano (Scenario 0)

ID	**Category**	**Name**	**Service**	**Peak type**	**Subject to precedence**	**Train class**	**Rides/h main dir.**		**Rides/h contrary dir.**	
							Peak	**Off-peak**	Peak	Off-peak
1	Merci	Merci	(Novara -) - Trecate - Mi. Lambrate	U	0	5	1	1	1	1
2	Merci	Merci	Domo II - Gallarate	U	1	5	0.5	1	0.5	1
3	Merci	Merci	Luino - Sesto C. - Gallarate	U	1	5	1	2	1	1
4	Merci	Merci	Domo II - Mi. Lambrate	U	1	5	0.5	1	0.5	1
5	Merci	Merci	Busto A. - Mi. Lambrate	U	1	5	0	1	0	0

Table 7: Actual Freight system of services – Domodossola-Milano (Scenario 0)

The information about peak type indicates if the services are unidirectional or bidirectional. Furthermore, information are about priority of the trains: as reported in the table, only freight trains could be subject to overpass.

With the application of the methodology, the results about utilization and utilization rate of the sections are in Table 8.

ID	Spacing Requirement (min)			Time lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Crossing/PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
1	6			20	23	50	53	**83.3**	**88.3**
2	5			4	4	49	39	**81.7**	**65.0**
3	5			16	14	56	49	**93.3**	**81.7**
4	5			23	17	63	52	**105.0**	**86.7**
5	5			4	2	34	27	**56.7**	**45.0**
6	5			8	8	48	43	**80.0**	**71.7**
7	5			0	0	30	10	**50.0**	**16.7**
8	5			6	2	41	17	**68.3**	**28.3**
9	5			0	0	10	15	**16.7**	**25.0**
10	5			0	0	20	20	**33.3**	**33.3**
11	5			0	0	40	20	**66.7**	**33.3**
12	5			0	0	20	15	**33.3**	**25.0**
13	5			0	0	10	0	**16.7**	**0.0**
14	5			4	4	44	24	**73.3**	**40.0**
15	5			1	0	16	10	**26.7**	**16.7**
16	5			0	0	10	10	**16.7**	**16.7**
17	5			2	1	47	16	**78.3**	**26.7**
18	5			0	0	10	10	**16.7**	**16.7**
19	5			1	0	51	40	**85.0**	**66.7**

Table 8: Utilization and Utilization rate: Domodossola-Milano line (Scenario 0)

For the line Seregno – Bergamo, the sections analyzed for this Scenario are in Table 9.

ID	SECTION	D/S
20	Seregno - Carnate	S
21	Carnate - Calusco	S
22	Calusco - Ponte San Pietro	S
23	Ponte S.Pietro - Bergamo	S

Table 9: Analyzed sections of line Seregno – Bergamo (Scenario 0)

This line has a single-track.

The actual system of services employing the sections considered above is in Table 10.

ID	Category	Name	Service	Frequency (min)		Peak type	Subject to precedence	Train class	Rides/h main dir.		Rides/h contrary dir.	
				Peak	Off-peak				Peak	Off-peak	Peak	Off-peak
12	R	R14	Milano P.G. - Carnate - Bergamo	30	60	B	0	4	2	1	2	1
22	R	R15	Seregno - Carnate	60	60	B	0	3	1	1	1	1
23	R	R7	Lecco - Bergamo	60	60	B	0	3	1	1	1	1
6	Merci	Merci	Chiasso - Lecco M.			U	1	5	0	0.5	0	0

Table 10: Actual system of services - Seregno-Bergamo line (Scenario 0)

With the application of the methodology, the results about utilization and utilization rate of the sections for the line Seregno – Bergamo are in Table 11.

ID	Spacing Requirement			Time lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Crossing/PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
20		2	1	0	0	19	26	**31.7**	**42.9**
21		2	1	0	0	32	16	**53.3**	**26.7**
22		2	1	0	0	30	15	**50.0**	**25.0**
23		2		0	0	58	40	**96.7**	**66.7**

Table 11: Utilization and Utilization rate - Seregno-Bergamo (Scenario 0)

All the results obtained for Scenario 0 are in Figure 38 according to the ranges defined in Tables 3 and 4.

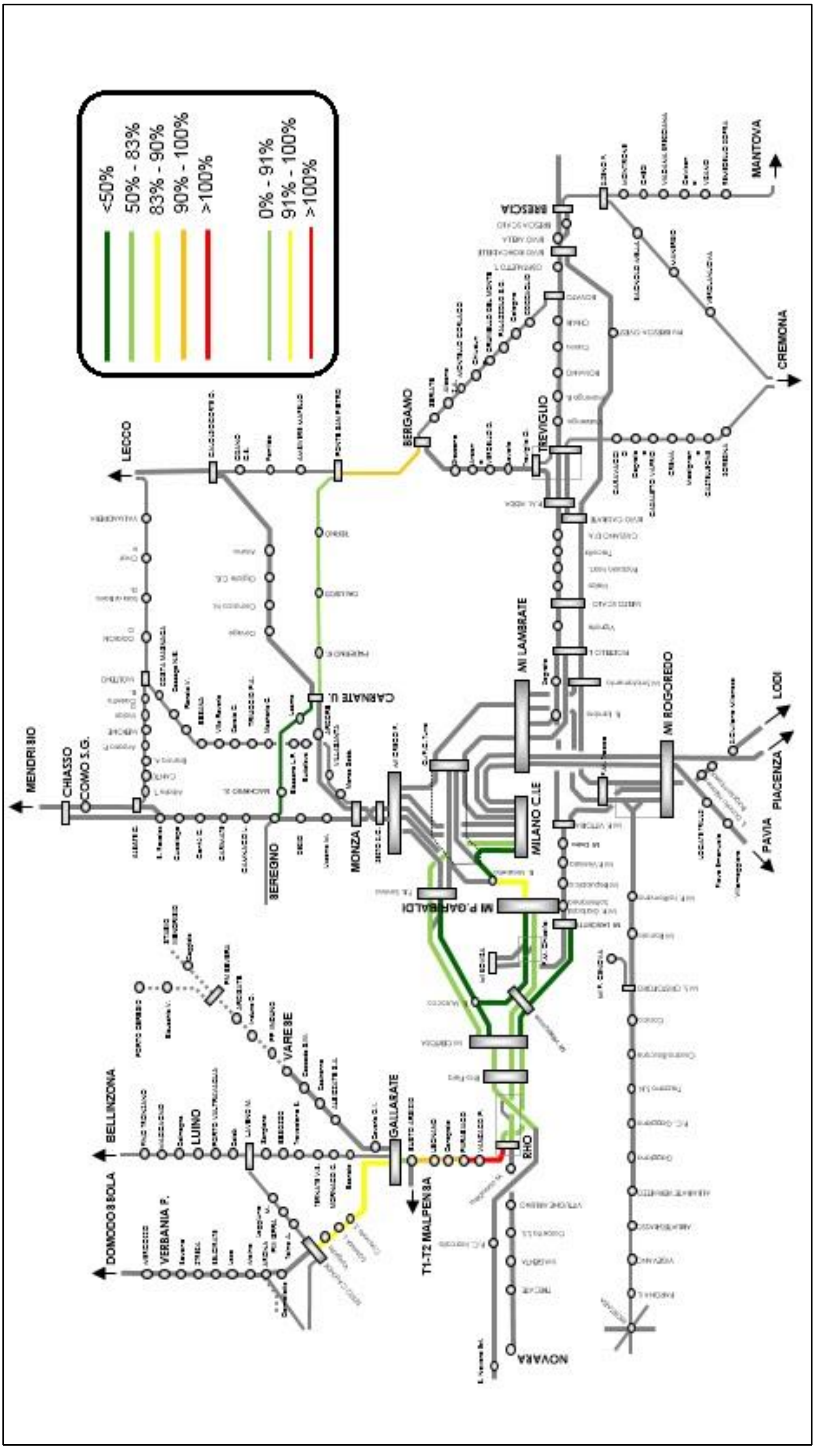

Figure 38: Graphic synthesis of results - Scenario 0

For the line Domodossola-Milano, the section with a utilization rate higher than 100% is Parabiago – Rho.

Other sections with a critical value of utilization rate are:

- Sesto Calende – Gallarate;
- Busto Arsizio – Parabiago;
- Bivio Mirabello – Milano Porta Garibaldi.

For the line Seregno – Bergamo, the only section with a critical value of utilization rate is Ponte S. Pietro – Bergamo.

It is clear that it is not possible to introduce new services to increase the current supply between Milan and Malpensa Airport without upgrades on the actual infrastructure. The line Domodossola-Milano in the sections between Busto Arsizio and Milano Certosa is not able to support an increase of the number of trains, given the current system of services. For the line Seregno-Bergamo, the single-track layout represents a bottleneck for the development of the traffic toward Malpensa Airport in the section Ponte S. Pietro - Bergamo. This section results critical because it is a common link with the Lecco-Bergamo line. These results require the interventions on the line Domodossola-Milano in the section between Legnano and Rho to develop the regional railway service between Milano Centrale/Milano Porta Garibaldi and Malpensa Airport. At the same time, results justify the planned infrastructural upgrades between Ponte S. Pietro and Bergamo.

7.2.2 Scenario 0: performances of the nodes

For the line Domodossola-Milano, the stations analyzed in this study are Rho, Busto Arsizio FS and Gallarate; for the line Seregno-Bergamo, the only station analyzed is Seregno.

7.2.2.1 Rho station

The railway station of Rho is an RFI station located in correspondence of the junction between line Torino – Milano and line Domodossola – Milano (common segment of lines Domodossola – Milano, Luino – Milano, Porto Ceresio – Milano). It is composed by 5 tracks: I and II are direct route tracks for the line "Varese" coming from Milano Certosa station; IV and V are direct route tracks for the line "Novara" coming from Milano Certosa. Track III is actually the end stop track for suburban service S11 Rho – Milano Porta Garibaldi – Como/Chiasso; it is equipped with 30 km/h switches to access with line "Novara". Junctions between lines Novara – Milano and Domodossola – Milano are equipped with 60 km/h switches on the west side and 30 km/h switches on the east side. Tracks I, II, III and V are equipped with platform for passengers boarding/alighting operations. Station is under the control of an ACC system[15]. Schematization of the station is in Figure 39.

[15] ACC Apparato Centrale Computerizzato: electronic interlock able to automatically lead train routes in remote basing on railway circulation plan. Spacing conditions of the trains for line sections between stations are checked by the system; the process is supervised by a signalman (Regolatore della Circolazione) that can act for modifications or updates of circulation plan. ACC (Apparato Centrale Computerizzato) system is able to manage and check a single station (stand-alone) while ACC-M (Apparato Centrale Computerizzato Multistazione) system can manage and check simultaneously several stations and the related block sections.

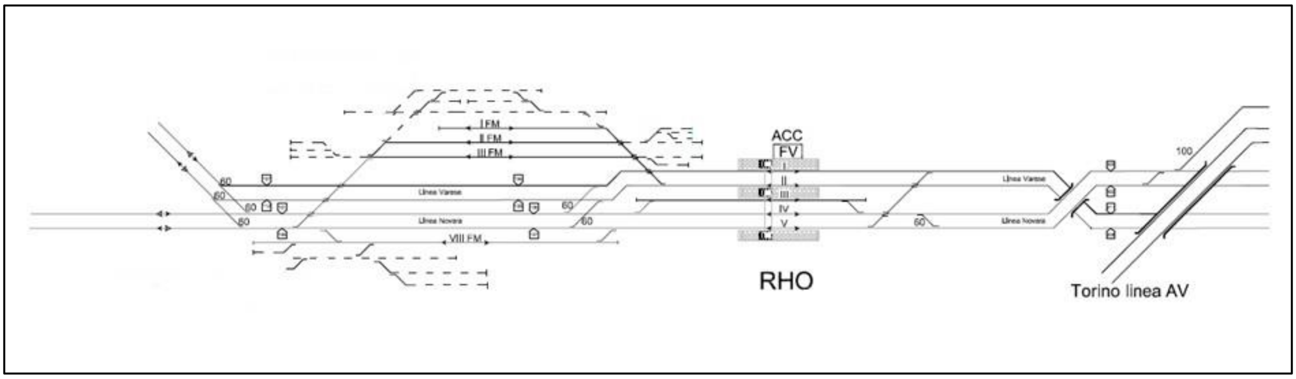

Figure 39: Schematization of actual layout of Rho station

Actually, Rho station carries out passenger operations only for suburban services S5 Varese – Treviglio, S6 Novara – Pioltello/Limito and S11 Rho – Milano Porta Garibaldi – Como/Chiasso.

For the following study, the station includes two complex nodes corresponding to the station roots: “Radice EST” and “Radice OVEST”. “Radice EST” is the station root between the main protection signals by the side of Milano Certosa station (“Varese” and “Novara” lines) and the axis of the station building (FV). “Radice OVEST” complex node is the station root individuated between the external main protection signals from Pregnana Milanese (Novara – Milano line) / Vanzago (Domodossola – Milano line) and the axis of the station building. After the individuation of station complex nodes, performances of the nodes are under evaluation for Scenario 0.

Starting with the analysis of the complex node “Radice EST”, a preliminary step is the individuation of line points on the schematization of the station for the identification of station routes. Line points *302* and *305* individuates respectively even and odd tracks on “Novara” line. Line points *208* and *211* individuates respectively even and odd tracks on “Varese” line. Routes are for arrival, transit and departure.

Conflicts of this node are by the arrival/departure routes to/from track III with trains on “Varese” and “Novara” lines. Practically, all routes with arrival or departure to/from track III interfere with arrival/departure/transit routes to/from tracks I, II and IV.

After the identification of the routes, the next step is to collect all information about services involved in the circulation of the station.

Rho station is interested by:

- **Transit passenger services from/to Torino and Milano;**
- **Stopping passenger services from/to Novara and Milano (S6 trains);**
- **Transit passenger services from/to Porto Ceresio, Luino, Arona, Domodossola and Milano;**
- **Stopping passenger services from/to Varese and Milano (S5 trains).**

Rho station is the terminus for the suburban service **S11 Rho - Milano Porta Garibaldi - Como/Chiasso.** Furthermore, in the station run transit freight services from/to Novara/Trecate, Busto, Domo II and Milano Lambrate/Smistamento.

By the layout of the station, it is possible to identify the lines leading to the node: so, it is necessary to analyze the distribution of the trains on the two lines according to their origin and destination. Trains from/to Milano Centrale and Milano Porta Garibaldi stations run on "Novara line"; trains from/to railway corridor "Passante di Milano" run on "Varese line". This check on the distribution of the trains uses a document called *M53*[16]. Routes and services of this complex node are graphically synthetized in Figure 40.

[16] *M53*: it is a document reporting daily information about all trains stopping or in transit for a given station. Information regards train codification, origin and destination of the train, arrival and departure times, track scheduled by operational plan and periodicity.

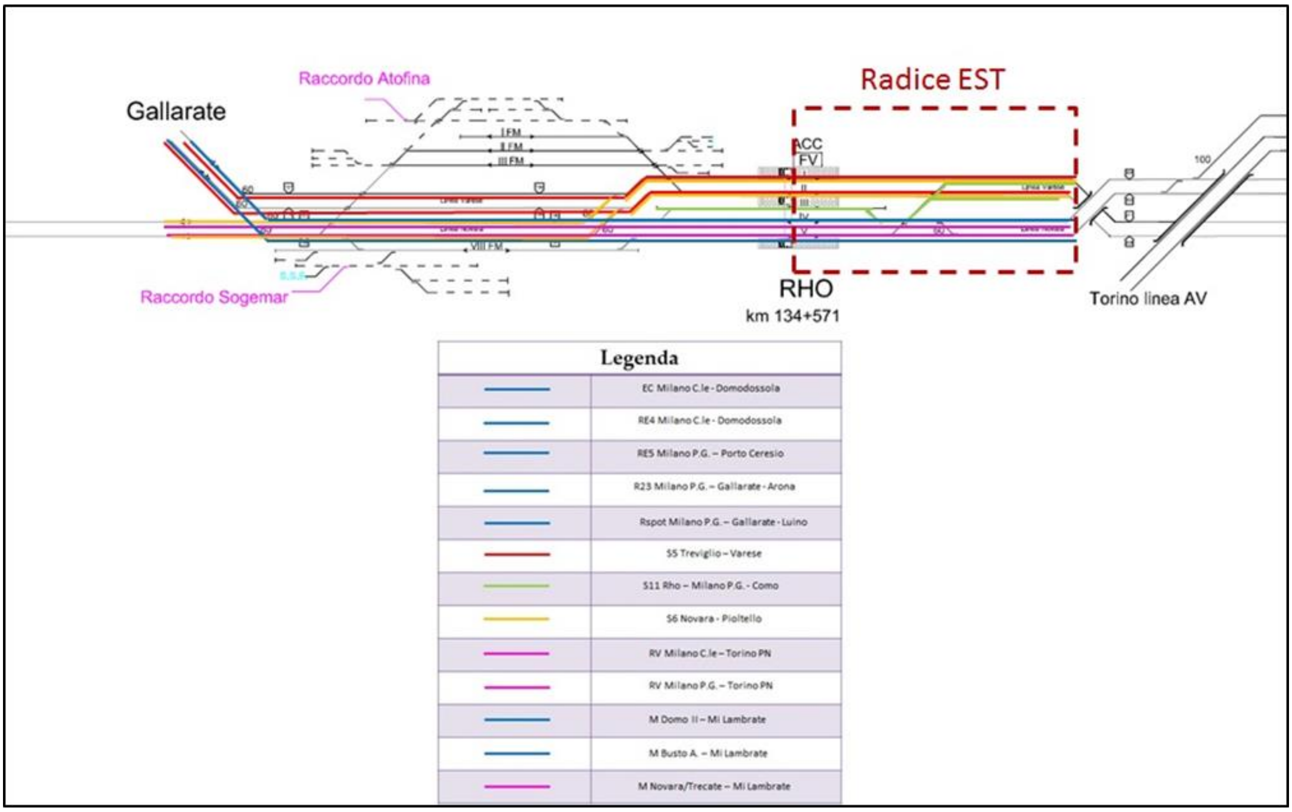

Figure 40: Graphic synthesis of routes and services for Rho station - Rad. EST - Scenario 0

After the identification of all services stopping or in transit for the station of Rho, we proceed with the analysis of the complex node by means of Potthoff method. At first, it is necessary to identify the routes of the node and to build the routes matrix differentiating arrival, transit and departure routes. For this complex node, route matrix is in Figure 41 (transit routes with letter T).

Routes		A-EST					P-EST		
		208-II	208-II (T)	208-III	302-V	302-V (T)	I-211	III-305	IV-305 (T)
A-EST	208-II	a	a	s	c	c	c	c	c
	208-II (T)	a	a	s	c	c	c	c	c
	208-III	s	s	a	c	c	c	u	u
	302-V	c	c	c	a	a	c	c	c
	302-V (T)	c	c	c	a	a	c	c	c
P-EST	I-211	c	c	c	c	c	a	c	c
	III-305	c	c	u	c	c	c	a	z
	IV-305 (T)	c	c	u	c	c	c	z	a

Figure 41: Route matrix for Scenario 0 - Rad. EST Rho

After the computation of routes matrix, the next step is the construction of occupation time matrix according to blocking time of the different routes. Preliminary, it is necessary to identify the length of the block sections for the calculation of blocking time.

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	Ts (s)	A/D (m/s^2)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
208-II	925	1077	1238	200	200	110	0	60	0.6	205	30	235	3.9
208-II (T)	925	1077	2368	200	200	110	0	0	0	156	30	186	3.1
208-III	925	1077	1238	200	200	110	30	60	0.6	329	30	359	6.0
302-V	960	918	1355	200	200	120	0	60	0.6	197	30	227	3.8
302-V (T)	960	918	2485	200	750	120	0	0	0	159	30	189	3.2
I-211	915	0	0	0	200	110	0	0	0.3	87	30	117	2.0
III-305	975	0	0	0	200	0	30	0	0.3	155	30	185	3.1
IV-305 (T)	975	0	0	0	750	120	0	0	0	52	30	82	1.4

Table 12: Parameters for calculation of blocking time - Scenario 0 Rad. EST Rho

D1, D2 and *D3* represent respectively the first, the second and the third block sections before the main departure signals (remembering that a fourth section is considered for code *180* requirement in the cab signal repetition system). *Dv* represents the visibility distance and *Ltr* the length of the train. *V1* and *V2* are respectively the speed of direct routes and the speed in the case of deviated routes. *Ts* represents the stopping time in station for boarding/alighting operations. For calculation of blocking time of a route, an acceleration of 0.3 m/s^2 and a deceleration of 0.6 m/s^2 are considered. Adding to the occupation time a technical additional time for the formation of the route, we obtain the total blocking time of each route *Tot.* The total occupation time of a route strictly depends on the length of the sections run by a train and on its travelling speed. For arrival routes (considering trains stopping for boarding/alighting operations), an occupation time equal to 3÷4 min may be considered acceptable; higher values may be considered for deviated routes with 30 or 60 km/h permitted speed. For departing routes (for trains completing passenger service), an occupation time of 2÷3 min may be considered acceptable. Transit routes (both entering and exiting) may have lower occupation times considering the absence of deceleration/stop/acceleration maneuvers.

Interdiction or occupation time matrix for this complex node is in Table 13.

Occupation		A-EST					P-EST		
		208-II	208-II (T)	208-III	302-V	302-V (T)	I-211	III-305	IV-305 (T)
A-EST	208-II	235	235	235	0	0	0	0	0
	208-II (T)	186	186	186	0	0	0	0	0
	208-III	359	359	359	0	0	0	359	359
	302-V	0	0	0	227	227	0	0	0
	302-V (T)	0	0	0	189	189	0	0	0
P-EST	I-211	0	0	0	0	0	117	0	0
	III-305	0	0	185	0	0	0	185	185
	IV-305 (T)	0	0	82	0	0	0	82	82

Table 13: Occupation time matrix for Scenario 0 - Rad. EST Rho

The last step is the computation of delays matrix according to the formulation proposed by Potthoff. According to the occupation time previously calculated, for each node routes, the delay matrix for this complex node is in Table 14.

Therefore, it is possible to calculate the regular and global utilization rates for the complex node in analysis.

The value of global utilization rate obtained by the application of the methodology to the complex node “Radice EST” of the Rho station is extensively under the threshold indicated for the peak hour. This output is consistent with the analysis station layout considering that the only interference is by arrival/departure routes to/from III track with train flow of IV track.

Delays		A-EST					P-EST		
		208-II	208-II (T)	208-III	302-V	302-V (T)	I-211	III-305	IV-305 (T)
A-EST	208-II	122	0	0	0	0	0	0	0
	208-II (T)	0	0	0	0	0	0	0	0
	208-III	0	0	0	0	0	0	18	170
	302-V	0	0	0	0	0	0	0	0
	302-V (T)	0	0	0	0	0	0	0	0
P-EST	I-211	0	0	0	0	0	0	0	0
	III-305	0	0	5	0	0	0	0	45
	IV-305 (T)	0	0	9	0	0	0	9	0

Table 14: Delay matrix for Scenario 0 - Rad. EST Rho

Potthoff parameters – Rad. EST Rho

N	nm	tm (s)	B (s)	T (s)	R (s)
28	3.21	151	1317	3600	378

Utilization rates – Rad. EST Rho

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.366	36.6	0.399	39.9

Table 15: Results of node analysis: Rho station - Rad. EST Scenario 0

Then, the study proceed analyzing the complex node “Radice OVEST”. By the layout of the station, it is possible to highlight that main interferences are in correspondence of this station root. In particular, conflicts between routes are by the junction between the two lines Domodossola-Milano and Torino-Milano. Intersection points generating by the layout of the lines are:

- Even train flow of the line Domodossola-Milano from Rho Fiera to Gallarate (“Novara line”) intersects odd train flow of the line Novara-Milano from Magenta (“Novara line”) to Rho Fiera;
- Odd train flow of the line Domodossola-Milano from Gallarate to Rho Fiera intersects even train flow of the line Domodossola-Milano from Rho Fiera to Magenta (“Varese line”);
- Even train flow from Rho Fiera (“Varese line”) to Magenta intersects odd train flow of the line Torino-Milano from Magenta to Rho Fiera (“Novara line”);

- Odd train flow from Magenta to Rho Fiera (“Varese line”) intersects even train flow from Rho Fiera (“Varese line”) to Gallarate.

Railway supply is the same of “Radice EST” with exception of suburban service S11 Rho-Milano Porta Garibaldi-Como/Chiasso, which is involved only in the previous complex node.

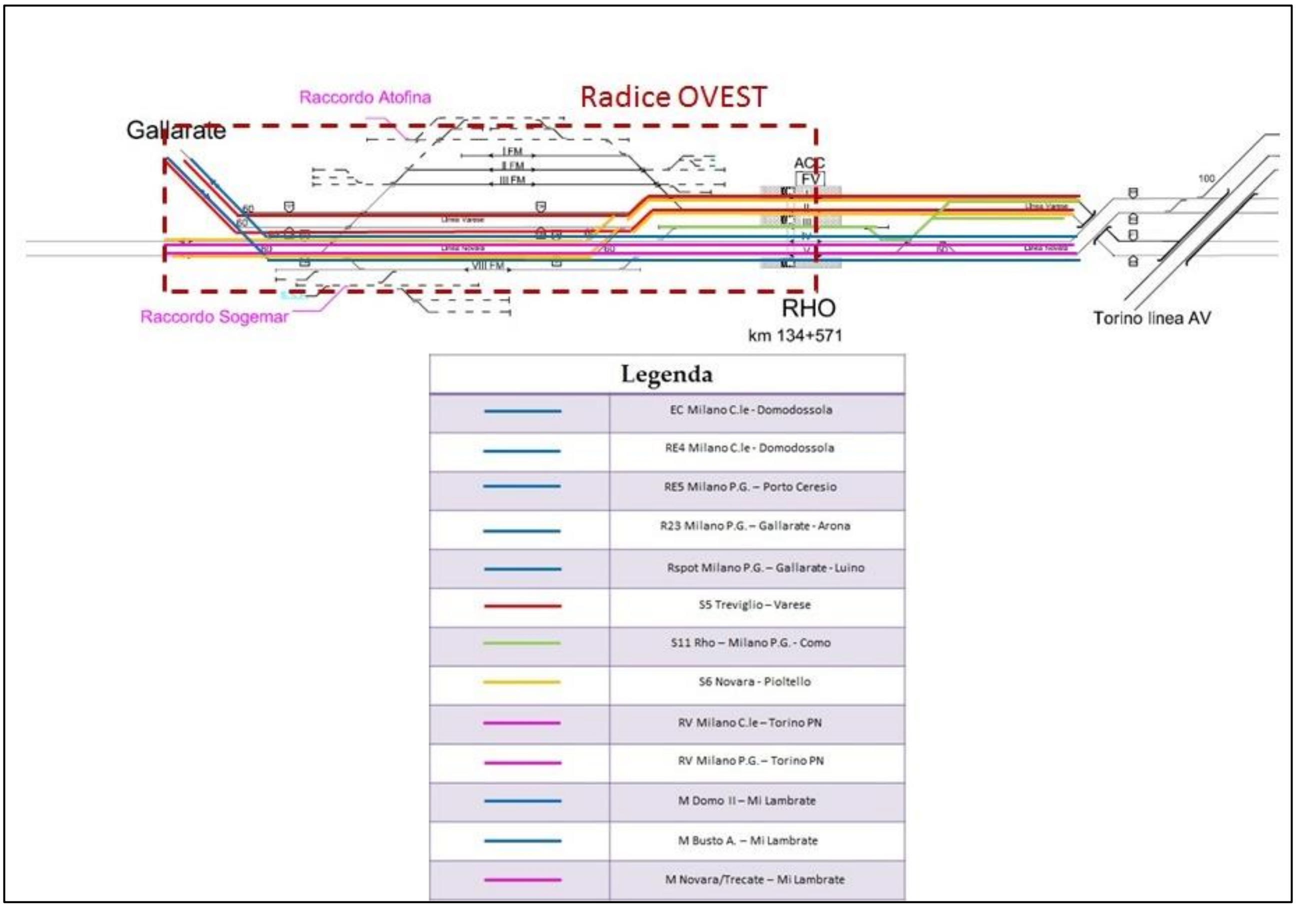

Figure 42: Graphic synthesis of routes and services for Rho station – Rad. OVEST – Scenario 0

To lighten the presentation of the results, all the tables obtained by the analysis are in a dedicated Annex (“A”) at the end of the paper.

Therefore, utilization rate values for the complex node “Radice OVEST” of Rho station are in Table 16.

Potthoff parameters – Rad. OVEST Rho

N	nm	tm (s)	B (s)	T(s)	R (s)
39.5	2.42	200	3267	3600	2075

Utilization rates – Rad. OVEST Rho

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.908	90.8	1.146	114.6

Table 16: Results of node analysis: Rho station - Rad. OVEST Scenario 0

The global utilization rate value obtained by the analysis results to be over the threshold indicated by Potthoff for the capacity of a complex node in peak hour. This output is understandable considering that Potthoff methodology overestimates the utilization rate of a complex node. In fact, the calculation of n_m average number of compatible movements is the empirical method with an overestimation between 20% and 50%. Furthermore, it is necessary to remember that Potthoff method considers the rigid release of the route and not the elastic release as in the reality.

Therefore, considering that the high number of trains anyway congests the node in the peak hour and the typology of conflicts of this node, the utilization rate obtained over the 100% for Scenario 0 is justified.

7.2.2.2 Busto Arsizio FS station

Busto Arsizio FS railway station is an RFI station located along the line Domodossola-Milano. It is both a transit station and a junction station considering the presence of a branch linking the FNM line with the RFI line. The passenger station area is composed by 6 tracks plus a blunt track. Actually, track I is used by trains from/to Busto Arsizio FN station (FNM line); tracks III and VI are direct routes tracks for the line Domodossola-Milano while tracks II, IV and V are overtaking tracks (deviated routes tracks) equipped with 30 km/h and 60 km/h switches. Only tracks I, IV and V are equipped with platforms for boarding/alighting operations. Furthermore, the station has a freight area not considered in this analysis. In Busto Arsizio station operates an ACEI system[17]. Schematization of the station is in Figure 43.

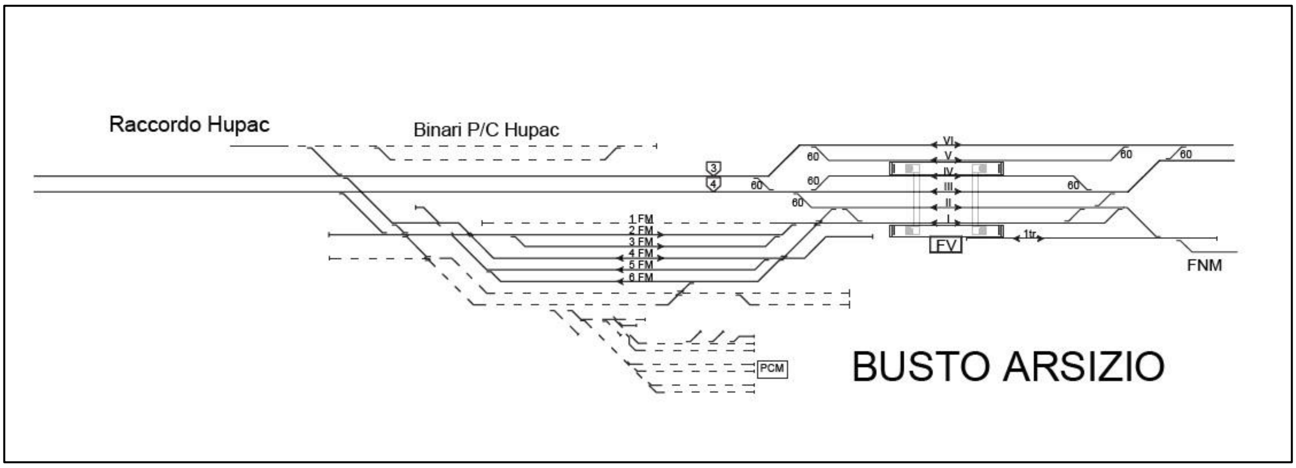

Figure 43: Schematization of actual layout of Busto Arsizio FS station

Services with scheduled stop in this station are:

- **RE4 Milano Centrale – Domodossola;**
- **RE5 Milano Porta Garibaldi – Varese – Porto Ceresio;**
- **R23 Milano Porta Garibaldi – Arona/Domodossola;**
- **S5 Treviglio – Varese;**
- **S40 Albate/Como – Mendrisio – Malpensa T1/T2.**

All the other services are in transit.

For Scenario 0, the complex node to study is "Radice NORD" considering the presence of crossing interferences between routes generated by trains from/to Gallarate to/from Busto Arsizio FN/Malpensa T1-T2. This complex node corresponds to the station area identified between the main protection signals by the side of Gallarate and the axis of the passengers building FV.

As before, the preliminary step is the identification of station routes by means of the schematization plan of the station. Line points *3* and *4* identify respectively odd and even

[17] ACEI *Apparato Centrale Elettrico a pulsanti di Itinerario*: it is an electro-mechanical interlocking system. ACEIs are the most diffused typology of interlocking system in the Italian network. They represent the evolution of ACE system (Apparato Centrale Elettrico), with a simplification of station operations control by means of the use of a unique key called "pulsante di itinerario".

tracks of the line Domodossola-Milano. As before, to simplify the organization of route matrix, divided in arrival, transit and departure. Conflicts of this complex node are generated by even/odd train flows from/to Gallarate to/from track I, coming from FNM line with even/odd train flows from/to Gallarate to/from Legnano.

To summarize, services and station routes are in Figure 44.

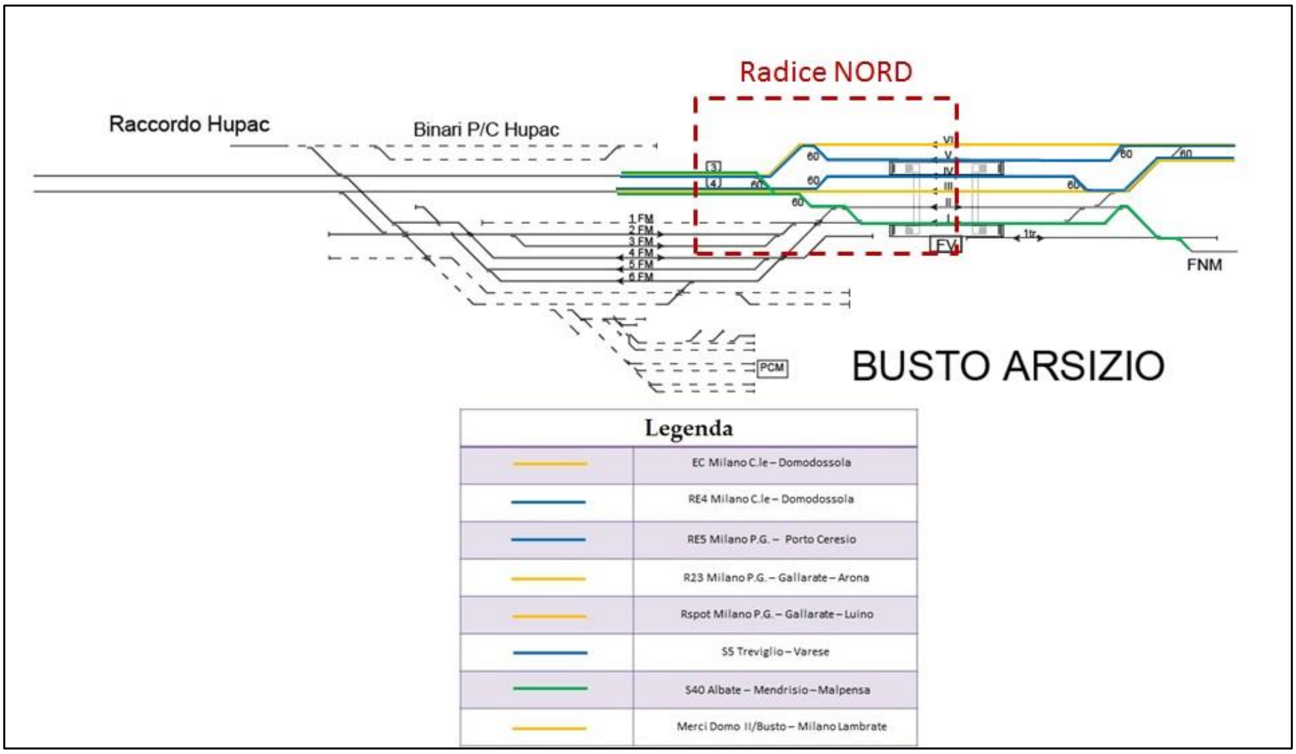

Figure 44: Graphic synthesis of routes and services for Busto A. station - Rad. NORD - Scenario 0

Tables with matrices are in a dedicated Annex ("B") at the end of the paper.

Results obtained by the application of the methodology are in Table 17.

Potthoff parameters – Rad. NORD Busto A.

N	nm	tm (s)	B (s)	T (s)	R (s)
18	1.81	193	1926	3600	193

Utilization rates – Rad. NORD Busto A.

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.535	53.5	0.565	56.5

Table 17: Results of node analysis: Busto A. FS station – Rad. NORD Scenario 0

As expected by the analysis, the global utilization rate value of this complex node results under the threshold indicated by Potthoff for capacity performances in peak periods. In fact, the number of trains involved in the circulation are low (considering for example the case of Rho station). Moreover, the crossing and opposite incompatibilities routes from/to track I actually involve only one train/per hour/per direction considering the frequency of suburban service S40 Albate C.-Varese-Malpensa T2. Therefore, traffic condition is sustainable by the actual layout of the station.

7.2.2.3 Gallarate station

Gallarate railway station is a RFI station along the line Domodossola-Milano in correspondence of the junction with the lines Luino-Milano and Stabio/Porto Ceresio-Milano. It is a typical transit-junction station. The passenger's station area is composed by 8 tracks: tracks I, II, III, V, VI, VII and VIII are circulation tracks while track IV is a secondary track actually not in operation. Tracks I, II, III, V and VI are equipped with platforms for passengers boarding/alighting operations. Normally, tracks I and II are used by trains from/to Domodossola to/from Rho/Milano; track III is used by trains from/to Luino/Cadenazzo/Bellinzona to/from Gallarate while tracks V and VI are used by trains from/to Varese/Porto Ceresio to/from Rho/Milano. Tracks VII and VIII are used as overtaking tracks or stop tracks for freight trains waiting maneuver operations to intermodal terminals located near the station (e.g. HUPAC Busto A.-Gallarate terminal, AMBROGIO terminal). Freight station area is out of the analysis. In the station operates an ACEI system. The layout of the station is in Figure 45.

All the services stop in Gallarate station with exception of EC Domodossola – Milano Centrale.

Freight services arriving or departing at Gallarate are:

- **Merci Domo II – Gallarate;**
- **Merci Luino – Sesto Calende – Gallarate;**
- **Merci Luino – Ternate – Gallarate.**

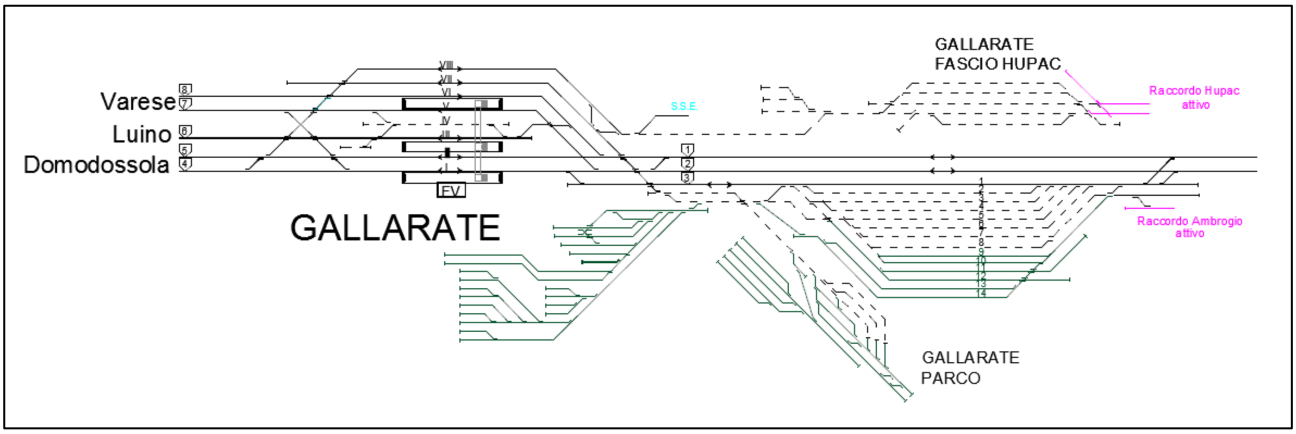

Figure 45: Schematization of the layout of Gallarate station

The other services are in transit. Normally, trains with destination HUPAC intermodal terminal stop at tracks VII and VIII while trains with destination AMBROGIO intermodal terminal stop at track indicated with line point 3.

For this Scenario, complex nodes analyzed are “Radice NORD” and “Radice SUD”: the first one is the station root by the side of Domodossola while the second one is the station root by the side of Busto Arsizio/Rho. “Radice NORD” is the station area identified between the main protection signals by the side of Casorate/Domodossola and the axis of the station building. “Radice SUD” is the station area identified between the internal main protection signals by the side of Busto Arsizio and the axis of the station building.

Nowadays, the main traffic problems of the station are due to crossing conflicts in correspondence of “Radice NORD”, of routes from/to tracks VII and VIII and crossing/opposite conflicts between route from/to junction track “Ambrogio” and odd train flow run on track I.

Freight trains run these routes: this generates high interdiction times due to length of the trains and travel speed of deviated routes (30 km/h). Therefore, freight traffic of the station heavily influences its circulation.

The complex node “Radice SUD” has the following interferences:

- Crossing routes between even track to Varese and odd track from Domodossola;

- Converging routes between odd track from Varese and odd track from Domodossola;
- Opposite routes between even track to Domodossola and route run by freight trains from Domodossola to “Raccordo Ambrogio” (line point *3*);
- Converging routes between track from “Raccordo Ambrogio” and even track from Busto Arsizio.

To summarize, Figure 46 shows services and routes of this complex node.

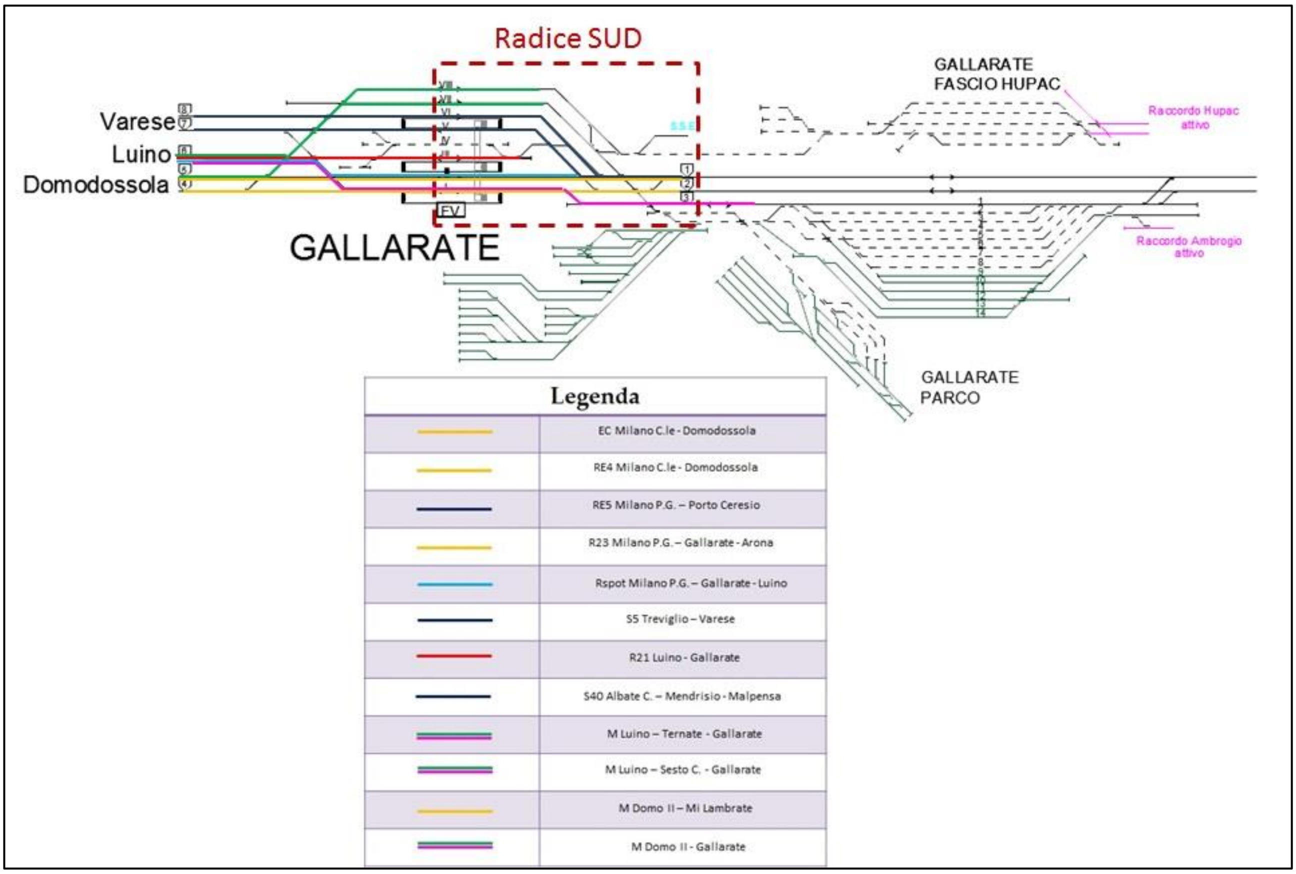

Figure 46: Graphic synthesis of routes and services for Gallarate station – Rad. SUD – Scenario 0

As usual, the first step is the identification of station routes. For “Radice SUD”, line points *1* and *2* identify respectively even and odd tracks of the line from/to Rho; line point *3* identifies track from/to “Raccordo Ambrogio”.

Tables with matrices are in a dedicated Annex (“C”) at the end of the paper.

Results obtained by the application of Potthoff method are in Table 18.

Potthoff parameters: Rad. SUD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
19	1.68	207	2351	627	3600

Utilization rates: Rad. SUD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.653	65.3	0.757	75.7

Table 18: Results of node analysis: Gallarate station - Rad. SUD Scenario 0

The global utilization rate obtained by the analysis is slightly over the threshold individuated by Potthoff for capacity in peak hour. Considering the overestimation given by the application of the methodology, it is possible to say that capacity condition for the node "Radice SUD" is satisfied without congestion phenomena in the current Scenario.

Criticalities arise in correspondence of the complex node "Radice NORD". This node includes the presence of crossing points between station routes generated by freight trains flow from/to tracks VII and VIII. Crossing incompatibilities between routes are:

- Routes generated by tracks from/to Domodossola to/from station tracks VII and VIII with route from/to Luino to/from station track III;
- Routes generated by tracks from/to Domodossola to/from station tracks VII and VIII with routes from/to Varese (odd and even tracks) to/from station tracks V and VI;
- Routes generated by track from/to Luino to/from station tracks VII and VIII with routes from/to Varese (odd and even tracks) to/from station tracks V and VI;
- Route generated by track from/to Luino to/from railway junction "Ambrogio" with route generated by even track from Domodossola to station track II.

Considering the length of freight trains (600÷750 m) and the running speed permitted equal to 30 km/h, the blocking time of a route to freight station tracks becomes long. Consequently, average occupation time and delays generated by incompatibilities assume values that may affect general capacity condition of the node.

Routes and services are in Figure 47.

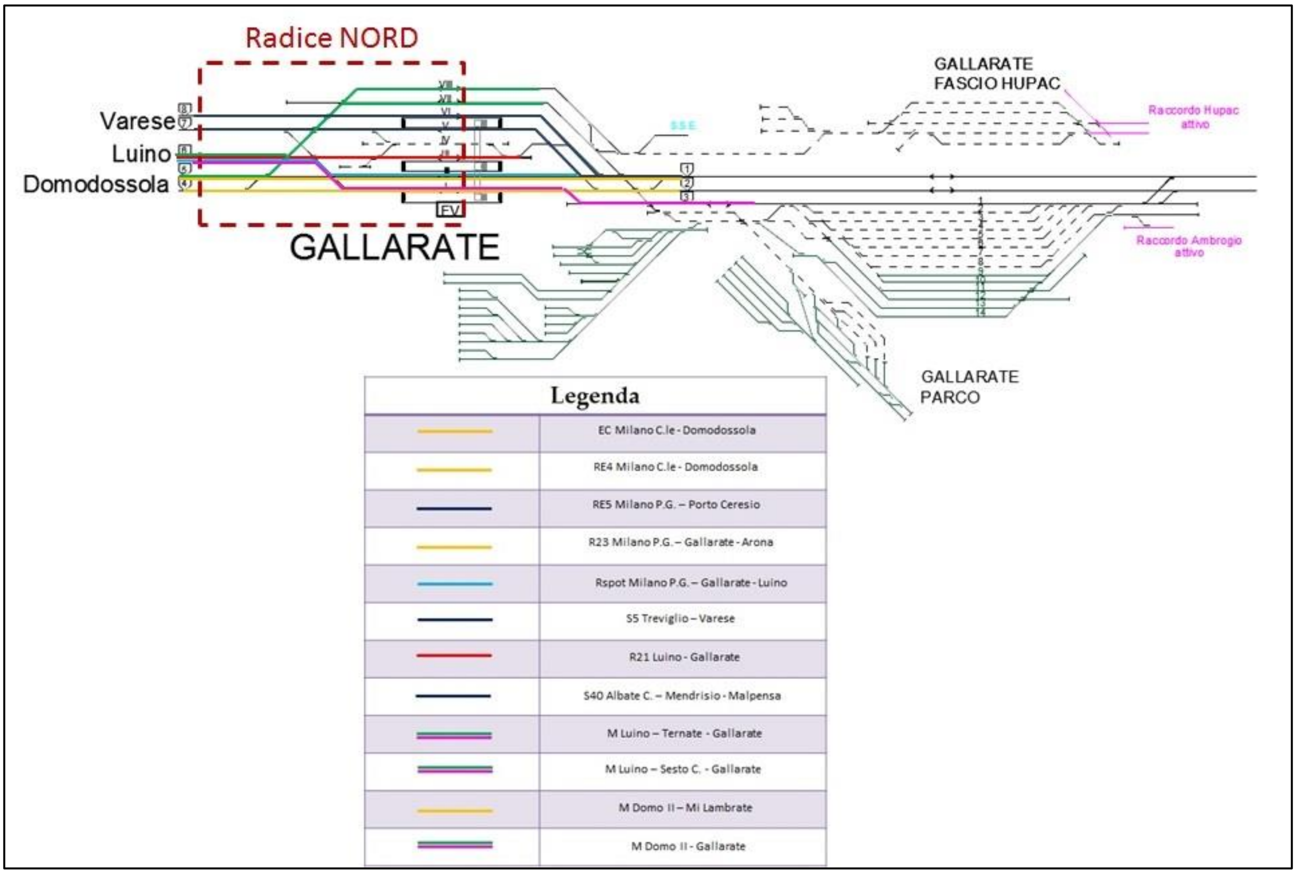

Figure 47: Graphic synthesis of routes and services for Gallarate station – Rad. NORD – Scenario 0

Line points 4 and 5 identify respectively odd and even tracks of the line from/to Domodossola while line points 7 and 8 identify respectively odd and even tracks of the line from/to Varese. Point 6 identifies line from/to Luino.

The output obtained by the application of the method are in Table 19.

Potthoff parameters – Rad. NORD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
25	2.43	253	2608	1876	3600

Utilization rates – Rad. NORD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.724	72.4	0.939	93.9

Table 19: Results of node analysis: Gallarate station - Rad. NORD Scenario 0

As expected by general considerations about the layout of the node, the values of utilization rate are over the threshold indicated by Potthoff for the peak period capacity. As explained above, delays are due to crossing interferences between routes from/to tracks VII and VIII and the imposed running speed of 30 km/h. Moreover, opposite incompatibility between route from/to "Raccordo Ambrogio" and odd track trains flow from Rho to Domodossola increases the delays generated by the complex node. Therefore, the actual layout of the station root affects operations generating delays and possible congestion in peak period. The station root is anyway manageable considering the overestimation of the values with the application of Potthoff method.

7.2.2.4 Seregno station

Seregno station is an RFI station along the line Milano-Chiasso located at the junction with lines Seregno-Bergamo (RFI line) and Seregno-Saronno (FNM line). It is a transit-junction station. The station area is composed by 6 tracks plus a blunt track (called "I TRONCO"). Tracks from I to V and I TRONCO are equipped with platform for boarding/alighting operations. Tracks I and II are direct routes tracks for the line Milano-Chiasso while tracks III and IV are deviated routes tracks used by trains from/to Saronno to/from Milano Greco Pirelli. Track I TRONCO is an end stop track for trains from/to Carnate/Bergamo. In the station operates an ACEI system. The layout of the station is reported in Figure 48.

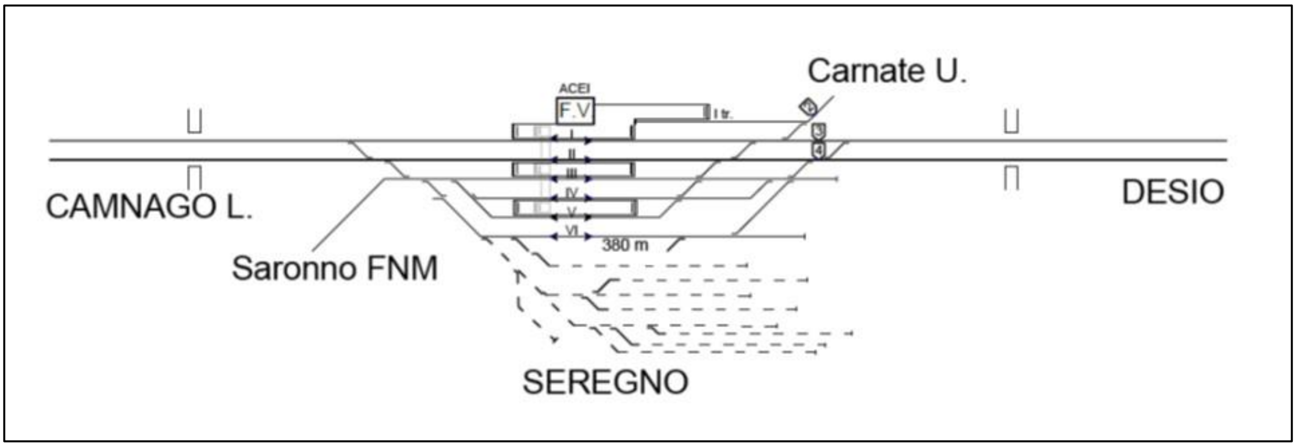

Figure 48: Schematization of the layout of Seregno station

Services with scheduled stop in Seregno are:

- S11 Rho – Milano Porta Garibaldi – Como/Chiasso;
- S9 Saronno – Albairate;
- RE10 Milano Centrale – Como – Chiasso – Bellinzona;
- R15 Seregno – Carnate.

All the other services (passengers and freight) are in transit.

For this Scenario, the only station root analyzed is the complex node “Radice SUD”: it is the station area between the main protection signals by the side of Desio station and the axis of the station building. Possible criticalities are due to the crossing interferences between trains Saronno FNM, Carnate and line Milano-Chiasso.

To summarize, Figure 49 shows services and routes of this complex node.

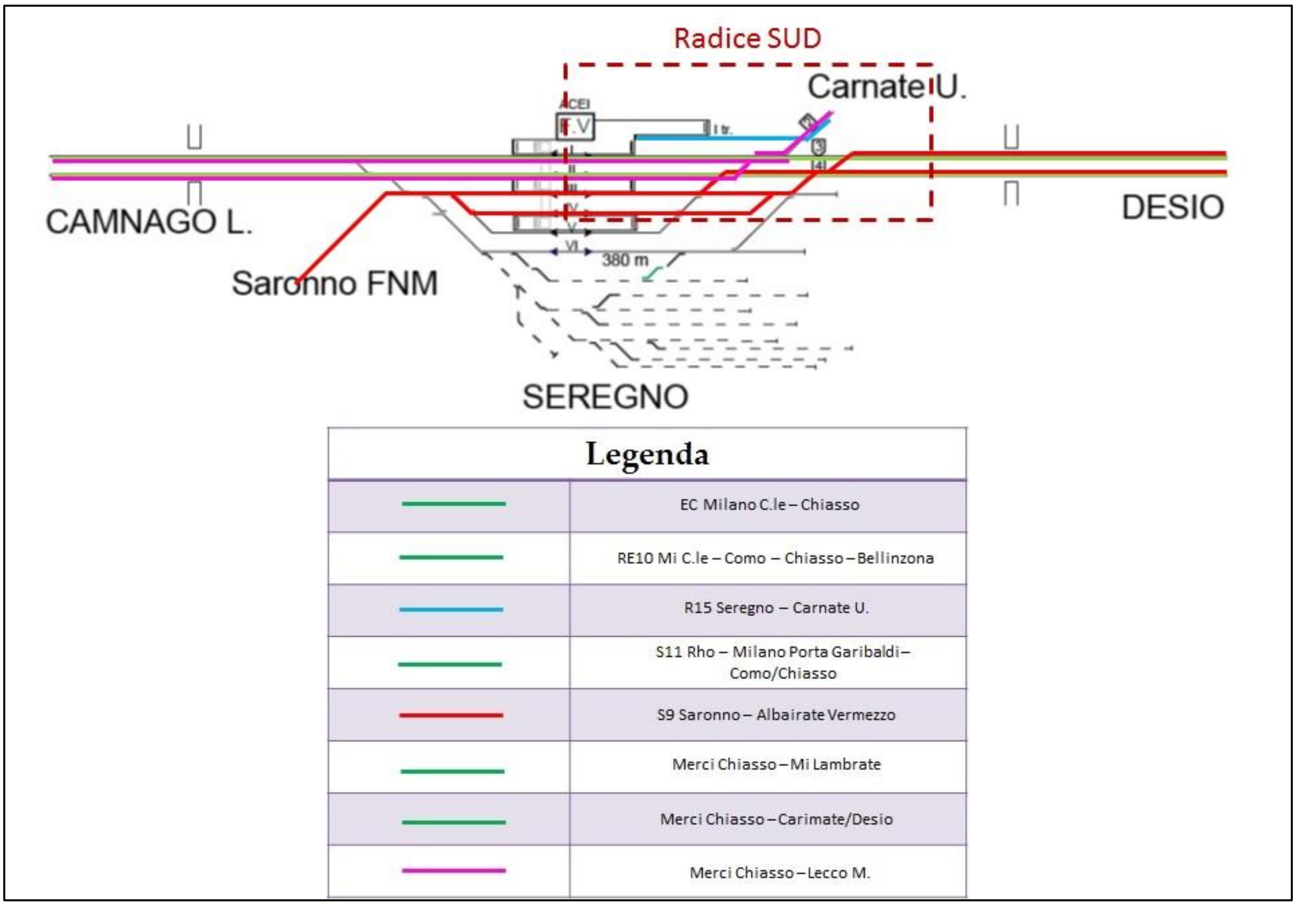

Figure 49: Graphic synthesis of routes and services for Seregno station – Rad. SUD – Scenario 0

Line points *3* and *4* identify respectively even and odd tracks of the line Milano-Chiasso; line point *2* identifies track of the line Seregno-Bergamo.

Tables with matrices are in a specific Annex ("D") at the end of the paper.

Results obtained by the application of the method are in Table 20.

Potthoff parameters – Rad. SUD Seregno

N	nm	tm (s)	B (s)	R (s)	T (s)
21.5	2.0	190	2057	502	3600

Utilization rates – Rad. SUD Seregno

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.571	57.1	0.641	64.1

Table 20: Results of node analysis: Seregno station - Rad. SUD Scenario 0

Global utilization rate value of the station root is under the critical threshold indicated by Potthoff for peak-hour. Crossing route from track V to line point *3* is run only by suburban trains S9 (2 trains per hour) while in peak hour there is no freight trains from/to Chiasso to/from Lecco Maggianico running the crossing route from line point *2* to track II. Therefore, the low number of trains involved in interferences generates a restrained delay that does not compromise the performance of the node.

7.2.3 Synthesis of the results obtained

By the application of the methodology of analysis proposed, Scenario 0 highlights criticalities in terms of capacity of some sections of the lines and some station roots. Line section Parabiago-Rho is in saturation with 2020 railway scheduled traffic with no scheduled introduction of new services (essentially equal to current railway supply). As in Figure 50, station roots characterized by congestion phenomena are Rho station - Radice OVEST and Gallarate station – Radice NORD. The crossing interferences between station routes penalize the performances. These results demonstrate that to increase and develop the railway connections between Milan and Malpensa International Airport some infrastructural upgrades to support an increase of the number of trains are necessary.

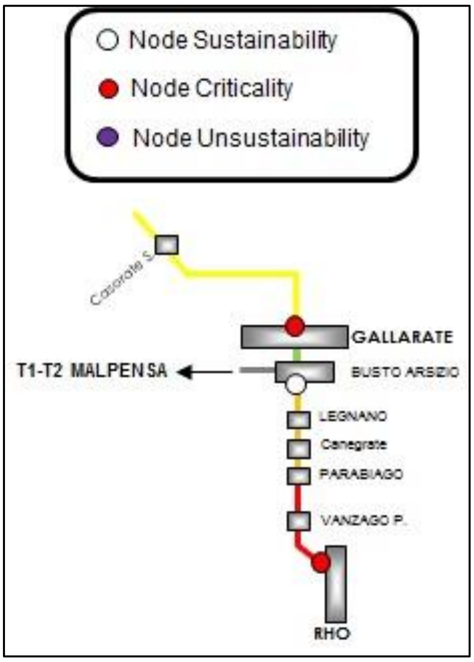

Figure 50: Node performances - Rho-Gallarate segment – Scenario 0

7.3 SCENARIO 1: RESULTS OBTAINED BY THE METHODOLOGY APPLICATION

After the presentation of Scenario 0 results, this chapter is dedicated to the presentation of the results obtained by the analysis of the infrastructural upgrades of the relevant lines and nodes designed and planned by the infrastructure manager. These projects are part of the scheduled 2026 upgrades for the development of the railway infrastructure already discussed and approved by the stakeholders. The interventions analyzed regard the layout of the line Domodossola-Milano in the segment Rho-Gallarate-Malpensa with the subsequent re-configuration of Rho station and the new layout in the segment Ponte San Pietro-Bergamo for the line Seregno-Bergamo.

7.3.1 Scenario 1: performances of the lines

For the line Domodossola-Milano, the upgrades considered are the **new 4-track layout between Rho and Parabiago** and the **new T2-Gallarate North Railway Link.** The sections analyzed in this Scenario are (in bold the new sections introduced):

ID	SECTION	D/S
24	**Sesto Calende - Bivio Casorate**	**D**
2	Gallarate - Busto Arsizio	**D**
3	Busto Arsizio - Parabiago	D
25	**Parabiago - Rho (DD)**	**D**
26	**Parabiago - Rho (LL)**	**D**
27	**Bivio Cardano - Gallarate Deviatoio Estremo**	**D**
28	**Gallarate Deviatoio Estremo (lato T2) - Gallarate**	**D**
29	**Bivio Casorate - Gallarate Dev. Estremo**	**D**
5	Rho - Milano Certosa (Varese)	D
6	Rho - Milano Certosa (Novara)	D
7	Rho - Milano Certosa (AV/AC)	D
8	Milano Certosa - PM Ghisolfa (Novara)	D
9	Milano Certosa - Bivio Musocco (Cintura)	D
10	Milano Certosa - Milano Lancetti	D
11	Milano Certosa - Triplo Bivio Seveso (Viaggiatori)	D

12	Bivio Musocco - Triplo Bivio Seveso (Cintura)	D
13	Bivio Musocco - PM Ghisolfa (Cintura)	D
14	Triplo Bivio Seveso - Milano Centrale (Viaggiatori)	D
15	Bivio Mirabello - Quadrivio Turro	D
16	Quadrivio Turro - Milano Centrale (MXP)	D
17	PM Ghisolfa - Milano Porta Garibaldi (Novara)	D
18	PM Ghisolfa - Milano Porta Garibaldi (Cintura)	D
19	Bivio Mirabello - Milano Porta Garibaldi	D

Table 21: Analyzed sections of line Domodossola-Milano – Scenario 1

Section 1 of Scenario 0 is changing to section 24 and new sections 27, 28, 29 are introduced with Malpensa Terminal 2 – Gallarate station link.

New tracks layout between Rho and Parabiago stations is in the analysis with the introduction of new sections 25 and 26: a section for fast trains called "DD" and a section for slow trains called "LL".

The sections of the line Seregno – Bergamo analyzed in this Scenario are in Table 22.

20	Seregno - Carnate	S
21	Carnate - Calusco	S
22	Calusco - Ponte San Pietro	S
32	**Ponte San Pietro - Bergamo**	**D**

Table 22: Analyzed sections of line Seregno-Bergamo (Scenario 1)

The only planned infrastructural intervention of the line is the **new double-track layout of section Ponte San Pietro – Bergamo.**

The future railway traffic plans the introduction of the new following services:

- **Modification of actual suburban service S5 Varese-Treviglio in the new S5 Malpensa-Gallarate-Treviglio;**
- **Extension of actual suburban service S11 Milano Porta Garibaldi-Como to Parabiago;**
- **New suburban service S14 Milano Rogoredo-Magenta;**
- **New suburban service S15 Milano Rogoredo-Parabiago;**
- **New suburban service S16 Abbiategrasso-Milano Lambrate-Parabiago;**

- **Introduction of new RegioExpress service RE MXP Milano Centrale-Rho Fiera-Gallarate-Malpensa;**
- **Introduction of new RegioExpress service RE Bergamo-Malpensa Airport**
- **Substitution of actual Regional service R14 Milano Porta Garibaldi-Carnate-Bergamo with new suburban service S18 Milano Porta Garibaldi-Carnate-Bergamo-Montello;**
- **Introduction of new Regional service R7 Lecco-Bergamo-Montello;**
- **Introduction of new Regional service R Ponte San Pietro – Montello.**

In the following table, characteristics of new services are in Table 23.

ID	Category	Name	Service	Frequency (min)		Peak class	Subject to precedence	Trains' class	Rides/h main dir.		Rides/h contrary dir.	
				Peak	Off-peak				Peak	Off-peak	Peak	Off-peak
24	RE	MPX	Milano C.le - Rho Fiera - Gallarate - Malpensa	30	30	B	0	2	2	2	2	2
30	RE	x	Malpensa - Bergamo	30	30	B	0	2	2	2	2	2
31	R	R7	Lecco - Bergamo - Montello	60	60	B	0	3	1	1	1	1
32	R	RX	Ponte S.Pietro - Montello	60	60	B	0	4	1	1	1	1
25	S	S5	Malpensa - Gallarate - Treviglio	30	30	B	0	4	2	2	2	2
26	S	S11 pros.	Milano P.G. - Rho - Parabiago	30	30	B	0	4	2	2	2	2
27	S	S14	Mi. Rogoredo - Magenta	30	30	B	0	4	2	2	2	2
28	S	S15	Mi. Rogoredo - Parabiago	30	30	B	0	4	2	2	2	2
29	S	S16	Abbiategrasso - Mi. Lambrate - Parabiago	30	30	B	0	4	2	2	2	2

Table 23: New services considered for Scenario 1

Freight services are the same of Scenario 0, maintaining unchanged the rides/h per direction in peak periods and off-peak.

Results obtained by the application of the methodology are in Table 24.

ID	**Spacing Requirement**			**Time lost for speed variability**		**Utilization (min)**		**Utilization Rate**	
	BAB/AB	**MEB/ACB**	**Cross./PBI**	**Peak**	**Off-peak**	**Peak**	**Off-peak**	**Peak**	**Off-peak**
24	5			20	23	45	48	**75.0**	**80.0**
2	5			7	6	63	50	**105.0**	**83.3**
3	4			21	22	65	58	**108.3**	**96.7**
25	4			13	7	45	27	**75.0**	**45.0**
26	4			8	16	44	56	**73.3**	**93.3**
27	5			0	0	30	30	**50.0**	**50.0**
28	4			0	0	44	44	**73.3**	**73.3**
29	4			0	0	20	20	**33.3**	**33.3**
5	4			0	0	40	40	**66.6**	**66.6**
6	4			11	12	59	48	**98.3**	**80.0**
7	4			0	0	24	8	**40.0**	**13.3**
8	4			8	6	48	30	**80.0**	**50.0**
9	5			6	6	26	31	**43.3**	**51.7**
10	5			0	0	40	40	**66.7**	**66.7**
11	5			0	0	40	20	**66.7**	**33.3**
12	5			0	0	30	25	**50.0**	**41.7**
13	5			0	0	10	0	**16.7**	**0.0**
14	5			4	4	44	24	**73.3**	**40.0**
15	5			1	0	26	20	**43.3**	**33.3**
16	5			0	0	20	20	**33.3**	**33.3**
17	5			3	2	53	32	**88.3**	**53.3**
18	5			0	0	20	10	**33.3**	**16.7**
19	5			1	0	66	60	**110.0**	**100.0**
20		2	1	0	0	57	64	**95.0**	**106.3**
21		2	1	0	0	64	64	**106.7**	**106.7**
22		2	1	0	0	60	60	**100.0**	**100.0**
32	5			2	2	32	32	**53.3**	**53.3**

Table 24: Utilization and Utilization rate for sections of Scenario 1

All the results obtained for this Scenario are in Figure 51.

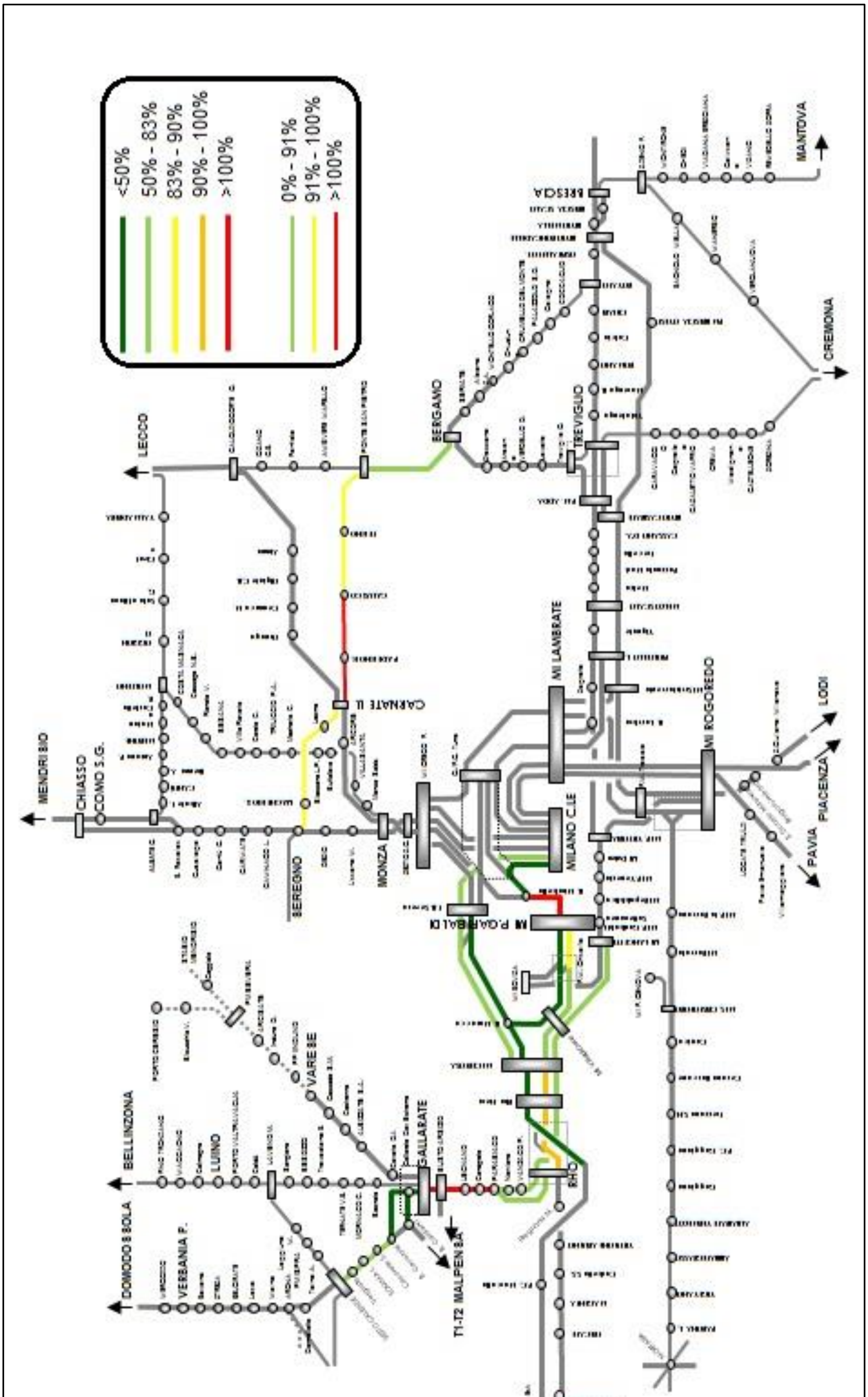

Figure 51: Graphic synthesis of results - Scenario 1

Results highlight criticalities with a utilization rate greater than 100% in the following sections for the line Domodossola-Milano:

- Gallarate-Busto Arsizio;
- Busto Arsizio – Parabiago;
- Bivio Mirabello – Milano Porta Garibaldi.

The upgrade of track-layout in the section Rho – Parabiago from double-track to 4-track layout involves a decongestion of this segment. The project plans the specialization of the line according to the class of the train with the aim to minimize the time lost for speed variability: a line (indicated as "LL") is reserved for suburban services S stopping in all stations while a parallel line (indicated as "DD") is for "fast" trains stopping only in main stations. The sections Gallarate – Busto Arsizio and Busto Arsizio – Parabiago are bottlenecks with the utilization rate values over 100% due to a high value of time lost for speed variability.

The results of Scenario 1 highlight that the new infrastructure between Rho and Parabiago is not able to generate performance benefits in terms of line capacity. The values of utilization rate indicate a saturation of the segment Gallarate – Parabiago with an inability of the infrastructure to support the expected railway traffic deriving by the introduction of new services.

Another criticality is representing by service point Bivio Mirabello. The utilization of the section B. Mirabello – Milano Porta Garibaldi is equal to 66 minutes in peak hour with a total number of 13 trains running on it. Here, infrastructural upgrades to solve interferences among the routes are difficult to realize. For this reason, it is necessary to decongest this section acting on planned supply. In Scenario 0, the current supply presents the RE service Milano Centrale-Milano Bovisa FN-Malpensa Airport with a frequency of 30 min. In this Scenario 1, future supply introduces a new RE service Milano Centrale-Rho Fiera-Gallarate-Malpensa Airport with frequency 30 minutes and it confirms the actual RE service towards Malpensa via FNM line. This means that frequency of services from Milano Centrale to Malpensa Airport is equal to 15 minutes with 4 trains per hour per direction. To reduce the congestion of the section, a solution may be the reduction of the number of rides/h for the trains with the same destination. So, the choice is to confirm the introduction of the new RE service Milano Centrale-Malpensa via Rho-Gallarate and to eliminate the service RE Milano Centrale-Malpensa via Bovisa FN (FNM line) maintaining a frequency from the main station of Milan of 30 minutes. Utilization rate of the section Bivio Mirabello – Milano Porta Garibaldi without RE service mentioned above is equal to 93.3% in peak hour and 83.3% in off-peak hour with a utilization respectively equal to 56 minutes and 50 minutes. In this way, the utilization value is under the threshold of saturation and then it is manageable.

For the line Seregno – Bergamo, the extension of the regional service R7 Lecco – Bergamo to Montello and the introduction new services R Ponte San Pietro – Montello and RE Bergamo-Malpensa Airport involve an infrastructural intervention on this line. In this Scenario, the section Ponte San Pietro – Montello has a new double-track layout. The congestion issues are located in the sections characterized by the single-track layout between Seregno and Ponte San Pietro. Possibilities of infrastructural upgrade with new double-track layout of the line for these sections are limited particularly in correspondence of the bridge on the river Adda connecting towns of Paderno and Calusco. Critical section is Carnate-Calusco with a utilization rate of 106.7%; the other sections characterized by a single-track layout are on partial congestion with utilization rate between 91% and 100%.

In Figure 52, the results after the modification of future supply with elimination of RE service Milano Centrale-Bovisa FN-Malpensa Airport and consequent decongestion of section Bivio Mirabello-Milano Porta Garibaldi.

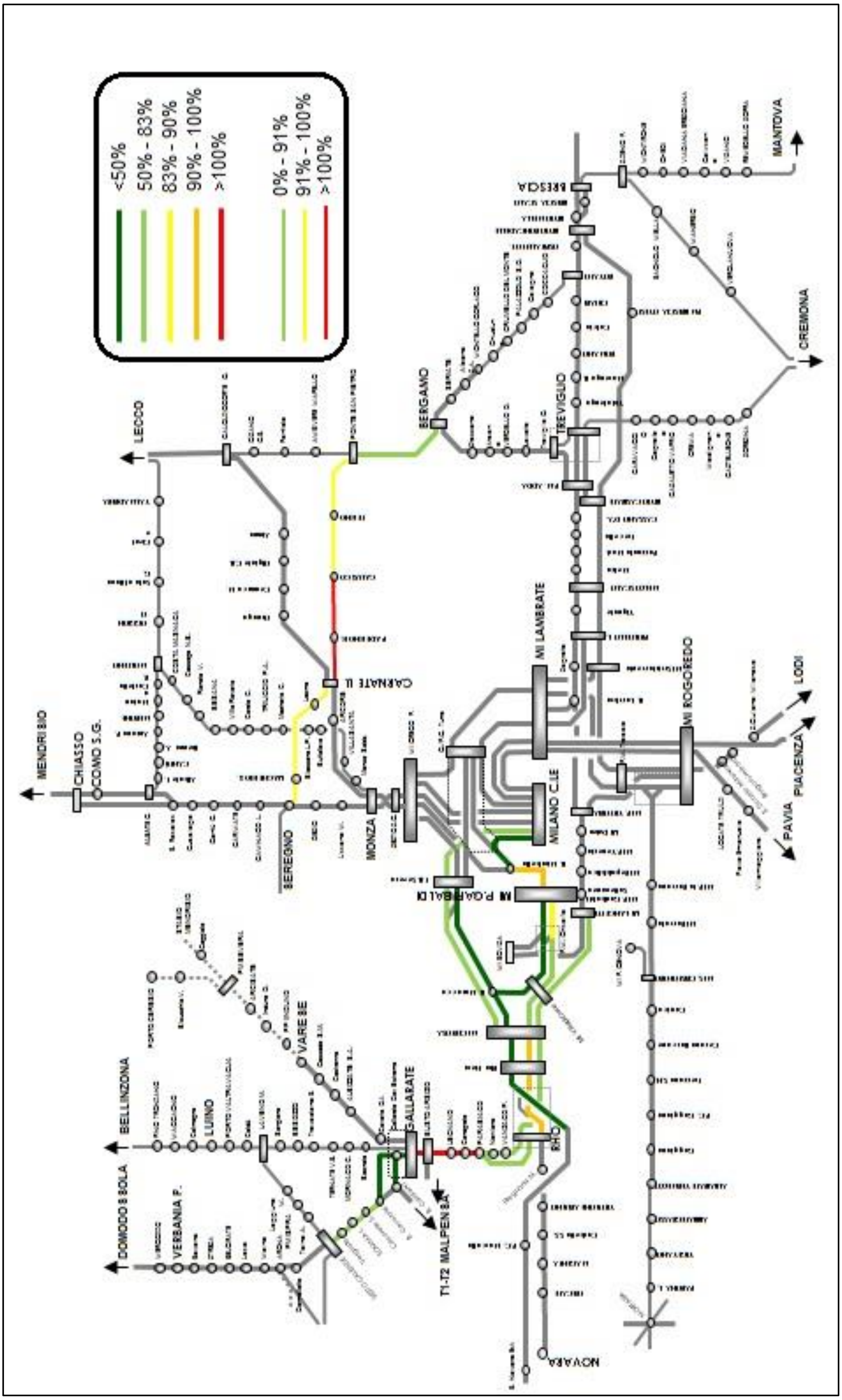

Figure 52: Graphic synthesis of results - Scenario 1 - Decongestion of Bivio Mirabello

7.3.2 Scenario 1: new layout of Rho station

In this Scenario, the node infrastructural upgrade analyzed is the new layout of Rho station. With the introduction of new services, it is necessary to evaluate a new station layout considering the criticalities of the actual one verified in Scenario 0. The layout here proposed, designed and developed by RFI, is in the documentation related to the upgrade of the segment Rho-Gallarate.

The infrastructural upgrades involve both the station roots "Radice EST" and "Radice OVEST" of Rho station. The new layout provides for tracks II and III as direct routes from/to Rho Fiera ("Varese" line) to/from Gallarate for slow line (indicated as "LL") and tracks I and IV as direct routes from/to Rho Fiera ("Novara" line) to/from Magenta/Novara. Track V is for stopping trains in deviated route coming from Rho Fiera ("Varese" line) with destination Magenta/Novara. Fast line (indicated as "DD") from/to Gallarate is given by a deviated route diverging from track IV for even train flow and a deviated route converging to track I for odd train flow. The main civil infrastructure of the project is the overpass of odd track of Novara-Milano line: it permits to avoid all the crossing conflicts between the station routes eliminating the delays generated by actual interferences.

The results obtained by the application of Potthoff method in Scenario 0 highlight a saturation condition for the station root "Radice OVEST" of Rho station. By these results, it is clear that the actual station configuration is not able to support the future expected traffic with the increase of the number of trains. For this reason, the upgrade of the station layout is unavoidable, considering also an upgrade of the line layout.

The analysis starts with the identification of station routes and related services running on. In Figure 53, the station roots "Radice EST" and "Radice OVEST".

The tables with matrices related to the methodology application are in a specific Annex at the end of the paper. Results obtained by Potthoff method are in Table 25.

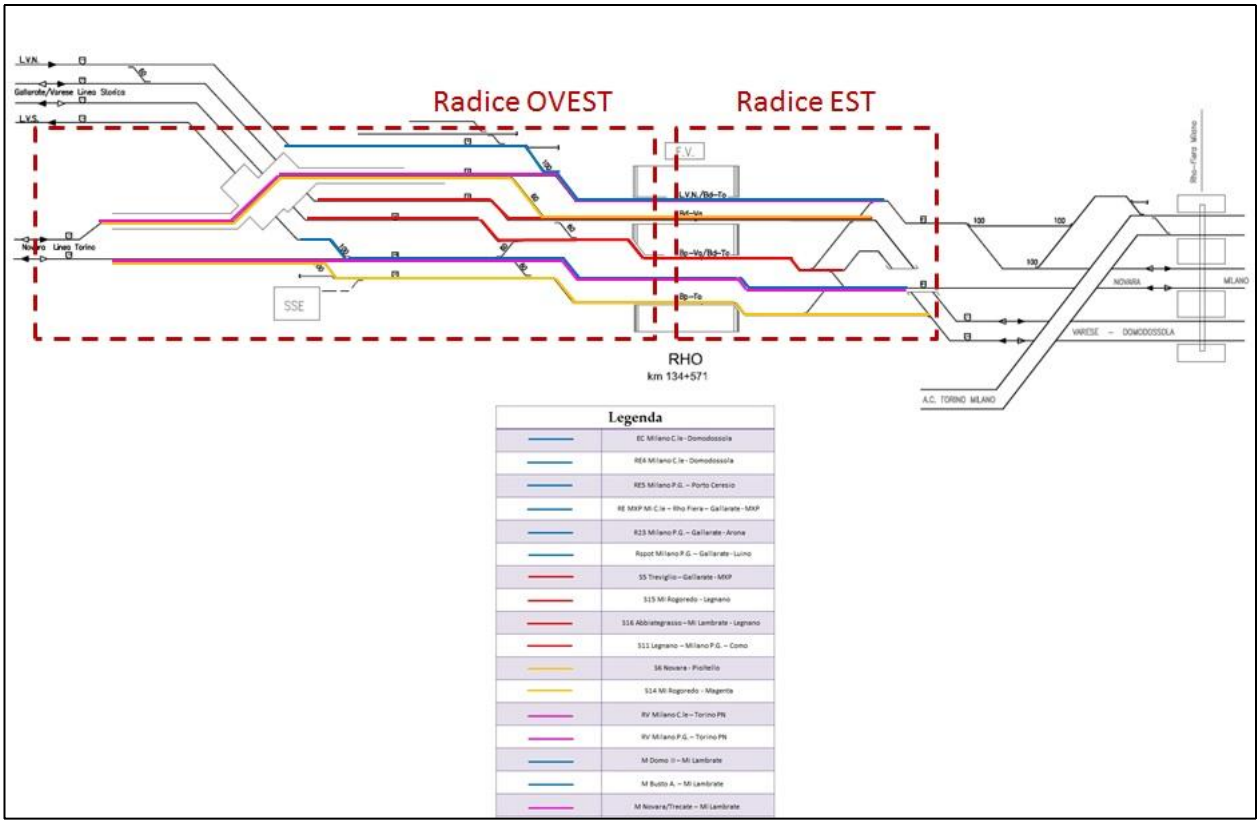

Figure 53: Graphic synthesis of routes and services for Rho station - Rad. OVEST/EST - Scenario 1

Potthoff parameters – Rad. EST Rho

N	nm	tm (s)	B (s)	T (s)	R (s)
46	4.0	153	1764	3600	0

Regular and Global utilization rates – Rad. EST Rho

U	U (%)
0.490	49.0

Table 25: Results of node analysis: Rho station - Rad. EST Scenario 1

Potthoff parameters – Rad. OVEST Rho

N	nm	tm(s)	B(s)	T(s)	R(s)
92	9.5	170	1644	3600	985

Utilization rates – Rad. OVEST Rho

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.457	45.7	0.486	48.6

Table 26: Results of node analysis: Rho station - Rad. OVEST Scenario 1

As expected, the new layout of Rho station is able to support the traffic generated by the future system of services. Utilization rate obtained by the application of Potthoff method to the actual infrastructure and the future railway supply identifies an unsustainable condition of traffic with a value widely over 100%. The elimination of all crossing conflicts ensures a remarkable decrease of delays with respect to previous analysis. Therefore, the global utilization rate values obtained in this Scenario is under the threshold indicated by Potthoff for node capacity in peak hour.

The analysis clearly demonstrates the need of this station upgrade for the increase of the number of railway services toward Gallarate and Malpensa Airport.

7.3.3 Synthesis of the results

Scenario 1 reports an infrastructural configuration for the line Domodossola-Milano with a new 4-track layout between Rho and Parabiago and the upgrade of the Rho station layout. The results highlight the effectiveness of the layout proposed, as in Figure 54 but demonstrate the inability of the line upgrades to increase the infrastructural capacity as looked for. This Scenario must have additional upgrades in order to obtain an infrastructural configuration able to support the future traffic as scheduled by the development agreements between Lombardy Region and RFI.

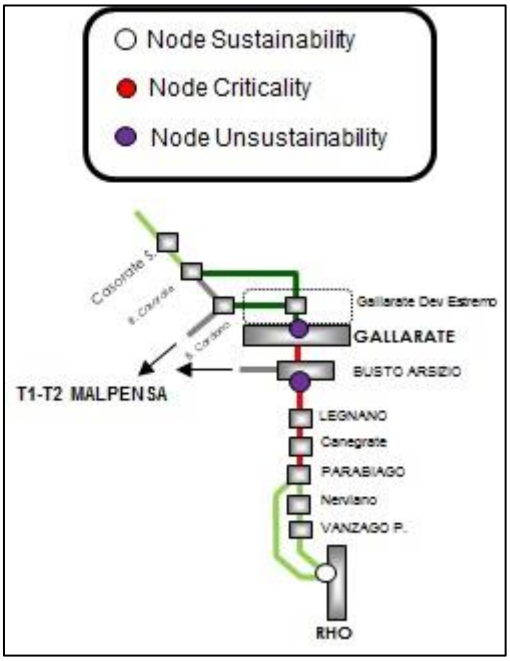

Figure 54: Node performances - Rho-Gallarate segment – Scenario 1

7.3.4 Focus on performances of Milano Certosa station

In the scope of the study of development of Milan railway network, a focus about the performances in terms of node capacity of Milano Certosa station. The methodology applied is the same used for the analysis previous reported. The study involves both the station roots of the station called respectively "Radice EST" and "Radice OVEST"; the layout of the station is the actual one, and the supply is the 2026 future one.

Service and routes of the station roots are in figures 55 and 56.

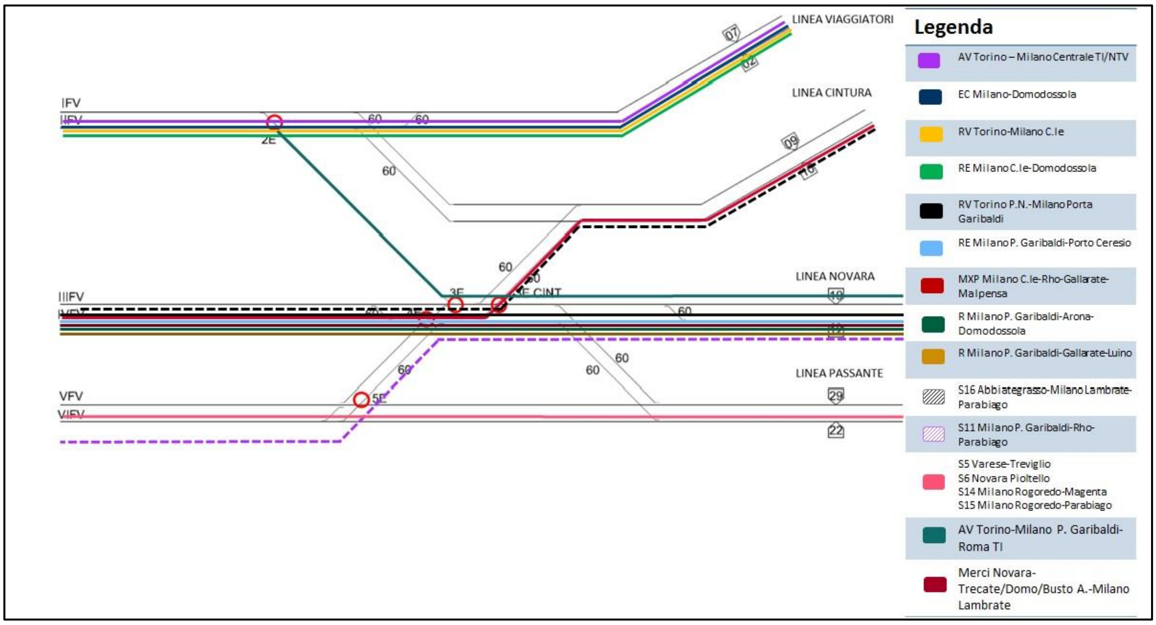

Figure 55: Schematization with services and routes of Milano Certosa station - Rad. EST - Scenario 1

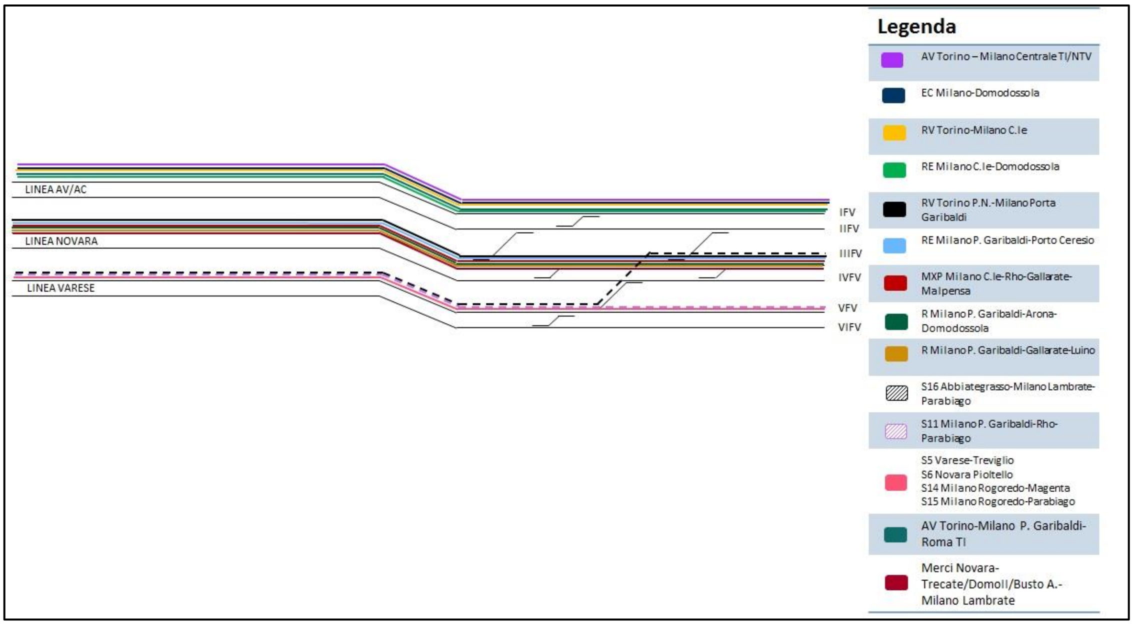

Figure 56: Schematization with services and routes of Milano Certosa station - Rad. OVEST – Scenario 1

The results obtained by the application of the methodology are in Table 27.

For what concern results obtained for "Radice EST", the utilization rate value is over the threshold considered by Potthoff for peak hour capacity. Considering that, the threshold is at 75% and the overestimation of the method, the value obtained is anyway acceptable.

The value obtained for this station root highlights the saturation of the node and possible congestion phenomena with delays in the station circulation.

Potthoff parameters: Rad. EST MI Certosa

N	nm	tm (s)	B (s)	R [s]	T [s]
54	3.86	162	2251	1887	3600

Utilization rate: Rad. EST MI Certosa

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.625	62.5	0.761	76.1

Potthoff parameters: Rad. OVEST MI Certosa

N	nm	tm (s)	B (s)	R (s)	T (s)
54	4.34	170	2092	797	3600

Utilization rates: Rad. OVEST MI Certosa

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.581	58.1	0.632	63.2

Table 27: Analysis results: Milano Certosa station - Rad. EST-OVEST - Scenario 1

In correspondence of the other node "Radice OVEST", the utilization rate value is under the threshold considered by Potthoff for the peak hour.

This analysis highlights an acceptable situation from a circulation point of view in correspondence of this node characterized by the presence of crossing interferences. The introduction of new services in 2026 future railway supply implicates the achievement of the maximum node capacity in peak hour.

8 PROPOSALS OF ADDITIONAL INFRASTRUCTURE UPGRADES

This chapter is dedicated to the description of new additional infrastructure upgrades subsequent to the analysis of the line layout assumed in Scenario 1. The following proposals concern the upgrade of the segment Rho-Gallarate-Malpensa of the line Domodossola-Milano and the upgrade of the layout of the relevant stations. For the line Seregno-Bergamo, a new layout for the station of Seregno is proposed.

8.1 RHO-GALLARATE-MALPENSA: PROPOSALS OF INFRASTRUCTURE UPGRADE

The infrastructural upgrades of the segment Rho-Gallarate-Malpensa here proposed may be considered essential to reach an acceptable capacity value according to the expected traffic, as planned with the 2026 supply.

The paper presents two different scenarios:

- **Scenario 1.1.:** it assumes a **4-track layout between Rho and Legnano**; with respect to the configuration of Scenario 1, the new layout is extended northward to Legnano station. The line upgrade involves a **new layout of the station of Legnano**, according to the need to design end stop tracks for the suburban services S11, S15 and S16.
- **Scenario 1.2.:** it assumes the upgrades considered in Scenario 1.1. and an additional line upgrade between **Busto A. FS and Gallarate** with a **4-track line layout**. The line upgrade involves a **new layout for the stations of Busto A. FS and Gallarate**.

8.1.1 Scenario 1.1.: description of the upgrades

Considering the results obtained in Scenario 1, the solution here proposed assumes the extension of the 4-track line layout up to the station of Legnano. The objective is to reduce as possible the length of the bottleneck consisted in the double-track line configuration.
Legnano represents the limit in which the realization of a 4-track layout is possible: in fact, the infrastructural upgrade northward is difficult due to the lack of space for the construction of new railway tracks crossing the urban areas. For this reason, the infrastructural upgrade of the section Legnano-Busto A. may not be considered and evaluated. The realization of a 4-track line configuration returns to be possible between Busto A. and Gallarate. The schematization of the line layout is reported in Figure 57.

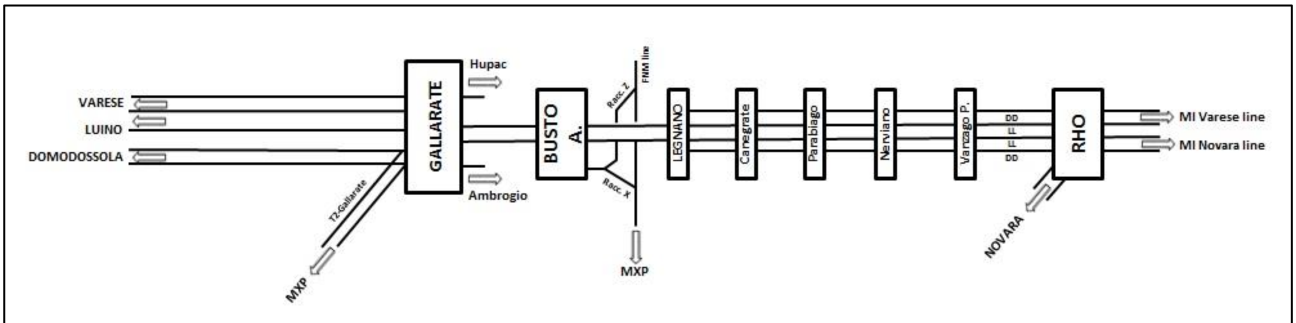

Figure 57: Schematization of the line segment Rho-Gallarate-Malpensa - Scenario 1.1.

This solution permits to extend the line segment characterized by the specialization of the flows according to the typology of the services ("fast" services in "DD" and suburban services in "LL"). The result is a consequent reduction of the global time lost for speed variability. Spacing of the trains is regulated as in the previous case by signalling system implemented by sections with a length of 900÷1060 m (4′ headway).
Extending the infrastructural upgrade up to Legnano implies the possibility to extend also the suburban services originally planned from/to Parabiago. The services involved are:

- S11 Chiasso-Milano Porta Garibaldi-Rho-Legnano;
- S15 Milano Rogoredo-Mi Passante-Legnano;
- S16 Abbiategrasso-Mi Lambrate-Legnano.

The modification of the line layout and the extension of the services imply the need to realize a new station. The solution here proposed is a new terminus-transit station with 4 end stop tracks and 2 line tracks all equipped with platform for boarding/alighting operations. The actual location of the station is at the kilometer point 13+253 from Rho station, in correspondence of the urban area of the town. Considering the top view of the urban area, as reported in Figure 58, it is possible to observe that the availability of space for the realization of the station is limited. The only possibility is to consider a station extension southward.

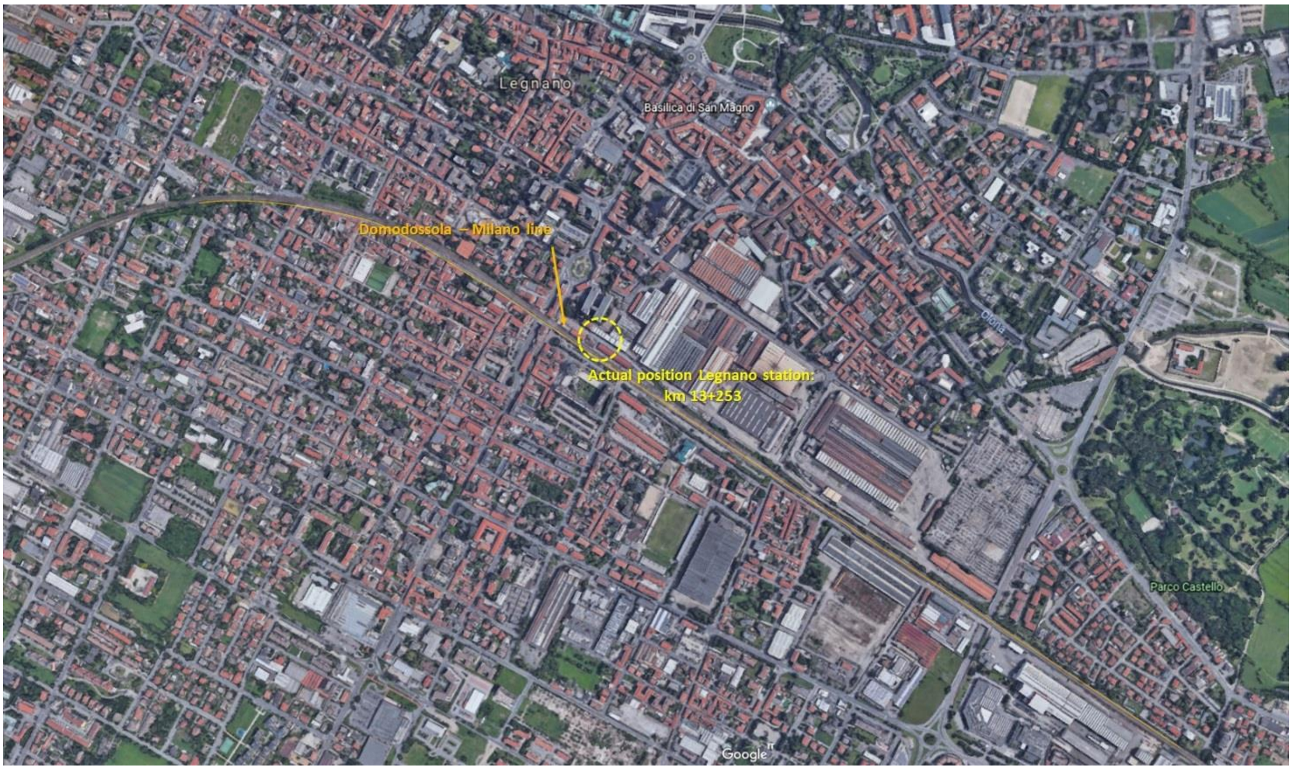

Figure 58: Urban area of Legnano - actual position of the station building

Considering the scheduled demolition of the actual station building, the new one should be shifted of about 350m southward (by the side of Rho station). This value is obtained after a brief calculation of the area necessary for the realization of the new station building. The layout here proposed interests an area of about 1000÷1200 m of length and 30÷35 m of width considering the realization of four tracks and the subsequent widening of the related interaxle for the realization of the platforms. Moreover, it is necessary to consider the spacing for the re-position of tracks at the standard interaxle (4 m) after the station. The length of the area derives from a broad calculation considering:

- the length of platform according to the length module of running trains (about 250 m);
- the estimated length occupied by the switches considering a running speed of 30 km/h (about 350 m);
- the estimated length occupied by inflections of the alignment (about 350 m for a speed of 150 km/h according to train category "C").

These considerations are summarized in the following figure.

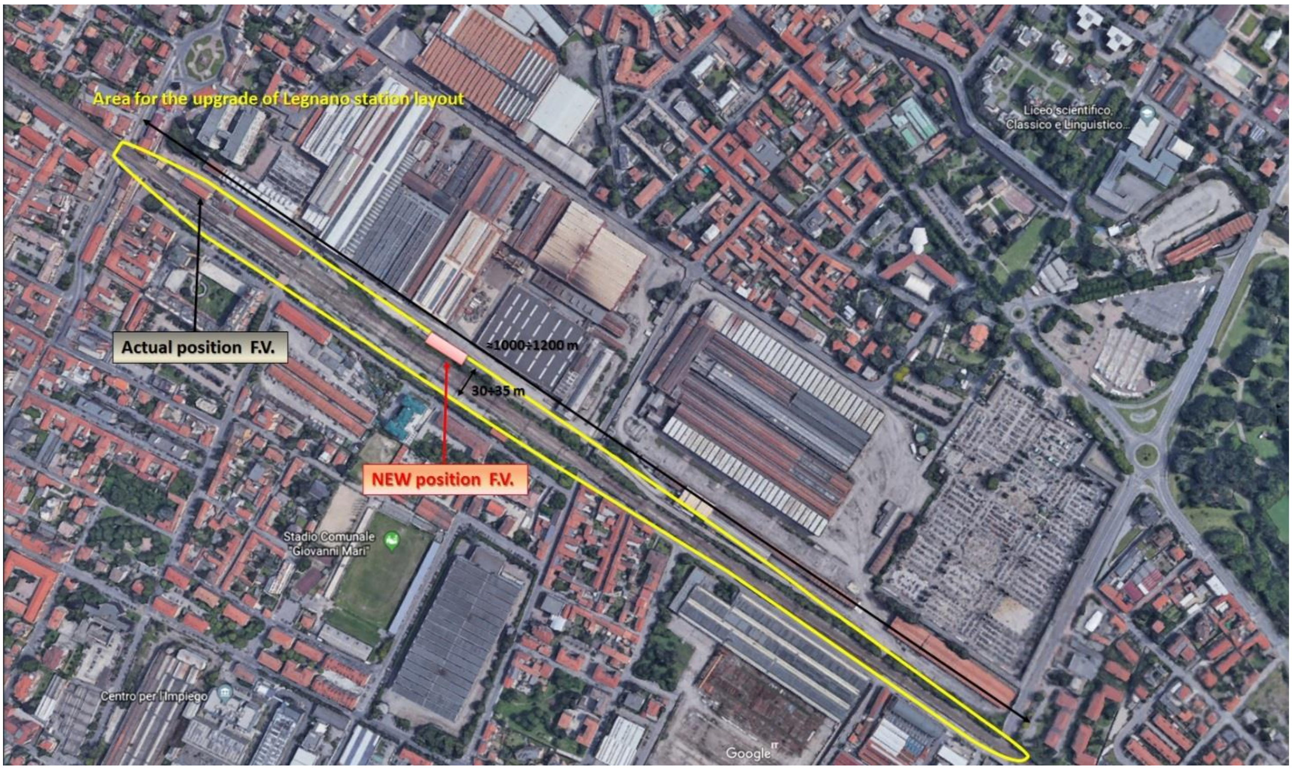

Figure 59: Legnano station upgrade: interested area

The new station plans four blunt tracks for stopping suburban services plus the two line tracks continuing toward Busto Arsizio. The number of end stop tracks may be reduced to three after a specific timetable study. The new station may be realized considering a lateral position of the station building F.V. as a typical passing station with central tracks as terminus for “LL” line; another solution may be realized with a central position of F.V. as a typical terminus station with the two continuing line tracks. The position of the station facility must be carefully evaluated with a precise calculation of the space availability.
A possible station layout is proposed in Figure 60.

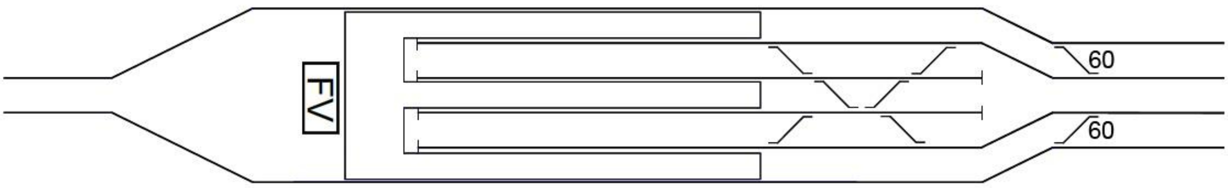

Figure 60: Possible new layout of Legnano station

8.1.2 Scenario 1.2.: description of the upgrades

This Scenario may be considered a successive step of Scenario 1.1. The infrastructural solution assumes the realization of a new 4-track line layout between the stations of Busto Arsizio FS and Gallarate, as a further upgrade of Scenario 1.1.

The layout of the segment Busto A.-Gallarate presents the specialization of the infrastructure according to the origin/destination of the services: a line for the trains from/to Varese/Porto Ceresio and a line for the trains from/to Malpensa/Domodossola. Moreover, the solution plans the realization of a new underpass in order to avoid conflicts between the lines. Considering the actual position of the lines Porto Ceresio-Varese-Milano, Luino-Milano and Domodossola-Milano in correspondence of the station of Gallarate, it is necessary to plan the passage of the line Varese-Milano under the line Domodossola-Milano in order to maintain the actual position of the lines at Gallarate.

The schematization of the line layout considered in this Scenario is reported in Figure 61.

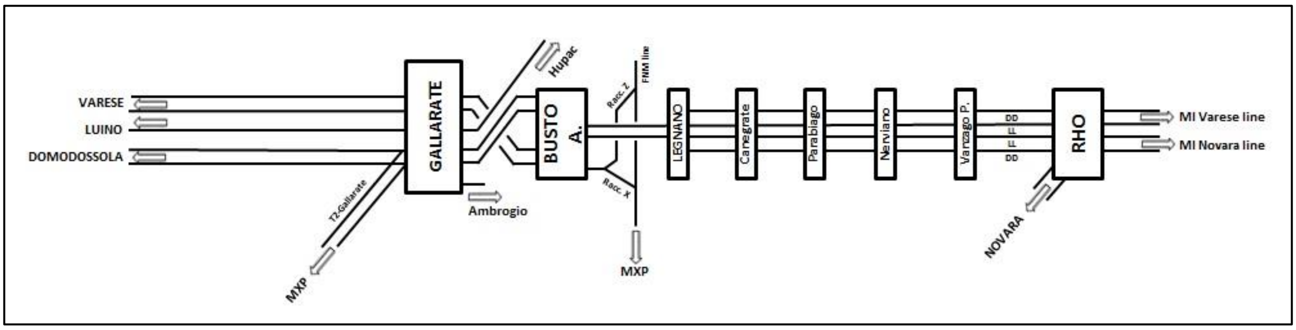

Figure 61: Schematization of the line segment Rho-Gallarate-Malpensa - Scenario 1.2.

The upgrade of the line layout is followed to the subsequent upgrade of the layout of the stations of Busto A. and Gallarate. Considering the new layout of Busto A. station, as proposed in Figure 62, it is possible to observe the choice to maintain the line Domodossola-Milano in direct route, taking into account the prevalent traffic from/to Malpensa airport and Domodossola. The trains coming from Rho with destination Varese/Porto Ceresio are forwarded to the suitable line in correspondence of the station root “Radice Sud” of Busto FS station. The position of the line from/to Varese in correspondence of the station root “Radice Nord” is justified taking also into account of the use of tracks I-II by trains of the service S40 Como-Mendrisio-Varese-Malpensa: the solution permits to avoid interferences with the trains from/to Domodossola in direct route.

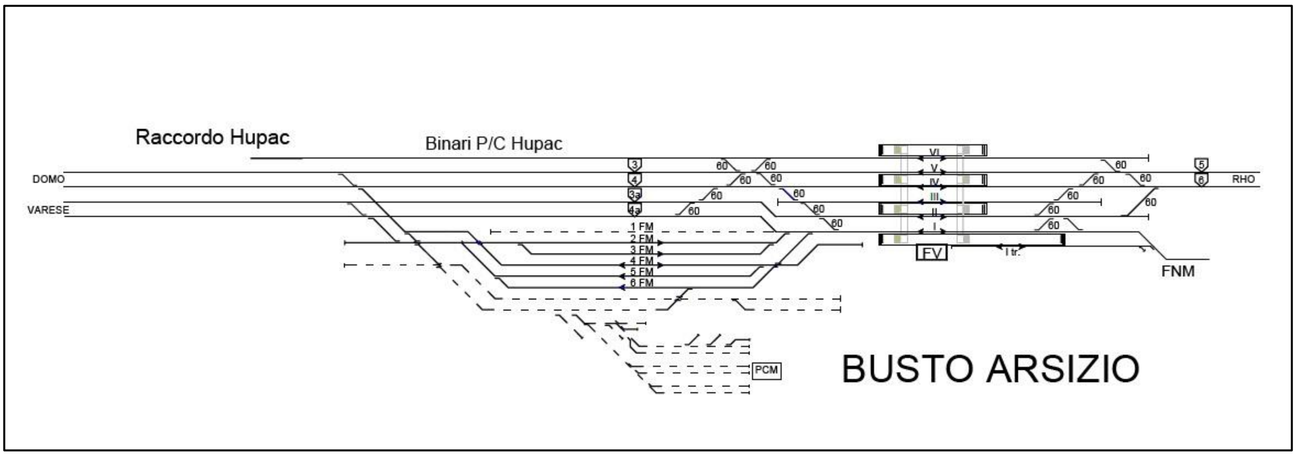

Figure 62: New layout of Busto A. FS station - Scenario 1.2.

Tracks I and II will be used by trains from/to Varese/Gallarate to/from Rho and to/from Malpensa Airport via FNM line. Tracks IV and V are direct route tracks for trains from/to Domodossola/Gallarate to/from Rho; tracks III and VI will be used as overtaking tracks. With this layout, all the tracks are equipped with platforms for boarding/alighting operations. Furthermore, track VI can be used by freight trains for the access/egress from/to HUPAC area. An unavoidable interdiction is generated between route from track II to odd track of the line to Rho; possible crossing conflicts are generated by trains from/to tracks I and II to/from Gallarate/Domodossola. Both the station roots are equipped with 60 km/h switches.

The new layout of the line segment Gallarate-Busto A. is strictly linked to the new configuration of Gallarate station, as reported in Figure 63. This new layout plans the modifications of railway equipment for both the station roots with respect to the actual one. Tracks II and III becomes direct route tracks for the line from/to Domodossola and tracks VII and VIII becomes direct route tracks for the line from/to Varese. Track VI is used by trains from/to Luino; tracks IV and V are used by freight trains from/to HUPAC terminal or eventually as priority track for the line “Domodossola”. Track I is used by trains from/to Ambrogio terminal. All tracks are equipped with platforms with exception of tracks IV and V. Moreover, the station roots are equipped with 30 and 60 km/h switches. This solution permits to avoid all the conflicts generated by the station roots, as detected in Scenario 0, solving the main issues of crossing interferences of the freight trains from/to HUPAC terminal.

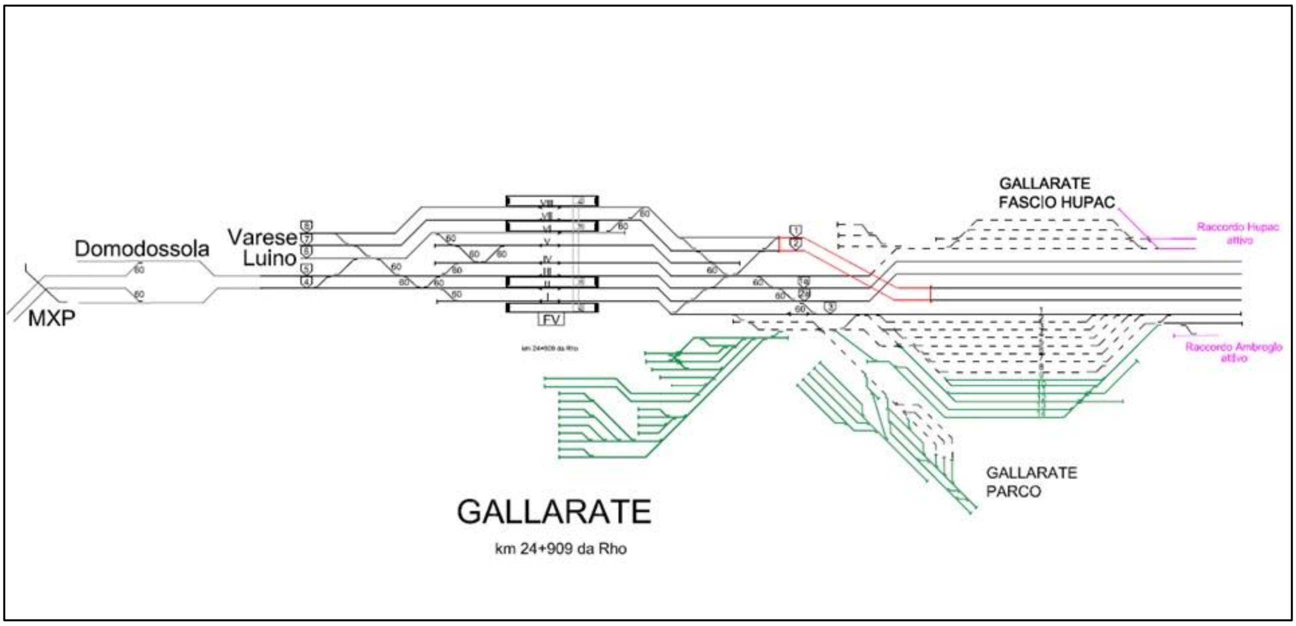

Figure 63: New layout of Gallarate station – Scenario 1.2.

The figure shows in red the new underpass of the line from/to Varese merging at the station tracks VII and VIII without interferences with “Domodossola” line. The realization of this solution can make necessary the elimination of external tracks of “Gallarate Fascio Hupac” and “Gallarate Parco”.

8.2 SEREGNO-BERGAMO: PROPOSAL OF INFRASTRUCTURE UPGRADE

The proposal of infrastructure upgrade here presented is a **new configuration of the station of Seregno**, located in correspondence of the junction between the lines Milano-Chiasso (RFI line), Seregno-Bergamo (RFI line) and Seregno-Saronno (FNM line). The objective of this upgrade is the resolution of the interferences among the services.

8.2.1 New layout of Seregno station

The new station layout is planned with the aim to avoid the interferences between the flow of the trains of the line Milano-Chiasso with the flow of the trains from/to FNM line (Saronno). Actually, the trains of the suburban service S9 Albairate-Saronno use the station tracks III and IV: their deviated routes of arrival and departure generate conflicts with the direct route of the trains running on the line Milano-Chiasso in correspondence of the station root "Radice Sud", as detected in Scenario 0. Considering also the possible introduction of a service Malpensa-Bergamo via Seregno, the actual layout of the station appears unsuitable to support the traffic with crossing interferences and subsequent high interdiction times between the routes. As in Figure 64, the upgrade proposes the realization of a new overpass able to leap over the line Milano-Chiasso, merging at track I in correspondence of the station root "Radice Nord". The actual "Saronno FNM" line branch merging at track IV in correspondence of "Radice Nord" is maintained. This solution is adopted to eliminate the crossing conflicts actually characterizing the station root "Radice Sud": the arrival route to the track IV generates diverging conflicts implying no delays while the departure route from the track I generates simple converging interferences with direct route of the track II. The branch departing from track I merges successively at the "Saronno FNM" line, with the realization of a suitable junction point. The tracks of the line Milano-Chiasso are shifted from their actual position.

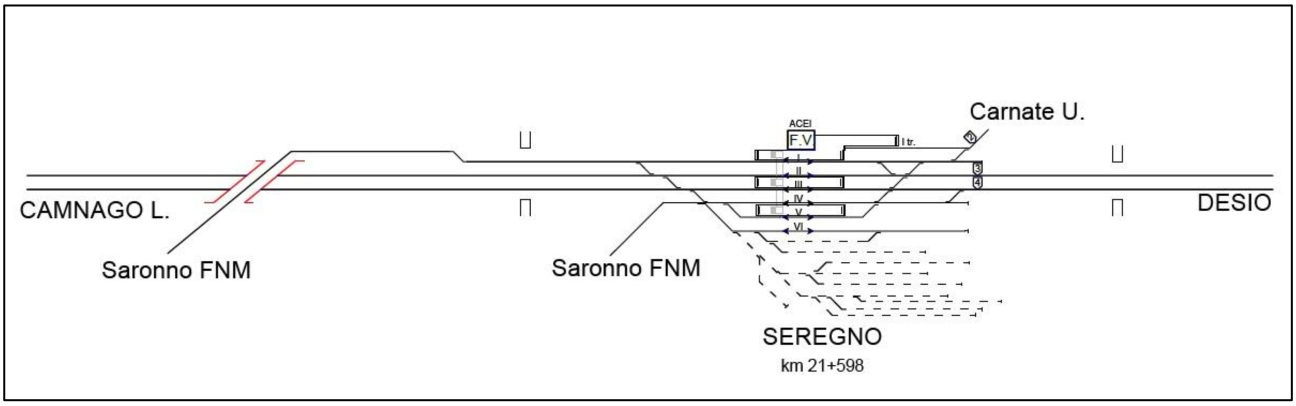

Figure 64: New layout of Seregno station - Scenario 1.2.

This study does not examine in depth the infrastructural problem for the realization of the overpass, but it simply focus on the possible benefits to the station capacity subsequent to the realization of this civil work.

9 METHODOLOGY APPLICATION TO THE PROPOSED INFRASTRUCTURE UPGRADE

This chapter is dedicated to the presentation of the results obtained with the application of the analysis methodology to the infrastructure upgrade layouts proposed in the previous chapter. The study focuses on scenarios 1.1 and 1.2 by analyzing the performances of the line and the nodes according to the solutions previously presented. The objective of this analysis is to assess the effective benefits of the solutions proposed identifying the sustainable configuration of the lines and the nodes able to support the expected traffic according to the future railway supply.

9.1 SCENARIO 1.1.: METHODOLOGY APPLICATION

Scenario 1.1 presents the extension of the 4-track layout up to the station of Legnano. The layout of the stations of Busto Arsizio and Gallarate are as the actual ones. The traffic in this analysis is the same of Scenario 1, deriving from the future 2026 regional railway supply. Moreover, an additional analysis is carried out evaluating the results of infrastructural performances without the introduction of the service RE Bergamo-Malpensa.

9.1.1 Scenario 1.1: performances of the lines

For the line Domodossola-Milano, the sections analyzed in this Scenario are in Table 28 (in bold the new sections introduced).

ID	SECTION	D/S
24	Sesto Calende - Bivio Casorate	D
2	Gallarate - Busto Arsizio	D
33	**Busto Arsizio - Legnano**	**D**
34	**Legnano – Parabiago (DD)**	**D**
35	**Legnano – Parabiago (LL)**	**D**
25	Parabiago - Rho (DD)	D
26	Parabiago - Rho (LL)	D
27	Bivio Cardano - Gallarate Deviatoio Estremo	D
28	Gallarate Deviatoio Estremo (lato T2) - Gallarate	D
29	Bivio Casorate - Gallarate Deviatoio Estremo	D
5	Rho - Milano Certosa (Varese)	D
6	Rho - Milano Certosa (Novara)	D
7	Rho - Milano Certosa (AV/AC)	D
8	Milano Certosa - PM Ghisolfa (Novara)	D
9	Milano Certosa - Bivio Musocco (Cintura)	D
10	Milano Certosa - Milano Lancetti	D
11	Milano Certosa - Triplo Bivio Seveso (Viaggiatori)	D
12	Bivio Musocco - Triplo Bivio Seveso (Cintura)	D
13	Bivio Musocco - PM Ghisolfa (Cintura)	D
14	Triplo Bivio Seveso - Milano Centrale (Viaggiatori)	D
15	Bivio Mirabello - Quadrivio Turro	D
16	Quadrivio Turro - Milano Centrale (MXP)	D
17	PM Ghisolfa - Milano Porta Garibaldi (Novara)	D
18	PM Ghisolfa - Milano Porta Garibaldi (Cintura)	D
19	Bivio Mirabello - Milano Porta Garibaldi	D

Table 28: Analyzed sections for the line Domodossola-Milano - Scenario 1.1.

With respect to Scenario 1, section 3 is now section 33 Busto Arsizio-Legnano and the two new sections are Legnano-Parabiago (DD) and Legnano-Parabiago (LL).

For the line Seregno-Bergamo, the sections are the same of Scenario 1.

Infrastructural interventions with new track layout extended up to Legnano generates the following operational scenario (Table 29).

ID	Spacing Requirement			Time Lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Cross./PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
24	5			20	23	45	48	**75.0**	**80.0**
2	5			7	6	63	50	**105**	**83.3**
33	4			5	5	49	41	**81.7**	**68.3**
34	4			0	0	32	20	**53.3**	**33.3**
35	4			1	2	37	42	**61.7**	**70.0**
25	4			13	7	45	27	**75.0**	**45.0**
26	4			8	16	44	56	**73.3**	**93.3**
27	5			0	0	30	30	**50**	**50**
28	4			0	0	44	44	**73.3**	**73.3**
29	4			0	0	20	20	**33.3**	**33.3**
5	4			0	0	40	40	**66.6**	**66.6**
6	4			11	12	59	48	**98.3**	**80.0**
7	4			0	0	24	8	**40.0**	**13.3**
8	4			8	6	48	30	**80.0**	**50.0**
9	5			6	6	26	31	**43.3**	**51.7**
10	5			0	0	40	40	**66.7**	**66.7**
11	5			0	0	40	20	**66.7**	**33.3**
12	5			0	0	30	25	**50.0**	**41.7**
13	5			0	0	10	0	**16.7**	**0.0**
14	5			4	4	44	24	**73.3**	**40.0**
15	5			1	0	26	20	**43.3**	**33.3**
16	5			0	0	20	20	**33.3**	**33.3**
17	5			3	2	53	32	**88.3**	**53.3**
18	5			0	0	20	10	**33.3**	**16.7**
19	5			1	0	56	50	**93.3**	**83.3**

Table 29: Utilization and Utilization rate for the sections of Scenario 1.1.

By evaluating the results obtained by the analysis, it is possible to observe a general decongestion of all the sections between Rho and Legnano on the line Domodossola-Milano. The section with the main criticality is Gallarate-Busto Arsizio, with a utilization of 63 min and a utilization rate equal to 105% in peak period, meaning that the section is saturated. The section Busto Arsizio – Legnano characterized by a double-track layout has a utilization rate of 81.7%, under the threshold of partial saturation.

For the line Seregno-Bergamo, the results remain the same of Scenario 1.

Considering a possible modification of the future supply with the elimination of the service Bergamo-Malpensa, we observe a decongestion of the following sections:

- 27-Bivio Cardano – Gallarate Deviatoio Estremo;
- 28-Gallarate Deviatoio Estremo – Gallarate;
- 2-Gallarate – Busto Arsizio;
- 20-Seregno – Carnate;
- 21-Carnate – Calusco;
- 22-Calusco – Ponte San Pietro;
- 32-Ponte San Pietro – Bergamo.

Table 29 resumes the results without the service Bergamo-Malpensa.

ID	Spacing Requirement			Time Lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Cross./PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
2	4			7	6	55	42	**91.7**	**70**
27	5			0	0	20	20	**33.3**	**33.3**
28	4			0	0	36	36	**60.0**	**60.0**
20		2	1	0	0	19	26	**31.7**	**42.9**
21		2	1	0	0	32	32	**53.3**	**53.3**
22		2	1	0	0	30	30	**50.0**	**50.0**
32	5			2	2	22	22	**36.7**	**36.7**

Table 30: Utilization rate of the sections involved by the itinerary of the service Bergamo-Malpensa after its elimination – 1.1.

This modification implies a utilization rate of 91.7% for the section Gallarate – Busto Arsizio of the line Domodossola-Milano; for the line Seregno-Bergamo, this solution involves a utilization rate of the sections under the saturation threshold, as in the actual condition.

Considering the performances of the line, this Scenario represents an additional step of Scenario 1, with an improvement of the line capacity of the segment Rho-Legnano and solving the main criticality of the previous scenario represented by the saturation condition of the section Busto Arsizio – Legnano.

9.1.2 Scenario 1.1.: performances of the nodes

The analysis is for two nodes: Busto Arsizio and Gallarate. The new layout of Rho station in Scenario 1 assumes no infrastructural upgrades of the section Gallarate – Busto Arsizio: so, the choice is to maintain the actual layout of the stations. The objective of this analysis is to evaluate whether the actual configuration of the stations is able to support the expected traffic or layout upgrades are necessary.

9.1.2.1 Busto Arsizio FS station

The results obtained by the methodology application, considering the station root "Radice NORD" characterized by interferences between routes, are in Table 31.

Potthoff parameters – Radice NORD Busto Arsizio

N	nm	tm (s)	B (s)	T (s)	R (s)
26	1.63	202	3217	3600	786

Utilization rates – Radice NORD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.894	89.4	1.027	102.7

Table 31: Utilization rates - actual layout and future expected traffic - Busto A. station Rad. NORD

The global utilization rate value obtained by the analysis is over the threshold identified by Potthoff for the capacity of a complex node in peak periods. Considering that Potthoff methodology overestimates the utilization rate, this value is acceptable knowing that it indicates a saturation condition of the node. Therefore, possible congestion and bottleneck phenomena with involvement on the railway circulation must to take into account.

As in the analysis of the line performances, the results of node capacity without the service Malpensa-Bergamo indicate a decrease of the regular and global utilization rates of the station root (Table 32).

Potthoff parameters – Radice NORD Busto Arsizio

N	nm	tm (s)	B (s)	T (s)	R (s)
22	1.84	193	2311	3600	242

Utilization rates – Radice NORD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.642	64.2	0.679	67.9

Table 32: Utilization rates without service Malpensa-Bergamo - actual layout and future expected traffic - Busto Arsizio Radice NORD

The results indicate that the elimination of the service Bergamo-Malpensa from the future supply generate a decongestion of the station root "Radice NORD" with a decrease of the global utilization rate value under the threshold individuated by Potthoff for peak periods capacity of a complex node. This value may ensure an acceptable circulation condition.

9.1.2.2 Gallarate station

The results obtained by the methodology application, considering both the station roots "Radice SUD" and "Radice NORD" characterized by interferences between the routes, are in Table 33.

Potthoff parameters: Radice SUD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
27	1.73	190	2973	1055	3600

Utilization rates: Radice SUD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.826	82.6	0.995	99.5

Potthoff parameters: Radice NORD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
33	2.56	225	2904	2181	3600

Utilization rates: Radice NORD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.807	80.7	1.044	104.4

Table 33: Utilization rates - actual layout and 2026 supply - Gallarate station Radici NORD-SUD

The utilization rate values of both the station roots are over the threshold indicated by Potthoff. As for the station of Busto Arsizio, these values may be acceptable considering possible congestion phenomena, in particular for the root "Radice NORD" characterized by freight traffic entering/exiting from terminals HUPAC and Ambrogio.

As in the analysis of Busto Arsizio station layout, the paper presents the results obtained analyzing the actual configuration of the station without the service Malpensa-Bergamo (Table 34)

Potthoff parameters: Radice SUD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
23	1.71	192	2584	839	3600

Utilization rates: Radice SUD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.718	71.8	0.854	85.4

Potthoff parameters: Radice NORD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
29	2.53	234	2677	1957	3600

Utilization rates: Radice NORD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.744	74.4	0.959	95.9

Table 34: Utilization rates - actual layout and 2026 supply - Gallarate station Radici NORD-SUD

The results obtained by the analysis considering the elimination of the service Malpensa-Bergamo highlight a decongestion of both the station roots of Gallarate station. The values are over the threshold indicated by Potthoff but, considering the overestimation of the method, they ensure an acceptable circulation of the trains.

9.1.3 Synthesis of the results

From a line capacity point of view, the upgrades of the infrastructure generate benefits in the section Legnano-Rho considering a decrease of the utilization rate value from 108.3% to 81.7%. With this solution, a good infrastructural capacity is available in this section with circulation improvements thanks to the realization of the new configuration of Rho station. The section Gallarate-Busto Arsizio persists in a saturation condition. Moreover, the utilization rate values obtained by the application of Potthoff method to the complex nodes highlight potential criticalities in terms of circulation.

The analysis highlight a possible decongestion of the lines and the nodes applying modifications to the supply with the elimination of the service Malpensa-Bergamo and the subsequent reduction of the traffic. This solution implies a decrease of the utilization rate value of the section Gallarate-Busto Arsizio from 105% to 91.7%, on the line Domodossola-Milano. Moreover, the sections of the line Seregno-Bergamo assumes utilization rate values under the saturation threshold, as in the actual condition.

The possibility to adopt this configuration of the infrastructure in the segment Rho-Gallarate without modification of the supply is constrained by the bottleneck represented by the section Gallarate-Busto Arsizio. In this case, it is anyway necessary the realization of some punctual infrastructural upgrades in correspondence of the roots of Gallarate and Busto Arsizio stations. For the line Seregno-Bergamo, the introduction of the service Malpensa-Bergamo without any additional improvement of the infrastructural layout generates the saturation of the line sections, as demonstrate in Scenario 1.

The elimination of the service Malpensa-Bergamo generate a decongestion of all the line sections involved with a decrease of their utilization rate value under the saturation threshold.

The adoption of the infrastructural configuration of this Scenario may be possible only with the elimination of service considered. Without modifications of the supply and the subsequent reduction of the traffic, this Scenario could only represent a transient configuration of the infrastructure between the actual layout and a complete and optimal configuration considering the need to adopt additional infrastructure upgrades in a successive step.

Results of the analysis are graphically summarized in Figure 65 and 66 (without the service RE Malpensa-Bergamo).

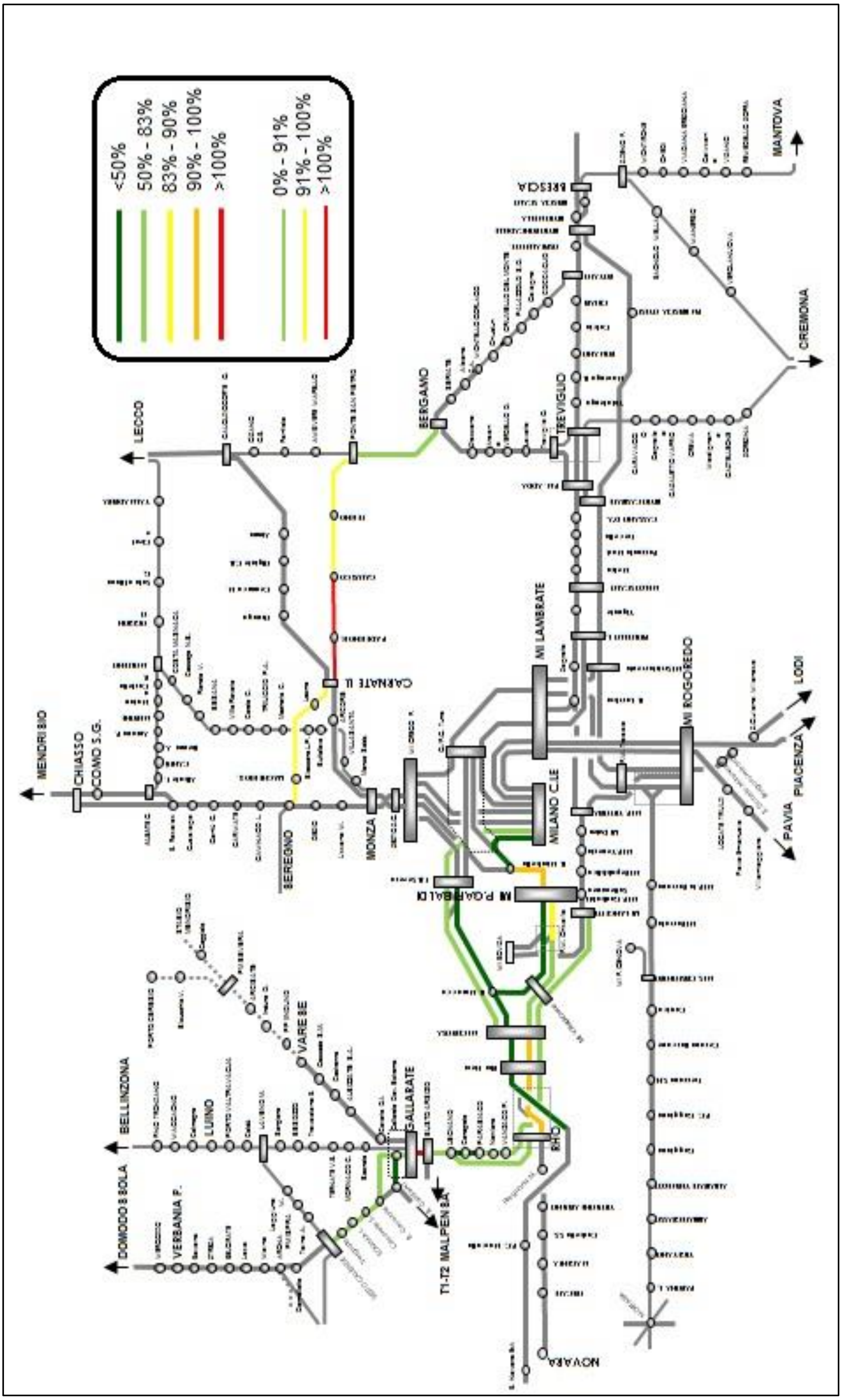

Figure 65: Graphic synthesis of the results - 2026 railway supply – Scenario 1.1.

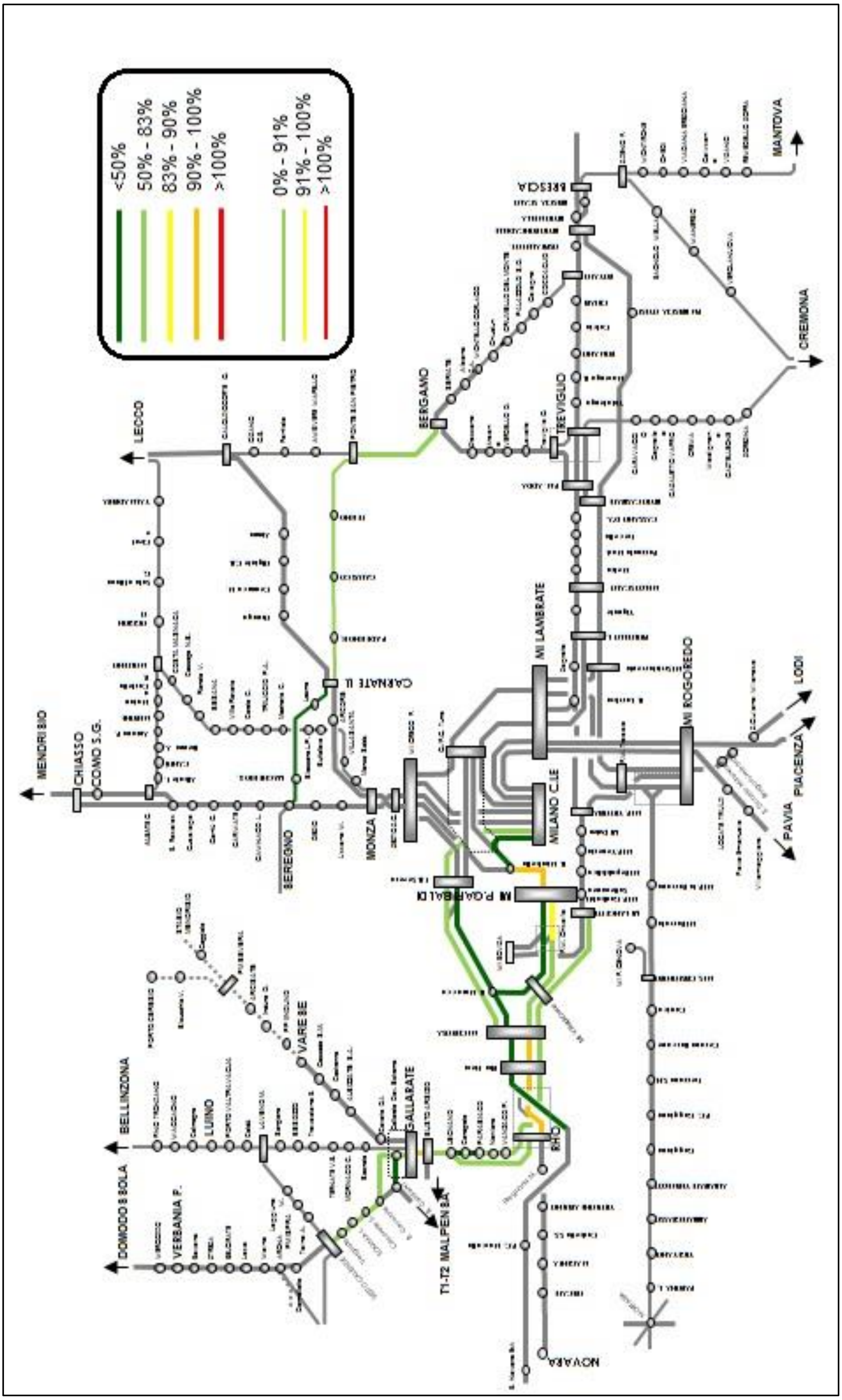

Figure 66: Graphic synthesis of the results without service Bergamo-Malpensa - Scenario 1.1.

9.2 SCENARIO 1.2.: METHODOLOGY APPLICATION

Scenario 1.2 presents the same infrastructural configuration of Scenario 1.1 for the segment Legnano-Rho. The innovation is the new 4-tracks layout between Gallarate and Busto Arsizio with the subsequent modification of the station layouts. The traffic is the same of Scenario 1, deriving from the future 2026 regional railway supply. As in the previous case, an additional analysis is carried out without considering the introduction of the service RE Malpensa-Bergamo.

9.2.1 Scenario 1.2: performances of the lines

For the line Domodossola-Milano, the sections analyzed in this Scenario are in Table 35 (in bold the new sections).

The section 2 Gallarate – Busto Arsizio of the previous scenarios are now the sections 30 Gallarate – Busto Arsizio (V), representing the line from/to Varese, and 31 Gallarate – Busto Arsizio (D), representing the line from/to Domodossola and Malpensa.

The results obtained for the line Domodossola-Milano are in Table 36.

For the line Seregno-Bergamo, the results are equal to Scenario 1 with the criticalities of the saturated sections.

Considering the 2026 railway supply and the related expected traffic, the results highlight a complete decongestion of the segment Rho-Gallarate on the line Domodossola-Milano. All the utilization rate values are under the threshold of saturation condition. This layout of the line segment Rho-Gallarate-Malpensa permits to ensure an optimal infrastructural capacity and a good railway circulation.

Considering the elimination of the service RE Malpensa-Bergamo, the results highlight a decongestion of all the sections involved by its itinerary (Table 37).

ID	SECTION	D/S
24	Sesto Calende - Bivio Casorate	D
31	**Gallarate - Busto Arsizio (D)**	**D**
30	**Gallarate - Busto Arsizio (V)**	**D**
33	Busto Arsizio - Legnano	D
34	Legnano – Parabiago (DD)	D
35	Legnano – Parabiago (LL)	D
25	Parabiago - Rho (DD)	D
26	Parabiago - Rho (LL)	D
27	Bivio Cardano - Gallarate Deviatoio Estremo	D
28	Gallarate Deviatoio Estremo (lato T2) - Gallarate	D
29	Bivio Casorate - Gallarate Dev. Estremo	D
5	Rho - Milano Certosa (Varese)	D
6	Rho - Milano Certosa (Novara)	D
7	Rho - Milano Certosa (AV/AC)	D
8	Milano Certosa - PM Ghisolfa (Novara)	D
9	Milano Certosa - Bivio Musocco (Cintura)	D
10	Milano Certosa - Milano Lancetti	D
11	Milano Certosa - Triplo Bivio Seveso (Viaggiatori)	D
12	Bivio Musocco - Triplo Bivio Seveso (Cintura)	D
13	Bivio Musocco - PM Ghisolfa (Cintura)	D
14	Triplo Bivio Seveso - Milano Centrale (Viaggiatori)	D
15	Bivio Mirabello - Quadrivio Turro	D
16	Quadrivio Turro - Milano Centrale (MXP)	D
17	PM Ghisolfa - Milano Porta Garibaldi (Novara)	D
18	PM Ghisolfa - Milano Porta Garibaldi (Cintura)	D
19	Bivio Mirabello - Milano Porta Garibaldi	D

Table 35: Analyzed sections for the line Domodossola-Milano - Scenario 1.2.

ID	Spacing Requirement			Time Lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Cross./PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
24	5			20	23	45	48	**75.0**	**80.0**
31	4			6	5	46	37	**76.7**	**61.7**
30	4			1	1	21	16	**35.0**	**26.7**
33	4			5	5	49	41	**81.7**	**68.3**
34	4			0	0	32	20	**53.3**	**33.3**
35	4			1	2	37	42	**61.7**	**70.0**
25	4			13	7	45	27	**75.0**	**45.0**
26	4			8	16	44	56	**73.3**	**93.3**
27	5			0	0	30	30	**50**	**50**
28	4			0	0	44	44	**73.3**	**73.3**
29	4			0	0	20	20	**33.3**	**33.3**
5	4			0	0	40	40	**66.6**	**66.6**
6	4			11	12	59	48	**98.3**	**80.0**
7	4			0	0	24	8	**40.0**	**13.3**
8	4			8	6	48	30	**80.0**	**50.0**
9	5			6	6	26	31	**43.3**	**51.7**
10	5			0	0	40	40	**66.7**	**66.7**
11	5			0	0	40	20	**66.7**	**33.3**
12	5			0	0	30	25	**50.0**	**41.7**
13	5			0	0	10	0	**16.7**	**0.0**
14	5			4	4	44	24	**73.3**	**40.0**
15	5			1	0	26	20	**43.3**	**33.3**
16	5			0	0	20	20	**33.3**	**33.3**
17	5			3	2	53	32	**88.3**	**53.3**
18	5			0	0	20	10	**33.3**	**16.7**
19	5			1	0	56	50	**93.3**	**83.3**

Table 36: Utilization and Utilization rate for the sections of Scenario 1.2.

ID	Spacing Requirement			Time Lost for speed variability		Utilization (min)		Utilization Rate	
	BAB/AB	MEB/ACB	Cross./PBI	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
31	4			4	4	36	28	**60**	**46.7**
27	5			0	0	20	20	**33.3**	**33.3**
28	4			0	0	36	36	**60.0**	**60.0**
20		2	1	0	0	19	26	**31.7**	**42.9**
21		2	1	0	0	32	32	**53.3**	**53.3**
22		2	1	0	0	30	30	**50.0**	**50.0**
32	5			2	2	22	22	**36.7**	**36.7**

Table 37: Utilization rate of the sections involved by the itinerary of the service Bergamo-Malpensa after its elimination – 1.2.

9.2.2 Scenario 1.2.: performances of the nodes

The methodology applies to the analysis of two nodes: Busto Arsizio and Gallarate. This scenario assumes the infrastructural upgrades of the section Gallarate – Busto Arsizio and the consequent upgrade of the layout of the stations. The objective of this analysis is to check whether the new configuration of the stations is able to support the expected traffic.

9.2.2.1 Busto Arsizio station

Figure 67 shows services and routes of the complex nodes "Radice NORD" and "Radice SUD" of the new layout of the station.

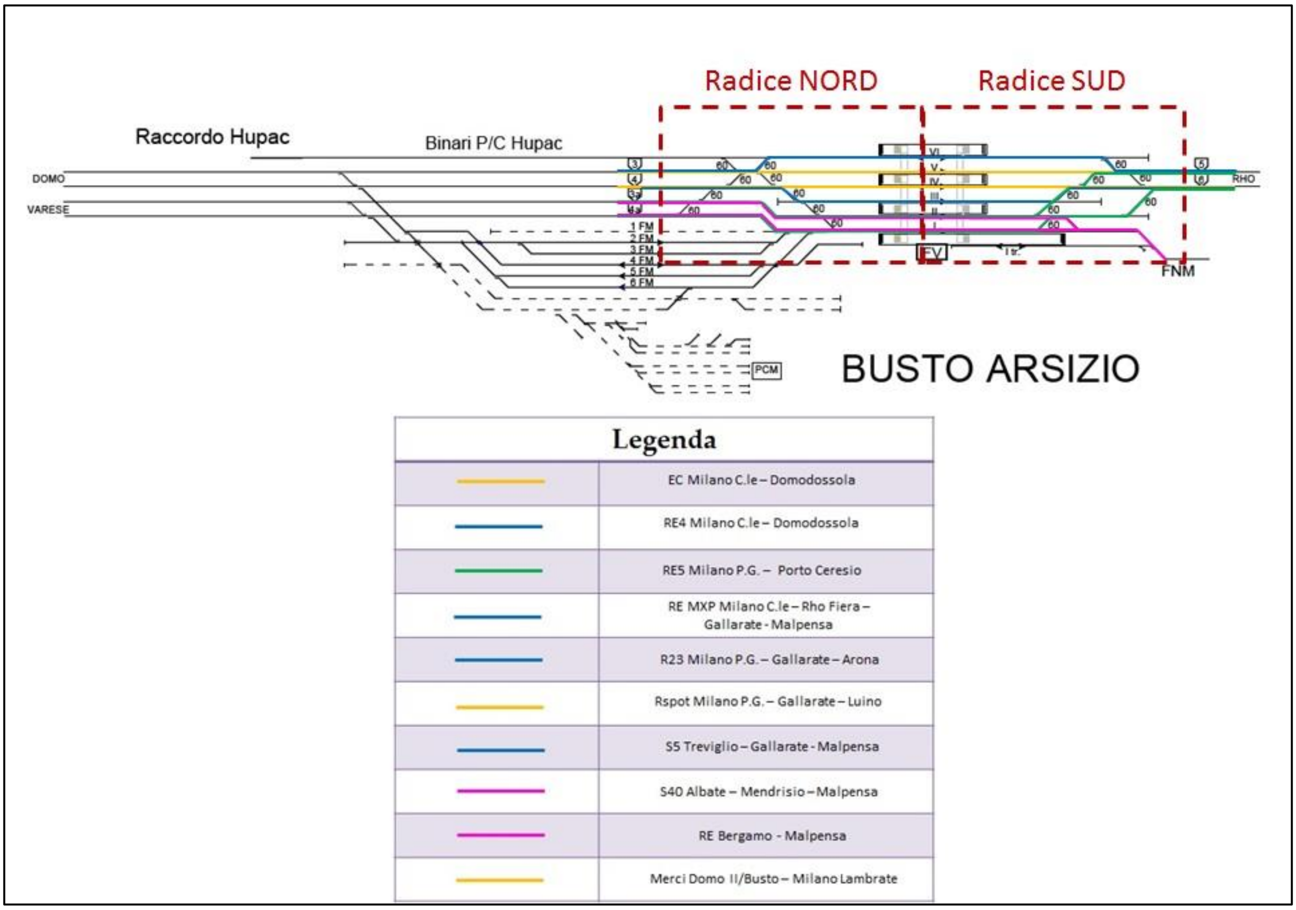

Figure 67: Graphic synthesis of routes and services for Busto A. FS station - Radici NORD/SUD - Scenario 1.2

Starting with the station root "Radice NORD", the only crossing interference is by trains from/to FNM line (track I and II) to/from Gallarate/Malpensa. Only service assign to this route is RE Malpensa-Bergamo.

Line points are following the numeration reported in the schematization of actual layout. For "Radice NORD", line points *3* and *4* identify respectively odd and even tracks of the line from/to Domodossola/Gallarate while lines points *3a* and *4a* identify respectively odd and even tracks of the line from/to Varese/Gallarate.

The output obtained by the application of the method for the analysis of new station layout with future expected traffic is in Table 38.

Potthoff parameter – Radice NORD Busto Arsizio

N	nm	tm(s)	B(s)	R(s)	T(s)
26	2.31	167	1881	395	3600

Utilization rates – Radice NORD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.522	52.2	0.570	57.0

Table 38: Results of node analysis: Busto A. FS station - Rad. NORD Scenario 1.2

As expected, the value of global utilization rate obtained by the analysis is under the threshold indicated by Potthoff for peak periods. With specialization of the lines coming from Gallarate, trains from/to Domodossola run on direct tracks IV and V without conflicts with trains from/to Varese run on track I and track II.

Crossing conflicts are, for this layout, in the complex node "Radice SUD" in correspondence to the double-track layout. This root includes the presence of crossing conflicts in correspondence of transfer from 4-tracks to double-track layout. Therefore, it is to verify the capacity condition of the complex node.

Line points are following the numeration reported in the schematization of actual layout. For "Radice SUD", lines points 5 and 6 identify respectively odd and even tracks of the line from/to Rho.

The output obtained by the application of the method are in Table 39.

Potthoff parameters: Radice SUD Busto Arsizio

N	nm	tm(s)	B(s)	R(s)	T(s)
26	2.33	184	2061	645	3600

Utilization rates: Radice SUD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.572	57.2	0.649	64.9

Table 39: Results of node analysis: Busto Arsizio FS station - Radice SUD Scenario 1.2

The global utilization rate obtained by the analysis of the complex node is under the 75% threshold for capacity in peak periods. Despite the crossing conflicts between routes, capacity condition is satisfied, and the complex node operates without congestion phenomena. This is justified considering the hypothesis that only trains running the crossing route are RE5 Porto Ceresio-Milano Porto Garibaldi trains. Possible modification on this assignation of services to the station routes can change the results on the utilization rate.

The analysis here reported demonstrates that a new layout for the station is necessary to satisfy the expected traffic of the 2026 railway supply.

Considering the modification of the future railway supply with the elimination of the service RE Malpensa-Bergamo, the utilization rate values of the station routes are in Tables 40 and 41.

Potthoff parameter – Radice NORD Busto Arsizio

N	nm	tm(s)	B(s)	R(s)	T(s)
22	3.30	164	1095	31	3600

Utilization rates – Radice NORD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.304	30.4	0.307	30.7

Table 40: Results of node analysis without service Malpensa-Bergamo: Busto Arsizio FS station - Radice NORD Scenario 1.2

Potthoff parameters: Radice SUD Busto Arsizio

N	nm	tm(s)	B(s)	R(s)	T(s)
22	2.00	167	1842	316	3600

Utilization rates: Radice SUD Busto Arsizio

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.512	51.2	0.555	55.5

Table 41: Results of node analysis without service Malpensa-Bergamo: Busto Arsizio FS station - Radice SUD Scenario 1.2.

9.2.2.2 Gallarate station

Figure 68 shows services and routes of the complex nodes “Radice NORD” and “Radice SUD” of the new layout of the station.

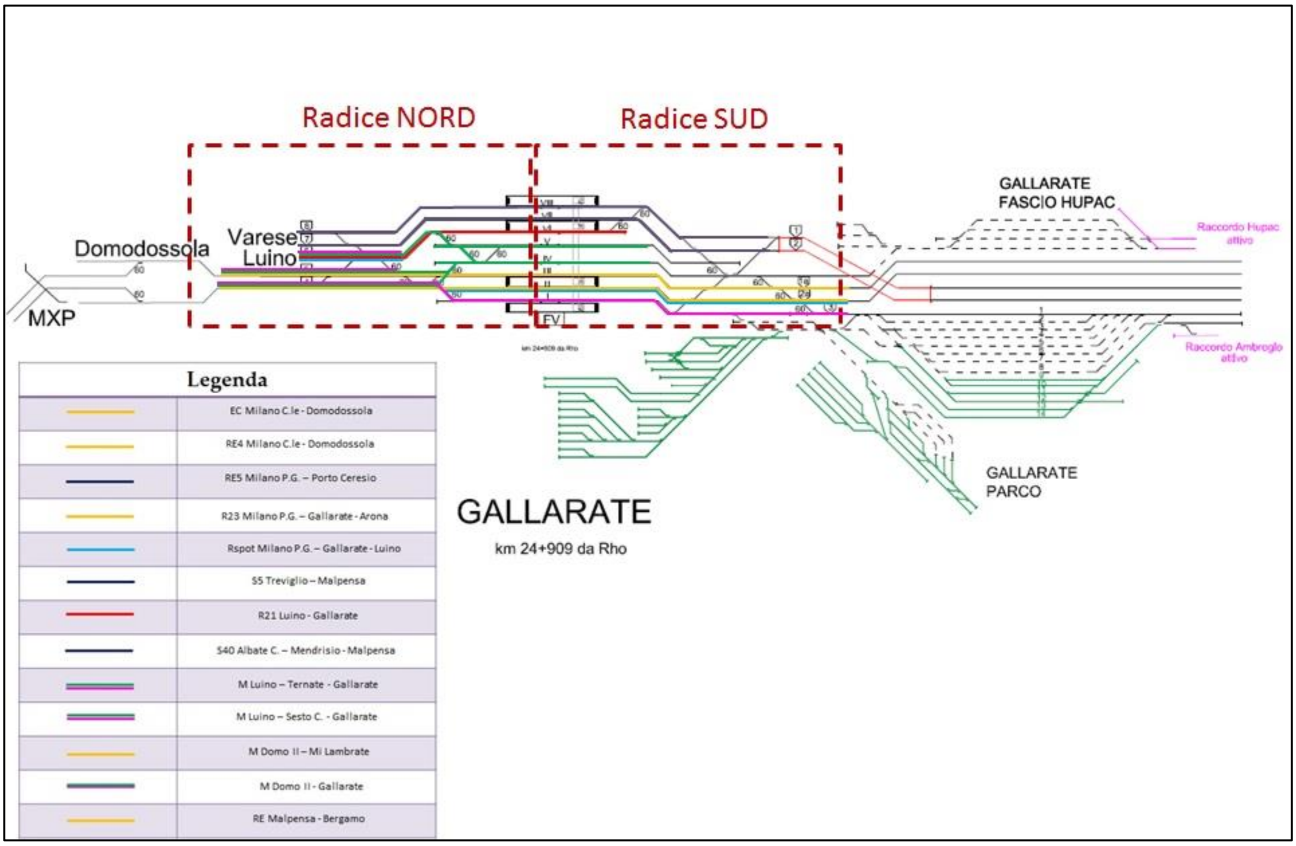

Figure 68: Graphic synthesis of routes and services for Gallarate station - Radici NORD/SUD - Scenario 1.2

Results obtained by the analysis are:

Potthoff parameters: Radice SUD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
27	3.32	165	1338	1.75	3600

Regular and Global utilization rate: Radice SUD Gallarate

U	U (%)
0.372	37.2

Table 42: Results of node analysis: Gallarate station - Radice SUD Scenario 1.2

The complete elimination of the interferences from the root generate no delays with the consequent regular and global utilization rates assuming the same value. The output obtained is under the threshold for peak periods capacity individuated by Potthoff. The new infrastructure layout and the separation of the flows according to the origin/destination of the trains produces a decongestion of the station root with respect to the same node evaluated in the scenarios 0 and 1.1.

Potthoff parameters: Radice NORD Gallarate

N	nm	B (s)	tm (s)	R (s)	T (s)
33	3.02	2002	183	595	3600

Utilization rates: Radice NORD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.556	55.6	0.611	61.1

Table 43: Results of node analysis: Gallarate station - Radice NORD Scenario 1

As expected, with the new station layout the utilization rate of the root is widely decreases due to the elimination of many crossing interferences between routes. In particular, this layout reduces the occupation times of the routes running by freight trains: in fact, the shift of tracks for freight end stop with respect to the current layout and the introduction of 60 km/h switches permits to reduce the delays generated by conflicts with the other station routes. Therefore, with this layout, the station root is manageable without congestion phenomena in peak hour period.

Considering the elimination of the service Malpensa-Bergamo, the results obtained by the application of Potthoff method on the station root layout are in Table 44.

Potthoff parameters: Radice SUD Gallarate

N	nm	tm (s)	B (s)	R (s)	T (s)
23	3.59	163	1044	2	3600

Regular and global utilization rate: Radice SUD Gallarate

U	U (%)
0.290	29.0

Table 44: Results of node analysis without service Malpensa-Bergamo: Gallarate station – Radice SUD Scenario 1.2

Potthoff parameters: Radice NORD Gallarate

N	nm	B (s)	tm (s)	R (s)	T (s)
29	3.14	1701	184	496	3600

Utilization rates: Radice NORD Gallarate

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.473	47.3	0.516	51.6

Table 45: Results of node analysis without service Malpensa-Bergamo: Gallarate station - Radice NORD Scenario 1.2

9.2.3 Synthesis of the results

The additional infrastructural upgrade of the section Gallarate-Busto Arsizio with a new 4-track layout permits to reach a suitable capacity rate of the segment Malpensa-Gallarate-Rho. The realization of this upgrade, together with the realization of the T2-Gallarate North Railway Link, the 4-track section Rho-Legnano and the new layout of Rho station permits to ensure a sustainable configuration of this line segment with the possibility to support completely the expected traffic deriving by the 2026 railway supply. With these infrastructural upgrades, it is possible to ensure a development of the connections between the city of Milan, the north-west metropolitan area and Malpensa International Airport, improving its accessibility and enlarging its railway catchment area.

The analysis highlights that the introduction of a new service Malpensa-Bergamo is uneasy to realize without the improvement of the layout from single-track to double-track layout of the line Seregno-Bergamo. For this reason, the analysis reports the results considering the elimination of this service by the future 2026 supply.

Therefore, the configuration of the line Domodossola-Milano in the segment Rho-Gallarate-Malpensa as thought in this Scenario is the best solution to adopt according to the results of the capacity of the lines and the nodes obtained by this study.

Figures 69, 70 and 71 report a graphic synthesis of the results Scenario 1.2.

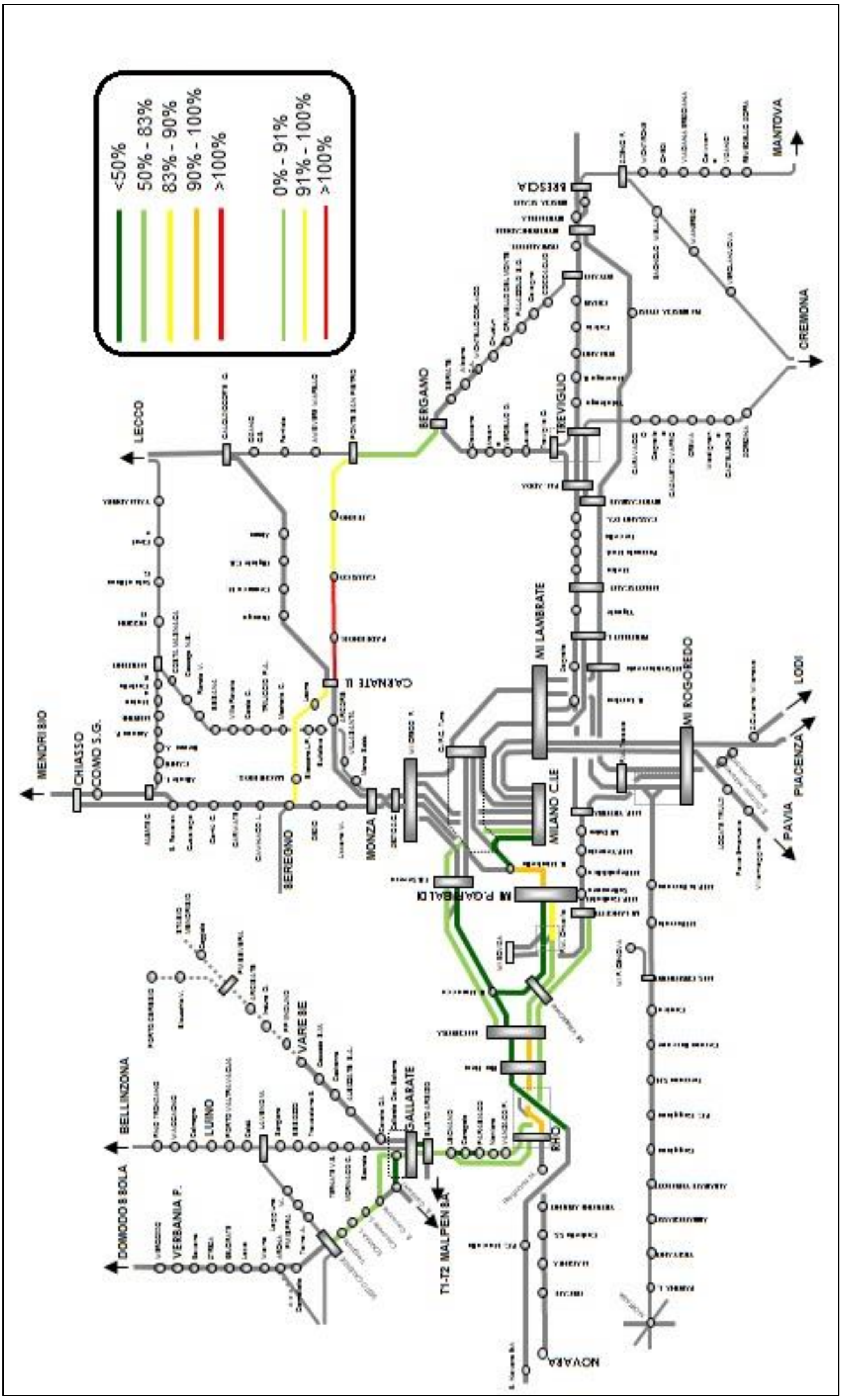

Figure 69: Graphic synthesis of the results - 2026 railway supply – Scenario 1.2.

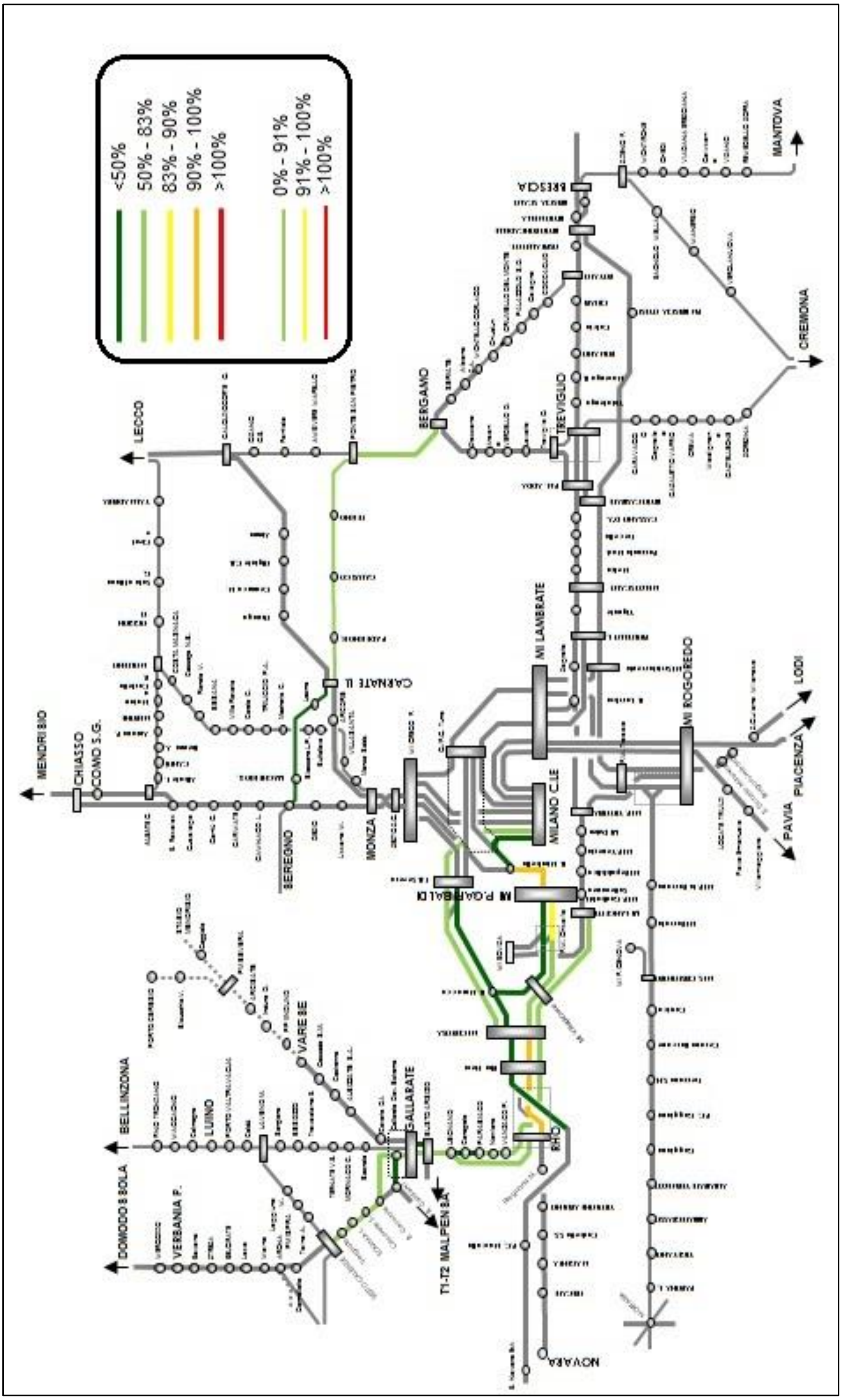

Figure 70: Graphic synthesis of the results without service Bergamo-Malpensa - Scenario 1.2.

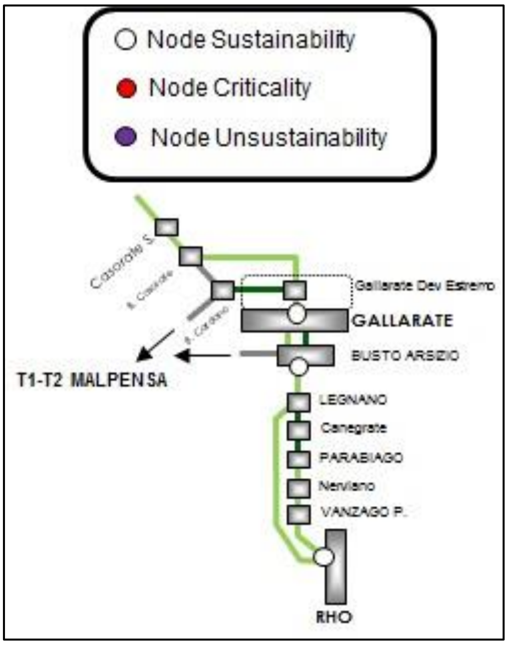

Figure 71: Node performances - Rho-Gallarate segment - Scenario 1.2

9.3 NEW LAYOUT OF SEREGNO STATION: METHODOLOGY APPLICATION

The paper presents the results obtained by the application of Potthoff method to the new layout proposed for the station of Seregno. The analysis is carried out without taking into account the service RE Malpensa-Bergamo for the considerations favored in 9.2.3.

Figure 72 shows the services and the related station routes for the new layout.

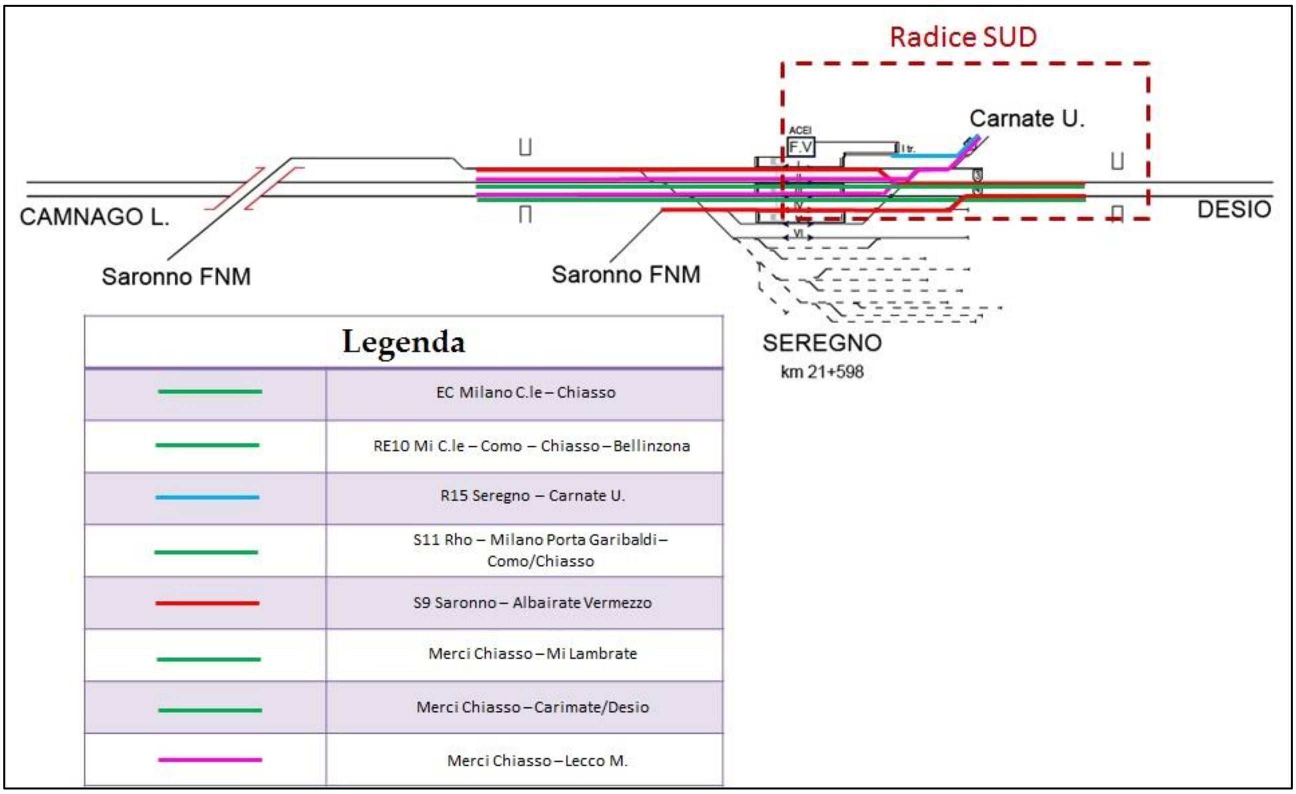

Figure 72: Graphic synthesis of routes and services for PRG Seregno - Rad. SUD

The solution here proposed takes into account an operational model plans the complete elimination of all the crossing interferences in peak hour: the even trains of the suburban service S9 generate diverging conflicts with even flow of the line Milano-Chiasso while the odd trains of S9 service generate converging interferences with odd flow of the line Milano-Chiasso. It is necessary to consider that there are no freight trains Chiasso-Lecco Maggianico in peak hour. No interferences are existing in the other station root.

The results obtained are:

Potthoff parameters: Radice SUD Seregno

N	nm	tm (s)	B (s)	R (s)	T (s)
22	2.38	181	1637	169	3600

Utilization rates: Radice SUD Seregno

U_{reg}	U_{reg} (%)	U_{glob}	U_{glob} (%)
0.455	45.5	0.474	47.4

Table 46: Results of node analysis- PRG Seregno - Radice SUD

With reference to the results obtained in Scenario 0 (7.2.2.4), the results indicate a considerable decrease of the delays generated by the interferences between the station routes. The values obtained are under the threshold indicated by Potthoff for the capacity of a complex node in peak periods. Therefore, the results demonstrate the efficiency of this solution, which permits to produce benefits in terms of station circulation.

10 SCHEDULING ANALYSIS

Following the analysis of the capacity of the lines and the nodes of study interest, the paper focuses on a scheduling analysis, to evaluate if services and infrastructural solutions presented in the previous chapter are effectively compatible with the time constraints fixed by the circulation regime. As usual, the analysis evaluates the timetable of the services running on the lines Domodossola-Milano and Seregno-Bergamo. In particular, for the line Domodossola-Milano, the section of interest is Rho-Gallarate, because of the development projects with the introduction of new services in which it is involved. The introduction of new services for the future 2026 railway traffic involves not only the lines of study interest, but also other lines of the network; so, the analysis considers other line sections in order to evaluate timetable compatibilities between the existing services and the new ones. The new timetable here proposed is basing on the actual one: in fact, it is necessary to maintain timetable constraints imposed by the infrastructure and systematic headway between services in correspondence of the main nodes (e.g. Milano Centrale scheduled timetable).

10.1 CLOCK-FACE SCHEDULING

A clock-face schedule or cyclic schedule is a timetable system under which public transport services run at consistent intervals, as opposed to a timetable that is irregular and purely demand-driven. The framework of the scheduling consists of a system in which at each hour, at the same minute, a ride of a certain service passes in correspondence of a location. The efficiency of this typology of scheduling consists of the easiness for users to memorize it, due to its repetitiveness for arrival and departure times and stations supplied. The framework of this typology of scheduling is basing on the hierarchy of services and stations. The system of railway regional transport in Lombardy includes different services characterized by different frequencies and stops as reported in Chapter 4 (4.4.3).

Moreover, not only the services but also the stations have their hierarchy considering differences among simple stops and hubs where it is possible to find correspondences between services with different destination. Figure 73 synthetizes this concept.

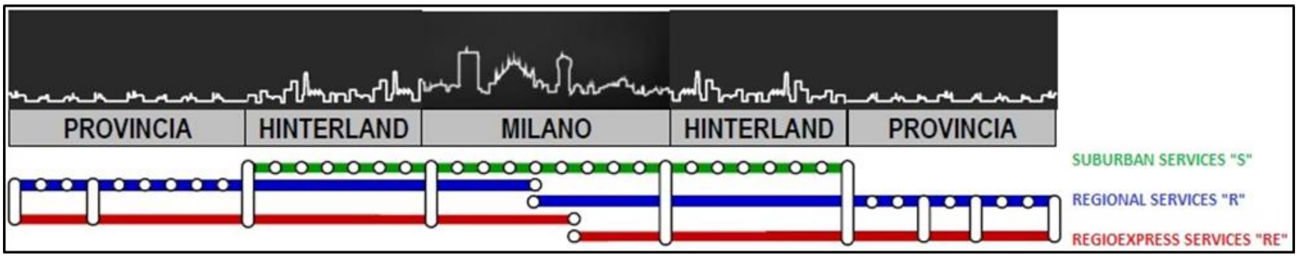

Figure 73: Hierarchy of services supplying the region

The hierarchy of towns and cities generates primary and secondary stations supplied by services with different speed levels. A typical example is in Figure 74.

In this example, services with different speed levels are according to the scheduling that it is necessary to realize. The first case presents two services with different speed scheduled with the aim to obtain a better distribution on the secondary stations: the correspondence of services is in the first node. In the second case, the concept is the same: the correspondence of services is in the last node. The third case presents a scheduling realized with the aim to splitting in half the frequency of "fast" services in the main nodes with the introduction of "slow" services. The first two cases represents a service integration while the third one represents a frequency integration.

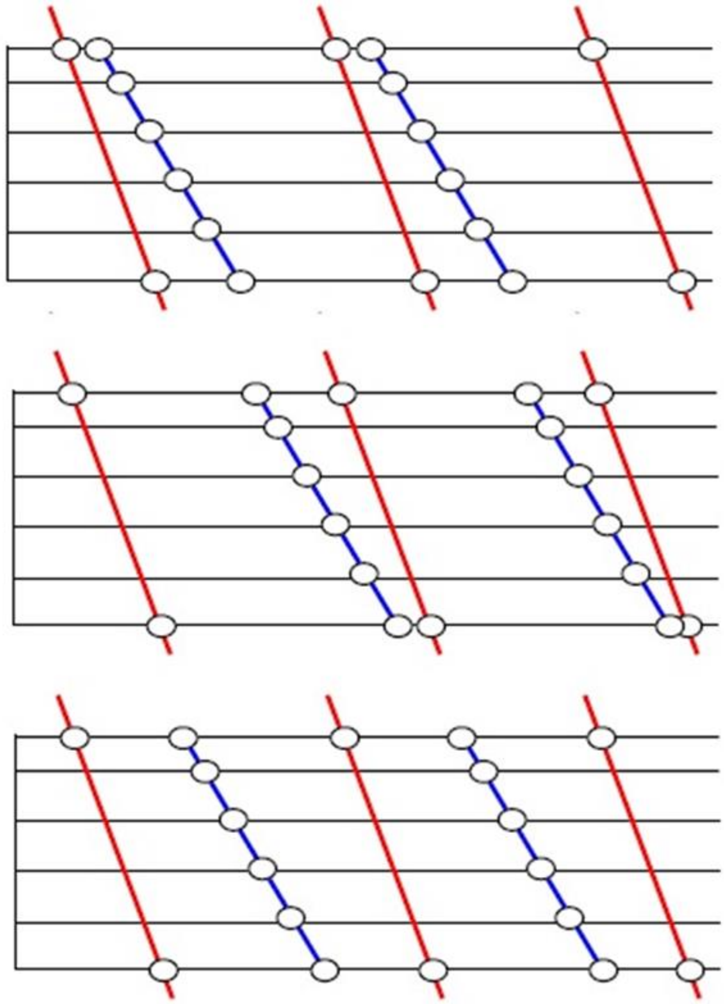

Figure 74: Frequency integration vs. Service integration

The design of a clock-face scheduling must ensure correspondences between services in the main nodes. Normally, it is difficult to plan high frequencies for all the services: the financial resources and the infrastructural and vehicle fleet availability limits the realization of direct rides only for the situation of high demand.

Simple clock-face scheduling of different lines permits to optimize the correspondences for an O/D couple. The symmetric clock-face scheduling of different lines permits to optimize the correspondences for an O/D couple in both the directions: the extension of this concept to all the services optimizes the correspondences in a node.

A typical example of clock-face scheduling is the station of Lecco, as shown in Figure 75.

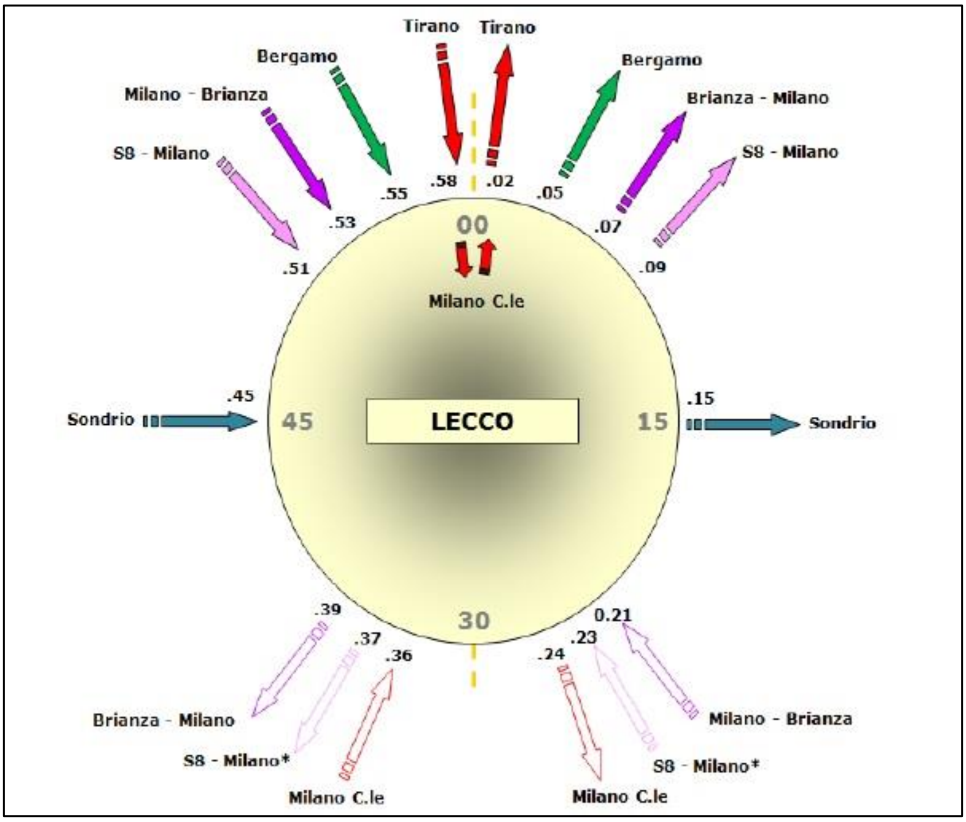

Figure 75: Symmetric clock-face scheduling of the node of Lecco

Considering a European widespread use, the axis chosen for the designing symmetry of a clock-face scheduling is the axis 00-30. Observing the representation above, the main nodes of symmetry are the node 00-30 and 15-45. The axes of the clock represent symmetry for the services according to their frequency. For the axis 00-30:

- Around minute 00 symmetry for services with 60′ interval;
- Around minutes 00 and 30 symmetry for services with 30′ interval;
- Around minutes 00, 15, 30 and 45 symmetry for services with 15′ interval.

For the axis 15-45:

- No symmetry for services with 60′ interval;
- Around minutes 15 and 45: symmetry for services with 30′ interval;

- Around minutes 00, 15, 30 and 45: symmetry for services with 15′ interval.

This kind of framework permits to reach the equity of a transport system: the availability of services and the number of rides are proportional to the importance of towns and cities (and consequent of the stations) and each service is part of a system with an optimal degree of connections.

Criticalities of clock-face scheduling are:

- Punctuality: a system based on correspondences must ensure the functioning, so it is necessary to fix a punctuality level compatible with interchange times at nodes. The optimal value of interchange time in Lombardy is fixed in 7′.
- Investments: this typology of scheduling is basing on headways of 60′ and 30′ and this might mean to ensure rides under the threshold of profitability. Therefore, the economic investment is remarkable.
- Rigidity: the framework of this system does not permit flexibility and adaptations. The only exception is by spot services.
- Costs for additional road services: the design of optimal interchanges between trains and buses generates long and no-profitable stops in correspondence of the nodes.

Therefore, the choice to adopt a clock-face scheduling for railway system is an efficient choice with benefits in terms of modal split and economic sustainability of the services. However, this choice is political, and decision-makers must support it.

10.2 REALIZATION OF A GRAPHIC TIMETABLE

The typical example of graphic timetable is the RFI time-distance graph called *TrainGraph*, as shown in Figure 76.

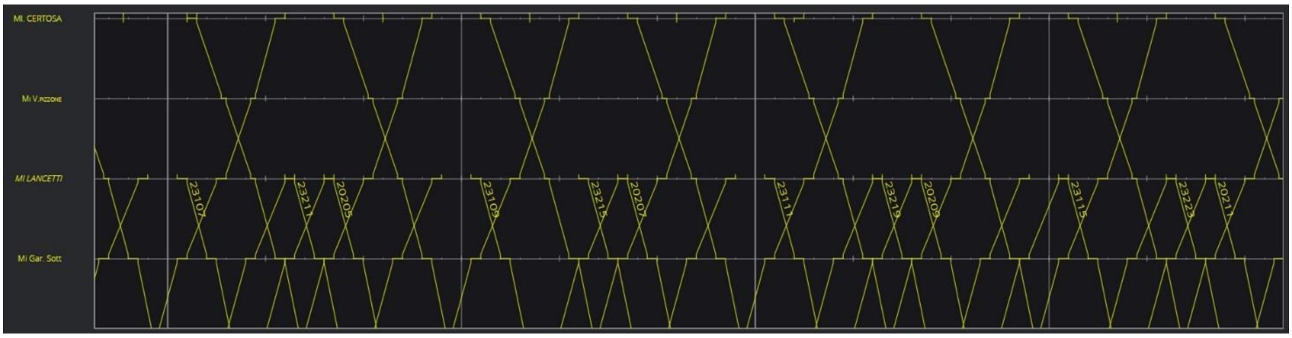

Figure 76: RFI time-distance graph "TrainGraph"

Each line represents a train path: conventionally, trains with even number are from the right to the left while trains with odd number are from the left to the right according to the time abscissa. The inclination of the lines represents the speed of the trains.

Therefore, the design process of a graphic timetable passes through the graph of train paths. The input data are by:

- **Infrastructural data:** length of the sections, alignment characteristics, presence of tunnels;
- **Vehicle fleet data:** traction, resistances, maximum speed, braking efficacy, length of the train.

To simplify the calculation process, there are specific tables reporting pure travel time for each couple of time points considering the input data. The travel time is under the hypothesis of normal run conditions and takes into account four possible run combinations: stop-stop, transit-stop, stop-transit and transit-transit.

To increase regularity, punctuality and stability of the system, it is necessary to consider additional time to the pure travel time of the train. For example, the run of a train may be slow down due to imposed reduced speed in correspondence of a section in equipment maintenance or it is necessary to plan additional time to the travel time of a train running a segment with imposed low speed in station (30 km/h switches). Therefore, there are different typologies of additional times:

- Technical: e.g. deviated route of a train, priority maneuver in a station, etc.;
- Maintenance: distributed on a section or concentrated in correspondence of a node;
- Punctuality: the general rule is to assign 2′ of buffer time per 100 km of train run.

The sum of pure travel time and additional times generates the effective travel time of a train from an origin to a destination; this time is to graph a train path.

Time paths composing the graphic timetable of a certain line must be spaced according to some rules based on spacing requirements: for the lines according to the block technology and for the nodes according to interferences between flows. Spacing requirements of the lines are of two different typologies:

- Time-based spacing requirement: it is the train spacing in lines equipped with Automatic Block or ETCS L2; the headway must be in the range 4′÷6′ according to the section length or 5′ for ETCS;
- Release-based spacing requirement: for the lines equipped with Manual Electric Block the headway must be equal to the occupation time of the section plus 3′ while for the lines with Axle Counter Automatic Block the headway is equal to the occupation time plus 2′.

Spacing requirements of the nodes depend upon typology of interferences between routes:

- Diverging routes spacing requirement: normally 4′ with Automatic Block system;
- Converging routes spacing requirement: 2′ with Automatic Block system;
- Crossing routes spacing requirement: 4′ with 30 km/h or 3′ with higher speed;
- Spacing requirement to ensure safe crossing movements of passengers without station underpass: it is necessary to impose particular headways between trains to protect passengers during their tracks crossing movements. These headways are 3′ before the arrival and 3′ after the departure of the trains, to ensure tracks crossing movement.

- Lost times for deviated routes: additional times depending upon imposed running speed of deviated routes; 2′ for arrival routes at 30 km/h, 1.5′ for departure routes at 30 km/h, 0.5′ for arrival/departure routes at 60 km/h and 0′ for arrival/departure routes at 100 km/h.

The above-mentioned values are very important, because the spacing requirement between two following trains on a line section in the graph process of a train path in order to avoid in the real circulation delays due to perturbed conditions of train runs. Normally, a line spacing requirement, as dimensioned above, is by the sum of the blocking time (purely given by the technology adopted) plus a margin with the aim to avoid propagation of delays from one train to the following one. This margin has a regularity effect while the punctuality additional time has the aim to permit to the train to regain possible time deviations from the scheduled running time.

Stopping time of the trains in a station is normally 1′, 2′ for some trains in the main stations.

Given a certain line section, its graphic timetable is by the set of the paths of running trains in both directions graphed on the time-space chart according to the requirements described above.

10.3 EVALUATION OF THE ACTUAL SCHEDULING

In this paragraph, the actual timetable (2018) of the services involved on the lines of study interest is to understand its framework. Considering the 2026 railway supply and the introduction of new services, it is necessary to understand the actual distribution of the trains on the lines involved in the upgrade. After this preliminary step, it is possible to evaluate whether the introduction of new services is compatible with timetable constraints considering that a train path always involves many line sections. Therefore, the introduction of a new train may be compatible with the circulation for a certain segment, but it may be incompatible for another one, because of overlying on other train paths. For this reason, the analysis is not limited to the studied sections, but it is extended as much as possible.

10.3.1 Passante di Milano: actual timetable

The analysis of the actual timetable starts with the section Milano Porta Garibaldi Sotterranea - Milano Certosa of the railway corridor "Passante di Milano". The actual scheduling system is based on a clock-face framework with 5 suburban services "S" plus one "spot" service in the morning peak period; each service has a daily frequency of 30'. This frequency implies an average headway between trains running on the corridor of about 5÷6 minutes. The involved services are:

- **S1 Saronno-Milano Passante-Lodi;**
- **S2 Mariano Comense-Milano Passante-Milano Rogoredo;**
- **S5 Varese-Milano Passante-Treviglio;**
- **S6 Novara-Milano Passante-Pioltello Limito;**
- **S13 Milano Bovisa-Pavia;**
- **S12 Melegnano-Milano Passante-Milano Bovisa FN (only one couple of trains in the morning peak hour).**

The section Milano Porta Garibaldi Sotterranea-Milano Certosa includes the stops of Milano Lancetti and Milano Villapizzone. Between them, there is the junction from/to Milano Bovisa and FNM network. The sub-section Milano Porta Garibaldi Sotterranea-Milano Lancetti involves all the services reported above; the sub-section Milano Lancetti-Milano Certosa involves only the suburban services S5 and S6.

Actually, the sequence of services in a typical hour of a weekday is **S5-S2-S1-S6-S13-(S12)**. In the peak hour, there is the additional spot service S12 (indicated in brackets in the previous sequence), occupying the "channel" located after the path of the service S13. The sequence is with 30′ interval following the headway between services.

As in Figure 77, it is possible to observe the presence of two free "channels" for the introduction of new services: the first one between the services S5 and S2 and the second one between the services S6 and S13. In blue, the "channel" normally occupied by the train path of the suburban service S12, with one ride per direction in peak hour. This process is valid for the even flow and symmetrically for the odd flow thanks to the features of the clock-face scheduling.

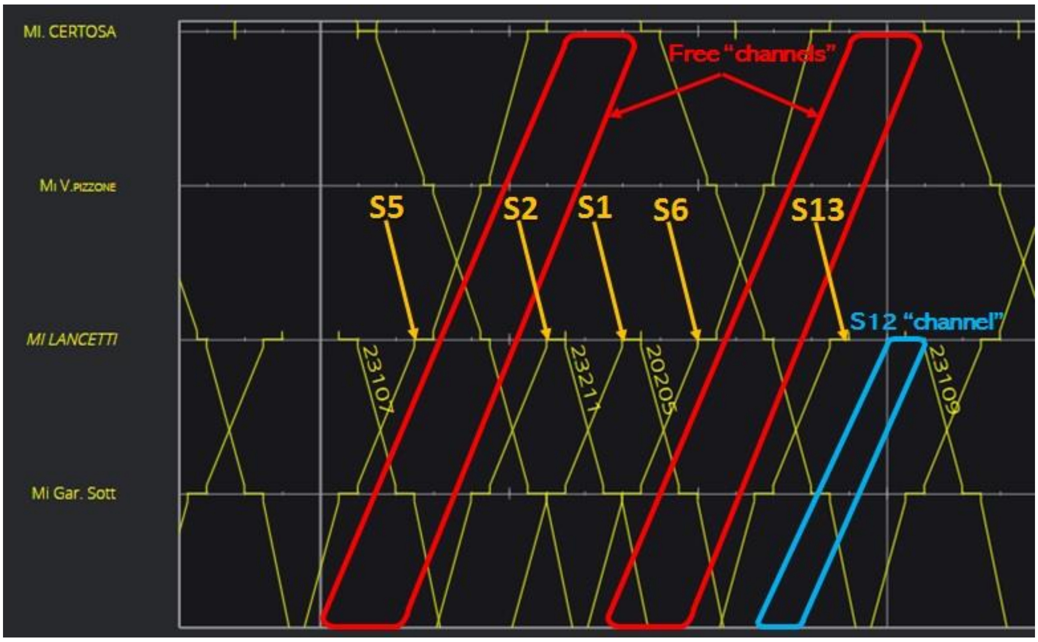

Figure 77: Actual train graph - "Channels" of railway corridor "Passante di Milano"

10.3.2 Milano Porta Garibaldi-Milano Certosa: actual timetable

This section is in the analysis to evaluate actual timetable in correspondence of the station of Milano Porta Garibaldi. The section Milano Porta Garibaldi-Milano Certosa includes the stop of Milano Villapizzone and the service point Ghisolfa (as scheduling time point). Services running on this section are:

- **RE5 Milano Porta Garibaldi-Varese-Porto Ceresio (interval: 30′ peak, 60′ off-peak);**
- **R23 Milano Porta Garibaldi-Arona/Domodossola (interval: 60′);**
- **RV Mi Porta Garibaldi-To Porta Nuova/Torino Lingotto (spot service);**
- **S11 Chiasso/Como-Mi P. Garibaldi-Rho (interval: 30′ Mi Porta Garibaldi, 60′ Rho);**
- **Rspot Luino-Gallarate-Milano Porta Garibaldi (spot service).**

The framework of the scheduling is basing on the clock-face model. The RE5 from/to Varese-Porto Ceresio with interval 30′ is under schedule around the minutes 00-30. Services R23 and S11 are scheduled around the minute 00. RV Milano Porta Garibaldi-Torino Porta Nuova/Lingotto and R21 Luino-Milano Porta Garibaldi are spot services with a 30′-60′ interval only in the morning/evening peak periods to strengthen the existing connections from/to Milano Centrale.

The possible introduction of new services in this section must be compatible with the actual system evaluating also the presence of spot services in peak hour.

10.3.3 Milano Certosa-Rho: actual timetable

The analysis of the actual timetable continues with the section Milano Certosa-Rho. This section includes the stop of Rho Fiera. The lines leading to Milano Certosa station are:

- "Linea Viaggiatori" from/to T.B. Seveso/Milano Centrale;
- "Linea Cintura" from/to T.B. Seveso/Milano Lambrate;
- "Linea Novara" from/to Milano Porta Garibaldi;

- "Linea Varese" from/to Milano Passante.

The lines originating from Milano Certosa station are:

- "Linea AV/AC";
- "Linea Novara";
- "Linea Varese".

Distribution of the services on the lines are:

- AV services Milano Centrale-Torino Porta Nuova: "Linea Viaggiatori" – "Linea AV/AC";
- EC Milano Centrale-Domodossola (interval: 60′): "Linea Viaggiatori" – "Linea AV/AC" – "Linea Novara";
- RE4 Milano Centrale-Domodossola (interval: 60′): "Linea Viaggiatori" – "Linea AV/AC" – "Linea Novara";
- RV Milano Centrale-Torino Porta Nuova (interval: 60′): "Linea Viaggiatori" – "Linea AV/AC" – "Linea Novara";
- RE5 Milano Porta Garibaldi-Porto Ceresio: "Linea Novara";
- RV Milano Porta Garibaldi-Torino Porta Nuova/Lingotto: "Linea Novara";
- R23 Milano Porta Garibaldi – Arona/Domodossola: "Linea Novara";
- Rspot Luino-Milano Porta Garibaldi: "Linea Novara";
- S11 Chiasso-Mi Porta Garibaldi-Rho: "Linea Novara";
- S5 Varese-Treviglio: "Milano Passante" - "Linea Varese";
- S6 Novara-Pioltello Limito: "Milano Passante" - "Linea Varese".

The lines of study interest are "Linea Novara" and "Linea Varese". The high-speed line and the related AV services are not in this analysis. The even trains of the services EC, RE4 and RV Milano Centrale-Torino Porta Nuova, coming from Milano Centrale station and running on the line "Viaggiatori", are forwarded on the line "Novara" in correspondence of the station of Rho Fiera (through a branch equipped with a 100 km/h switch). Vice versa, the odd trains of these services, coming from Rho through the line "Novara", are on the line "Viaggiatori" in correspondence of Rho Fiera through the same branch.

By the analysis of the timetables (reported at the end of the paper) it is interesting to evaluate the framework of the scheduling based on the succession of "fast" and "slow" trains set according to common origin/destination of the services (e.g. RV Milano Centrale-Torino Porta Nuova/S6 for the line Novara-Milano and RE5/S5 for the line Porto Ceresio-Varese-Milano).

10.3.4 Rho-Gallarate: actual timetable

As reported in the chapter of line capacity analysis, the station of Rho represents the junction between the lines Domodossola-Milano and Novara-Milano. In this part, we focus on the line segment Rho-Gallarate and its scheduling. All the services with origin/destination Domodossola/Luino/Varese run on this line section; moreover, it is necessary to consider the suburban service S40 Albate Camerlata-Mendrisio-Malpensa T2 for the sub-section Busto A.-Gallarate.

In Figure 78, it is possible to observe the set of trains repeating for each hour. Services with hourly frequency are in red while suburban services with semi-hourly frequency are in orange. Spot services are in blue.

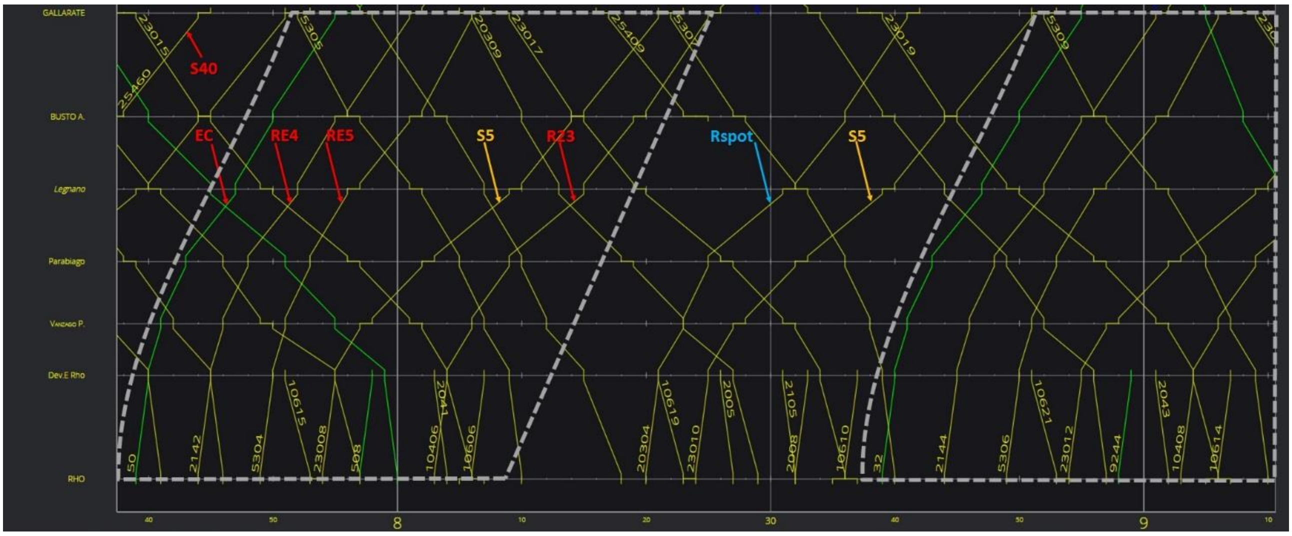

Figure 78: Timetable of Rho-Gallarate section - Example of even flow in peak hour

Moreover, it is possible to observe the two arrays of trains inside the dotted frame: the first array of “fast” trains (EC, RE4 and RE5) and the following array of “slow” trains (S5, R23 and Rspot). This procedure is a typical solution used to decrease the time lost on a line characterized by a high-speed variability. The figure shows the possibility to introduce other trains, individuating a free “channel” after the path of service R23: this observation could result in contradiction with the analysis of the line capacity carried out on the actual scenario. In Scenario 0, the analysis considers the presence of freight trains in peak hour and the realization of 30′ interval of the service RE4 in peak hour. Then, the presence of the free “channel” is justified by the need to ensure the possibility of the introduction of freight trains, considering the no-systematic services. Moreover, it is necessary to consider the adjustment of 30′ interval in peak period of the service RE4, not yet realized. These considerations justified the apparent differences between the two analyses.

10.3.5 Seregno-Bergamo: actual timetable

For what concern the line Seregno-Bergamo, the analysis of the actual timetable needs to evaluate if the introduction of a new service connecting Bergamo with Malpensa airport may be realized or not without any upgrades of the infrastructure. In fact, we should remember that the sections Seregno-Carnate and Carnate-Ponte S. Pietro have a single-track layout and only the section Ponte San Pietro-Bergamo is involved in the upgrade process with a new double-track layout.

The section Seregno-Carnate includes the stops of Macherio and Lesmo; the only service running on this segment is the regional service R15 Seregno-Carnate with interval 60′.

The section Carnate-Ponte S. Pietro includes the stops of Paderno, Calusco and Terno; the service run on this segment is the regional service R14 Milano Porta Garibaldi-Carnate-Bergamo with interval 30′ in peak periods and 60′ off-peak. By the timetable analysis, the systematic passing maneuver between even and odd trains of the service R14 is located in correspondence of the station of Calusco.

The section Ponte S. Pietro-Bergamo includes the stop of Bergamo Ospedale; the running services are the R14 and the regional service R7 Lecco-Bergamo with interval 60′.

10.4 DESIGN OF A FUTURE SCHEDULING SYSTEM

The introduction of new services with the 2026 railway supply and the planned infrastructural upgrades needs a re-evaluation of the actual timetable. The design of this new possible timetable follows the clock-face framework of the actual one; the introduction of new services is trying to minimize the deviations from the actual train paths, respecting the constraints imposed by the infrastructure. Moreover, some systematic headways between services must be satisfied as actually imposed by the commercial agreements. So, the design concept of the future timetable here proposed is basing on the introduction of new services without important modifications, which may imply the re-design of timetable of strategic nodes (e.g. Milano Centrale timetable). This timetable is considering the line upgrade of the section Rho-Legnano (4-track layout) and the section Busto Arsizio-Gallarate (4-track layout).

10.4.1 Passante di Milano: future timetable

The new 2026 railway supply includes the introduction of 3 new suburban services:

- **S12 Melegnano – Milano Passante – Cormano** (systematization of 30′ interval in peak hour);
- **S14 Milano Rogoredo – Mi Passante – Magenta** (interval: 30′);
- **S15 Milano Rogoredo – Mi Passante – Legnano** (interval: 30′).

As identified in the analysis of the actual timetable of this section, the two free "channels" for the introduction of these services are:

- "Channel" between the services S5 and S2 → introduction of service S14 with 4 minutes headway between trains (according to spacing requirements of the line[18]);
- "Channel" between the services S6 and S13 → introduction of service S15 with 4 minutes headway with S6 and 6 minutes headway with S13;

[18] This line presents block sections with a length of 450÷900 m (defined abnormally short) implying 3.5′÷4′ of spacing requirement.

- "Channel" after the service S13 is dedicated to the systematization of the service S12.

In this way, the systematic headway is 15′ between S5 and S6; moreover, this solution fixes a headway of 12÷18 minutes between the services S14 and S6 forwarded in the same line (Milano-Novara). The only modification of this section timetable is an imposed deviation of train paths of the services S5 and S6 equals to ±1 min with respect to the actual timetable.

The simple introduction of the service S15 in the available "channel" maintaining the service S5 as in the actual condition generates the need to introduce a priority maneuver between S5 service and EC Milano Centrale-Domodossola. With the aim to avoid the introduction of this maneuver, another solution is the inversion of the "channels" between services S5 and S15 and between the S6 and S14. Moreover, considering the addiction of 2′ to the pure travel time of all the suburban services due to the introduction of the new stops of Stephenson[19] and Nerviano, we ensure the presence of no conflicts between "fast" and "slow" trains in the section Rho-Gallarate, exploiting the fact that new service S15 has its origin/destination in Legnano station. Headway between services is unchanged.

10.4.2 Milano Certosa-Rho: future timetable

A new suburban service to consider is the **S16 Abbiategrasso-Milano Lambrate-Legnano** with interval 30′ in the 2026 railway supply. The service leads to Milano Certosa from the line "Cintura" continuing its run through the line "Varese". The introduction of this service is considering two constraints:

- Spacing requirements between suburban services running on the line "Varese" from/to Milano Passante;
- Compatibility in the section Albairate Vermezzo-Milano Lambrate with the suburban service S9 Albairate Vermezzo-Milano Lambrate-Seregno-Saronno

[19] "Stephenson" is a new railway stop planned between the stations of Milano Certosa and Rho Fiera, along the line "Varese". In the analysis of line and node capacity, the presence of this stop is not evaluated because its sustainability is in phase of study.

(interval: 30’) and regional service R31 Milano Porta Genova-Mortara/Alessandria (interval: 60’).

Therefore, the service is in the free “channel” between S14 and S6 services. The compatibility with the services R31 and S9 is in a specific paragraph.

All the paths of the suburban services (S5, S15, S6, S14, S11 and S16) have an additional time of 2 minutes in their pure travel time considering the possibility to introduce a new stop between the stations of Milano Certosa and Rho Fiera (“Stephenson”).

10.4.3 Rho-Gallarate-MXP T2: future timetable

Considering the new services introduced, it is necessary to evaluate the time compatibility between services according to the spacing requirement of the line. Remember that the infrastructural layout of this scenario considers the new layout of Rho station and the new 4-track layout in the sections Rho-Legnano and Busto Arsizio-Gallarate. For the section Rho-Legnano, the project plans the realization of block sections (of both the lines DD and LL) with a length of about 900 m: this permit to graph the trains with headways of 4’. The section Legnano-Busto Arsizio must be equipped with block sections with length 900÷1060 m permitting a greater capacity of the segment. For the section Busto Arsizio-Gallarate, the solution proposed is to adopt standard sections with spacing requirement 5’.

Clearly, the section with four tracks between Rho and Legnano does not present any problems in terms of scheduling: S5 and S15 follow the headway imposed in the “Milano Passante” corridor while the S11 extension and the introduction of S16 respect the minimum spacing of 4’ without interferences.

The main interference between “slow” service S5 and “fast” service EC is solvable with the inversion of “channels” between S5 and S15, as reported in paragraph 1.4.1. This solution avoids 6 minutes[20] stop of the service S5 in Busto Arsizio station for overpass by EC.

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[20] Priority rules according to technical requirements impose that first train arrives 4’ before the arriving of the second one and that the first train departs from the station 2’ after the departure of the second one. Considering a transit train, the priority stop time of a train in a station is 6’.

In the section Legnano-Busto Arsizio, “fast” trains are with 4÷6 min of headway. Between Busto A. and Gallarate stations, the trains are in the two lines according to their origin/destination (Domodossola and Varese).
The introduction of the new service RE MXP via Rho-Gallarate implies the elimination of the spot service Luino-Gallarate-Milano Porta Garibaldi in both directions. This new service from/to Malpensa with 30′ frequency ensures “fast” connections between Gallarate and Milan. The proposed timetable plans a system of correspondences ensuring transfer between trains from/to Luino and to/from Milan (Milano Porta Garibaldi and Milano Centrale) in correspondence of the station of Gallarate. It is anyway possible to evaluate the planning of spot services in morning or evening peak hour considering that the presence of EC services in this section is constrained to time and direction (connections with Switzerland need to consider the arrival/departure times according to the direction of the trains).
The infrastructural upgrades with the realization of the north link with Malpensa T2 introduce two new time points in the graphic timetable: Bivio Cardano and Bivio Casorate. The services using the new infrastructure are the RE MXP service and the suburban service S5. The existing service S40 already operating from/to Malpensa maintains its itinerary via Busto FN. The travel time between exit signals of Gallarate and Malpensa T2 station is according to distances reported in the schematization plans and line speed.

10.4.4 Rho-Magenta: future timetable

The timetable compatibility of the new service S14 Milano Rogoredo-Magenta must be in the section Rho-Magenta considering the infrastructure layout and the existing “fast services”. The line is rich of speed variability considering the presence of “fast” and “slow” trains. These services are S6, S14 and fast regional trains RV Milano Centrale-Torino Porta Nuova and Milano Porta Garibaldi-Torino Porta Nuova/Torino Lingotto. The introduction of S14 does not imply any incompatibility with the existing services. However, the inversion of the “channels” between the services (as reported in paragraph

1.4.1) implies a conflict between S6 and RV Milano Centrale-Torino Porta Nuova: so, it is necessary to plan a priority maneuver in correspondence of the station Vittuone, with 6′ stop of the service S6.

This solution implies a headway after Vittuone station of only 7′ between suburban service S6 and the following S14. An optimal solution may be the planning of a headway between S6 and S14 close to 15′. Therefore, a timetable with 15′ between these services in the section Rho-Magenta needs a re-evaluation of the actual scheduling of RV Milano Centrale-Torino Porta Nuova services and spot services RV Milano Porta Garibaldi-Torino Porta Nuova/Torino Lingotto. For this reason, it is probably necessary to evaluate a possible new 4-track layout in the section Pregnana-Magenta in order to avoid priority maneuvers between the different services.

10.4.5 Focus on the section Abbiategrasso-Milano San Cristoforo-Milano Lambrate: future timetable

It is necessary to evaluate the compatibility of new S16 timetable with the existing services S9 Albairate-Saronno and R31 Milano P. Genova-Mortara/Alessandria (interval: 60′ with spot services in peak hour). By the check, S16 scheduling is compatible with the actual S9 timetable with a headway of 10′÷20′ between following trains. The incompatibility is detected with the service R31, which needs to be re-positioned in the "channel" between services S9 and S16. With this kind of solution, it is necessary to consider an infrastructural upgrade of the actual line section Abbiategrasso-Albairate passing from single-track layout to double-track layout.

10.4.6 Seregno-Bergamo: future timetable

Actually, the line presents a single-track layout and the future planned layout upgrades regard only the section Ponte San Pietro-Bergamo. By the analysis of the actual timetable of the service R14 Milano Porta Garibaldi-Carnate-Bergamo (interval: 30′) and the infrastructural constraints, the introduction of a service Bergamo-Malpensa with interval

30′ is difficult to realize. Moreover, it is necessary to consider that the introduction of a new service Bergamo-MXP is constrained to the services S5 and RE MXP on the section Busto Arsizio-Gallarate-Cardano-Malpensa T2 and other services on the FNM line. So, considering also the travel time of a train in the FNM line section Busto-Saronno-Seregno, the train paths of this new service is not compatible with paths of the existing service R14 (future S18). In fact, it is not possible to ensure crossing maneuvers in the service points of the section Carnate-Ponte San Pietro. The introduction of the RE service Bergamo-MXP is constrained to the infrastructural layout upgrades of the line section.

10.4.7 Evaluation of parking timing in Legnano station

The evaluation of parking times of suburban services S11, S15 and S16 arriving at Legnano is developed to understand the number of stopping tracks to plan in the new layout of the station. The layout presented in the previous analysis chapters plans four tracks by an initial brief analysis. By the timetable analysis, the result is that there is the possibility to plan 3 stopping tracks for the future station layout.

10.5 SYNTHESIS OF THE RESULTS

The results of the timetable analysis are:

- The introduction of new suburban services S14 Milano Rogoredo-Magenta and S15 Milano Rogoredo-Legnano is compatible with the other existing services. Train paths of the new services are individuating the free "channels" of the graphic timetable in the railway corridor "Passante di Milano". The introduction of new services produces a global supply in the railway corridor with a frequency equal to 4′-5′.
- The elimination of the priority maneuvers between Legnano and Gallarate between "fast" and "slow" services by the inversion of the "channels" between S5 and S15 and between S6 and S14.
- The extension of suburban service S11 is up to Legnano station maintaining the actual timetable (Rho-Milano Porta Garibaldi-Chiasso) and deriving the new path between Rho and Legnano from existing services of the same train category.
- The introduction of new suburban service S16 Abbiategrasso is compatible with the other suburban services in correspondence of the section Milano Certosa-Legnano. The new service is also compatible with the actual timetable of the suburban service S9 in the section Abbiategrasso-Milano Lambrate. However, it is necessary to modify the actual timetable of the regional service R31 Milano Porta Genova-Mortara/Alessandria supposing a double-track layout of the line Milano-Mortara in the section Abbiategrasso-Albairate.
- The introduction of the new Malpensa Express RE Milano Centrale-Rho-Gallarate is compatible with the existing services of the section Rho-Gallarate. The service is graphed following the actual timetable constrains (Milano Centrale-Bivio Mirabello-Milano Porta Garibaldi actual timetable).
- The service S5 with the new path from/to Malpensa together with the new RE MXP via Rho-Gallarate ensure trains from/to the airport with headway of 14′÷16′.

- Interferences between S6 service and RV Milano Centrale-Torino Porta Nuova in the section Rho-Magenta needs the introduction of priority maneuvers in correspondence of Vittuone station. To solve the issue of high stop times of suburban services, the solution may be the shifting of RV Milano Centrale-Torino Porta Nuova actual path in correspondence of the actual path of RV Milan Porta Garibaldi-Torino Porta Nuova/Lingotto service. The spot service is under reposition with possible additional times.
- The introduction of a new service connecting Bergamo with Malpensa Airport is difficult to realize. The scheduled infrastructural upgrades of the line Seregno-Bergamo appears insufficient from an operational point of view for the introduction of another service. Moreover, the timetable presents constrains linked to actual and future services from/to Malpensa on both RFI and FNM line. Therefore, the introduction of this new service is of difficult evaluation.
- All the other services maintain the actual timetable with possible shifting of 1÷2 minutes. The only service eliminated is the spot Milano Porta Garibaldi-Luino; its permanence is not compatible with the other services. However, it is possible to ensure spot services in the "channel" normally occupied by EC service (morning peak hour toward Milan and vice-versa in evening peak hour).
- Gallarate becomes a strategic node with correspondences between services from/to Rho, Varese, Luino and Malpensa.
- The future timetable for peak period following the characteristics of the clock-face scheduling.

The future graphic timetable are in figures 79÷82.

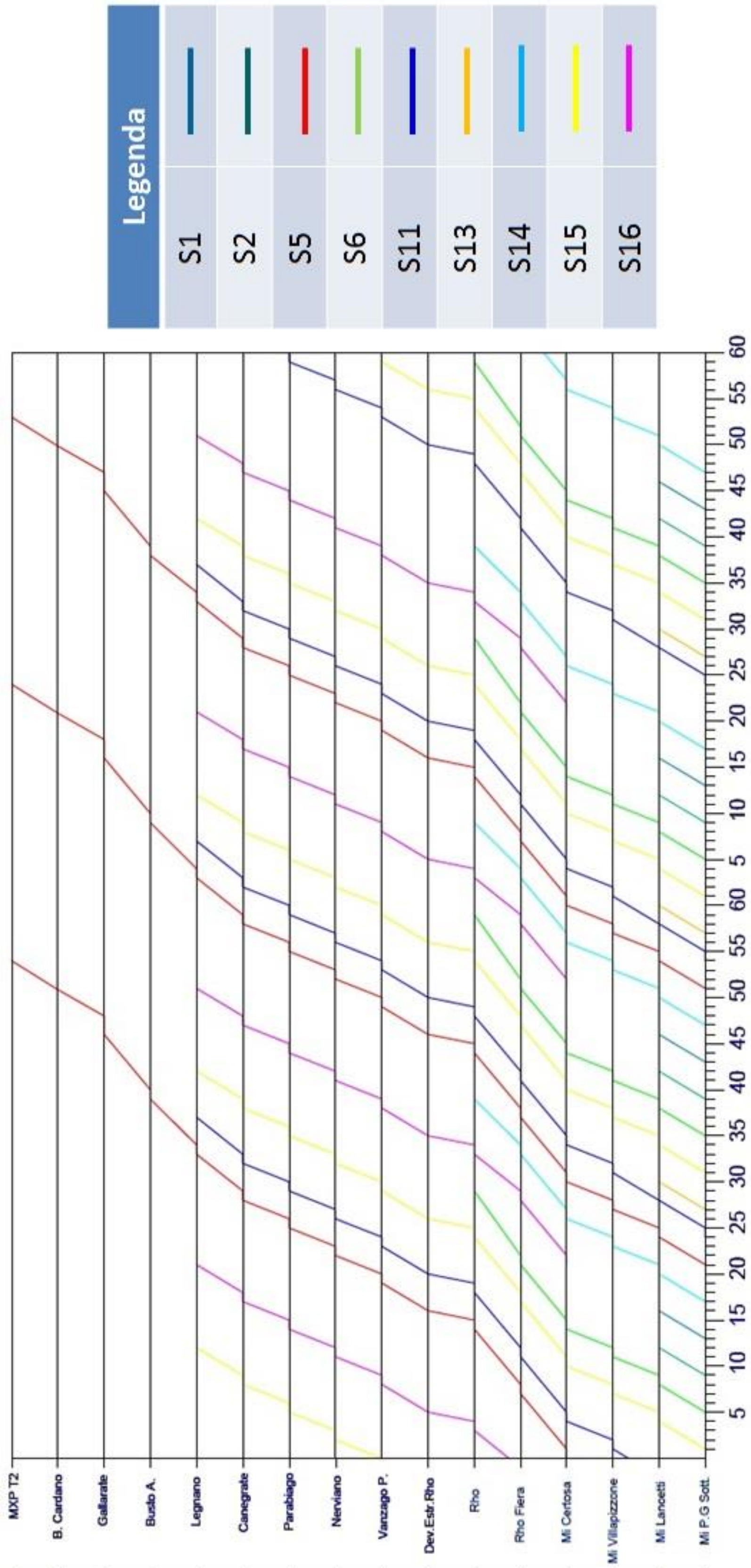

Figure 79: Future timetable S services - Even flow

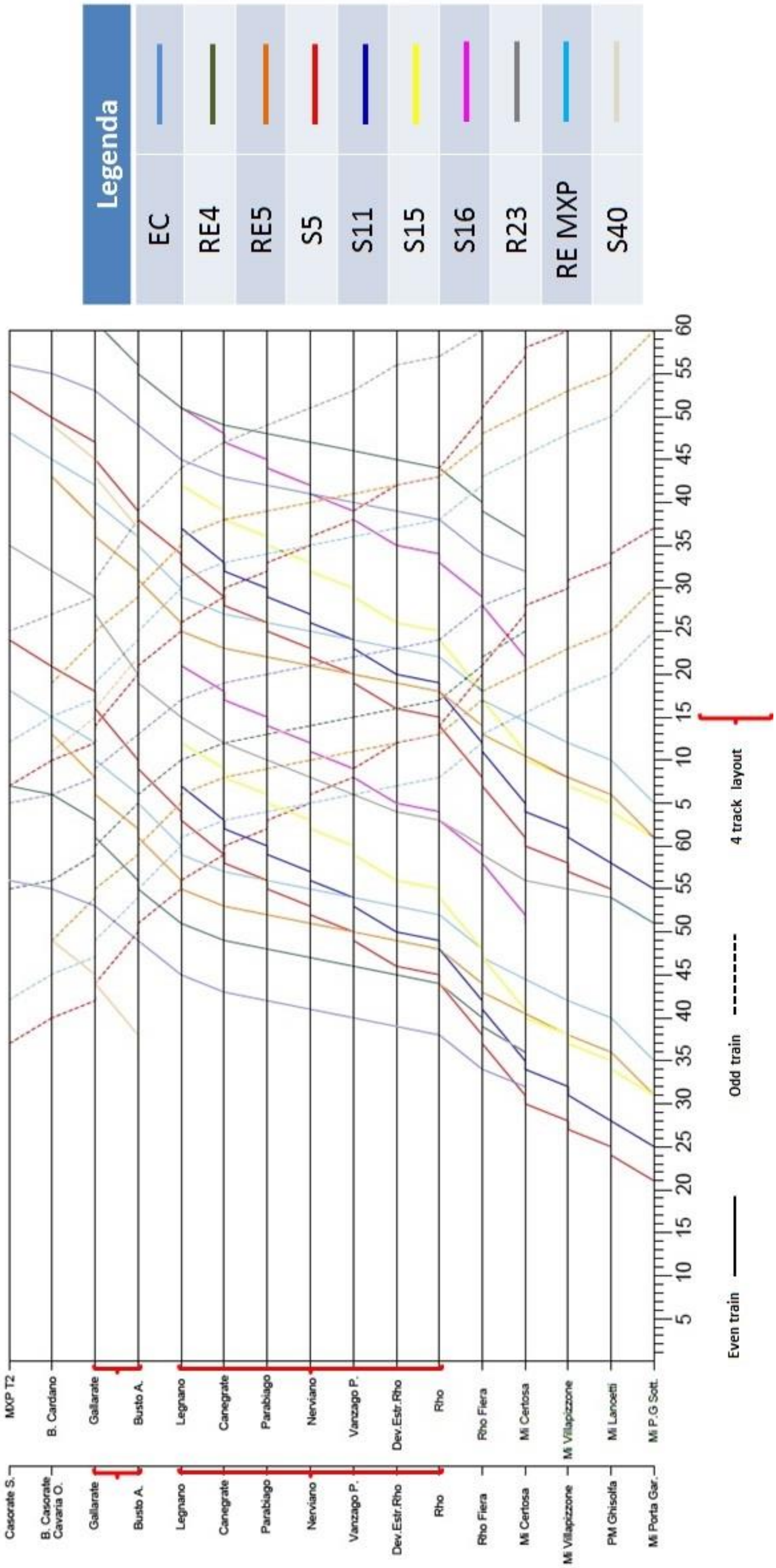

Figure 80: Future timetable - Rho-MXP T2 corridor

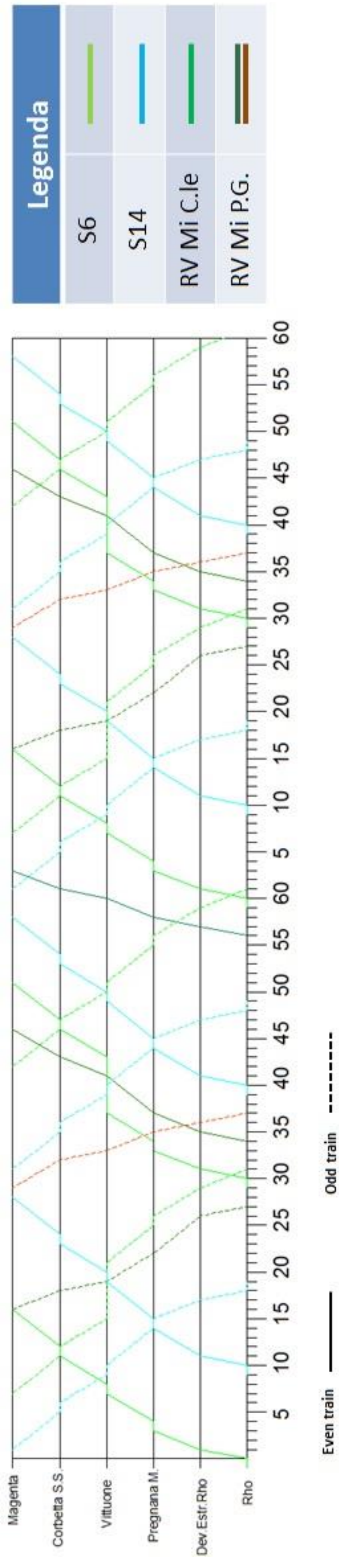

Figure 81: Future timetable - Rho-Magenta section

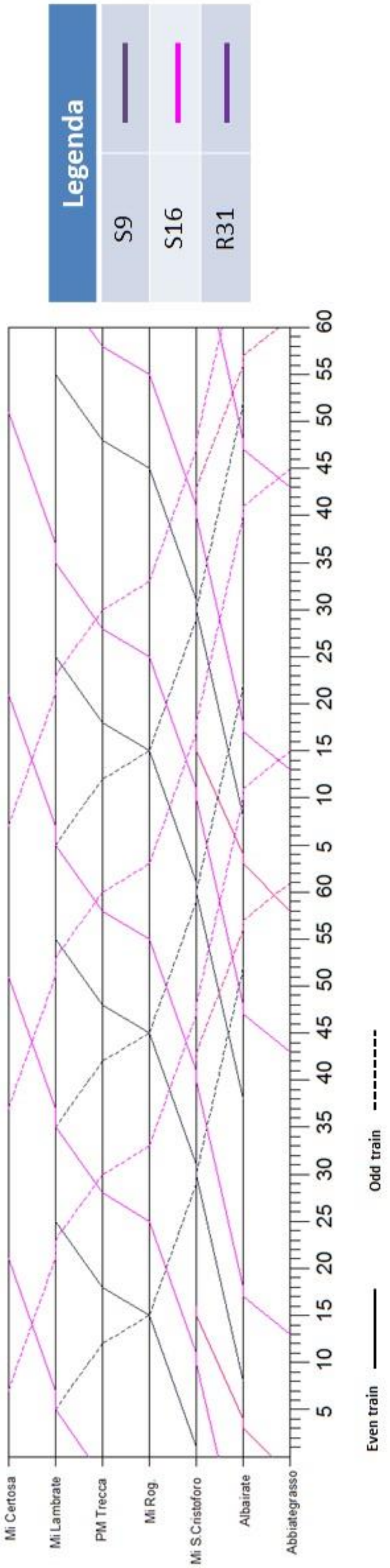

Figure 82: Future timetable - Abbiategrasso-Mi Lambrate-Mi Certosa

11 APPLICATION OF A SIMULATION METHOD

The last part of this study is for the application of a simulation method. These methodologies reproduce the railway operation on a defined portion of the network giving the possibility to highlight and analyze the variables involved in the design process of a railway system. The software chosen for this analysis is *Opentrack*: it is a dynamic micro-simulation model used for the representation of railway circulation during a defined time interval instant by instant. The correct used of this simulation software permits to reproduce the railway operation very close to the real one.

The portion of infrastructure here analyzed is the section Rho-Gallarate for Scenario 0 and Rho-Gallarate-MXP T2/Sesto Calende for Scenario 1. This section has a particular interest in the study about the development of connections between Milan and Malpensa Airport.

11.1 OPENTRACK

This software originated in the mid-1990s by the Swiss Federal Institute of Technology. Today, it represents a well-established railway planning software, used by railway companies, railway supply industries, consultancies and universities in different countries.

Input data of the tool are infrastructural parameters, network effects and operational parameters. Network data consist of the description of a railway network in special graphs called double vertex graphs; a user can edit the network topology graphically. Rolling stock data consist of main locomotive technical features stored in the software database; these data include tractive effort/speed diagrams, load, length, adhesion factor and power systems. Another input data category is the timetable including arrival and departure times and minimal stop time at the stations.

Output of the software are train graphs, diagrams (e.g. speed/distance diagram), occupation and delay statistics. The simulation can proceed with an animation mode, which shows the trains running; in this way, the user can also analyze occupied tracks, reserved tracks and signal aspects.

11.1.1 Infrastructural Data

The railway network is represented by means of a schematization defined “double vertex graph”; the work environment is defined “Worksheet”. The framework of the graphic representation includes elements called Vertices and Edges. The vertices are points in the railway network where at least one route attribute (as gradient, speed, etc.) changes or where there is a signal. Vertices appear in pairs in order to provide information at each vertex about the edge, via which to reach the vertex. By means of a palette called “Vertex Inspector”, it is possible to insert *Name, Kilometer Point, Station Sign* and *Station Vertex* (meaning that the vertex is the reference point of station position).

Edges are lines symbolizing railroad track segments. With the inspector palette, it is possible to give them attributes: *length, radius* and *gradient*. Normally, it is possible to calculate automatically the distances, according to km points of the vertices. Each edge has its direction: it is important to indicate gradient, radius and line speed attributes. The best solution to adopt is to maintain the same direction for all the edges. According to the train category, it is possible to insert the line speed per direction. Information about speed and section length are by infrastructure manager documentation[21].

Figure 83 shows an example of infrastructure representation with *Opentrack*.

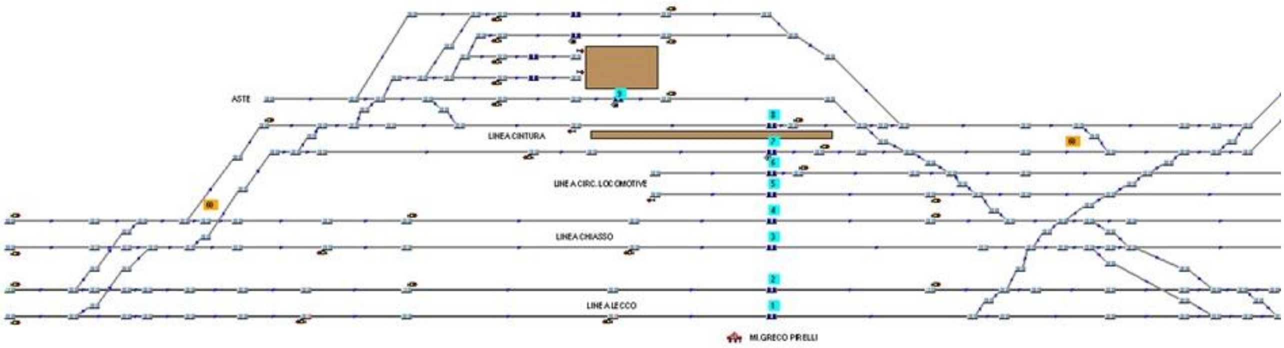

Figure 83: Example of Opentrack infrastructure

After the construction of the network, it is necessary to represent the signalling system. A signal is assignable to a vertex only. There are different typologies and functions of signals that the software proposes:

- Typologies: main signal, distant signal or main/distant signal;
- Functions: home signal (protection signal), exit signal or block signal;
- Approaching speed and running speed imposed by the signal;
- Visibility distance.

Train stop position is by a specific signal (head, central or tail stop position of the train in correspondence of the signal point).

Station area has a specific function selecting data from a database containing information as name, acronyms, coordinates, etc.

[21] *Fascicolo Linea*: it is a document reporting information for each line about permitted speed, according to the different train categories (A, B, C and P), km points, with related length of the sections, block technology, etc.

11.1.2 Definition of Itineraries

The software uses several types of data structure to describe the track used by a train in its operation. These data are different by level and by type of information included.
These levels are:

- Route: it represents the first level of a train path; it is an order of vertices of one direction of travel. It contributes to form part of the safety apparatus of the track system.
- Path: it consists of 1-to-*n* routes of one direction of travel. A path is built as a set of routes that are often used together (e.g. from the exit signal of a station to the exit signal of the next station).
- Itinerary: it consists of one or several successive paths. It represents the complete path of a train from its origin to its destination. Each itinerary has its own priority: during the simulation, the train can choose the available one with the highest priority.

11.1.3 Vehicle fleet data

The characteristics of the vehicle fleet belong to the input data of the software. Opentrack classifies the services in three different train categories:

- High speed trains (Intercity IC);
- Regional trains;
- Freight trains.

The software has a database, which contains pre-defined trains according to their composition. It is anyway possible to insert new train typologies by means of the option "Trains". The window "Edit Trains" permits to assign the following attributes at each train:

- Name of the train;
- Train typology (IC, Regional, Freight);

- Service category (e.g. "Malpensa Express", RE4, S5, etc.);
- Maximum acceleration;
- Minimum time between braking end and acceleration;
- Average deceleration;
- Train composition (number of locomotives and coaches/wagons);
- Length and weight of the traction vehicles;
- Length and weight of pulled wagons;
- Air resistance formula.

11.1.4 Courses/services

In *Opentrack*, the word "course" indicates a service operated by a train in a certain period. The window "Courses/Services" permits to assign the itineraries to the trains identified by a number (each service has its own number). Each train may have one or more itineraries given with different priority levels. Moreover, each course has its assigned vehicle typology (loco engine and composition) and the timetable with arrival/departure time of each station or service point crossed by a train during its itinerary. Considering the possibility to assign more itineraries with different priorities, the default setting of the software is to follow the itinerary with priority 1; however, the presence of obstacles in the assigned itinerary impeding the train run implies the assignation of a lower priority itinerary.

The window "Courses/services" permits to access to the window "Timetable" in which it is possible to manually modify the arrival and departure times of the trains. Another option given by the software is the possibility to manage the use of vehicles according to the scheduling shift rotation by means of the window "Connections". This option simulates what happens in correspondence of a terminus station: a given vehicle operates different rides during a day and there is a specific minimum stopping time[22] at the station between the arrival of a ride and departure of the successive one. These "connections" are useful to simulate the stopping time of a given vehicle between successive rides and to define the occupation time of a station track. In a new infrastructure, this option is usable to understand the minimum number of tracks that a new station needs.

11.1.5 Simulation

The window "Simulation" permits to set the parameters of the simulation:

- Initial and final time of the simulation;
- Intermediate time instant to stop the simulation (if necessary);
- Time step of the simulation (in seconds)[23] and data elaboration speed[24];
- Delay scenario: simulates perturbed conditions of the circulation assigning delays to a certain number of trains according to a pre-defined distribution;
- Performance parameter: represents the difference between the maximum speed and the speed effectively maintained by the train during its run; this condition simulates a possible low performance of the driver and other factors implying a non-optimal circulation;
- Animation characteristics (labels visualization with data related to the specific ride, current time and simulation messages).

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[22] The minimum stopping time at the station between successive rides of a given vehicle is considering the operational time of the personnel to reach the new head of the train and to set the train for a new ride. In Italy, this is the "giro-banco" operation and its minimum defined time is 10-15 minutes.

[23] During the simulation, the software solves different equations to calculate speed and position of trains in defined time instants. For example, setting a step of 1'' the simulation is very precise, but it results to be very slow.

[24] The software gives the possibility to set the simulation speed: the option "Best" permits to the software to self-set the speed according to the quantity of data to elaborate.

11.1.6 Output

The final objective of the simulation is the elaboration of data and results represented by means of graphs and/or text documents. The software generates for each train inserted a text file reporting scheduled and simulated timetables with arrival and departure times of the localities crossed by the trains. Moreover, the software generates also a graphic timetable reporting the scheduled and simulated trains' path for a section defined by the user (called corridor). For each simulation, the software generates data elaborated by the user for the evaluation of delays and punctuality in order to understand the stability of a scheduled timetable. *Opentrack* gives also the possibility to have graphs about the occupation track time of a station (e.g. terminus station) and a timetable reporting the effective blocking time of the sections of a line in order to evaluate the possibility to insert new paths.

11.2 SIMULATED SCENARIOS: RESULTS

The software simulates two different scenarios according to the analysis carried out during this study and the considerations and proposals making about:

- **Scenario 0,** representing the actual infrastructure and railway supply;
- **Scenario 1,** representing the new infrastructural layout with 2026 railway supply.

Scenario 0 reports the actual infrastructure for the line section Rho-Casorate Sempione considering also the leading sections Pregnana Milanese-Rho, Busto FN-Busto FS (FNM line), Mornago-Gallarate and Cavaria-Gallarate. Scenario 1 reports the future infrastructure between Rho, Gallarate and Malpensa T2 as proposed in Scenario 1.2 considering the same leading line sections and the new link T2-Gallarate. The new infrastructural layout and the future railway supply here reported are the same explained during the analysis of the previous chapters (Figure 84).

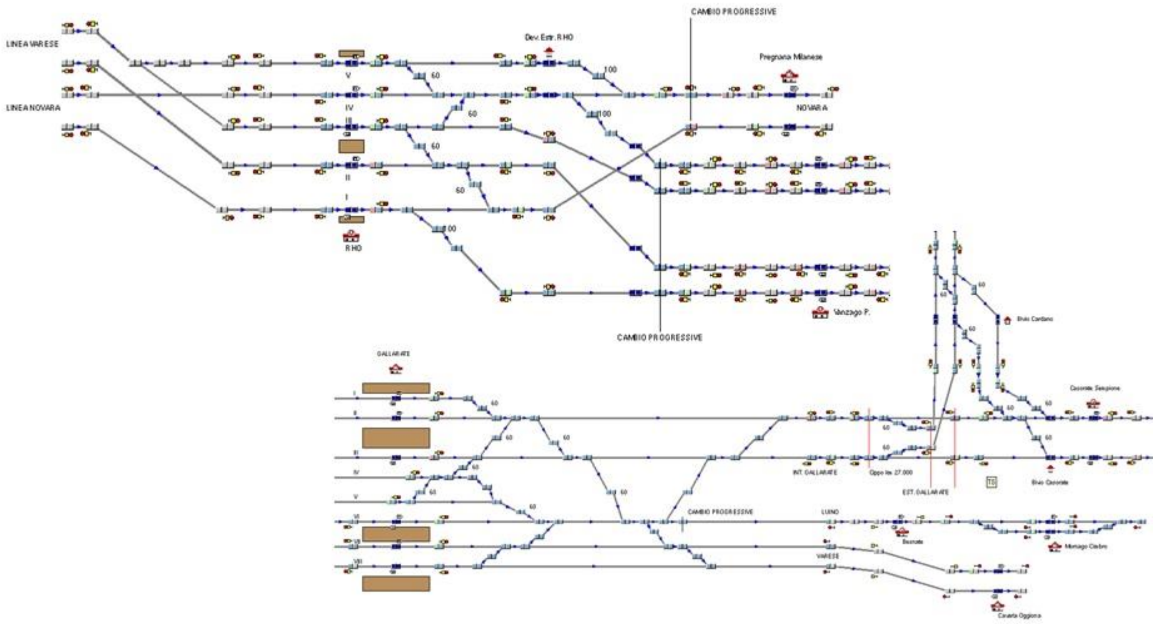

Figure 84: Opentrack future infrastructure layout - Rho-Gallarate-Bivio Cardano

The simulation includes in different steps:

1. The first simulation is implemented on the current timetable in order to calibrate the performance index[25] and to evaluate stability or possible issues of the actual schedule;
2. Then, the simulation is implemented on the future planned timetable to evaluate its stability;
3. At the end, it is necessary to implement a certain number of simulations (e.g. 30 repetitions is a suggested value) in perturbed conditions: the software assigns a delay to a defined number of entering trains according to the distribution of the delays previously set. This distribution of delays is basing on the historical delay data characterizing the line.

Results are in the following paragraphs.

11.2.1 Scenario 0: results

The presentation of the results are according to different simulation condition: without traffic perturbation and with perturbations generated by delays assigned to entering trains.

11.2.1.1 Simulation without perturbed conditions

As previously explained, at first it is necessary to simulate the current scenario without perturbations in order to calibrate the model.

The results obtained by this first simulation highlight the stability of the current timetable. The results (Tables 47 and 48) focuses on regional trains considering the prevalent traffic

[25] The performance index is a parameter defining the run quality of a train: normally this index is in the range 80÷100%. For example, a performance equal to 100% means that all the trains run at the maximum permitted speed of the line. Therefore, the performance index aims to simulate the real circulation condition of the trains that normally may not be optimal. Moreover, the index simulates the human factor of the personnel.

of the line. By the simulation, the punctuality index (*IP5*) is equal to 100% for all the regional services in both directions (even and odd flows).

Even	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	100%						**100%**
RV	100%						**100%**
R23	25%	75%					**100%**
RE5	100%						**100%**
R21	100%						**100%**
S40	100%						**100%**
S5		100%					**100%**
S6		100%					**100%**

Table 47: Punctuality Index for even exiting trains - Regional category – Scenario 0 without perturbations

Odd	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	100%						**100%**
RV	100%						**100%**
R23	100%						**100%**
RE5		100%					**100%**
R21	40%	60%					**100%**
S40	50%	50%					**100%**
S5	60%	40%					**100%**
S6	100%						**100%**

Table 48: Punctuality Index for exiting odd trains - Regional category – Scenario 0 without perturbations

All the services running on the analyzed line section presents a negative average delay meaning that the trains simulated are normally in advance with respect to their scheduled arrival and departure times at each station

11.2.1.2 Simulation with perturbed conditions

After the simulation of Scenario 0 without perturbations of the railway circulation, the successive step is the simulation implemented considering delays assigned to the entering trains according to the distribution characterizing the line. The number of simulation preliminary set is 31, including that without perturbations. The results obtained are in Figures 85 and 86.

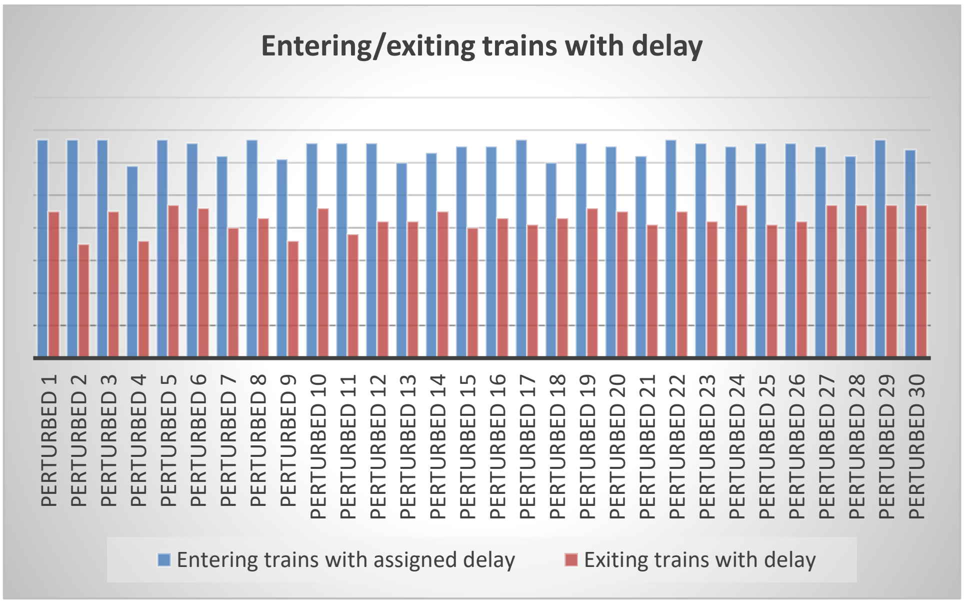

Figure 85: Chart with entering/exiting trains with delay - Scenario 0 with perturbations

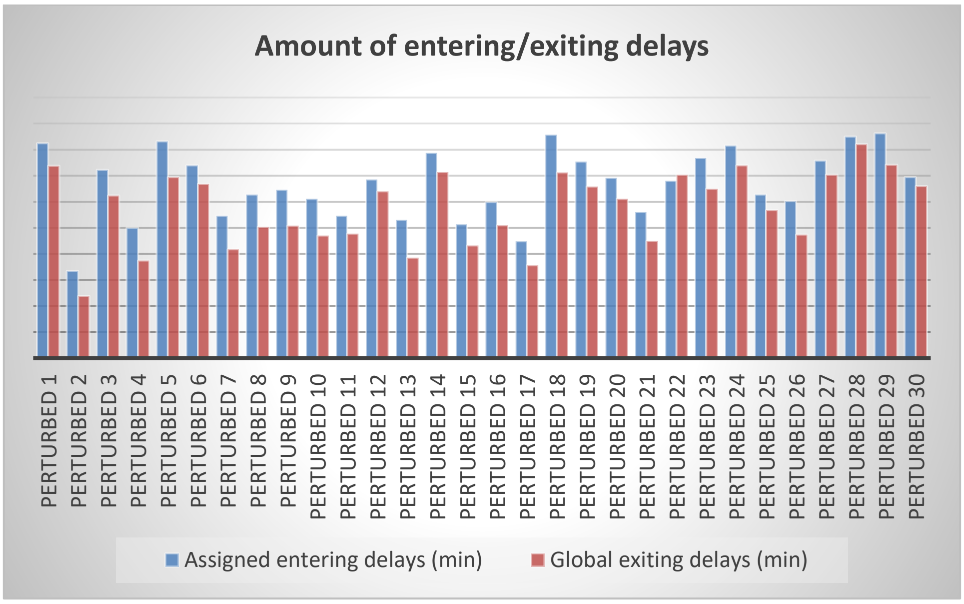

Figure 86: Chart with the amount of entering/exiting delays - Scenario 0 with perturbations

From Figure 82, it is possible to observe that considering a certain amount of entering trains with assigned delays, the number of exiting trains with delays is lower than the number of entering ones. Figure 83 reports a bar chart with the global amount of entering assigned delays and the amount of delays for the exiting trains. In this case, it is possible to observe that the system is able to absorb the entering delays without that the delay increases during the run of the trains. Many trains are able to recover delays assigned in departure by the software. Considering a total number of **69 trains** and an average number of **65 trains** with assigned delay in departure, the average number of exiting trains with delay is equal to **43.** This means that **22 perturbed trains** are able to recover the delay, equivalent to the **34%.** Considering the amount of delays, the average global assigned delay in departure is equal to **334 min** and the average delays in exit are equal to **287 min**. Therefore, the system recovers the **14%** of delays are by the trains running on the actual infrastructure.

Table 49 reports the results about recovered/lost time considering the total number of trains in departure during the simulations in perturbed conditions. The values are average weight among train categories (EC, R and M).

Av. Nr. recovering time trains	58
Av. Global recovered time [min]	96
Av. Min recovered time [s]	23
Av. Max recovered time [s]	416
Av. recovered time/rec. trains [s]	121
Av. Nr. time lost trains	9
Av. Global time lost [min]	28
Av. Min time lost [s]	26
Av. Max time lost [s]	465
Av. time lost/time lost trains [s]	188

Table 49: Average values of recovering/lost time trains – Scenario 0 with perturbations

By evaluating these results, it is possible to observe that the average regained global time is greater than the average global time lost by the trains in perturbed traffic conditions. Therefore, the actual scheduling system is able to ensure possible delay recovers in conditions of congested circulation.

Considering the regional trains, the punctuality index in perturbed conditions is in Tables 50 and 51 for each service.

The punctuality index of the regional service R21 from Gallarate to Luino is **53%** for the odd flow considering that the line has a single track-layout and delays of even trains propagate due to crossing maneuver in the station of Mornago.

Even	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	39%	1%	15%	15%	11%	19%	**70%**
RV	15%		29%	20%	14%	22%	**65%**
R23	23%	60%	4%	1%	6%	6%	**89%**
RE5	33%		17%	10%	8%	32%	**60%**
R21	26%		56%	15%	4%		**96%**
S40	48%		27%	5%	11%	8%	**81%**
S5			69%	11%	10%	10%	**81%**
S6	3%	19%	34%	24%	9%	11%	**80%**

Table 50: Punctuality Index for even exiting trains - Regional category – Scenario 0 with perturbations

Odd	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	34%		35%	13%	10%	8%	**83%**
RV	52%		11%	7%	6%	23%	**71%**
R23	79%		6%	5%	6%	4%	**90%**
RE5			55%	12%	4%	29%	**67%**
R21	5%		19%	29%	34%	13%	**53%**
S40	29%	29%	17%	9%	4%	13%	**84%**
S5	34%		35%	9%	12%	9%	**78%**
S6	48%		19%	17%	5%	12%	**83%**

Table 51: Punctuality Index for odd exiting trains - Regional category – Scenario 0 with perturbations

The regional service RE5 has a low punctuality index in perturbed conditions, maybe due to a propagation of delays generated by the previous delayed trains. The other regional services have an acceptable punctuality index in perturbed conditions.

Figure 87 shows a graphic timetable obtained by a simulation of the actual timetable with perturbations of the circulation. The scheduled train paths are in dotted line while the simulated train paths are in continuous line.

11.2.2 Scenario 1: results

As for the previous analysis, results are according to perturbed and unperturbed conditions of the circulation. The comparison of the results with respect to previous scenario must take into account that the global amount of trains is higher with the introduction of new services (69 trains in Scenario 0 versus 119 trains in Scenario 1).

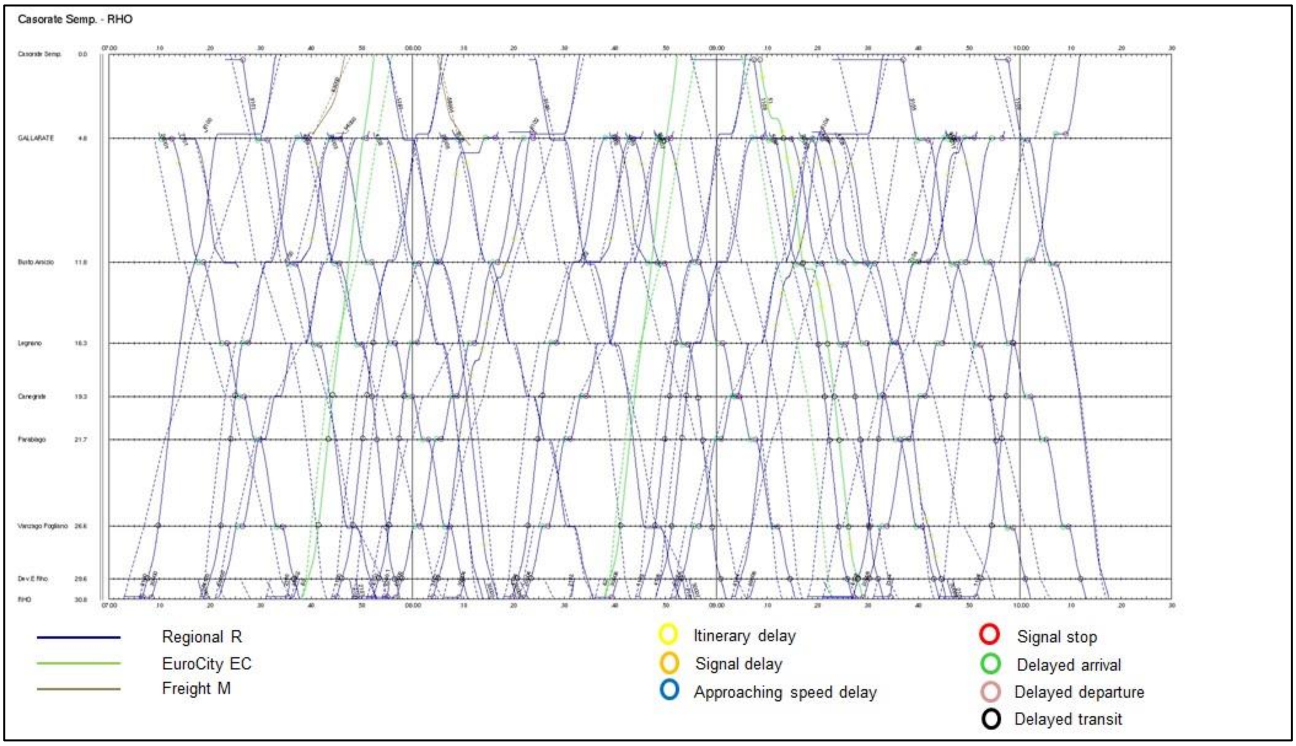

Figure 87: Graphic timetable of the section Casorate S.-Rho - Scenario 0 with perturbations

11.2.2.1 Simulation without perturbed conditions

The results obtained by this simulation considering the future designed timetable without perturbed conditions of the circulation highlights a stability of the system. Focusing on the regional trains (prevalent traffic of the line), the punctuality index *IP5* is equal to 100% for all the services in both directions (even and odd flows) (Tables 52 and 53).

Even	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
R21	100%						**100%**
R23		100%					**100%**
RE4	100%						**100%**
RE5	100%						**100%**
REMXP		100%					**100%**
RV	100%						**100%**
S11	17%	83%					**100%**
S14	17%	83%					**100%**
S15		100%					**100%**
S16		100%					**100%**
S40	100%						**100%**
S6	17%	83%					**100%**
S5		100%					**100%**

Table 52: Punctuality Index for even exiting trains - Regional category – Scenario 1 without perturbations

Odd	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
R21	40%	60%					**100%**
R23	100%						**100%**
RE4	100%						**100%**
RE5	100%						**100%**
REMXP	100%						**100%**
RV	100%						**100%**
S11		100%					**100%**
S14		100%					**100%**
S15		100%					**100%**
S16		100%					**100%**
S40	50%	50%					**100%**
S6	100%						**100%**
S5		100%					**100%**

Table 53: Punctuality Index for odd exiting trains - Regional category – Scenario 1 without perturbations

11.2.2.2 Simulation with perturbed conditions

The results obtained by simulation with perturbed condition of the circulation highlights that the designed scheduling system is able to avoid propagation of delays ensuring a certain stability level. Figures 88 and 89 show bar chart reporting respectively the comparison between entering and exiting trains with delay and the comparison between the global amount of delay for entering and exiting trains.

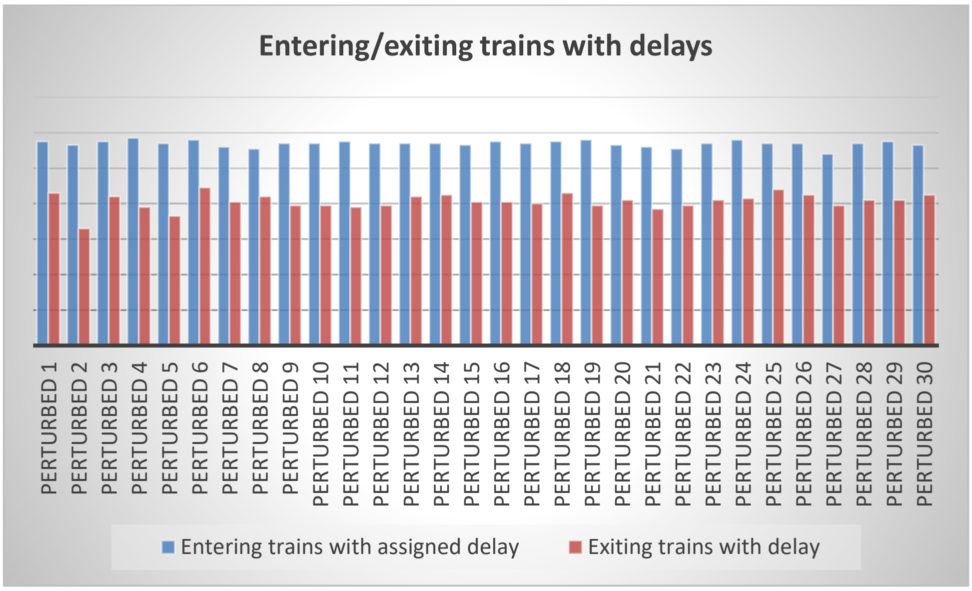

Figure 88: Chart with entering/exiting trains with delay - Scenario 1 with perturbations

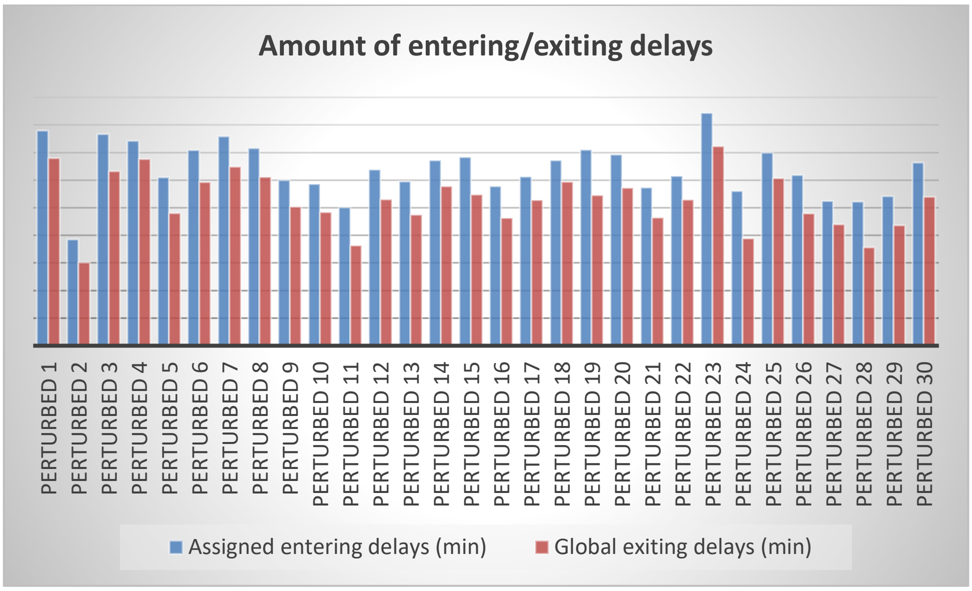

Figure 89: Chart with the amount of entering/exiting delays - Scenario 1 with perturbations

Considering a total number of **119 trains** and an average number of **114 trains** entering in the system with assigned delays, the average number of exiting trains with delays is equal to **81**. Therefore, 33 trains are able to recover their departure delays: this value is equal to the **29%** of the entering trains with delays. Moreover, it is possible to consider a global amount of delays for entering trains equal to **639 min;** the global amount of exiting delays is equal to **526 min**. Then, the system is able to recover **18%** of assigned departure delays. Table 54 reports the results about recovered/lost time considering the total number of trains in departure during the simulations in perturbed conditions.

Av. Nr. recovering time trains	79
Av. Global recovered time [min]	176
Av. Min recovered time [s]	10
Av. Max recovered time [s]	1283
Av. recovered time/rec. trains [s]	136
Av. Nr. time lost trains	29
Av. Global time lost [min]	42
Av. Min time lost [s]	8
Av. Max time lost [s]	410
Av. time lost/time lost trains [s]	87

Table 54: Average values of recovering/lost time trains – Scenario 1 with perturbations

By the results, it is possible to observe that the new infrastructure with the future railway supply permits the planning of a future scheduling system able to ensure a greater average global recovered time in the face of an important increase of the number of trains. By evaluating the average values of recovered time per recovering trains and the lost time per lost time trains, the results obtained by the simulations of Scenario 1 (Tables 55 and 56) is better than the results obtained for Scenario 0.

Even	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	55%	3%	3%	6%	10%	23%	**68%**
RV	18%		28%	15%	13%	26%	**61%**
R23			94%		3%	3%	**94%**
RE5	34%	1%	21%	13%	11%	21%	**68%**
REMXP		10%	28%	14%	16%	31%	**53%**
R21	27%		47%	10%	17%		**83%**
S40	62%		14%	11%	4%	9%	**87%**
S5			61%	19%	3%	16%	**81%**
S6	2%	83%	7%	4%	2%	2%	**96%**
S15		83%	8%	4%	4%	2%	**95%**
S14	8%	83%	2%	2%	3%	3%	**95%**
S11	6%	84%	5%	3%	2%	1%	**97%**
S16		83%	10%	3%	2%	2%	**96%**

Table 55: Punctuality Index for even exiting trains - Regional category – Scenario 1 with perturbations

Odd	Advance	On time	< 2 min.	>=2 min. <5 min.	>=5 min. <10 min.	> 10 min.	IP5
RE4	57%		14%	11%	9%	9%	**82%**
RV	52%		12%	8%	7%	20%	**73%**
R23	51%		35%	5%	5%	4%	**91%**
RE5	52%		16%	10%	5%	17%	**77%**
REMXP	43%		19%	8%	14%	17%	**70%**
R21	9%	59%	16%	9%	6%	1%	**94%**
S40	38%	38%	11%	4%	1%	8%	**91%**
S5	11%		49%	19%	10%	11%	**79%**
S6	24%	1%	29%	21%	9%	16%	**75%**
S15			34%	22%	22%	22%	**56%**
S14	16%		34%	22%	14%	14%	**72%**
S11	8%		25%	22%	21%	24%	**55%**
S16			46%	18%	15%	21%	**64%**

Table 56: Punctuality Index for odd exiting trains - Regional category – Scenario 1 with perturbations

By analyzing the punctuality index obtained by the simulations in perturbed conditions, it is possible to highlight the values obtained by the train set RE4-RE5-REMXP. Considering that these trains have a headway of 4′ coincident with the spacing requirement of the line section, delays for the first train of the set rapidly propagates to the following trains. For the even flow, the punctuality index decreases according to the succession of the trains running on the section Rho-Busto Arsizio. The punctuality results obtained by the simulations for the odd trains are better than the values of even trains of the same services: this is justified considering that delays assigned by the system when the trains are generated (entering trains) are partially recovered during the different paths of the services before the common section Busto Arsizio-Rho.

Another observation resulting by the simulations is the low punctuality index for odd flow of suburban services (S5-S6-S14-S15-S11-S16). This is justified by a criticality of the new planned layout of the station of Rho. By analyzing the new layout, all the trains of suburban services from Pregnana (Novara-Milano line) and Vanzago (Domodossola-Milano line) are arriving to track II of Rho station. This means that the high number of services given by 30′ interval of each suburban service produces a bottleneck implying an important propagation of delays for all the odd trains.

The situation for the even train is different considering that trains are able to partial recovery of the delays due to different itineraries corresponding to station tracks availability of Legnano station. Moreover, during the design process of the future timetable here proposed, the paths of odd trains of the suburban services S5, S11, S15 and S16 have an additional time of 1′ to ensure spacing requirement between service RE MXP and S5 in correspondence of Legnano station.

Figure 90 shows the graphic timetable of the section Malpensa T2-Rho for a simulation of the circulation in perturbed conditions.

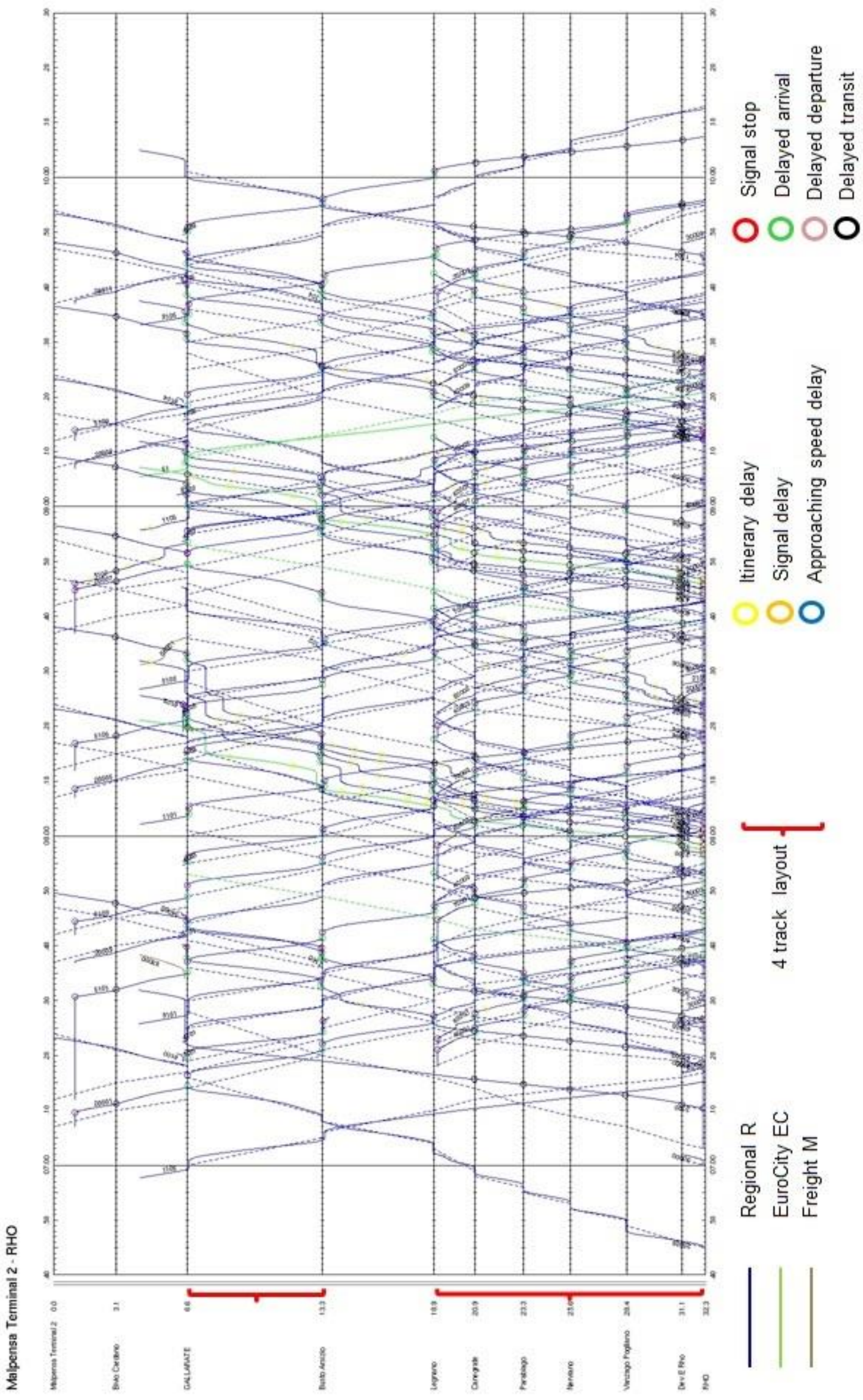

Figure 90: Graphic timetable of the section Malpensa T2-Rho - Scenario 1 with perturbations

12 CONCLUSIONS

This study elaborates a general model for the analysis of a railway infrastructure. Different methodologies are combining in a rational integration, by evaluating, modifying and innovating them with the aim to fulfill the analysis requirements. The application of these methodologies to the Malpensa airport link permits to evaluate throughout fundamental aspects of a railway infrastructure, related to its management and operational processes. The assessment of the infrastructural performances, starting from a consolidated actual and future railway supply, is important to understand whether a given network is able to absorb the expected traffic with or without significant impacts on traffic regularity. The application of this analysis model demonstrates its effectiveness by means of the results obtained: they are useful for the infrastructure manager planning activities, as well as to assist policy makers in their decision processes, when planning and scheduling investments on new infrastructures.

The analysis reported in this paper highlights the main results obtained on the railway connections between Milan and Malpensa airport. The study shows a saturation condition of the existing infrastructure in the section Rho-Gallarate of the railway line Domodossola-Milano. Considering a traffic increase to the future 2026 railway supply, when new services connecting the airport are in plan, the actual infrastructural layout of this line segment is unfit to support the expected traffic.

For this reason, the study analyzes new infrastructural layout solutions, in terms of line and node capacity, looking for the optimal one. The first solution analyzed relates to an existing project, that is a first step of enhancement of this line. It is an infrastructural layout planning four tracks between Rho and Parabiago and a new track layout at Rho station. It is coupling with new the T2-Gallarate North Link. The results obtained highlight a saturation condition upstream the upgraded line segment Rho-Parabiago, between the stations of Parabiago and Gallarate.

Because of these results, this paper proposes two upgrade scenarios. In the first scenario, we introduce the extension of the 4-track section northward to Legnano. In the second scenario, a second 4-track section, coupled with the first one, is between Gallarate and Busto Arsizio, as a further infrastructural upgrade of the previous scenario. The analysis of these solutions highlights an improvement of the capacity conditions of the line segments that eliminate the main bottlenecks influencing the railway circulation. The extension of the infrastructural upgrade up to Legnano station and the adoption of a new track layout between Gallarate and Busto Arsizio ensure sustainable circulation conditions for the traffic scenarios forecast with the new Malpensa link.

The analysis of the main nodes of the line Domodossola-Milano in the segment Rho-Gallarate highlights a general inability of the actual station layouts to support the expected traffic. The paper analyzes the new station layouts already planned by the infrastructure manager; moreover, new ones are proposing layout upgrades introduced during the study. The values of utilization rate of the nodes by the application of Potthoff method show a stable operation for the layout proposed.

The analysis of line and node capacity includes also a scheduling analysis. The objective is to evaluate the feasibility of the new services planned in the future railway traffic model or timetable and infrastructural constraints may impede their introduction. The study confirms the possibility to introduce new services from/to Malpensa airport throughout the line Domodossola-Milano using the future new airport link. Moreover, all the new suburban services planned by the agreements between the regional government and the infrastructure manager may be introduced as well, exploiting the new infrastructural upgrades of the Rho-Gallarate section.

On the other side, the introduction of a new service Malpensa-Bergamo via Seregno is uneasy to realize. The infrastructural constraints (the single-track layout of the line Seregno-Bergamo) impede the realization of this service, considering also the other services running on this line. Moreover, it is necessary to consider the timetable constraints deriving by the presence of other services with origin/destination Malpensa on the section Busto Arsizio-Gallarate-Malpensa.

In the end, the application of a simulation model demonstrates the stability of the timetable proposed for the Malpensa-Rho line, whereas the services to Bergamo are no longer considered.

This study demonstrates the importance to adopt a rational comprehensive methodology for the analysis, aimed to evaluate the impact the realization of new infrastructures has onto the existing ones. For the upgrade process of the railway segment Rho-Gallarate, it is important to consider that the realization of the new link T2-Gallarate is effectively beneficial only when the infrastructural upgrade projects between Rho, Legnano and Gallarate will be complete as well. Therefore, a comprehensive enhancement of the infrastructure leading to the airport is necessary to improve the railway accessibility to the Malpensa International Airport and enlarge its railway catchment area.

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In this Annex, there are all the tables computed applying Potthoff method during the capacity analysis of node.

SCENARIO 0: TABLES

The tables are in the paper at chapter 7 (7.2).

SCENARIO 1: TABLES (57÷63)

Routes		A-OVEST								P-OVEST						
		107a-130	107-134	101-132	101-132(T)	130-I	132-I	132-II	134-II	III-131	IV-133	V-135	131-112	133-112a	133-106	135-106
A-OVEST	107a-130	a	c	c	c	c	c	c	c	c	c	c	c	c	c	c
	107-134	c	a	c	c	c	c	c	c	c	c	c	c	c	c	c
	101-132	c	c	a	a	c	c	c	c	c	c	c	c	c	c	c
	101-132(T)	c	c	a	a	c	c	c	c	c	c	c	c	c	c	c
	130-I	c	c	c	c	a	z	c	c	c	c	c	c	c	c	c
	132-I	c	c	c	c	z	a	s	c	c	c	c	c	c	c	c
	132-II	c	c	c	c	c	s	a	z	c	c	c	c	c	c	c
	134-II	c	c	c	c	c	c	z	a	c	c	c	c	c	c	c
P-OVEST	III-131	c	c	c	c	c	c	c	c	a	c	c	c	c	c	c
	IV-133	c	c	c	c	c	c	c	c	c	a	c	c	c	c	c
	V-135	c	c	c	c	c	c	c	c	c	c	a	c	c	c	c
	131-112	c	c	c	c	c	c	c	c	c	c	c	a	c	c	c
	133-112a	c	c	c	c	c	c	c	c	c	c	c	c	a	s	c
	133-106	c	c	c	c	c	c	c	c	c	c	c	c	s	a	z
	135-106	c	c	c	c	c	c	c	c	c	c	c	c	c	z	a

Table 57: Route matrix for Scenario 1 – Rad. OVEST Rho

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	A/D (m/s2)	Ts (s)	tocc (s)	Tt (s)	Tot (s)	Tot (min)
107a-130	906	912	900	200	750	110	100	0	0	125	30	155	2.6
107-134	906	912	900	200	200	110	0	0	0	102	30	132	2.2
101-132	1472	1350	1350	200	200	120	60	0	0	187	30	217	3.6
101-132(T)	1472	1350	1350	200	750	120	0	0	0	154	30	184	3.1
130-I	975	906	1812	200	750	110	100	0	0	161	30	191	3.2
132-I	975	1472	1350	200	750	120	0	0	0	142	30	172	2.9
132-II	975	1472	1350	200	200	120	60	0.6	60	279	30	309	5.2
134-II	975	906	1812	200	200	110	0	0.6	60	219	30	249	4.2
III-131	907	0	0	0	200	110	0	0.3	0	102	30	132	2.2
IV-133	907	0	0	0	750	110	0	0.3	0	102	30	132	2.2
V-135	907	0	0	0	200	100	0	0.3	0	93	30	123	2.0
131-112	905	0	0	0	200	110	0	0.3	0	102	30	132	2.2
133-112a	905	0	0	0	750	110	0	0.3	0	102	30	132	2.2
133-106	920	0	0	0	750	100	0	0.3	0	93	30	123	2.0
135-106	920	0	0	0	200	100	0	0.3	0	93	30	123	2.0

Table 58: Parameters for the calculation of blocking time - Scenario 1 - Rad. OVEST Rho

Occupation		A-OVEST								P-OVEST						
		107a-130	107-134	101-132	101-132(T)	130-I	132-I	132-II	134-II	III-131	IV-133	V-135	131-112	133-112a	133-106	135-106
A-OVEST	107a-130	155	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	107-134	0	132	0	0	0	0	0	0	0	0	0	0	0	0	0
	101-132	0	0	217	217	0	0	0	0	0	0	0	0	0	0	0
	101-132(T)	0	0	184	184	0	0	0	0	0	0	0	0	0	0	0
	130-I	0	0	0	0	191	191	0	0	0	0	0	0	0	0	0
	132-I	0	0	0	0	172	172	172	0	0	0	0	0	0	0	0
	132-II	0	0	0	0	0	309	309	309	0	0	0	0	0	0	0
	134-II	0	0	0	0	0	0	249	249	0	0	0	0	0	0	0
P-OVEST	III-131	0	0	0	0	0	0	0	0	132	0	0	0	0	0	0
	IV-133	0	0	0	0	0	0	0	0	0	132	0	0	0	0	0
	V-135	0	0	0	0	0	0	0	0	0	0	123	0	0	0	0
	131-112	0	0	0	0	0	0	0	0	0	0	0	132	0	0	0
	133-112a	0	0	0	0	0	0	0	0	0	0	0	0	132	132	0
	133-106	0	0	0	0	0	0	0	0	0	0	0	0	123	123	123
	135-106	0	0	0	0	0	0	0	0	0	0	0	0	0	123	123

Table 59: Occupation time matrix for Scenario 1 - Rad. OVEST Rho

Delays		A-OVEST								P-OVEST						
		107a-130	107-134	101-132	101-132(T)	130-I	132-I	132-II	134-II	III-131	IV-133	V-135	131-112	133-112a	133-106	135-106
A-OVEST	107a-130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	107-134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	101-132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	101-132(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	130-I	0	0	0	0	0	129	0	0	0	0	0	0	0	0	0
	132-I	0	0	0	0	105	0	0	0	0	0	0	0	0	0	0
	132-II	0	0	0	0	0	0	0	425	0	0	0	0	0	0	0
	134-II	0	0	0	0	0	0	276	0	0	0	0	0	0	0	0
P-OVEST	III-131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	IV-133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	V-135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	131-112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	133-112a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	133-106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
	135-106	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0

Table 60: Delay matrix for Scenario 1 - Rad. OVEST Rho

Routes		A-EST					P-EST			
		208-III	208-III (T)	208-V	208-V (T)	302-IV (T)	I-305	I-305 (T)	II-211	II-211 (T)
A-EST	208-III	a	a	s	s	c	c	c	c	c
	208-III (T)	a	a	s	s	c	c	c	c	c
	208-V	s	s	a	a	c	c	c	c	c
	208-V (T)	s	s	a	a	c	c	c	c	c
	302-IV (T)	c	c	c	c	a	c	c	c	c
P-EST	I-305	c	c	c	c	c	a	a	c	c
	I-305 (T)	c	c	c	c	c	a	a	c	c
	II-211	c	c	c	c	c	c	c	a	a
	II-211 (T)	c	c	c	c	c	c	c	a	a

Table 61: Route matrix for Scenario 1 - Rad. EST Rho

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	Ts (s)	A/D (m/s2)	Tocc (s)	Tt (s)	Tot (s)	Tot(min)
208-III	900	900	900	200	200	110	0	60	0.6	187	30	217	3.6
208-III (T)	900	900	1800	200	200	110	0	0	0	131	30	161	2.7
208-V	900	900	900	200	200	110	60	60	0.6	230	30	260	4.3
208-V (T)	900	900	1800	200	200	110	60	0	0	185	30	215	3.6
302-IV (T)	900	900	1800	200	750	120	0	0	0	137	30	167	2.8
I-305	900	0	0	0	750	120	0	0	0.3	111	30	141	2.4
I-305 (T)	900	0	0	0	750	120	0	0	0	50	30	80	1.3
II-211	900	0	0	0	200	110	0	0	0.3	102	30	132	2.2
II-211 (T)	900	0	0	0	200	110	0	0	0	36	30	66	1.1

Table 62: Parameters for the calculation of blocking time - Scenario 1 - Rad. EST Rho

Occupation		A-EST					P-EST			
		208-III	208-III (T)	208-V	208-V (T)	302-IV (T)	I-305	I-305 (T)	II-211	II-211 (T)
A-EST	208-III	217	217	217	217	0	0	0	0	0
	208-III (T)	161	161	161	161	0	0	0	0	0
	208-V	260	260	260	260	0	0	0	0	0
	208-V (T)	215	215	215	215	0	0	0	0	0
	302-IV (T)	0	0	0	0	167	0	0	0	0
P-EST	I-305	0	0	0	0	0	141	141	0	0
	I-305 (T)	0	0	0	0	0	80	80	0	0
	II-211	0	0	0	0	0	0	0	132	132
	II-211 (T)	0	0	0	0	0	0	0	66	66

Table 63: Occupation time matrix for Scenario 1 - Rad. EST Rho

SCENARIO 0: TABLES (64÷67)

Routes		3-I	3-V	3-VI	I-4	III-4	IV-4
A-N	3-I	a	s	s	u	x	x
	3-V	s	a	s	c	c	c
	3-VI	s	s	a	c	c	c
P-N	I-4	u	c	c	a	z	z
	III-4	x	c	c	z	a	z
	IV-4	x	c	c	z	z	a

Table 64: Route matrix for Scenario 0 – Rad. NORD Busto A. FS

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	A/D(m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
3-I	937	915	1499	200	200	60	30	0.6	60	302	30	332	5.5
3-V	1076	915	1499	200	200	140	60	0.6	60	249	30	279	4.7
3-VI	1076	915	3374	200	750	140	0	0	0	162	30	192	3.2
I-4	642	0	0	0	200	30	0	0.3	0	115	30	145	2.4
III-4	571	0	0	0	750	140	0	0	0	34	30	64	1.1
IV-4	571	0	0	0	200	0	60	0.3	0	74	30	104	1.7

Table 65: Parameters for the calculation of blocking time - Scenario 0 - Rad. NORD Busto A. FS

Occupation		3-I	3-V	3-VI	I-4	III-4	IV-4
A-N	3-I	332	332	332	332	332	332
	3-V	279	279	279	0	0	0
	3-VI	192	192	192	0	0	0
P-N	I-4	145	0	0	145	145	145
	III-4	64	0	0	64	64	64
	IV-4	104	0	0	104	104	104

Table 66: Occupation time matrix for Scenario 0 - Rad. NORD Busto A. FS

Delays		3-I	3-V	3-VI	I-4	III-4	IV-4
A-N	3-I	0	0	0	15	23	92
	3-V	0	0	0	0	0	0
	3-VI	0	0	0	0	0	0
P-N	I-4	3	0	0	0	4	18
	III-4	1	0	0	1	0	5
	IV-4	9	0	0	9	14	0

Table 67: Delay matrix for Scenario 0 - Rad. NORD Busto A. FS

SCENARIO 1.2.: TABLES (68÷75)

Routes		3-II	3-V	3-VI	3a-II	I-4	I-4a	III-4	IV-4
A-N	3-II	a	s	s	z	u	c	x	x
	3-V	s	a	s	c	c	c	c	c
	3-VI	s	s	a	c	c	c	c	c
	3a-II	z	c	c	a	x	c	c	c
P-N	I-4	u	c	c	x	a	s	z	z
	I-4a	c	c	c	c	s	a	c	c
	III-4	x	c	c	c	z	c	a	z
	IV-4	x	c	c	c	z	c	z	a

Table 68: Route matrix for Scenario 1.2. – Rad. NORD Busto A. FS

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	A/D(m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
3-II	1081	900	1060	200	200	140	60	0.6	60	186	30	216	3.6
3-V	1081	900	2410	200	750	140	0	0	0	137	30	167	2.8
3-VI	1081	900	1060	200	200	140	0	0.6	60	181	30	211	3.5
3a-II	1081	900	1060	200	200	140	60	0.6	60	186	30	216	3.6
I-4	1456	0	0	0	200	140	0	0.3	0	102	30	132	2.2
I-4a	586	0	0	0	200	140	0	0.3	0	74	30	104	1.7
III-4	1456	0	0	0	200	140	0	0.3	0	102	30	132	2.2
IV-4	1456	0	0	0	750	140	0	0	0	57	30	87	1.4

Table 69: Parameters for the calculation of blocking time - Scenario 1.2. - Rad. NORD Busto A. FS

Occupation		3-II	3-V	3-VI	3a-II	I-4	I-4a	III-4	IV-4
A-N	3-II	216	216	216	216	216	0	216	216
	3-V	167	167	167	0	0	0	0	0
	3-VI	211	211	211	0	0	0	0	0
	3a-II	216	0	0	216	216	0	0	0
P-N	I-4	132	0	0	132	132	132	132	132
	I-4a	0	0	0	0	104	104	0	0
	III-4	132	0	0	0	132	0	132	132
	IV-4	87	0	0	0	87	0	87	87

Table 70: Occupation time matrix for Scenario 1.2. - Rad. NORD Busto A. FS

Delays		3-II	3-V	3-VI	3a-II	I-4	I-4a	III-4	IV-4
A-N	3-II	0	0	0	0	0	0	0	0
	3-V	0	0	0	0	0	0	0	0
	3-VI	0	0	0	0	0	0	0	0
	3a-II	0	0	0	0	0	0	0	0
P-N	I-4	0	0	0	0	0	0	0	0
	I-4a	0	0	0	0	0	0	0	0
	III-4	0	0	0	0	0	0	0	22
	IV-4	0	0	0	0	0	0	9	0

Table 71: Delay matrix for Scenario 1.2. - Rad. NORD Busto A. FS

Routes		6-III	6-IV	6-I	FNM-I	II-5	V-5	VI-5	II-FNM
A-N	6-III	a	s	s	c	x	c	c	c
	6-IV	s	a	s	c	x	c	c	c
	6-I	s	s	a	z	c	c	c	c
	FNM-I	c	c	z	a	c	c	c	u
P-N	II-5	x	x	c	c	a	z	z	z
	V-5	c	c	c	c	z	a	z	c
	VI-5	c	c	c	c	z	z	a	c
	II-FNM	c	c	c	u	z	c	c	a

Table 72: Route matrix for Scenario 1.2. - Rad. SUD Busto A. FS

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	A/D(m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
6-III	1015	900	900	200	200	140	60	0.6	60	229	30	259	4.3
6-IV	1215	900	1800	200	750	140	0	0	0	125	30	155	2.6
6-I	1015	900	900	200	200	140	60	0.6	60	229	30	259	4.3
FNM-I	1564	0	0	200	200	0	30	0.6	60	303	30	333	5.5
II-5	590	0	0	0	200	140	60	0.3	0	74	30	104	1.7
V-5	590	0	0	0	750	140	0	0	0	34	30	64	1.1
VI-5	550	0	0	0	200	140	60	0.3	0	74	30	104	1.7
II-FNM	1564	0	0	0	200	30	0	0.3	0	218	30	248	4.1

Table 73: Parameters for the calculation of blocking time - Scenario 1.2. - Rad. SUD Busto A. FS

Occupation		6-III	6-IV	6-I	FNM-I	II-5	V-5	VI-5	II-FNM
A-N	6-III	259	259	259	0	259	0	0	0
	6-IV	155	155	155	0	155	0	0	0
	6-I	259	259	259	259	0	0	0	0
	FNM-I	0	0	333	333	0	0	0	333
P-N	II-5	104	104	0	0	104	104	104	104
	V-5	0	0	0	0	64	64	64	0
	VI-5	0	0	0	0	104	104	104	0
	II-FNM	0	0	0	248	248	0	0	248

Table 74: Occupation time matrix for Scenario 1.2. - Rad. SUD Busto A. FS

Delays		6-III	6-IV	6-I	FNM-I	II-5	V-5	VI-5	II-FNM
A-N	6-III	0	0	0	0	112	0	0	0
	6-IV	0	0	0	0	10	0	0	0
	6-I	0	0	0	56	0	0	0	0
	FNM-I	0	0	92	0	0	0	0	138
P-N	II-5	18	5	0	0	0	8	18	9
	V-5	0	0	0	0	3	0	9	0
	VI-5	0	0	0	0	18	23	0	0
	II-FNM	0	0	0	77	51	0	0	0

Table 75: Delay matrix for Scenario 1.2. - Rad. SUD Busto A. FS

SCENARIO 0: TABLES (76÷83)

Routes		A-SUD						P-SUD			
		2-I	2-I (T)	2-V	3-I (T)	2-VII	2-VIII	I-3 (T)	II-1	II-1 (T)	VI-1
A-SUD	2-I	a	d	s	z	s	s	u	c	c	c
	2-I (T)	d	a	s	z	s	s	u	c	c	c
	2-V	s	s	a	c	s	s	c	x	x	c
	3-I (T)	z	z	c	a	c	c	u	c	c	c
	2-VII	s	s	s	c	a	s	c	x	x	x
	2-VIII	s	s	s	c	s	a	c	x	x	x
P-SUD	I-3 (T)	u	u	c	u	c	c	a	c	c	c
	II-1	c	c	x	c	x	x	c	a	d	z
	II-1 (T)	c	c	x	c	x	x	c	d	a	z
	VI-1	c	c	c	c	x	x	c	z	z	a

Table 76: Route matrix for Scenario 0 - Rad. SUD Gallarate

Routes	D1 (m)	D2 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	Ts (s)	A/D(m/s2)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
2-I	1186	1689	200	200	140	0	60	0.6	177	30	207	3.4
2-I (T)	1186	3088	200	750	140	0	0	0	134	30	164	2.7
2-V	1273	1689	200	200	0	60	60	0.6	276	30	306	5.1
3-I (T)	1186	0	200	750	0	30	0	0	256	30	286	4.8
2-VII	1216	1689	200	750	0	30	0	0.6	470	30	500	8.3
2-VIII	1216	1689	200	750	0	30	0	0.6	470	30	500	8.3
I-3(T)	1867	0	0	750	0	30	0	0	314	30	344	5.7
II-1	1875	0	0	200	140	0	0	0.3	118	30	148	2.5
II-1 (T)	1875	0	0	750	140	0	0	0	68	30	98	1.6
VI-1	1818	0	0	200	0	60	0	0.3	149	30	179	3.0

Table 77: Parameters for the calculation of blocking time - Scenario 0 - Rad. SUD Gallarate

Occupation		A-SUD						P-SUD			
		2-I	2-I (T)	2-V	3-I (T)	2-VII	2-VIII	I-3 (T)	II-1	II-1 (T)	VI-1
A-SUD	2-I	207	207	207	207	207	207	207	0	0	0
	2-I (T)	164	164	164	164	164	164	164	0	0	0
	2-V	306	306	306	0	306	306	0	306	306	0
	3-I (T)	286	286	0	286	0	0	286	0	0	0
	2-VII	500	500	500	0	500	500	0	500	500	500
	2-VIII	500	500	500	0	500	500	0	500	500	500
P-SUD	I-3 (T)	344	344	0	344	0	0	344	0	0	0
	II-1	0	0	148	0	148	148	0	148	148	148
	II-1 (T)	0	0	98	0	98	98	0	98	98	98
	VI-1	0	0	0	0	179	179	0	179	179	179

Table 78: Occupation time matrix for Scenario 0 - Rad. SUD Gallarate

Delays		2-I	2-I (T)	2-V	3-I (T)	2-VII	2-VIII	I-3	II-1	II-1 (T)	VI-1
		A-SUD						P-SUD			
A-SUD	2-I	0	18	0	4	0	0	8	0	0	0
	2-I (T)	11	0	0	2	0	0	4	0	0	0
	2-V	0	0	0	0	0	0	0	195	97	0
	3-I (T)	7	5	0	0	0	0	2	0	0	0
	2-VII	0	0	0	0	0	0	0	0	0	0
	2-VIII	0	0	0	0	0	0	0	0	0	0
P-SUD	I-3(T)	23	17	0	3	0	0	0	0	0	0
	II-1	0	0	46	0	0	0	0	0	14	46
	II-1 (T)	0	0	10	0	0	0	0	6	0	10
	VI-1	0	0	0	0	0	0	0	67	33	0

Table 79: Delay matrix for Scenario 0 - Rad. SUD Gallarate

Routes		5-I(T)	5-II(T)	5-II	5-VII	5-VIII	6-III	6-VII	6-VIII	6-II	8-VI	6-I(T)	I-4	I-4(T)	VII-4	VIII-4	III-6	VII-6	VIII-6	I-6	V-7
		A-NORD											P-NORD								
A-NORD	5-I(T)	a	s	s	s	s	c	c	c	z	c	z	u	u	x	x	c	c	c	u	c
	5-II(T)	s	a	d	z	z	c	c	c	z	c	x	c	c	x	x	c	c	c	x	c
	5-II	s	d	a	s	s	c	c	c	z	c	x	c	c	x	x	c	c	c	x	c
	5-VII	s	z	s	a	s	x	z	z	x	x	x	c	c	u	u	x	u	u	x	x
	5-VIII	s	z	s	s	a	x	x	z	x	x	x	c	c	u	u	x	u	u	x	x
	6-III	c	c	c	x	x	a	s	s	s	c	s	c	c	x	x	u	u	u	u	c
	6-VII	c	c	c	z	x	s	a	s	s	x	s	c	c	u	u	u	u	u	u	x
	6-VIII	c	c	c	z	z	s	s	a	s	x	s	c	c	u	u	u	u	u	u	x
	6-II	z	z	z	x	x	s	s	s	a	c	s	c	c	x	x	u	u	u	u	c
	8-VI	c	c	c	x	x	c	x	x	c	a	c	c	c	x	x	c	x	x	c	c
	6-I(T)	z	x	x	x	x	s	s	s	s	c	a	u	u	x	x	u	u	u	u	c
P-NORD	I-4	u	c	c	c	c	c	c	c	c	c	u	a	d	z	z	c	c	c	s	c
	I-4(T)	u	c	c	c	c	c	c	c	c	c	u	d	a	z	z	c	c	c	s	c
	VII-4	x	x	x	u	u	x	u	u	x	x	x	z	z	a	z	x	s	z	x	x
	VIII-4	x	x	x	u	u	x	u	u	x	x	x	z	z	z	a	x	x	s	x	x
	III-6	c	c	c	x	x	u	u	u	u	c	u	c	c	x	x	a	z	z	z	c
	VII-6	c	c	c	u	u	u	u	u	u	x	u	c	c	s	x	z	a	z	z	x
	VIII-6	c	c	c	u	u	u	u	u	u	x	u	c	c	z	s	z	z	a	z	x
	I-6	u	x	x	x	x	u	u	u	u	c	u	s	s	x	x	z	z	z	a	c
	V-7	c	c	c	x	x	c	x	x	c	c	c	c	c	x	x	c	x	x	c	a

Table 80: Route matrix for Scenario 0 - Rad. NORD Gallarate

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	Ts (s)	A/D(m/s2)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
5-I(T)	1284	1551	1775	200	750	110	30	0	0	359	30	389	6.5
5-II(T)	1284	1551	1775	200	750	110	0	0	0	182	30	212	3.0
5-II	1284	1551	0	200	200	110	0	60	0.6	191	30	221	3.2
5-VII	1386	1551	0	200	750	0	30	0	0.6	473	30	503	7.9
5-VIII	1386	1551	0	200	750	0	30	0	0.6	473	30	503	7.9
6-III	1147	698	0	200	200	125	85	60	0.6	172	30	202	2.9
6-VII	1147	698	0	200	750	125	30	0	0.6	324	30	354	5.4
6-VIII	1147	698	0	200	750	125	30	0	0.6	324	30	354	5.4
6-II	1147	698	0	200	750	125	30	0	0.6	324	30	354	5.4
8-VI	1184	1200	0	200	200	90	0	60	0.6	192	30	222	3.2
6-I(T)	1147	698	698	200	750	125	30	0	0	337	30	367	5.6
I-4	982	0	0	0	200	110	0	0	0.3	90	30	120	1.5
I-4(T)	982	0	0	0	200	110	0	0	0	39	30	69	0.6
VII-4	974	0	0	0	750	0	30	0	0.3	221	30	251	3.7
VIII-4	974	0	0	0	750	0	30	0	0.3	221	30	251	3.7
III-6	1147	0	0	0	200	85	125	0	0.3	94	30	124	1.6
VII-6	1147	0	0	0	750	30	125	0	0.3	173	30	203	2.9
VIII-6	1147	0	0	0	750	30	125	0	0.3	173	30	203	2.9
I-6	1147	0	0	0	750	30	125	0	0.3	173	30	203	2.9
V-7	3800	0	0	0	200	90	0	0	0.3	202	30	232	3.4

Table 81: Parameters for the calculation of blocking time - Scenario 0 - Rad. NORD Gallarate

Occupation		A-NORD											P-NORD									
		5-I(T)	5-II(T)	5-II	5-VII	5-VIII	6-III	6-VII	6-VIII	6-II	8-VI	6-I(T)	I-4	I-4(T)	VII-4	VIII-4	III-6	VII-6	VIII-6	I-6	V-7
A-NORD	5-I(T)	389	389	389	389	389	0	0	0	389	0	389	389	389	389	389	0	0	0	389	0
	5-II(T)	212	212	212	212	212	0	0	0	212	0	212	0	0	212	212	0	0	0	212	0
	5-II	221	221	221	221	221	0	0	0	221	0	221	0	0	221	221	0	0	0	221	0
	5-VII	503	503	503	503	503	503	503	503	503	503	503	0	0	503	503	503	503	503	503	503
	5-VIII	503	503	503	503	503	503	503	503	503	503	503	0	0	503	503	503	503	503	503	503
	6-III	0	0	0	202	202	202	202	202	202	0	202	0	0	202	202	202	202	202	202	0
	6-VII	0	0	0	354	354	354	354	354	354	354	354	0	0	354	354	354	354	354	354	354
	6-VIII	0	0	0	354	354	354	354	354	354	354	354	0	0	354	354	354	354	354	354	354
	6-II	354	354	354	354	354	354	354	354	354	0	354	0	0	354	354	354	354	354	354	0
	8-VI	0	0	0	222	222	0	222	222	0	222	0	0	0	222	222	0	222	222	0	0
	6-I(T)	367	367	367	367	367	367	367	367	367	0	367	367	367	367	367	367	367	367	367	0
P-NORD	I-4	120	0	0	0	0	0	0	0	0	0	120	120	120	120	120	0	0	0	120	0
	I-4(T)	69	0	0	0	0	0	0	0	0	0	69	69	69	69	69	0	0	0	69	0
	VII-4	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251
	VIII-4	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251	251
	III-6	0	0	0	124	124	124	124	124	124	0	124	0	0	124	124	124	124	124	124	0
	VII-6	0	0	0	203	203	203	203	203	203	203	203	0	0	203	203	203	203	203	203	203
	VIII-6	0	0	0	203	203	203	203	203	203	203	203	0	0	203	203	203	203	203	203	203
	I-6	203	203	203	203	203	203	203	203	203	0	203	203	203	203	203	203	203	203	203	0
	V-7	0	0	0	232	232	0	232	232	0	0	0	0	0	232	232	0	232	232	0	232

Table 82: Occupation time matrix for Scenario 0 - Rad. NORD Gallarate

Delays		A-NORD											P-NORD									
		5-I(T)	5-II(T)	5-II	5-VII	5-VIII	6-III	6-VII	6-VIII	6-II	8-VI	6-I(T)	I-4	I-4(T)	VII-4	VIII-4	III-6	VII-6	VIII-6	I-6	V-7
A-NORD	5-I(T)	0	0	0	0	0	0	0	0	11	0	2	21	18	14	0	0	0	0	1	0
	5-II(T)	0	0	19	0	9	0	0	0	9	0	2	0	0	12	0	0	0	0	1	0
	5-II	0	20	0	0	0	0	0	0	14	0	3	0	0	18	0	0	0	0	1	0
	5-VII	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-VIII	0	53	0	0	0	35	0	28	35	176	7	0	0	46	0	35	32	0	4	176
	6-III	0	0	0	0	6	0	0	0	0	0	0	0	0	7	0	6	5	0	1	0
	6-VII	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6-VIII	0	0	0	0	14	0	0	0	0	70	0	0	0	18	0	14	13	0	1	70
	6-II	9	26	35	0	17	0	0	0	0	0	0	0	0	23	0	17	16	0	2	0
	8-VI	0	0	0	0	34	0	0	27	0	0	0	0	0	45	0	0	31	0	0	0
	6-I(T)	2	6	7	0	4	0	0	0	0	0	0	7	6	5	0	4	3	0	0	0
P-NORD	I-4	2	0	0	0	0	0	0	0	0	0	1	0	7	5	0	0	0	0	0	0
	I-4(T)	1	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
	VII-4	6	17	23	0	11	11	0	9	11	57	2	23	19	0	0	11	0	0	1	57
	VIII-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	III-6	0	0	0	0	2	2	0	2	2	0	0	0	0	3	0	0	2	0	0	0
	VII-6	0	0	0	0	5	5	0	4	5	26	1	0	0	0	0	5	0	0	1	26
	VIII-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	I-6	0	1	1	0	1	1	0	0	1	0	0	0	0	1	0	1	1	0	0	0
	V-7	0	0	0	0	37	0	0	30	0	0	0	0	0	48	0	0	34	0	0	0

Table 83: Delay matrix for Scenario 0 - Rad. NORD Gallarate

SCENARIO 1.2.: TABLES (84÷91)

Routes		A-SUD						P-SUD			
		2a-II	2a-II (T)	2-VII	3-I (T)	2a-IV	2a-V	I-3 (T)	III-1a	III-1a (T)	VIII-1
A-SUD	2a-II	a	a	c	c	s	s	c	c	c	c
	2a-II (T)	a	a	c	c	s	s	c	c	c	c
	2-VII	c	c	a	c	c	c	c	c	c	c
	3-I (T)	c	c	c	a	c	c	u	c	c	c
	2a-IV	s	s	c	c	a	s	c	x	x	c
	2a-V	s	s	c	c	s	a	c	x	x	c
P-SUD	I-3 (T)	c	c	c	u	c	c	a	c	c	c
	III-1a	c	c	c	c	x	x	c	a	a	c
	III-1a (T)	c	c	c	c	x	x	c	a	a	c
	VIII-1	c	c	c	c	c	c	c	c	c	a

Table 84: Route matrix for Scenario 1.2. - Rad. SUD Gallarate

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	A/D (m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
2a-II	900	900	900	200	200	110	0	0.6	60	187	30	217	3.6
2a-II (T)	900	900	1800	200	750	110	0	0	0	149	30	179	3.0
2-VII	900	900	900	200	200	110	0	0.6	60	187	30	217	3.6
3-I (T)	1186	0	0	200	750	0	60	0	0	128	30	158	2.6
2a-IV	900	900	900	200	750	110	60	0.6	0	203	30	233	3.9
2a-V	900	900	900	200	750	110	60	0.6	0	203	30	233	3.9
I-3 (T)	1867	0	0	0	750	0	60	0	0	157	30	187	3.1
III-1a	900	0	0	0	200	110	0	0.3	0	102	30	132	2.2
III-1a (T)	900	0	0	0	750	110	0	0	0	54	30	84	1.4
VIII-1	900	0	0	0	200	110	0	0.3	0	102	30	132	2.2

Table 85: Parameters for the calculation of blocking time - Scenario 1.2. - Rad. SUD Gallarate

Occupation		A-SUD						P-SUD			
		2a-II	2a-II (T)	2-VII	3-I (T)	2a-IV	2a-V	I-3 (T)	III-1a	III-1a (T)	VIII-1
A-SUD	2a-II	217	217	0	0	217	217	0	0	0	0
	2a-II (T)	179	179	0	0	179	179	0	0	0	0
	2-VII	0	0	217	0	0	0	0	0	0	0
	3-I (T)	0	0	0	158	0	0	158	0	0	0
	2a-IV	233	233	0	0	233	233	0	233	233	0
	2a-V	233	233	0	0	233	233	0	233	233	0
P-SUD	I-3 (T)	0	0	0	187	0	0	187	0	0	0
	III-1a	0	0	0	0	132	132	0	132	132	0
	III-1a (T)	0	0	0	0	84	84	0	84	84	0
	VIII-1	0	0	0	0	0	0	0	0	0	132

Table 86: Occupation time matrix for Scenario 1.2. - Rad. SUD Gallarate

Delays		A-SUD						P-SUD			
		2a-II	2a-II (T)	2-VII	3-I (T)	2a-IV	2a-V	I-3 (T)	III-1a	III-1a (T)	VIII-1
A-SUD	2a-II	0	0	0	0	0	0	0	0	0	0
	2a-II (T)	0	0	0	0	0	0	0	0	0	0
	2-VII	0	0	0	0	0	0	0	0	0	0
	3-I (T)	0	0	0	0	0	0	1	0	0	0
	2a-IV	0	0	0	0	0	0	0	0	0	0
	2a-V	0	0	0	0	0	0	0	0	0	0
P-SUD	I-3 (T)	0	0	0	1	0	0	0	0	0	0
	III-1a	0	0	0	0	0	0	0	0	0	0
	III-1a (T)	0	0	0	0	0	0	0	0	0	0
	VIII-1	0	0	0	0	0	0	0	0	0	0

Table 87: Delay matrix for Scenario 1.2. - Rad. SUD Gallarate

Routes		A-NORD											P-NORD									
		5-I	5-III	5-III(T)	5-IV	5-V	6-VI	6-III	6-V	6-IV	6-I	8-VIII	I-4	I-6	II-4	II-4(T)	IV-4	IV-6	V-4	V-6	VI-6	VII-7
A-NORD	5-I	a	s	s	s	s	c	z	c	c	z	c	u	u	x	x	x	c	x	c	c	c
	5-III	s	a	a	s	s	c	z	c	c	x	c	c	x	c	c	x	c	x	c	c	c
	5-III(T)	s	a	a	s	s	c	z	c	c	x	c	c	x	c	c	x	c	x	c	c	c
	5-IV	s	s	s	a	s	c	z	c	z	x	c	c	x	c	c	x	c	u	c	c	c
	5-V	s	s	s	s	a	c	x	z	x	x	c	c	x	c	c	u	x	u	u	c	c
	6-VI	c	c	c	c	c	a	s	s	s	s	c	c	u	c	c	c	u	c	u	u	c
	6-III	z	z	z	z	x	s	a	s	s	s	c	c	u	c	c	x	u	u	u	u	c
	6-V	c	c	c	c	z	s	s	a	s	s	c	c	u	c	c	c	u	u	u	u	c
	6-IV	c	c	c	z	x	s	s	s	a	s	c	c	u	c	c	u	u	u	u	u	c
	6-I	z	x	x	x	x	s	s	s	s	a	c	u	u	x	x	x	u	x	x	u	c
	8-VIII	c	c	c	c	c	c	c	c	c	c	a	c	c	c	c	c	c	c	c	c	c
P-NORD	I-4	u	c	c	c	c	c	c	c	c	u	c	a	s	z	z	z	c	z	c	c	c
	I-6	u	x	x	x	x	u	u	u	u	u	c	s	a	x	x	x	z	x	z	u	c
	II-4	x	c	c	c	c	c	c	c	c	x	c	z	x	a	a	z	c	z	c	c	c
	II-4(T)	x	c	c	c	c	c	c	c	c	x	c	z	x	a	a	z	c	z	c	c	c
	IV-4	x	x	x	x	u	c	x	c	u	x	c	z	x	z	z	a	s	z	c	c	c
	IV-6	c	c	c	c	x	u	u	u	u	u	c	c	z	c	c	s	a	x	z	u	c
	V-4	x	x	x	u	u	c	u	u	u	x	c	z	x	z	z	z	x	a	s	c	c
	V-6	c	c	c	c	u	u	u	u	u	x	c	c	z	c	c	c	z	s	a	u	c
	VI-6	c	c	c	c	c	u	u	u	u	u	c	c	u	c	c	c	u	c	u	a	c
	VII-7	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	a

Table 88: Route matrix for Scenario 1.2. - Rad. NORD Gallarate

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	a/d (m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tot (min)
5-I	1350	1350	1350	200	750	110	60	0	0	300	30	330	5.5
5-III	1350	1350	0	200	200	110	0	0.6	60	187	30	217	3.6
5-III(T)	1350	1350	1350	200	750	110	0	0	0	164	30	194	3.2
5-IV	1350	1350	0	200	750	110	60	0.6	0	191	30	221	3.7
5-V	1350	1350	0	200	750	110	60	0.6	0	191	30	221	3.7
6-VI	1147	698	0	200	200	125	85	0.6	0	112	30	142	2.4
6-III	1147	698	0	200	200	125	60	0.6	60	202	30	232	3.9
6-V	1147	698	0	200	750	125	60	0.6	0	175	30	205	3.4
6-IV	1147	698	0	200	750	125	60	0.6	0	175	30	205	3.4
6-I	1147	698	0	200	750	125	60	0	0	161	30	191	3.2
8-VIII	1184	1200	0	200	200	90	0	0.6	60	192	30	222	3.7
I-4	1350	0	0	0	750	0	60	0	0	126	30	156	2.6
I-6	1147	0	0	0	750	125	60	0	0	90	30	120	2.0
II-4	1350	0	0	0	200	110	0	0.3	0	102	30	132	2.2
II-4(T)	1350	0	0	0	750	110	0	0	0	69	30	99	1.6
IV-4	1350	0	0	0	750	0	60	0	0	126	30	156	2.6
IV-6	1147	0	0	0	750	125	60	0	0	114	30	144	2.4
V-4	1350	0	0	0	750	0	60	0	0	126	30	156	2.6
V-6	1147	0	0	0	750	125	60	0	0	114	30	144	2.4
VI-6	1147	0	0	0	200	125	0	0.3	0	116	30	146	2.4
VII-7	3800	0	0	0	200	90	0	0.3	0	202	30	232	3.9

Table 89: Parameters for the calculation of blocking time - Scenario 1.2. - Rad. NORD Gallarate

Occupation		A-NORD											P-NORD									
		5-I	5-III	5-III(T)	5-IV	5-V	6-VI	6-III	6-V	6-IV	6-I	8-VIII	I-4	I-6	II-4	II-4(T)	IV-4	IV-6	V-4	V-6	VI-6	VII-7
A-NORD	5-I	330	330	330	330	330	0	330	0	0	330	0	330	330	330	330	330	0	330	0	0	0
	5-III	217	217	217	217	217	0	217	0	0	217	0	0	217	0	0	217	0	217	0	0	0
	5-III(T)	194	194	194	194	194	0	194	0	0	194	0	0	194	0	0	194	0	194	0	0	0
	5-IV	221	221	221	221	221	0	221	0	221	221	0	0	221	0	0	221	0	221	0	0	0
	5-V	221	221	221	221	221	0	221	221	221	221	0	0	221	0	0	221	221	221	221	0	0
	6-VI	0	0	0	0	0	142	142	142	142	142	0	0	142	0	0	0	142	0	142	142	0
	6-III	232	232	232	232	232	232	232	232	232	232	0	0	232	0	0	232	232	232	232	232	0
	6-V	0	0	0	0	205	205	205	205	205	205	0	0	205	0	0	0	205	205	205	205	0
	6-IV	0	0	0	205	205	205	205	205	205	205	0	0	205	0	0	205	205	205	205	205	0
	6-I	191	191	191	191	191	191	191	191	191	191	0	191	191	191	191	191	191	191	191	191	0
	8-VIII	0	0	0	0	0	0	0	0	0	0	222	0	0	0	0	0	0	0	0	0	0
P-NORD	I-4	156	0	0	0	0	0	0	0	0	156	0	156	156	156	156	156	0	156	0	0	0
	I-6	120	120	120	120	120	120	120	120	120	120	0	120	120	120	120	120	120	120	120	120	0
	II-4	132	0	0	0	0	0	0	0	0	132	0	132	132	132	132	132	0	132	0	0	0
	II-4(T)	99	0	0	0	0	0	0	0	0	99	0	99	99	99	99	99	0	99	0	0	0
	IV-4	156	156	156	156	156	0	156	0	156	156	0	156	156	156	156	156	156	156	0	0	0
	IV-6	0	0	0	0	144	144	144	144	144	144	0	0	144	0	0	144	144	144	144	144	0
	V-4	156	156	156	156	156	0	156	156	156	156	0	156	156	156	156	156	156	156	156	0	0
	V-6	0	0	0	0	144	144	144	144	144	144	0	0	144	0	0	0	144	144	144	144	0
	VI-6	0	0	0	0	0	146	146	146	146	146	0	0	146	0	0	0	146	0	146	146	0
	VII-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	232

Table 90: Occupation time matrix for Scenario 1.2. - Rad. NORD Gallarate

Delays		A-NORD											P-NORD									
		5-I	5-III	5-III(T)	5-IV	5-V	6-VI	6-III	6-V	6-IV	6-I	8-VIII	I-4	I-6	II-4	II-4(T)	IV-4	IV-6	V-4	V-6	VI-6	VII-7
A-NORD	5-I	0	0	0	0	0	0	8	0	0	2	0	2	1	61	11	10	0	0	0	0	0
	5-III	0	0	0	0	0	0	52	0	0	10	0	0	5	0	0	68	0	0	0	0	0
	5-III(T)	0	0	0	0	0	0	8	0	0	2	0	0	1	0	0	10	0	0	0	0	0
	5-IV	0	0	0	0	0	0	7	0	0	1	0	0	1	0	0	9	0	0	0	0	0
	5-V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6-VI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0
	6-III	4	60	11	7	0	0	0	0	0	0	0	0	1	0	0	10	0	0	7	7	0
	6-V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	0
	6-IV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6-I	1	8	2	1	0	0	0	0	0	0	0	0	0	8	2	1	0	0	1	1	0
	8-VIII	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P-NORD	I-4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	1	0	0	0	0	0
	I-6	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	II-4	10	0	0	0	0	0	0	0	0	4	0	4	2	0	0	25	0	0	0	0	0
	II-4(T)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
	IV-4	2	35	7	4	0	0	4	0	0	1	0	1	0	35	7	0	0	0	0	0	0
	IV-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	V-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	V-6	0	0	0	0	0	3	3	2	0	1	0	0	0	0	0	0	0	0	0	3	0
	VI-6	0	0	0	0	0	3	3	2	0	1	0	0	0	0	0	0	0	0	3	0	0
	VII-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 91: Delay matrix for Scenario 1.2. - Rad. NORD Gallarate

SCENARIO 0: TABLES (92÷94)

Routes		A-SUD					P-SUD				
		2-I tr.	2-II (T)	4-II	4-II (T)	4-IV	I tr.-2	I-2	I-3	I-3 (T)	III-3
A-SUD	2-I tr.	a	s	c	c	c	c	c	c	c	c
	2-II (T)	s	a	z	z	z	u	u	x	x	c
	4-II	c	z	a	a	s	c	c	c	c	x
	4-II (T)	c	z	a	a	s	c	c	c	c	x
	4-IV	c	z	s	s	a	c	c	c	c	z
P-SUD	I tr.-2	c	u	c	c	c	a	z	c	c	c
	I-2	c	u	c	c	c	z	a	s	s	z
	I-3	c	x	c	c	c	c	s	a	a	z
	I-3 (T)	c	x	c	c	c	c	s	a	a	z
	III-3	c	c	x	x	z	c	z	z	z	a

Table 92: Route matrix for Scenario 0 - Rad. SUD Seregno

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	a/d (m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot (s)	Tocc (min)
2-I tr.	608	705	3596	200	200	100	30	0.6	0	280	30	310	5.2
2-II (T)	712	705	3596	200	600	100	30	0.6	0	340	30	370	6.2
4-II	996	1570	700	200	200	130	0	0.6	60	192	30	222	3.7
4-II (T)	996	1570	1200	200	600	130	0	0	0	126	30	156	2.6
4-IV	996	1570	1200	200	200	130	30	0.6	60	293	30	323	5.4
I tr.-2	608	705	3596	0	200	100	30	0.3	0	241	30	271	4.5
I-2	712	705	3596	0	600	100	30	0	0	262	30	292	4.9
I-3	1637	0	0	0	200	130	0	0.3	0	120	30	150	2.5
I-3 (T)	1637	0	0	0	600	130	0	0	0	62	30	92	1.5
III-3	1637	0	0	0	200	0	30	0.3	0	234	30	264	4.4

Table 93: Parameters for the calculation of blocking time - Scenario 0 - Rad. SUD Seregno

Occupation		A-SUD					P-SUD				
		2-I tr.	2-II (T)	4-II	4-II (T)	4-IV	I tr.-2	I-2	I-3	I-3 (T)	III-3
A-SUD	2-I tr.	310	310	0	0	0	0	0	0	0	0
	2-II (T)	370	370	370	370	370	370	370	370	370	0
	4-II	0	222	222	222	222	0	0	0	0	222
	4-II (T)	0	156	156	156	156	0	0	0	0	156
	4-IV	0	323	323	323	323	0	0	0	0	323
P-SUD	I tr.-2	0	271	0	0	0	271	271	0	0	0
	I-2	0	292	0	0	0	292	292	292	292	292
	I-3	0	150	0	0	0	0	150	150	150	150
	I-3 (T)	0	92	0	0	0	0	92	92	92	92
	III-3	0	0	264	264	264	0	264	264	264	264

Table 94: Occupation time matrix for Scenario 1 - Rad. SUD Seregno

PRG SEREGNO: TABLES (95÷97)

Routes		A-SUD						P-SUD					
		2-I tr.	2-I	2-III (T)	4-III	4-III (T)	4-IV	I tr.-2	I-2	I-3	II-3	II-3 (T)	II-2 (T)
A-SUD	2-I tr.	a	s	s	c	c	c	u	u	c	c	c	u
	2-I	s	a	s	c	c	c	u	u	u	c	c	u
	2-III (T)	s	s	a	z	z	c	u	u	x	x	x	u
	4-III	c	c	z	a	a	s	c	c	c	c	c	c
	4-III (T)	c	c	z	a	a	s	c	c	c	c	c	c
	4-IV	c	c	c	s	s	a	c	c	c	c	c	c
P-SUD	I tr.-2	u	u	u	c	c	c	a	z	c	c	c	z
	I-2	u	u	u	c	c	c	z	a	s	c	c	z
	I-3	c	u	x	c	c	c	c	s	a	z	z	x
	II-3	c	c	c	c	c	c	c	c	z	a	a	s
	II-3 (T)	c	c	c	c	c	c	c	c	z	a	a	s
	II-2 (T)	u	u	u	c	c	c	z	z	x	s	s	a

Table 95: Route matrix PRG Seregno - Rad. SUD Seregno

Routes	D1 (m)	D2 (m)	D3 (m)	Dv (m)	Ltr (m)	V1 (km/h)	V2 (km/h)	a/d (m/s2)	Ts (s)	Tocc (s)	Tt (s)	Tot(s)	Tot (min)
2-I tr.	608	705	1000	200	200	100	30	0.6	0	186	30	216	3.6
2-I	712	705	1000	200	600	100	30	0.6	0	247	30	277	4.6
2-III (T)	712	705	1000	200	200	100	30	0.6	60	259	30	289	4.8
4-III	996	1570	700	200	200	130	0	0.6	60	192	30	222	3.7
4-III (T)	996	1570	1200	200	600	130	0	0	0	126	30	156	2.6
4-IV	996	1570	700	200	200	130	30	0.6	60	322	30	352	5.9
I tr.-2	485	705	0	0	200	100	30	0.3	0	104	30	134	2.2
I-2	580	705	0	0	600	100	30	0	0	117	30	147	2.4
I-3	1637	0	0	0	200	30	0	0.3	0	220	30	250	4.2
II-3	1637	0	0	0	200	130	0	0.3	0	120	30	150	2.5
II-3 (T)	1637	0	0	0	600	130	0	0	0	62	30	92	1.5
II-2 (T)	580	705	0	0	200	100	30	0.3	0	102	30	132	2.2

Table 96: Parameters for the calculation of blocking time – PRG Seregno - Rad. SUD Seregno

Delays		A-SUD						P-SUD					
		2-I tr.	2-I	2-III (T)	4-III	4-III (T)	4-IV	I tr.-2	I-2	I-3	II-3	II-3 (T)	II-2 (T)
A-SUD	2-I tr.	0	0	0	0	0	0	6	0	0	0	0	0
	2-I	0	0	0	0	0	0	0	0	0	0	0	0
	2-III (T)	0	0	0	0	0	0	0	0	0	0	0	0
	4-III	0	0	0	0	0	0	0	0	0	0	0	0
	4-III (T)	0	0	0	0	0	0	0	0	0	0	0	0
	4-IV	0	0	0	0	0	0	0	0	0	0	0	0
P-SUD	I tr.-2	3	0	0	0	0	0	0	0	0	0	0	0
	I-2	0	0	0	0	0	0	0	0	0	0	0	0
	I-3	0	0	0	0	0	0	0	0	0	52	78	0
	II-3	0	0	0	0	0	0	0	0	19	0	0	0
	II-3 (T)	0	0	0	0	0	0	0	0	11	0	0	0
	II-2 (T)	0	0	0	0	0	0	0	0	0	0	0	0

Table 97: Occupation time matrix for PRG Seregno - Rad. SUD Seregno