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Planning of an integrated transport network:

the integration in the railway node of Bologna

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1. Introduction

Given the increasing demand for mobility, planning an efficient transport network becomes more and more important. This work has the aim to define a method to measure the existing integration level in a specific station, throughout the explanation of appropriate key performance indicators. The name used to describe this method is IntegroSKOPIO©. It is useful to measure the integration level both in case of train-train connection and in case of a train-bus one and, besides, it can be used both when the transport supply is traditional and when it is structured (in case of periodic timetables). This method is applied to check and evaluate the integration level according the actual railway and bus supply: initially, considering a traditional structure for the railway services, the integration is measured between the high-speed trains running along the Milan-Rome axis and the regional traffic products in the station of Bologna. Then, referring to the structured services, the integration level is evaluated, both considering all possible exchanges among the regional services and between them and the high-speed ones, in six high-speed station on the axis from Turin and Rome, within the project called FrecciaNet©. The study considers only the passenger services managed by Trenitalia, even some pictures depict also those managed by Nuovo Trasporto Viaggiatori, since Trenitalia is the unique railway undertaking operating both in the national and regional scenario, selling many travel solutions requiring an interchange. Therefore, for the interchange node of Bologna, the integration level is measured both considering a traditional typology of the system and considering a structured one. So, the analysis of the railway node of Bologna, fundamental due to its strategic position in the Italian railway network, has served as a starting point for the framing of the problem and the explanation of the IntegroSKOPIO© method. Furthermore, the train-bus integration level is evaluated on four stations outside the high-speed axis and belonging to the Adriatic railway line. A crucial issue, both for the assessment of the existing level of integration and for the design of an integrated system, is the definition of the minimum interchange time to be considered for the connections, depending on the distances to be covered in the node (transfer time), the delay distributions of the arriving trains and the frequency of the leaving ones according to reliability levels. This theme has been treated in a specific concluding section. Finally, the last topics are related one to the potential demand analysis in the Emilia-Romagna region to evaluate which could be maximum improvement of the railway modal share both related to direct links and integrated ones; the second is related to the mathematical formulation of the optimization problem, which aim is to improve the performances of the railway system, modifying the “clock” of the station.

All the data collected and used in this work are reserved as well as all the results obtained and discussed in this paper want only to describe the actual integration level, without criticize the work of any company involved in the management of the railway infrastructures and of the railway passenger services. It, stressing these important issues related to the integration topic, has as unique scope to define a method to evaluate the integration level, to define the minimum connection time and to propose a mathematical formulation for the optimization problem.

The KPI IntegroSKOPIO© and the project FrecciaNet© have the copyright of the “Sales and Network Management Department” (“Direzione Commerciale ed Eserczio Rete”), exclusively used for its missions.

2. Abstract

This paper presents the overall methodology of measuring the integration level in different interchange nodes throughout the definition of a key performance indicators both to evaluate the performances of the integration in an actual and in a hypothetical scenario. Moreover, it provides a possible mathematical formulation of the optimization problem to solve the problem related to the connections inside an interchange node. Finally, the work presents a last methodology on evaluating the minimum connection time both to ensure the greatest reliability of the exchange and the minimum waiting time. Nowadays, the literature does not deal with about the problem related to this last topic in an accurate way, in despite of its centrality to design in the best way an integrated transport network. There are few articles dealing with most important aspects related to the design of ideal "clocks" for different interchange nodes (Ciuffini F. 2003) and related to the integration topic and its planning (Ciuffini F. 2002; Strube Martins S., Finger M., Haller A., Trinkner U.). Starting from this knowledge, the work will explain the method to evaluate the integration level. The topic related to the integration is also a key point of the 2016 Industrial Plan of "Ferrovie dello Stato", which defines the target of the company for the next 10 years. According to it, the integration issue covers a very important role in order to create new mobility integrated solutions through:

- an improving of the performances of the road and railway local public transport;
- entry in new market segments;
- train-bus integration with the granted railways.

Some papers deal with the problems of defining suitable lines in a public transportation system (Shobel A. 2011), focusing on optimization process which are cost or passenger oriented. Other works cope with the integration of line planning with timetabling, network design and vehicle scheduling (Barber 2008, Classens 1998, Israeli and Ceder 1995, Quack 2003).

3. The role of the integration

The liberalization process determined the separation between the manager of the railway infrastructure and the railway undertakings. In this new scenario, no longer integrated from the point of view of the organizational arrangements, the integration of different transport services, between the railway and the road transport mode or inside the same, will have to continue to exist or, better, will have to continue to grow up and to be improved. Therefore, the new challenge for the next future, in this context of liberalization and separation, is to try to create an integrated network. Infect, the integration among different transport services or transport modes is the fundamental premise in order to improve the attractiveness of the national railway service. This is the main reason for which the topic related to the integration is one of the central points of the local transport reform. Moreover, the realization of an integrated transport network will be also very important for the manager of the railway infrastructure as a fundamental aspect related to the development of the national railway system. However, its realization is much less simple that it may seem, because, generally, there are several actors involved in the planning of the integration. Planning an integrated service means defining an integrated regular interval timetables (IRIT) that can be better defined in an optimization process if the scheduling structure of the different services is cadenced. They offer to the passengers a regular interval timetable for services on the railway network, increasing the quality, efficiency and attractiveness of the railway passenger services in comparison to other transport modes. Then, an integrated network allows, by equal service, to multiply the movement possibilities of the users and, so, the number of useful relations. Thus, integration involves passenger services, which have a different function (e.g. the integration between a long-haul train and a regional one, which have the role of "feeder" of a more restricted area or between two long haul trains that have two different routes but a meeting point along them): thanks to an integrated network, they can complement each other. However, as it has already been said, its realization is not so easy: it is the final product of several design choices, even complex, in which the variables, the boundary constraints and the main target of the planning to be considered could be numerous. The final choice is inside different solutions that could create some advantages to particular relations and so to certain demand segments, or in other solutions that can bring advantages to other relations. For this reason, planning an integrated network is nothing else that the resolution of an optimization problem, which target is the optimum of the whole system. The successful introduction of IRIT requires a long-run implementation schedule, which identifies the necessary investment in the railway infrastructure and points out the financial resources available to make those investments. Further, IRIT requires a high level of punctuality of railway passenger services, the coordination between railway undertakings when designing the timetable and a priority rule for passenger railway services within IRIT, when there are capacity restrictions on the railway network.

Simply, it is possible to define two different kind of integration:

- a spatial integration (where a train does not arrive, there is the other);
- a temporal integration (when there is not one there is the other).

Of course, we are talking about passenger services that have different functions with a different level of specialization: single services (e.g. single trains or single buses) or systems of trains or buses. In this second case, the services have integrated regular interval timetables, in which each train or bus is equal to the others in terms of route, number of stops, running time where the departure and the arrival times are regular during a day.

1.1 The spatial integration

In this first kind of integration, there are three sub-groups:

- extreme node integration: between long-haul trains, with few intermediate stops, linking the main cities and regional trains running along secondary railway lines, or between regional trains and buses joining the little municipalities located in the surrounding area (see figure 1), or, finally, between trains and urban buses to reach the different zone of the city. In each case, various passenger services, having different transport features, are integrated each other, where, thanks to appropriate connections, the local services play the role of "feeder" of the "carrier" one which main result is the enlargement of the basin served. This, because, the two services work together in order to complete each other, otherwise, each service, alone, should serve a limited number of relations. The main constraint is to respect the connections only in the interchange node, but not in the extreme ones.

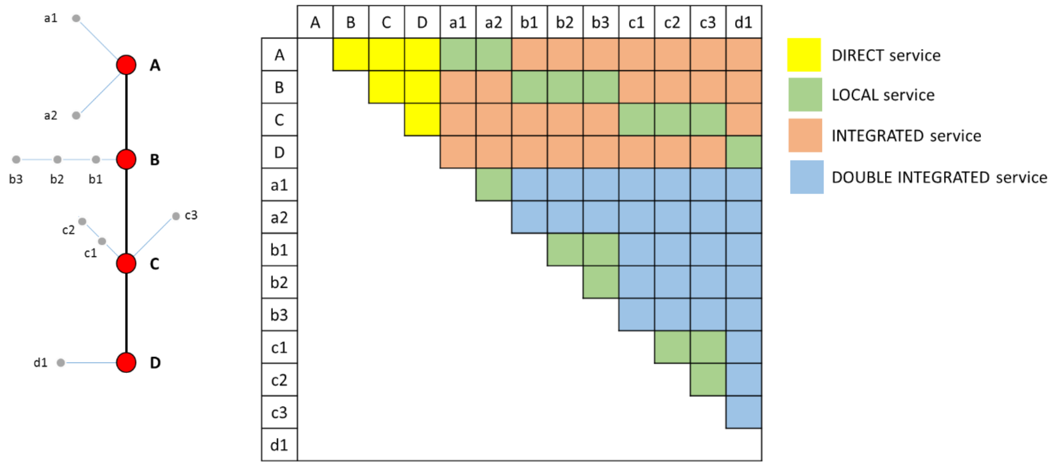


Figure 1 – Extreme node integration

- network integration: it is very similar to the previous one, but in this second case, the design of the integration is very complex because the connections are planned in each node along the network and, generally, its realization in one node could mean, for example, losing it in others or with some services. In the example in figure 2, it could happen that the secondary service Ferrara-Poggio Rusco was not integrated with the REG Bologna-Ferrara and the REG Ferrara-Ravenna and with the REG Bologna-Poggio Rusco in both the terminals. Moreover, these two services should respect the connection with all other traffic products leaving and arriving in Bologna. In this way, the planning of the integration becomes the resolution of an optimization problem where the result must be the choice among several solutions, with some advantages or disadvantages for certain relations, by respecting the boundary constraints. This case is widespread, especially in those basins of the Italian railway infrastructure where the interconnection degree between lines is very high. To note that the first case of the spatial integration can be assumed as a particular case of the second one because it is less constrained and, so, easier. So as, this second typology could be simplified in an extreme node integration problem in which some nodes have already been constrained in advance.

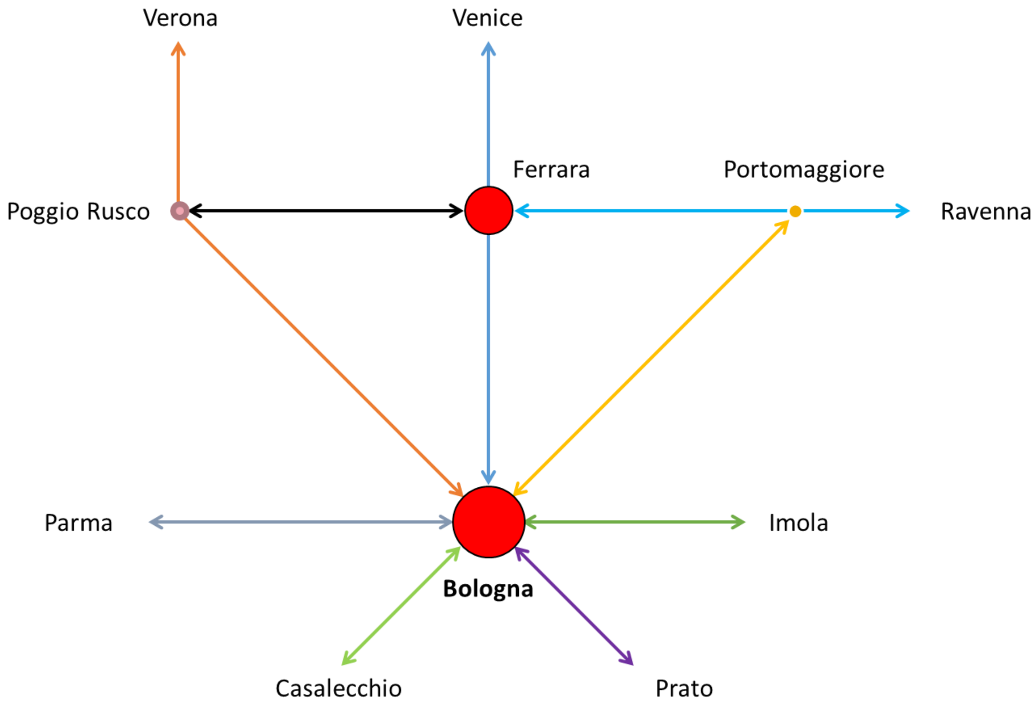


Figure 2 – Network integration

- route integration: in this case, the integration involves services that run along the same route, unlike the first two. They can be belonging to different transport mode or to the same, but having different functions inside it (e.g. a long-haul train and a regional one or between a train and a bus which route is parallel to the railway, where the road transport mode is able to gather and distribute more capillary passengers on the territory). The main advantage of this kind of integration is not to increase the number of relations, but to allow the specialization of the different products. For example, the railway service could emphasize its role to be a fast link between bigger cities, more accentuated by the increasing of the distance, if it is helped by a service (bus) of capillary gathering and distribution of users along the same route of the train (see figure 3). So, the regional train can increase its performances reducing the running time between the main cities avoiding stopping to each station along the route, while the bus ensures the link both among the municipalities and between these and the main station.

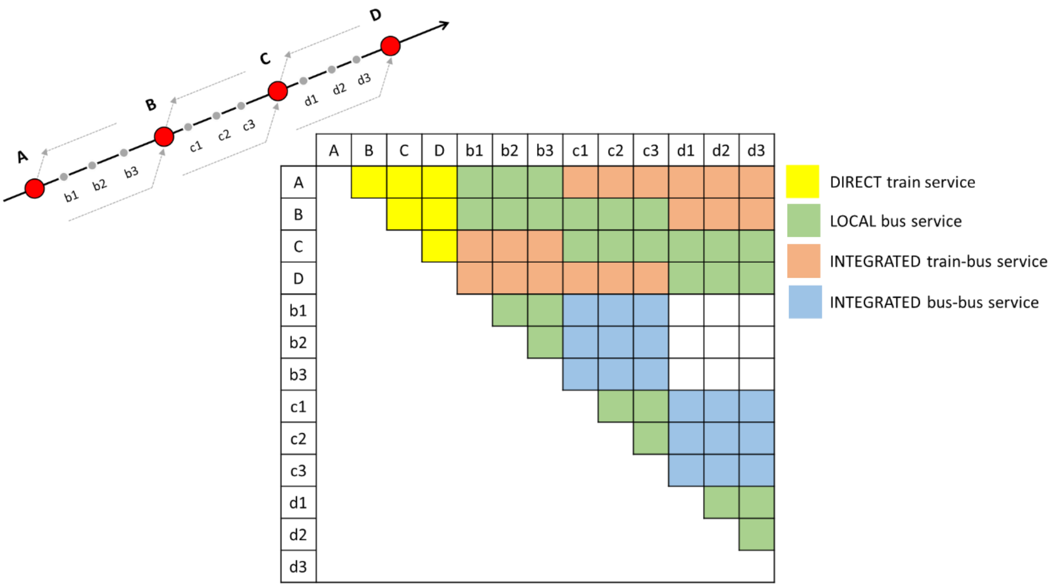


Figure 3 – Route integration

In conclusion, the spatial integration provides the interchange between services that have different functions, but one is essential for the other to complete the network, which are used "in series". This kind of integration is an "AND" case, because the travellers uses both of them. The realization of the integration means planning the connections, and so an integrated regular interval timetables. Of course, it is not always possible to design all of them and the problem becomes more and more difficult if the number of the constraints or the number of the interconnections increase. The problem is more and more relevant when the frequencies are low (one train every 30, 60, 120, minutes), because the absence of a great connection causes waiting time for the passengers longer and longer.

1.2 The temporal integration

This second kind of integration exploits the eventual overlays of two or more services on the same route, unlike the first where the possible interchanges between services are stressed. It is possible to define two sub-groups:

- frequency integration: you have it when different services are overlaid. The overlap can involve services, which have different itineraries but a little segment in common, or the same route but with different functions (e.g. different stops). In both cases, this integration can be used to increase the frequency on the overlapped routes: of course, this is possible only if the departure and arrival time are properly out of phase. This is the objective to be reached in case of a frequency integration planning: obviously, the boundary constraints must be taken into account. In the example in figure 4 (case a), there are three services equally spaced (high-speed trains with different destinations), that allows to have a frequency of three links per hour between Florence and Bologna. While, in the case b, the two services between Bologna and Castel SPT are equally spaced but do not have the same function (the second stops at all stations unlike the first one), ensuring, however, a frequency of two train every 30 minutes.

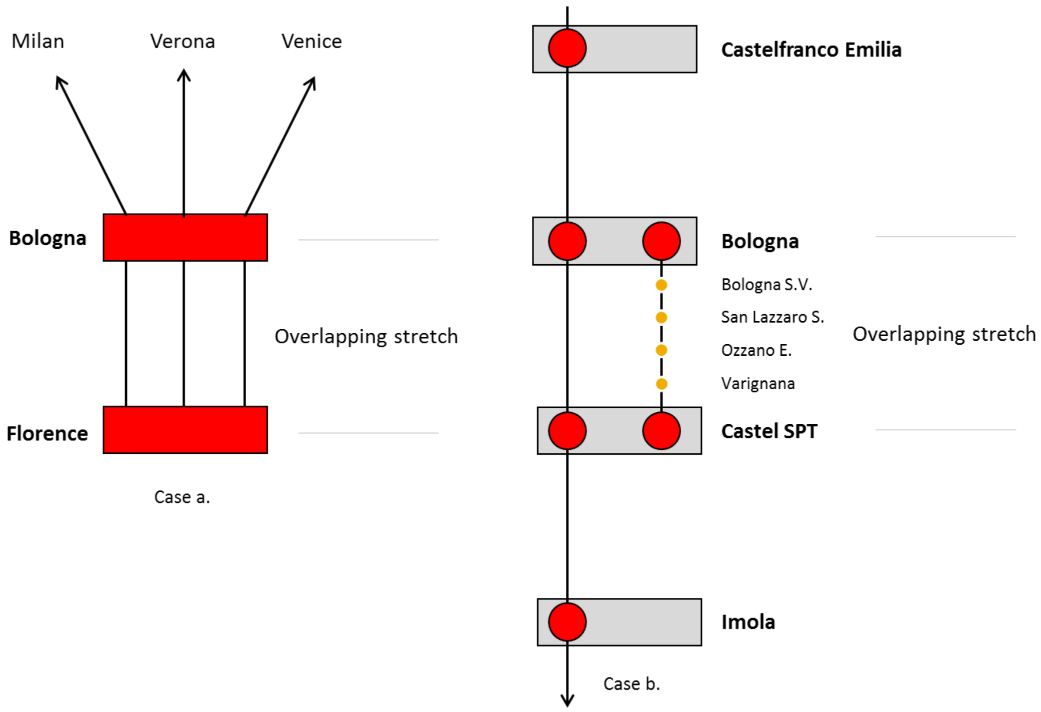


Figure 4 – Frequency integration

To note that, the frequency integration can be an alternative of the network one: in the figure 5 there are three possible cases of integration between a long-haul service and a regional one with all the stops, sharing a part of the network. In the example, only the train paths are reported; in the first case it is realized a frequency integration for the relation from A to B, along which it is possible to obtain a double of the frequency, even if the regional train is slower. In the second and third case, only the route integration is used, allowing to all intermediate stops (x_1, x_2, x_3 and x_4) to have a direct link with A and B, not ensuring, however, the correct out of phase between the departure and arrival time of the two railway services.

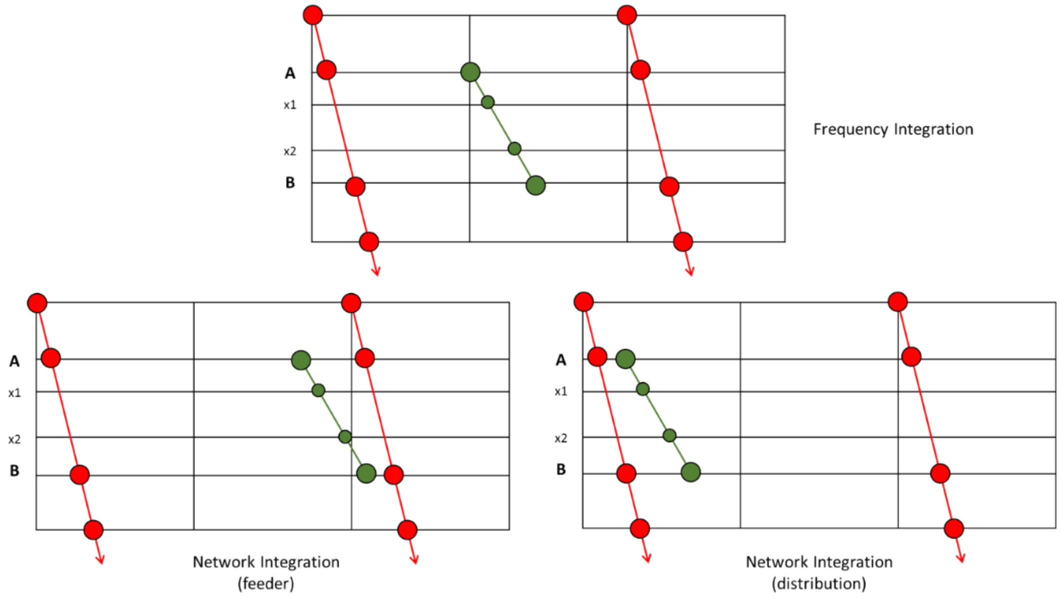


Figure 5 – Frequency or network integration?

- integration with time extension: in this case different services with the same route alternate depending on the hours of the day. For example, the train during the peak hours of the morning and of the evening when the demand is very high, the bus during the others, guaranteeing, at least one service. In this way, the time extension of the service for the passengers increases. Nevertheless, this solution, generally, doesn't involve saving of money, because, substituting the railway mode with the road one leads new costs for the buses, while the train staff and the infrastructural railway costs remain equal to the previous scenario in which there was only the railway service.

To conclude, the two analysed cases of temporal integration, can be also defined as an integration "in parallel"; infect this integration is an "OR" case, because the service are used alternatively.

1.3 Standardization, specialization and integration

The planning of the integration depends very much on the typology of the supply: it can be structured or not. When the supply is not structured, it means that there are different punctual situations: for example, the railway service does not have an integrated regular interval timetables and/or its traffic product is not standardised (the number and the stops are not always the same and so the running times are always different from each other). In this case, there are many micro problems to be solved, in which the final solution of the integration planning is not the optimum of the system, because it is quite impossible to proceed with optimization criteria. The quality of the transport plan is more difficult to measure. Instead, when the supply is structured, so as the timetables, all the traffic products are standardised: they are the result of precise transport choices, related to the structure of the demand. Each service (train or bus) has its own specialization: it has an own route, with defined stops, running time and frequency. In this case, the planning of the integration occurs in an optimization criterion, in which the solution is also the optimum of the whole system, where, of course, the infrastructural, rolling stock and financial constraints must to be considered. The quality of the transport plan is measurable. We have introduced the concept of traffic product: but what is its meaning? Focusing on the railway services, in which the level of differentiations is very high, a traffic product points out a particular service, which has a specific function and specialization (a defined route, frequency, number and classification of the stops) with an integrated regular interval timetables. The main difference between one product and another is its function that is the hierarchy of the stops. It is possible to cluster the traffic product into four levels, according to their function and specialization (see figure 6):

- first level (a): it is represented by the high-speed trains (ES) stopping only in the big cities (e.g. the ES Milan-Rome-Naples that stop only at Bologna and Florence), ensuring a fast link among them;
- second level (b): it is made up by Intercity (IC) trains which, often, guarantee the same link of an ES train, but stopping, also, in those stations which are of lower level (e.g. the IC Milan-Rome-Naples stops also at Piacenza, Parma, Reggio Emilia, Modena, Prato, Arezzo, Chiusi Chianciano Terme, Orte, Latina, Formia and Aversa), providing a direct link among the second level poles and between them and the main ones;
- third level (c): there are the interregional trains (RV), that link two main cities very close each other, stopping in many stations (e.g. the RV Milano-Bologna, Piacenza-Ancona, Florence-Rome, Rome-Naples and so on). Their role is to offer a direct link among third level poles and between them and those of the second and first;
- fourth level (d): it is composed by regional trains (REG) that or cover little distances stopping at all stations along the routes or greater distances but stopping only at some stations. In the first case, the link is local and capillary, ensuring to the biggest

cities to reach quickly the municipalities located in the surrounding area; in the second case, in reality, there is not a specific function because the service is a mix between that made by a RV and a REG train and, consequently, its quality level is low.

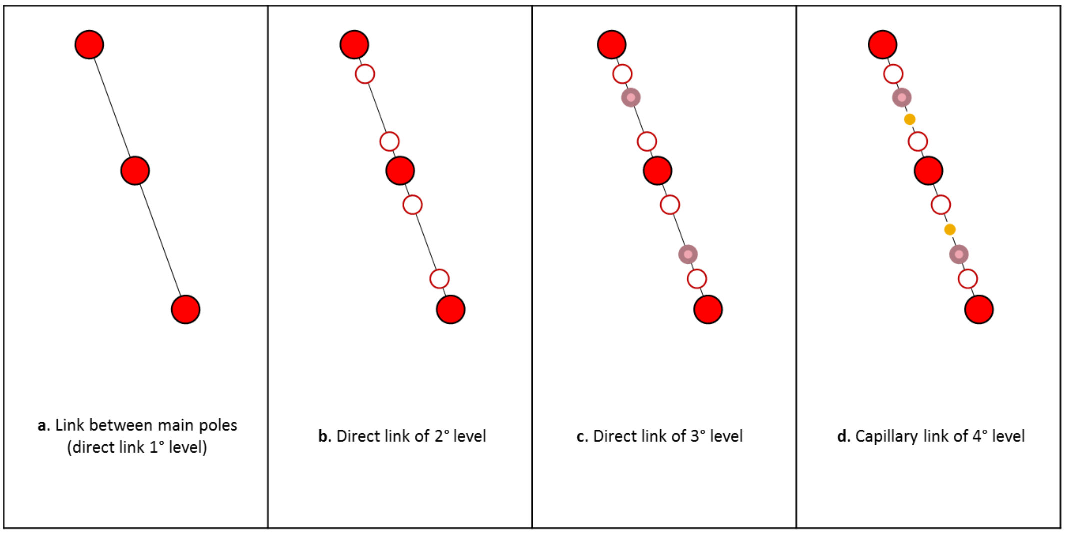


Figure 6 - Traffic products examples

Each single traffic product has its own specialization and function according to the hierarchy of the stations and of the cities to be linked. However, it provides only direct connections and, so, the number of relations is no so high. For this reason, the integration planning among different traffic products becomes fundamental to increase the number of possible relations, and so the attractiveness of the national railway system. In figure 7, there is the O-D matrix, which schematizes all possible relations along the same railway line: those on the main diagonal are served by direct connections (ES, IC, RV, REG), because it includes cities and poles belonging to the same hierarchical level (e.g. from Milan to Rome for the first level, from Modena to Prato for the second; from Castelfranco Emilia to Imola for the third one and so on). Moreover, the IC trains are able to serve directly the relation 1-2, so as for the RV trains for the link 1-3 and 2-3 and for the REG trains in 1-4, 2-4 and 3-4 connections.

	1	2	3	4
1	ES	IC ES+IC ES+RV	RV ES+RV IC+REG	REG ES+REG IC+REG
2		IC	RV IC+RV IC+REG	REG IC+REG
3			RV	REG RV+REG
4				REG

Figure 7 - Integration between traffic products according to the hierarchy of the stops

Nevertheless, if it is considered two different railway lines, the route integration becomes essential. For example, to move from Rome (1° level) to Poggio Rusco (3° level and belonging to the Bologna-Verona railway line) the interchange at Bologna is needed between an ES train and a RV or REG train (the time for connection is 17 minutes[1] in the best solution). In some cases, for the relation 2-1, the combination RV and ES could be more convenient than the direct link with IC: for example, to move from Prato (2° level) to Rome, the first takes 2h:10min with the interchange at Florence SMN and a connection time of 16 minutes[1]; while the second takes one hour more. At the end, it is possible to conclude that:

- in the second example (Prato-Rome) there are both the route integration (RV+ES) and the frequency integration (IC solution with the RV+ES one);
- the best function of the IC trains is to connect cities belonging to the second level (2-2), otherwise, in case of a 2-1 link, the fastest solution is the RV+ES;
- without the IC trains the relation 2-2 can be served only through a double interchange (RV+ES+RV), making this kind of connection not acceptable due to the importance of the cities involved in the relation.

[1] The data are referred to the winter scheduling 2017

Therefore, both in the network and in route integration planning, the designing of an integrated regular interval timetables is crucial: infect planning an integrated supply means to plan an integrated regular interval timetables. Hence, at the beginning it is necessary to define which the traffic products with their functions and specializations are and then how it was possible to integrate them together. Generally, this process can be iterative, because, among the different solutions, the possibilities or the opportunities to change a traffic product to create a better integration can arise: e.g. adding or removing a stop, extending the route… Finally, planning an integrated regular interval timetable means to choose the best solution among a set of possible ones, which is both the system optimum and respectful of all the constraints introduced in the problem. Obviously, when the system is very complex, as it happens in the biggest interchange nodes (Milan, Turin, Bologna, Rome, Naples and so on) belonging to a very large railway infrastructure, as the Italian one, it is no possible to satisfy all the relations: for this reason, the planner has to know in advance which are the most important connections that must to be respected.

2. The importance of the transport mode's schedule

The role of the integration is fundamental to increase the quality, the efficiency and the attractiveness of the national railway network; nevertheless, without a correct integrated regular interval timetables, it is impossible to reach the main goal of this work, which is the planning of an integrated transport network. Nowadays, due to the presence of several actors involved in this process, its realization is not easy: on one hand, there is the manager of the Italian railway network (RFI), which main target is both the optimization of the network capacity, allocating it to the different railway undertakings and the arrangement of the train paths. On the other hand, there are the railway undertakings that want to offer the best service to the users and to the passengers and the regional administrations responsible of the programming and of the assignment, through a call for tenders, of the local railway transport. Moreover, there are all the constraints to consider and coming from commercial, infrastructural and financial aspects that contribute to make this problem more and more complex. Therefore, the success of an excellent train service consists in planning a good schedule, which represents the main aspect of the marketing, because an integrated regular interval timetables summarizes the performances of a train service, defining its attractiveness that, together of its price, can influence the modal choice of the users. The transport mode's schedule is defined as the catalogue of the supply of a passenger company: moreover, summarizing all the schedules it is possible to obtain the total transport plan, which represent how passengers can move in a specified area. The timetable of a train or of a bus defines the terminals, the route and the departure and arriving time at all intermediate stops. Hence, it defines the functions (speed, number of stops), specializations (long haul or regional train) and the standardisation (frequency) of a traffic product. The scheduling could be:

- not structured and so traditional, where each train or bus is different to the others and the route, the terminals and the timetable are defined train by train (or bus by bus): the analysis level is punctual.
- structured and so innovative, where it is possible to individuate the traffic products and the set of all services which have all the same transport characteristics: the same terminals, the same route, the same number of stops and the same running time with an integrated regular interval timetables in each station (or stop) where the departure and the arrival occur always at the same minute. The schedule is cadenced in a global system.

A transport mode's schedule defines, also, the performances of a passenger company in terms of spatial accessibility, temporal accessibility and speed.

2.1 Spatial accessibility

The timetable defines the specializations of the service (in case of a train service there are the ES, IC, RV and REG), its terminals and stops and, so, the number of relation. This number is equal to N^2-N where N defines the number of the intermediate stops located along the route: greater is this number, the spatial accessibility is better, allowing reducing the time needed to reach each station. Nevertheless, it has no many senses to have a big spatial accessibility if the different traffic products are not integrated each other: so, one of the main role of an integrated regular interval timetable is to improve the accessibility, with equal services.

2.2 Temporal accessibility

The transport mode's scheduling defines the quantity of the services: if they are regular and repetitive, the service is structured and cadenced. In this case, it is possible to introduce the frequency of the service: one train or bus every 120, 60, 30, 15 minutes. However, the concept of frequency is relative to the specialization of the service (urban or extra urban context): in case of an urban service with short distances a train or a bus every 30 minutes is no so good (low frequency); while, in an extra urban context, where the distances are quite long, a frequency of 30 minutes becomes satisfactory.

2.3 Speed

The transport mode’s scheduling defines, also, the running time between two stations and, so, the speed of the service. It depends on the characteristics of the infrastructure, on the rolling stock and on the number of intermediate stops. If this number increases, the speed (or better the commercial speed) of the service decreases. Moreover, the commercial speed is influenced, not only by the number of the stops, but also by the time spent in the stations to allow the alighting and the boarding of the passenger and by the time needed to perform the connections with other services and, so, by the quality of the integration. Therefore, the integration is an element to improve the speed of the whole system.

These performances are directly connected to the time factor, which is the overall time spent by the passenger to reach the destination. It is made up by:

- travel time from the origin to the destination, connected to the infrastructure, rolling stock and to the commercial speed of the service and so to the number of stops and to the dwelling time;
- waiting time both in the initial station and in the interchange node where the connection occurs, related to the quality of the planned integration;
- lost time due to a non-perfect planning of the integration between two services;
- the transfer time needed to reach the second, third service, which depends on the characteristics of the interchange station (how much it is big, the number of lifts or escalators…);
- eventual delays to be added to the final time, related to the level of punctuality of the arriving train or bus, especially in case of an interchange;
- safety margin to be added to the waiting time, to guarantee the reliability of the connection.

Obviously, the weight of each element changes according to the length of the movement: if the distance to be covered is quite short, the waiting and the lost time are very crucial (their minimization makes the trips more comfortable); vice versa, the passengers are much interested to the travel time. Finally, the transport mode's schedule, the integration among different services and the punctuality become the main factors able to improve the performances and the attractiveness of a passenger company, in case of a railway or a road transport mode.

3. Supply systems with periodical timetables

The scheduled times are characterised by two fundamental elements: the standardization and the repetitiveness of the service. The traffic products are standard when the running time, the hierarchy and the number of the stop are always the same, while the timetables are repetitive when the product leaves and arrives always at the same minute, with a repetition over the time equal to the frequency. There are two main advantages in case of a supply systems at scheduled times: the first is related to commercial aspects, because the timetable is easy to be remembered by the users and, also, the integrated structure of the whole system is very clear, making it more attractable. In the second case, from a technical point of view, the transport plan is the result of an optimization problem, where the variables are not the single train or the single bus, but the traffic products that repeat over time on regular basis. However, in order to reach the optimum of the system, it is necessary to know in advance, not only which are the variables, but also, the relation between them, the parameters, the constraints and the domain where the solution is in.

3.1 Theoretical elements

Repetitive modules over time with regular time intervals characterize an integrated regular interval timetables. The hourly paths in both directions, which represent the space-time diagram of a transport system, define each module. The figure 8, shows the hourly path of a railway transport service in both directions, where there is only one traffic product between the two terminals A and B. The single module describes the speed and the dwelling time at each station (even if in this graph it is not represented) and, so, the running time along each segment. All the modules define the grid, which represents the total supply of the railway service and, overall, the time period "I" between two departures (the inverse of the frequency "f"). Hence, the main variables that define a structured system are:

- the running time "T_P" between A and B, that influences the shape of the paths;
- the time period "I" which individuates the frequency of the service over time;
- the mutual position of the hourly paths in both direction through the value of "ΔT_A" which is the distance in time between one arrive and on departure of the same traffic product in a specific node.

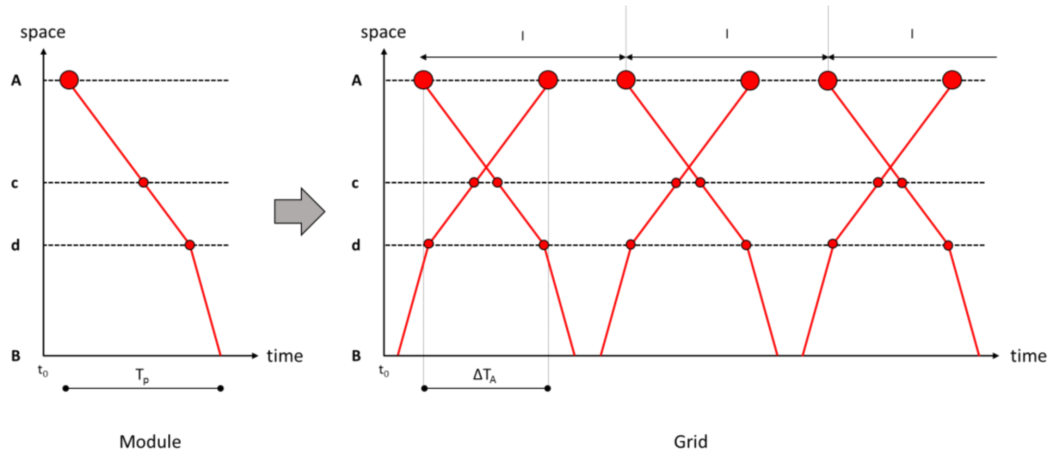


Figure 8 - Module and grid

3.2 The concept of "clock" for integrated regular interval timetables

The repetitiveness of the modules over time allows building the "clock" of different services for each station, where the arriving and departure minutes are described. Thus, this clock represents the whole railway or bus supply of a station (see figure 9). Of course, due to the nature of the clock, only services with a time period "I" equal or lower than the hour are realizable, otherwise, it is necessary to create particular "clocks" where there are 120 minutes (in case of a train or bus every two hours) instead the normal 60. It is fundamental, especially, to plan an integrated transport service in which the network is very large and complex and the number of different traffic products is considerable, as it happens in the biggest stations such as Milano C.le, Roma Termini, Bologna C.le, Firenze SMN and so on.

In this way, the definition of a structured system allows to determine which the time period and the running time are and what the structure of the whole system is. However, before studying how the system changes according to these parameters, it is right to consider that the system has been defined in the time-space diagram from a relative point of view: this means that the system can shift along the temporal abscissa without any changes to its structure. This property is quite important, since it is possible move the system according to the arrival and departure minutes of the other services to obtain a better planning integration, without varying the time period and the running time. Therefore, it is possible to define two different kind of variations for the system:

- the geometric variations, in which the parameters that influence the shape of the grid (time period and running time) and the structure of the system change;
- the position variation, where the grid does not change, but it shifts along the temporal abscissa.

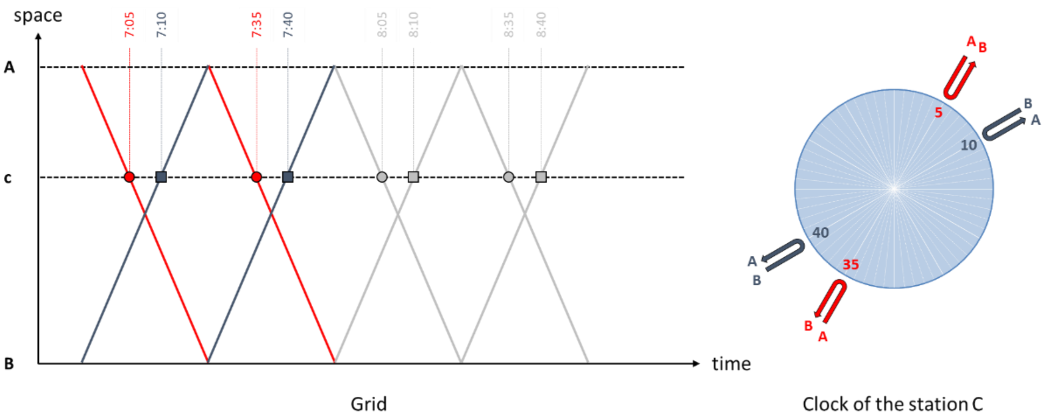


Figure 9 - The clock concept

In both cases, the clocks of all stations change:

- in case of a geometric variation, the structure of the system is not the same and, so, it is possible to have more or less trains or buses arriving and leaving from one station;
- in case of a position variation, the structure is the same, but all the arrival and departure minutes rotate along the clock.

Therefore, the most important question that arises after these assessments is how much the possible configurations of the system are and so how much large the domain of the possible solution of the problem is? This is very important, because varying the time period (adding or removing trains or buses), the running time (adding or removing stations) and the structure of the system by changing the reciprocal position of the hourly paths of the service in both directions and/or by shifting them along the temporal abscissa, the structure of the cadenced system changes. Consequently, it is fundamental to know in advance the number of possible solutions from an optimization point of view, because each solution can bring advantages or disadvantages to different traffic products involved in the problem. Considering the example in figure 10 in which the time period "I" is 30 minutes for both services (even and uneven direction) and the hourly fraction "F" which represents the arrival or the departure minute of one train or bus (F=1 means that the service can arrive or leave at every minutes), the maximum number of solutions is 810000. Of course, not all solutions are possible due to the constraints to be added to the problem: for example, the departure time is bonded to the maximum dwelling time and, so it cannot assume all the values and, hence, the domain shrinks. Generally, the total number of possible solutions, without considering the constraints, is $(I/F)^2$. But, the constraints are many and all of them can reduce the domain of possible solutions: in the next two paragraphs the symmetry and the rolling stock ones are described.

3.3 The symmetry constraint

In case of a position variation, the system can shift along the temporal abscissa, without changing its geometric parameters: among all possible solutions, two of them are defined symmetric because they have the symmetry axis coinciding with the axis of the clock, which, conventionally, crosses the minutes 00-30.

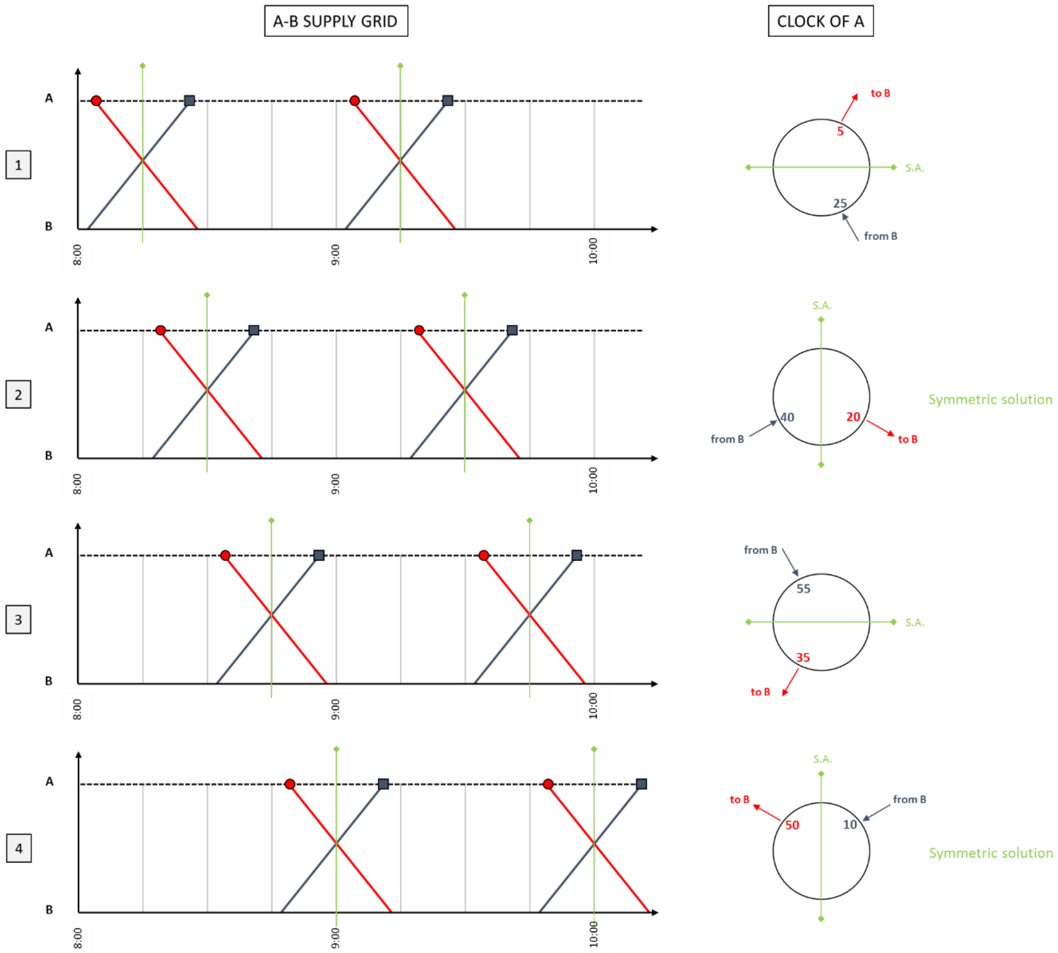
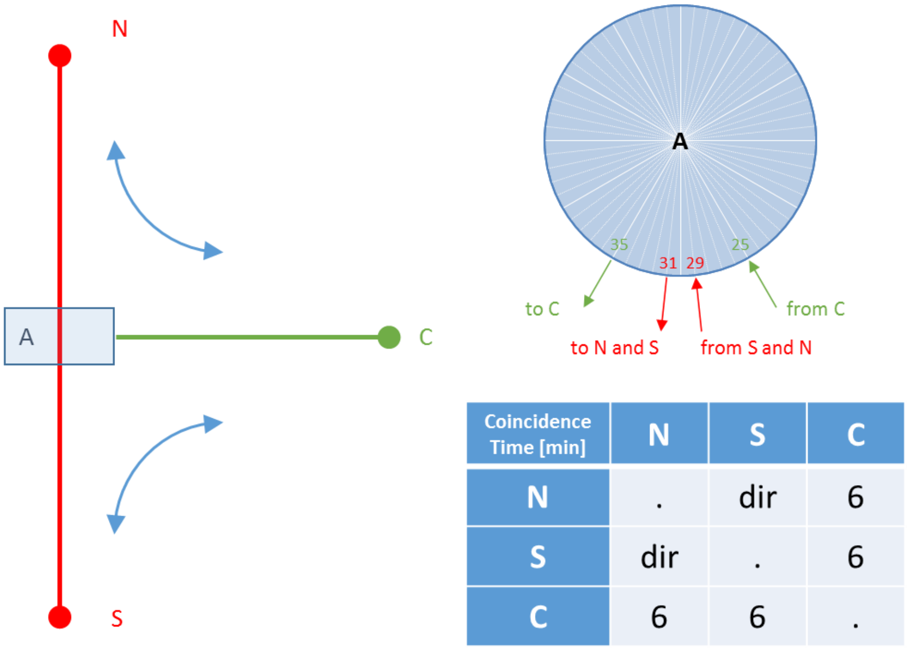


Figure 10 - The concept of the symmetry

In the figure 10, there are four possible solutions for the same structured system, where only the second and the fourth resolutions are symmetric, which are the unique for this kind of system. It is easy to recognize a symmetric system through the clock because the arrival and the departure minutes are equally spaced from the minute 60: their sum is, infect, equal to sixty. For each module, the symmetric axis is the vertical one crossing the hourly paths of the service in their meeting point. An important concept is that the space between the symmetric axes of the modules is equal to the half of the time period: this means that shifting the system along the temporal abscissa of a value equal to the half of the time period, the new obtain structured system is still symmetric. For this reason, there are always two symmetric solutions for each cadenced system. The concept of symmetry for a unique cadenced system does not entail any advantages; instead, in case of a network integration, the symmetry allows having the same connection time in both directions and minimizing the number of possible conflicts between two symmetric systems. Thank to this constraint, it is possible to reduce, substantially, the domain of all possible solutions. Finally, for this reason, when possible, planning an integrated network in which the systems are all symmetric is much more convenient. The figure 11 represents a simple integration in the node A, where there is the main product crossing the interchange station A and linking N to S and the feeder service between A and C. The possible solution is symmetric because the arrival and the departure are symmetric to the vertical axis of the clock, crossing the minutes 00-30 and, consequently, the connection times are equal in both directions. Of course, the results will be the same if the whole system will shift of the half of the time period (in this case 30 minutes), due to the property of a symmetric cadenced system.



Coincidence Time [min]	N	S	C
N	.	dir	6
S	dir	.	6
C	6	6	.

Figure 11 - Integration between two symmetric traffic products

Nevertheless, to ensure this kind of integration, it is necessary to consider the amount of rolling materials (in case of a railway system) or the number of vehicles (in case of a bus service), available to perform this kind of system with defined running time and time period. For this reason, introducing a second typology of constraint is fundamental.

3.4 The rolling material constraint

In case of a position variation, in which the geometric parameters (time period, running time and the structure of the system) does not change, it is possible to define two possible solutions, without considering now the symmetry constraint, where the first minimizes the amount of rolling materials "N_{OTT}" to perform the service and the second requests a unit more. The generic train or bus to run from the terminal A to the terminal B and vice versa has to wait for the first hourly path available: the total dwelling time is the sum of the time spent in A and in B waiting for the leaving: $T_{DTOT} = T_{DA}+T_{DB}$. However, the dwelling time in a terminal cannot be lower than the minimum turnaround time: the total minimum one is $T_{RTOT} = T_{RA}+T_{RB}$. Therefore, the amount of rolling materials needed to perform the system is $N = (2*T_P+T_{DTOT})/I$ where T_P is the running time in one direction and I the time period. However, it is possible to calculate the minimum amount of rolling material needed for the service only knowing the minimum turnaround time at terminus, without any kind of information on the schedule: $N_{OTT} = (2*T_P+T_{RTOT})/I$. When the turnaround time is greater than the planned dwelling one, the train or the bus has to wait for the second hourly path because it is not able to departure immediately: in this case a unit more than the minimum is needed. Hence, according to different cadenced structures, it is possible to optimize the amount of the rolling materials, which result causes:

- the minimization of the amortization and personnel costs, interesting for the transport company;
- the minimization of the dwelling time, optimizing the used capacity of the stations, useful for the infrastructure manager;
- a decreasing of the regularity level, because the buffer times at the terminal are lower, very important in case of delays.

It is possible to make some considerations:

- if the time period decreases, the minimum amount of vehicles increase, but no proportionally to the growing of the frequency: for example, if the running time is one hour and the time period decreases from 120 minutes up to 30, the value of N_{OTT} is, respectively, two, three and five. This element is important in case of an intensification of the service for the trade-off costs and quality of the transport service;
- if the speed changes but the distance remains the same, the value of N_{OTT} and so the costs can be different;

- if the route becomes longer, with a constant speed, the running time increases and in this case, it is possible to minimize the dwelling time and optimize the utilization factor of the terminal, with constant value of N_{OTT}.

4. How to measure the integration level: KPI IntegroSKOPIO©

The integration is a powerful tool because it multiplies the number of possible relations at equal transport supply, otherwise, without an integrated transport network there are only direct links, reducing, very much, the possibilities to reach other destinations. To have an integrated transport network, it is fundamental to create an integrated regular interval timetables to improve the attractiveness and the quality of the transport service to favour the time coordination among different traffic products belonging or to the same transport mode or to two dissimilar ones. The scheduling is the soul of a transport service because, from a commercial point of view, it represents its availability on the space-time diagram, mostly when the frequencies are quite low; instead, from a productive point of view, it is fundamental, regardless of frequency, because operators, according to a specific timetable, must manage each transport service. Hence, the scheduling defines the accessibility to a train, bus, ship or air for a precise O-D relation, the possibility to use a determined transport service at the desired time and, finally, the running time, which is one of the most important comparison attributes between transport modes. The composition of the timetable is the result of an optimization process at short and long term, which target is a transport plan taking into account the infrastructural, rolling materials and financial constraints. A transport service's scheduling can be traditional, in which the hourly tracks are different each other and the supply design is punctual, or it can be structured where the module is repetitive over time according to a specific time period.

The KPI IntegroSKOPIO© allows measuring the integration level:

- in case of the scheduling of the main and the feeder service is traditional and so each module has its own characteristics in terms of arrival and departure time, running time and number of stops;
- in case of the scheduling of all services is structured, where each modules of the different traffic products approaching an interchange node are equal in terms of

arrival and departure time, running time and number of stops and each railway or road service has its specific time period.

In the first case, the measurement of the integration level is computed module by module, where only the knowledge about the arrival time of the first service and the departure time of the second one is sufficient to reach the result; the second needs the acquaintance of the timing structure of the whole system. The first approach is called "IntegroSKOPIO© for single modules", while the second "IntegroSKOPIO© for structured systems". In both cases, to calculate the quality of the integration in one node, the minimum and the maximum connection time are needed, with which it is possible to define a connection good or not. The minimum depends on two important parameters:

- the transfer time, required to move inside the interchange node to move from the arrival point to the departure one and, generally, it depends on the physical characteristics of the station;
- the safety margin, that considers the level of punctuality of the arriving train or bus to make the connection more reliable. It depends on the frequency of the departing service, on the distribution of the delays of the arriving one (average delay and standard deviation) and on the level of reliability of the connection that we want to guarantee to the passengers.

Instead, the maximum connection time depends on the frequency of the departure service and on the maximum time that the passengers are willing to wait for the leaving of the train or bus.

4.1 IntegroSKOPIO© for single modules

When the system is not structured, the modules of the two involved services are different each other: the arrival times of the feeder service and the departure times of the main one are always dissimilar. Therefore, for each arriving train or bus it is needed to look for the first available transport mean to continue the trip and to check if the founded connection time belong or not to the range defined in advance or not. The amplitude of this range depends on a minimum and maximum value according to the assessment that they have just been mentioned. The computation of the KPI IntegroSKOPIO© involves the calculation of two indexes called:

- integration index, which measures the effects of the integration level on the main service and how the main and the feeder ones are integrated among them and, besides, if the supplies of the two services are balanced or not;
- coordination/supply index, which provides the integration level between the two involved services and it explains the causes for which the system is well integrated or not stressing the presence of a lack of time coordination.

The integration index on the x-axis and the coordination one on the y-axis define, uniquely, the IntegroSKOPIO© value (see figure 12), which, at the same time, provides information on the quality of the integration allowing to define what strategies to implement to improve its level.

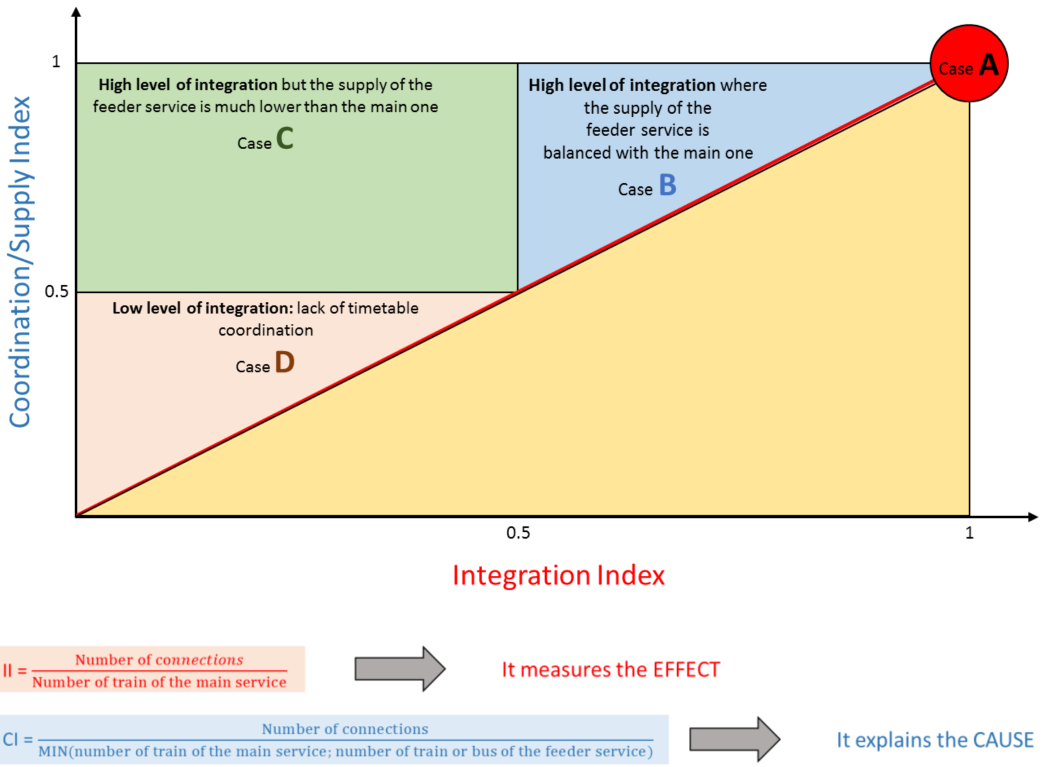


Figure 12 - Representation of IntegroSKOPIO©

The previous figure provides, also, the mathematical formulation of the two indexes: the number of connections includes the amount of relations between the feeder and the main service which connection time is included in the range defined by the minimum and the maximum value; the number of trains and buses are, intuitively, the supply of both services to match. Very interesting is the concept related to the denominator of the coordination/supply index: the number of connections cannot assume values greater than the minimum number of train and/or buses of the main and feeder service because the maximum number of existing relations is upper bounded by the service which has the lowest transport supply. For example, if the feeder service supply is four buses per day and that of the main service is ten train per day, the number of connections is at most four. Infect, in the link train-bus there are only four buses leaving and so only four possible good relations, while in the vice versa relationship, even if there are ten trains departing, good relations are those with the first available trains and, thus, at most four. Thanks to this last consideration, the value of the coordination index is always lower or equal to the integration one: equal when the feeder service supply is equal or greater than that of the main service. Consequently, IntegroSKOPIO© does not assume values belonging to the orange area: at most, it can belong to its upper boundary represented in the figure 12 by 45° degrees red line inclined. The remaining domain is further divided in four sub areas with four different meanings: the red represents the best situation where the feeder and the main service are perfectly integrated in which the feeder service supply is equal or greater than that of the main service (very typical situation in the urban context). The blue area is not the best solution, but it could be a very good result to reach in the planning of an integrated network because the integration level is very high. Both the integration and coordination index are greater than 0.5: the meaning is that, respectively, the feeder and the main service supply are balanced and that the number of satisfied connections, according to the defined range, is very good. The green area provides an important result from the timetable coordination point of view: the coordination index is greater than 0.5 and this means that the two services are well integrated; nevertheless, the integration index is very low because the two transport service supplies are not balanced. This is the typical scenario in the extra urban context in which the road transport mode (generally the feeder) supply is much lower than the railway one (the main) where the arrival and the leaving of the buses are coordinated to the departure and to the arrival of the train. Finally, the pink area represents the worst situation in which both the indexes are lower than 0.5 and so the integration level is very low (lack of timetable coordination) so as the feeder and main service supplies are not balanced. The next figure (13) gives a graphically representation of the four mentioned cases:

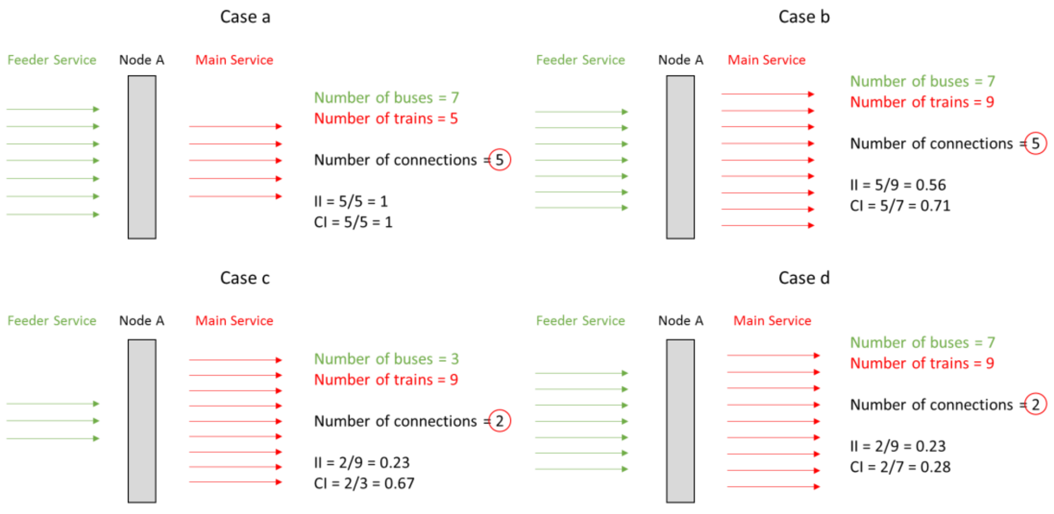


Figure 13 - Application of IntegroSKOPIO©

Therefore, an accurate reading of the chart in figure 12, can provide some important information on the actual level of integration situation and it helps to understand which are the causes, if any, and to understand what kind of strategies to implement to improve the nowadays scenario. For example, supposing to have a lack of timetable of coordination for which the integration level is so low that it is impossible to realize an integrated network, in order to reach the final target, which is also the title of this paper, it is possible to follow the path in the figure 14:

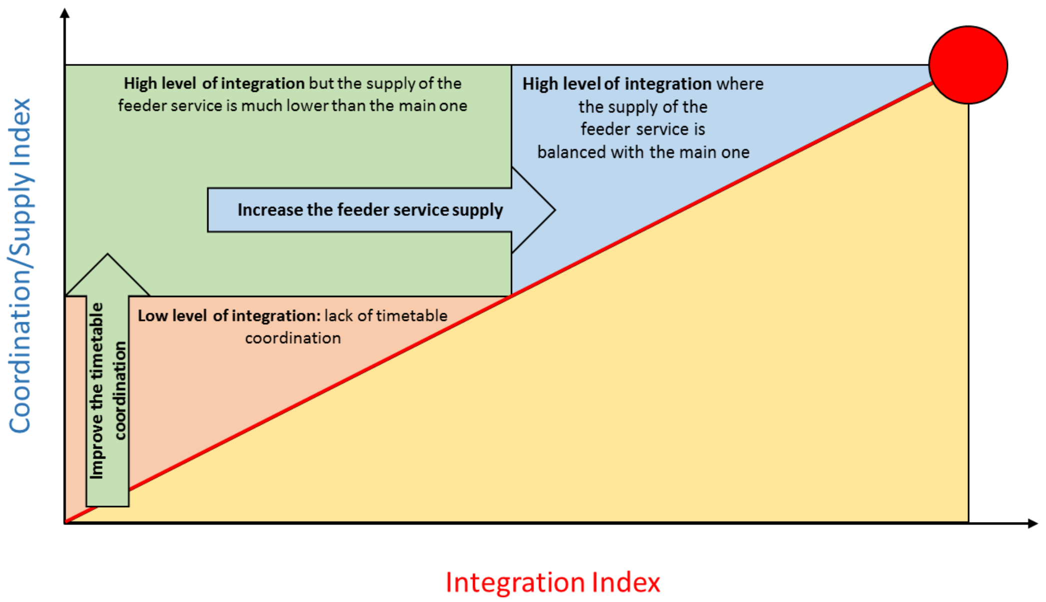


Figure 14 - How to improve the integration level

At the beginning, in case of an optimization process which main objective is to improve the integration level without modifying the feeder and the main service supply (short-term scenario), the improvement of the timetable coordination is the first result to achieve to guarantee to the users a high level of integration (moving from the pink area to the green one). Later, with a new transport plan according to which an increase of the demand on the feeder service has been forecasted (long-term scenario), its supply can be improved to reach the blue area where the integration level is still high, but now, the feeder and the main service supplies are balanced. The following logical sequence (figure 15) explains graphically the previous considerations.

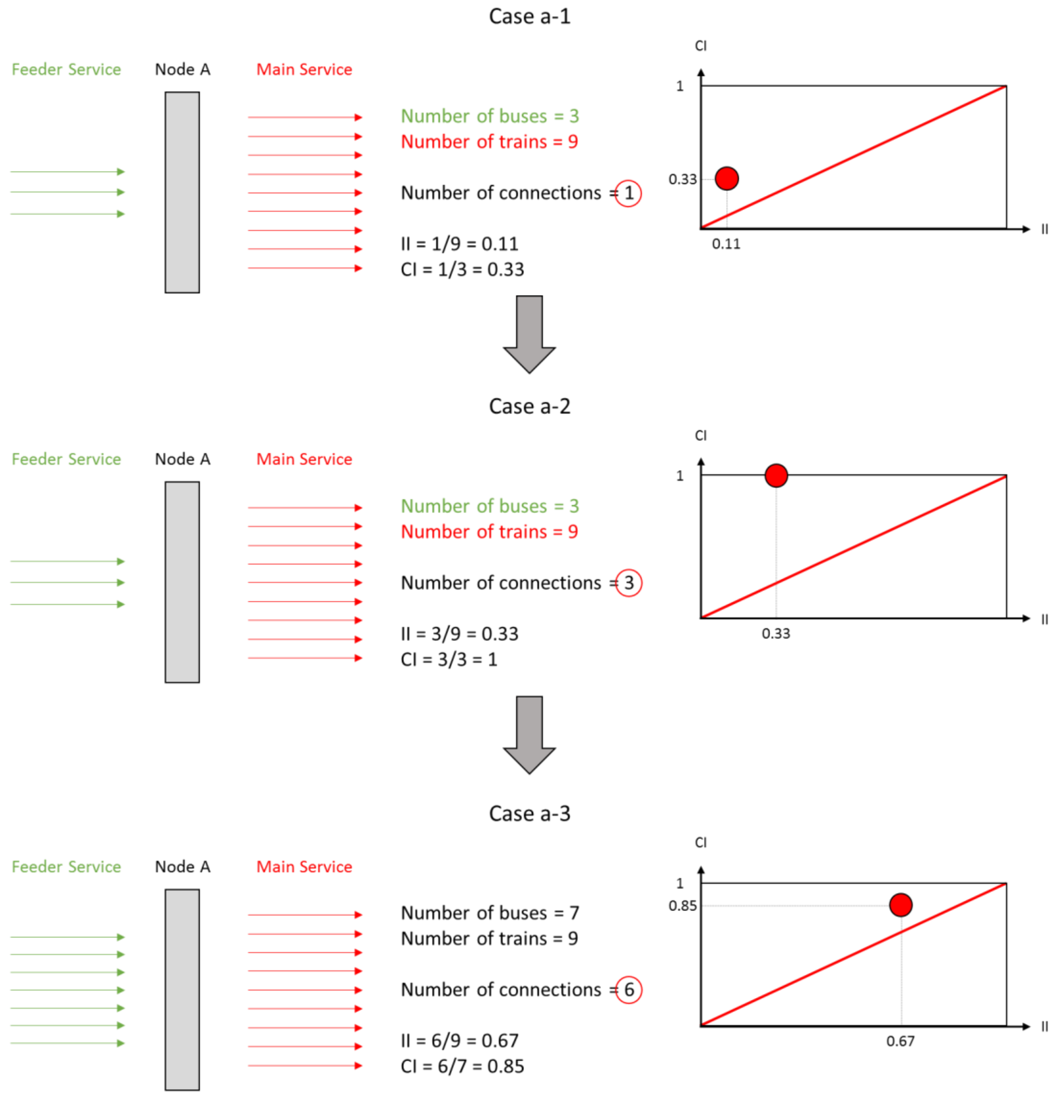


Figure 15 - How to improve the integration level (case a)

Instead, when the two services are already balanced from the viewpoint of the supply, but the integration level is low, it is necessary to improve, only, the timetable coordination to reach the best results in the IntegroSKOPIO© chart: of course, to make more attractive the whole transport system, it would be preferable to have a very high level of supply. In figure 16, the case in which the feeder and the main service have the same transport supply is analysed.

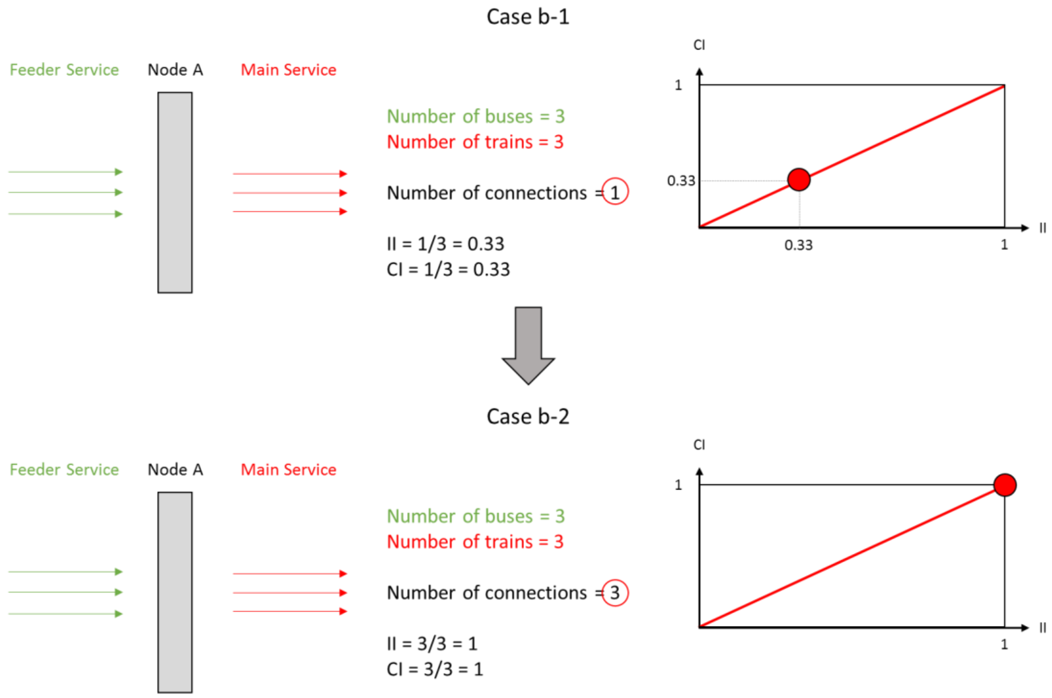


Figure 16 - How to improve the integration level (case b)

In figure 17, the feeder service supply is greater than that of the main one:

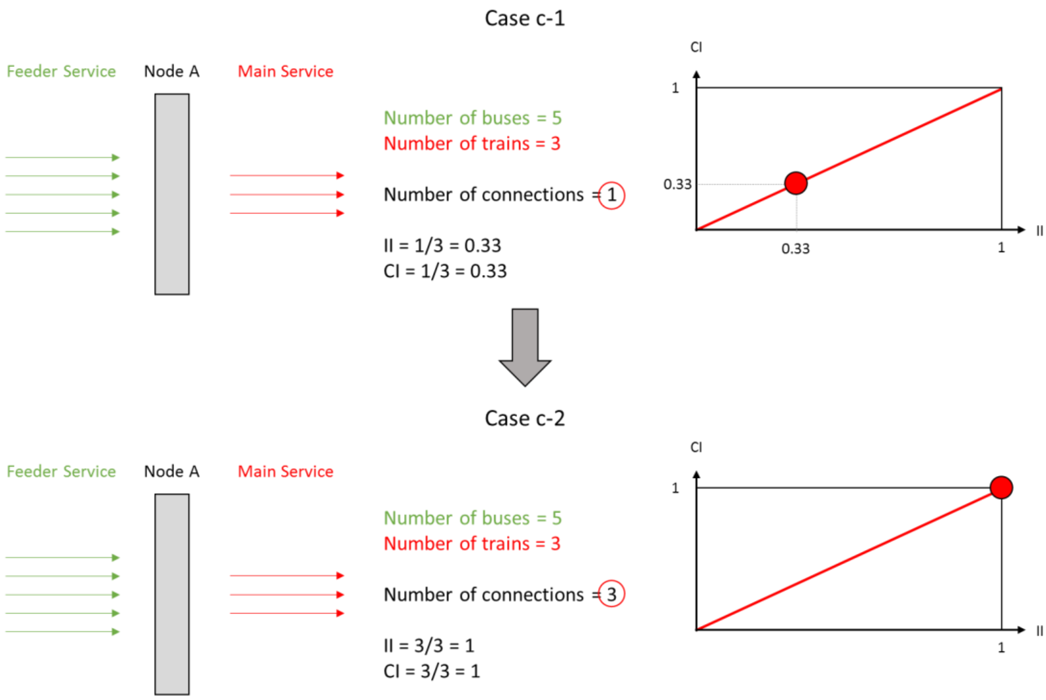


Figure 17 - How to improve the integration level (case c)

The results obtained in figure 16 and 17 are the same, in despite of the supply of the feeder service is not the same: this because the coordination index is measured taking into account the minimum between the supply of the involved services. From an integration point of view, the computation of IntegroSKOPIO© considers, only, the maximum number of available connections, which, as it has already explained, depends on the amount of trains or bus of the lowest transport supply. For this reason, there are no differences between the case "b" and the case "c": to measure the integration level, having a feeder service supply equal or greater than that of the main one, does not change the result.

4.2 IntegroSKOPIO© for structured systems

When the system is structured, the modules of each traffic products are always the same in terms of arrival and departure times, running time and hierarchy of the stops and they make up the grid of the railway or road transport service where the time period is reported. In this case, the clock of the interchange node represents the whole transport system supply, where the modules of each traffic product approaching this station arrive and leave always at the same minute. Hence, in this case, to compute the IntegroSKOPIO© value, it is important to know what the structure of the system is, in which the supply of all services is generally the same. This means that the calculation of "IntegroSKOPIO© for structured systems" provides a unique value because the integration and the coordination index are the same. Of course, the result has a meaning a little bit different from that computed in case of not structured systems, because it provides information only on the quality of the integration level and, better, the percentage of good relations with respect to the total useful ones. Now, it is no so interesting to know if the services are balanced each other in terms of supply, since, from a system-wide perspective, a cadenced system should already provide a balanced of the supply between the various services. The figure 18 and 19 show a little example of a structured system where different and curious results are obtained:

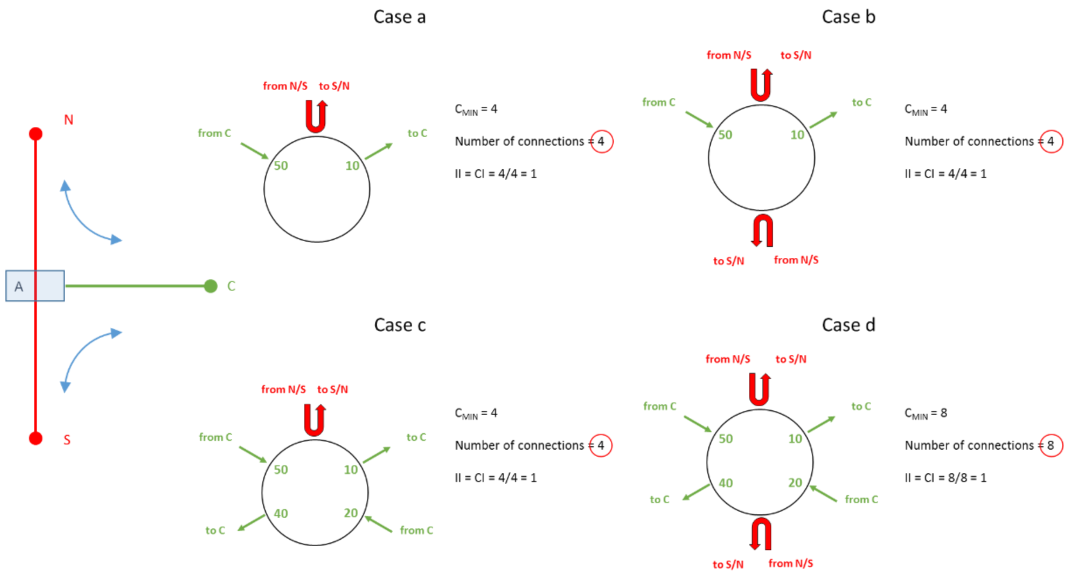


Figure 18 - Measuring of the integration level (first scenario)

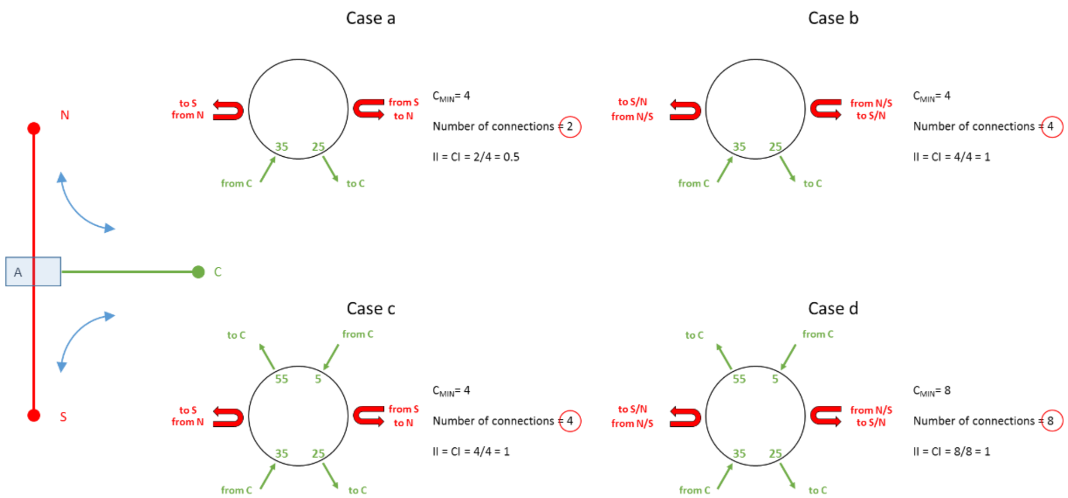


Figure 19 - Measuring of the level of integration (second scenario)

Both scenarios are realized with respect to the symmetry constraints, where the symmetry axis crosses the minutes 00-30 but, in the first scenario the main service arrive and leave at the minutes 00 and/or 30, while in the second one at the minutes 15 and/or 45 (45 and/or 15 for the opposite direction due to the symmetry constraint). Moreover, for each scenario, four little cases analyse what happens if the frequency doubles only for the main service (case b), then only for the feeder service (case c) and, finally, if it changes for both (case d). When the frequency of the two services (the red is the main and the green the feeder) is not the same, to compute the value of the KPI IntegroSKOPIO©, the same considerations mentioned before are still valid for which only the connection for the first available train or bus can be considered good. For example, in the case b of the first scenario (figure 18), coming from C, the first train to N leaves at 00 and so for the calculation of all possible connections, the solution C-N with the train leaving at minute 30 must not be considered. The most useful case to understand the differences between the first and the second scenario is the case a. In the first, the arrivals and the departures of both services are located in the top of the clock, making good all the possible connections (this particular configuration is very important in case we want to privilege all the travel combinations): the IntegroSKOPIO© value is one. Instead, in the second case, due to the particular positioning of the main service on the minute 15 for the uneven direction and on the minute 45 for the even one, only two connections over four are realized: the IntegroSKOPIO© value is one half. Probably, this configuration is the unique possible to implement due to some constraints that must be respected in other interchange nodes upstream and downstream; therefore, since only two connections can be realized, it becomes crucial to know which relation is more attractive from a demand point of view. Despite the systems was structured and symmetric in both scenarios, the KPI IntegroSKOPIO© provides two different results: this means that the symmetry and the design of structured system are not, alone, sufficient conditions to plan an integrated network, as the case "a" in the second scenario shows. All the other cases, both in the first and second scenario, have the value of IntegroSKOPIO© equal to one: this because, regardless of the system structure, there is at least one service with a double frequency, ensuring, always, all the connections in the defined range time.

The figure 18 and 19 propose two particular cases of an interchange node (A) where there are a crossing carrier service and a feeder terminus one. It is possible to generalize, considering all possible combinations obtainable changing the arrival and the departure time of the main service before and, later, the scheduling of the feeder. IntegroSKOPIO© for structured systems computes the integration level for each combination, and, finally, it is possible to understand which the best configuration of the clock will be for an interchange node with these transport system characteristics. The figure 20 shows 84 possible combinations, supposing a step of five minutes for both services for each variation: the calculation considers that the departure and the arrival occurs at the same time. In reality, this is no possible, but the results do not change if they happen just one or two minutes later or before than the minute reported in the table. Both services are symmetric: the connection time is the same for the same relation in the opposite directions.

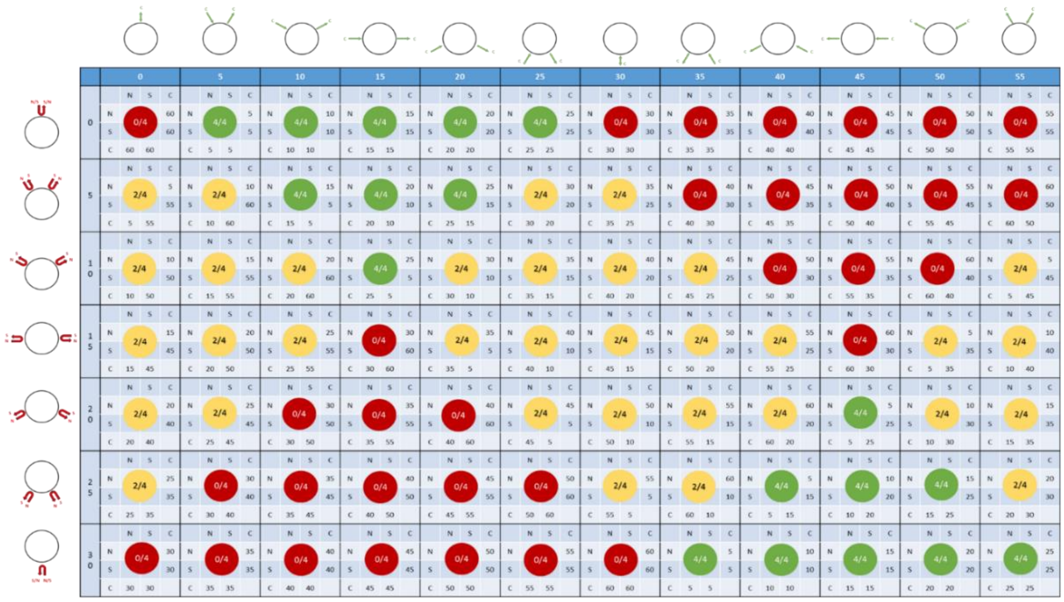
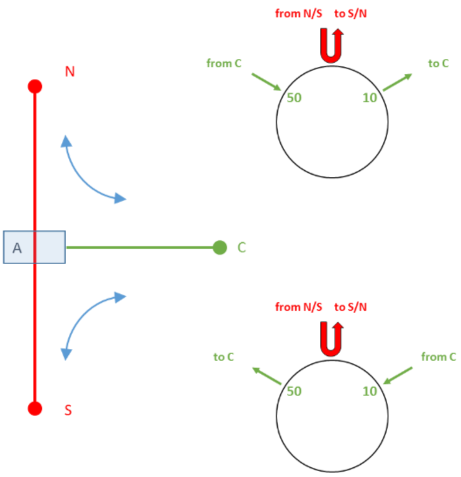


Figure 20 - Clock combinations

To measure the integration level a minimum time connection of five minutes and a maximum one of twenty-five minutes are considered. To be more precise, the table lacks the last five combinations of the carrier service: for the link from S to N, there are not the arrival and departure times from the minute 35 to the minute 55 (the same for the opposite direction). This because the table is symmetric from the integration level point of view, where the symmetric axes is the row representing the minute 30 for the main service. This means that the value of IntegroSKOPIO© for structured systems computed for the combination 35 is equal to the 25 one and so on, because the four connection times values are the same but related to the other relation. The red circles represent the worst clock configurations, because it does not even provide a good match between the two services. The yellow ones could be regarded as a good solution, because two connections over four are satisfied according to the imposed timing constraints: obviously, to plan an efficient transport plan, the link that has a good connection time must be the most important from the viewpoint of the transport demand. Finally, the best configurations are pointed out by green circles, allowing to each possible relation to have a connection time respectable of the initial constraints. The greatest results in terms of number of green circles are achievable in four cases: when the carrier service arrives and leaves at the minute 00 and 30 and when the feeder arrive and departs at the minute 15 and 45 (consequently the arrival occurs respectively at 45 and 15). Vice versa, the worst when the main service has the arrival and the departure time occurring at 15 and 45 minutes and when the feeder leaves and arrives at 00 and 30. Immediately, it is possible to observe that the best clock combinations are those for which all the transport supplies are located or in the upper part (around the minute 00) or in the lower one (around the minute 30). Infect, when the main service arrives and leaves at the minutes 00 or 30, there are, respectively, five good configurations over the possible twelve. However, having a symmetric system where the arrival and the departure of all services are located in the upper or lower part is not, alone, a sufficient condition (see figure 21):



Case a

Coincidence Time [min]	N	S	C
N	.	dir	10
S	dir	.	10
C	10	10	.

C_{MIN} = 4

Number of connections = 4

II = CI = 4/4 = 1

Case b

Coincidence Time [min]	N	S	C
N	.	dir	50
S	dir	.	50
C	50	50	.

C_{MIN} = 4

Number of connections = 0

II = CI = 0/4 = 0

Figure 21 - Sufficient conditions to plan an integrated network

The case "b" shows a very bad clock configuration because the value of IntegroSKOPIO© is equal to zero, in despite of both services are symmetric and located on the top of the "clock". Instead, the case "a" has a very good integration level (IntegroSKOPIO© equal to one): the main difference is that in the first case the departures and the arrivals are collocated in the same clock face (arrivals before the minute 00 and the departures later);

while in the second they are opposite. Hence, having all the departures and the arrivals in the same clock face ensures a great level of integration. Therefore, this last consideration together to the symmetry constraint and to the collocation rules of the services along the clock are the sufficient conditions to plan an efficient integrated network. Of course, there are to consider all the other constraints, first of all, those related to the station capacity and to the infrastructure, because, for example, the station could be not able to manage a lot of arrivals or departures at the same time due to the absence of free tracks to stop the trains or some services share the same routes and, so they cannot arrive or leave simultaneously. Coming back to the figure 20, the number of good configurations decreases as the arrival and the departure time of the carrier service depart from the minute 00 and the minute 30. Thus, the possibilities to plan an efficient integration in the interchange node decreases to zero, when they occur at the minute 15 and 45. This is the worst situation to plan an integrated network because there are none opportunities to satisfy, at the same time, all the relations. Anyhow, the number of red circles is the lowest in this case, therefore, the probability to integrate at most two relations, and so to have two fulfilled connections over four, is very high. This solution is generally used when there are other important constraints to respect such as the frequency one in case of more services along the same route or when one particular relation has more transport demand in both directions than the other one. Obviously, at equal values of IntegroSKOPIO©, the connection times vary with respect to the departure time of the feeder service and the good ones are those included in the range between five and twenty-five minutes. Their values, of course, are not fixed, but they can change according to the made considerations: lower is the minimum time, lower will be the waiting time for the feeder service departure but higher will be the probability to lose the connection in case of delay. Instead, higher is the maximum one, higher will be the reliability of the connection but the waiting time increases. Therefore, as it often occurs, it is fundamental to define a trade-off between the waiting time and the reliability of the connection, taking into account that the main target is the attractiveness of the whole transport system and this can be reached ensuring the maximum number of connection to the passengers in a reliable and comfortable way. Moreover, the infrastructural constraint implies, automatically, a greater spacing between two arrivals and two departures due to the incompatibility of two routes and so the minimum connection time increases. The next figure, the number 22, shows how the connection time varies according to the departure minute of the feeder service, supposing that the main one leave and arrive at 00.

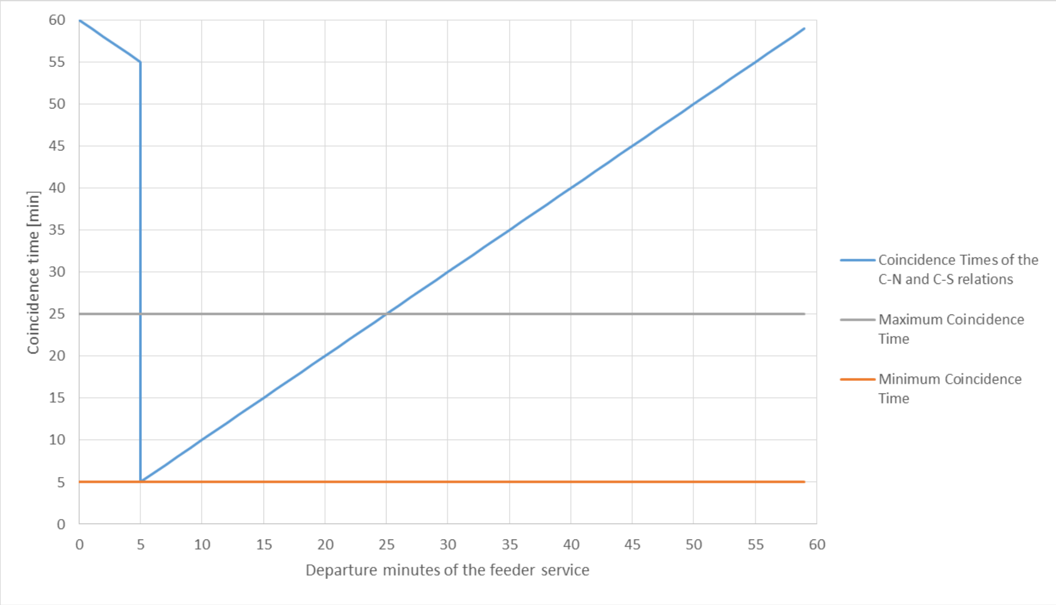


Figure 22 – Connection times with the main service on the minute 00

The following one (figure 23), represents, instead, the connection time variation in case of the main service is located on the minute 15 and the opposite direction on the minute 45:

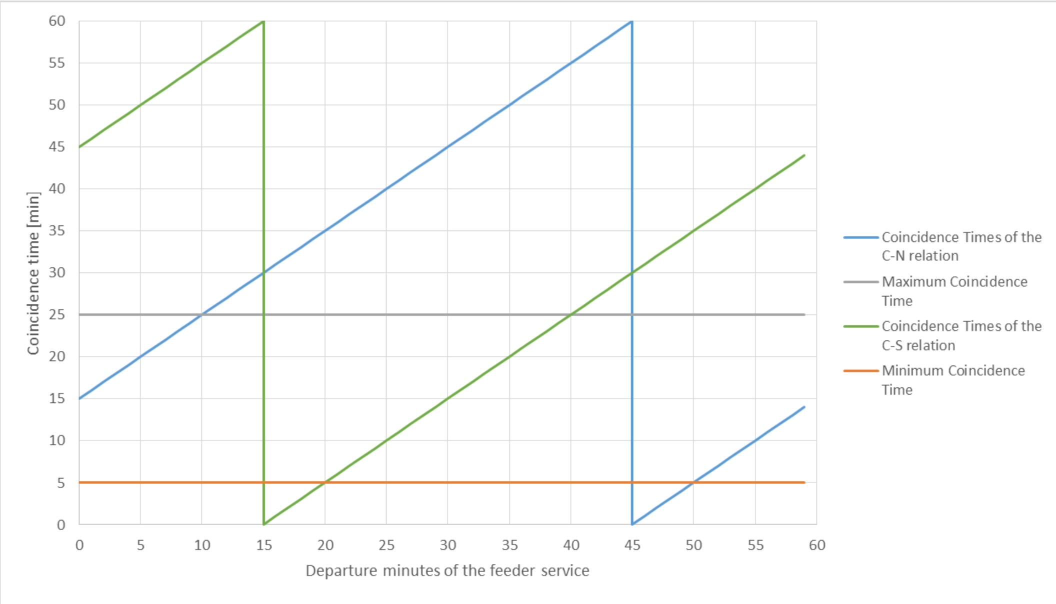


Figure 23 - Connection times with the main service on the minute 15

The chart shows, clearly, how the two relations are never satisfied simultaneously. The following table illustrates the average connection time per relation for each combination and then, in the last column, the average related to all feeder service variation, fixing the clock supply of the main one. The red cells represent those combinations creating an average connection time not respectable of the timing constraints, but it does not rule out that there are no good connections (at most two); while the green ones symbolize that at least two relations are always satisfied.

		FEEDER SERVICE												
	MINUTES	0	5	10	15	20	25	30	35	40	45	50	55	Average coincidence time per relation
MAIN SERVICE	0	60	5	10	15	20	25	30	35	40	45	50	55	32.5
	5	30	35	10	15	20	25	30	35	40	45	50	55	32.5
	10	30	35	40	15	20	25	30	35	40	45	50	25	32.5
	15	30	35	40	45	20	25	30	35	40	45	20	25	32.5
	20	30	35	40	45	50	25	30	35	40	15	20	25	32.5
	25	30	35	40	45	50	55	30	35	10	15	20	25	32.5
	30	30	35	40	45	50	55	60	5	10	15	20	25	32.5

Table 1 - Average connection times

The above table confirms how the arrival and the departure of the feeder service at 00 and 30 minutes solutions does not ever guarantee the possibility to plan an integrated network for all relations.

So far, the paper has illustrated the different kinds of integration (spatial and temporal) and how measuring the integration level in an interchange node in case the system is structured (IntegroSKOPIO© for structured systems) or not (IntegroSKOPIO© for single modules). The last considerations explain how the morphology of the interchange node can influence the shape of the "clock of the station" and where the case of a simple node with a crossing railway service and a merging one has been analysed.

5. Ideal "clocks" station for different interchange nodes

The aim of this chapter is to provide a general rule to realize the ideal "clock" of several interchange nodes, taking into account that their shape and functions are very often different. The shape regards the morphology of the nodes and so if they are crossing or head stations. The functions consider the number of approaching services and if they are crossing or terminal.

To plan an integrated network, it is important to know which the main variables are characterizing the system, such as the frequency, the running time and the structure for each service, and, then, how they work together. Obviously, there are many constraints to be respected related to the symmetry, to the rolling material, to financial, infrastructural and circulating aspects. They can reduce the amplitude of the solutions domain very much. Finally, the objective function depends on the actor's point of view: for the railway undertaking the most important target is to improve the attractiveness of the service, for the infrastructure manager to optimize the capacity, and so on. Therefore, the clocks designing varies according to the temporal intervention scenarios:

- short-term scenario: the frequency and the running times of all services have already been defined and the structure of the system is the variable to optimize to improve the integration level;
- long-term scenario: the optimization problem considers not only the structure of the system but, also, the standardization and the functions of all services in terms of frequency, hierarchy of the stops modifying the running time, without excluding the costs necessary to implement all the interventions. Of course, the final benefits are related both to the railway undertakings and to the infrastructure manager.

The following considerations related to the design of an ideal "clock" station regards only possible interventions reachable in the short-term scenario, working on the integration among the services. The connection can be:

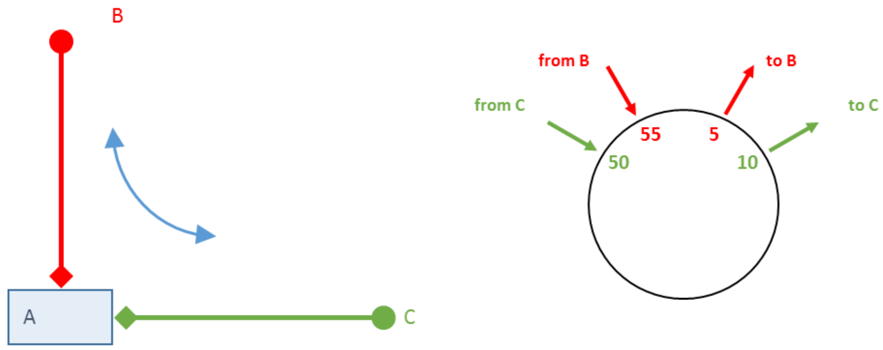
- among services belonging to different railway lines (network integration);
- among services belonging to the same railway line but having different functions (route integration).

The constraints that will be considered in the next formulations are:

- the minimum and the maximum connection time;
- the symmetry constraint to guarantee the same results in both directions.

5.1 Interchange nodes with a "V" or "L" shape

In this kind of node, only two services approach the station (see figure 24):



Connection Time [min]	B	C
B	.	15
C	15	.

$C_{MIN} = 2$

Number of connections = 2

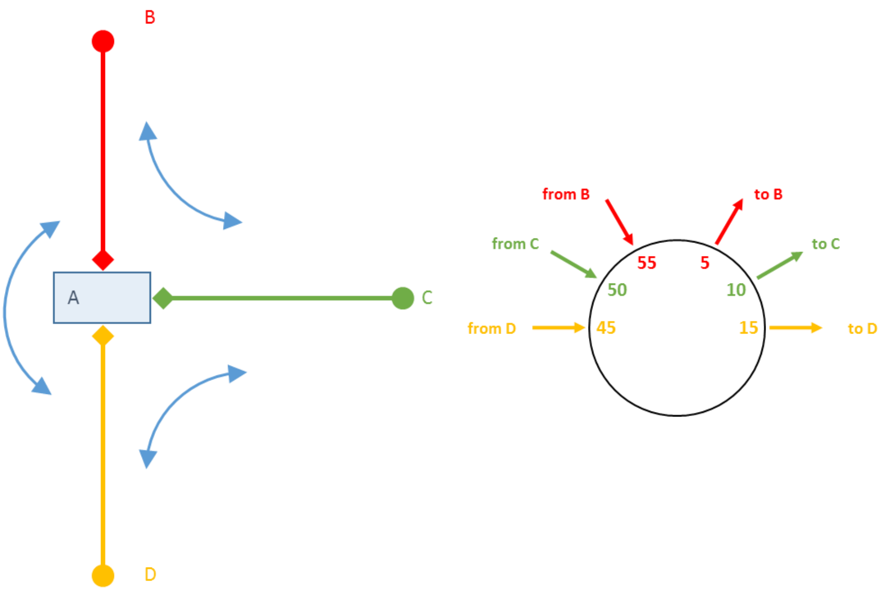
II = CI = 2/2 = 1

Figure 24 - Ideal clock for a "V" or "L" shape node

Respecting the symmetry constraint allows having the same connection time in both directions and collocating the departures and the arrivals on the top of the “clock” and in the same clock face lets to minimize the total connection time. Of course, it is possible to bring near the departures and the arrivals of the two services, but it must consider the minimum turnaround time for the terminal traffic products. Moreover, it is possible to have the arrivals and the departures at the same minute: this condition provides the minimum connection time, but it has to take into account the infrastructural constraints for which the two services must have the routes compatible each other. From a morphological point of view, the station has to be equipped with, at least, two tracks to guarantee the approach of the two services, trying to realize compatible routes to minimize the connection time. Besides, the tracks are occupied for a maximum of twenty minutes (in this scenario) allowing to the infrastructure manager to optimize the capacity of the station and to the railway undertaking to minimize the total dwelling time at the terminal to reduce the variable and fixed costs related to the circulation of the rolling material.

5.2 Interchange nodes with a “T” shape

In this kind of node, there are three merging branches, which can be independent of each other (first scenario) or linked, in which one service crosses the station (second scenario).



Connection Time [min]	B	C	D
B	.	15	20
C	15	.	25
D	20	25	.

$C_{MIN} = 6$

Number of connections = 6

II = CI = 6/6 = 1

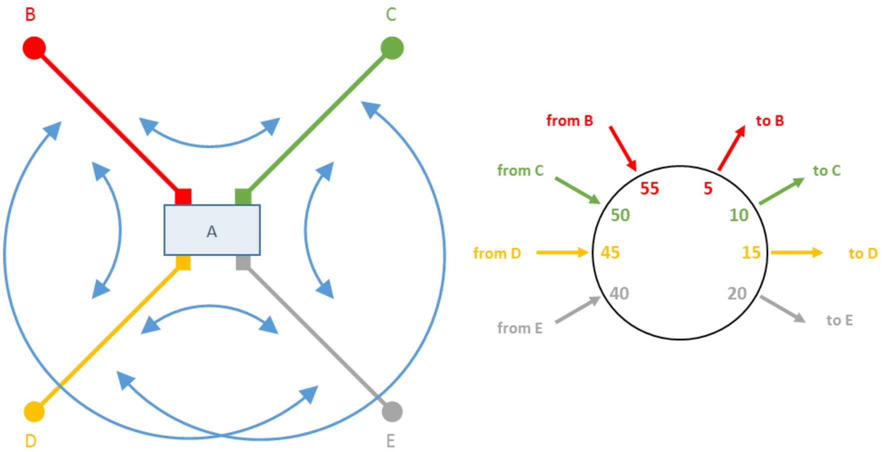
Figure 25 - Ideal "clock" for a "T" shape node (first scenario)

This first scenario is planned by using the same theory of the previous one. The difference is that, having three different services, the connection times are not equal each other: for this reason, during the design phase, it is crucial to know which the strongest relation from the transport demand point of view is and will be, in order to minimize the average connection time per passenger. Also in this scenario, as the previous one, it is possible to have all the arrivals and the departures at the same time, realizing the so-called “integral node” where all the relations have the same connection time: clearly, the entering and the exiting routes of the three services must be compatible each other. Consequently, the minimum number of tracks to ensure this kind of integration is three.

In the second scenario, there are two services, but one of them crosses the interchange node, generating four possible relations. This particular configuration of the services has already been discussed extensively in the previous chapter, where there are all the considerations and assessments of the case.

5.3 Interchange nodes with a "X" shape

Four branches make up this interchange node typology and in this case, the route and the network integration can be realized. According to the services, it is possible to individuate two scenarios: in the first, four services are terminus, (figure 26); in the second there are only two services crossing the station (see figure 27).



Connection Time [min]	B	C	D	E
B	.	15	20	25
C	15	.	25	30
D	20	25	.	35
E	25	30	35	.

$C_{MIN} = 12$

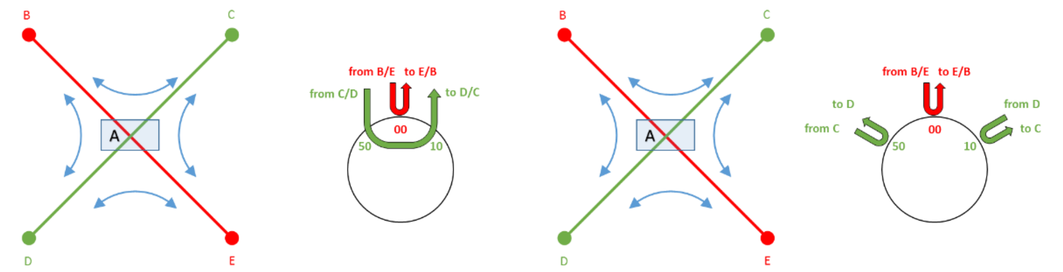
Number of connections = 8

II = CI = 8/12 = 0.67

Figure 26 - Ideal "clock" for an "X" shape node (first scenario)

The represented "clock" is not the ideal one from the integration level point of view, because considering a connection time greater than 25 minutes excessive, only eight relations over twelve are satisfied, but it is good from the designing viewpoint. Infect, to improve the IntegroSKOPIO© value up to one, it is necessary to bring near the arrival and the departure times of the services, taking into account the infrastructural constraint. If this solution is no possible, the planning of the "clock" has to privilege those relations, which are the most important in terms of demand. The creation of the "integral node" is possible if all the services arrive and leave at the same minute: this requests that the four routes to enter and to exit from the station are compatible each other. Generally, the probability that this event occurs decreases with respect to the increase of the amount of tracks. In this case, the minimum is four.

The second scenario is a little bit different because there are only two crossing services, but one of them has to give the right of the way to the other, as it happens in the Castelfranco Veneto station where the Bassano-Venice railway service meets the Treviso-Padova one.



Connection Time [min]	B	C	D	E
B	.	10	10	dir
C	10	.	dir	10
D	10	dir	.	10
E	dir	10	10	.

C_{MIN} = 8

Number of connections = 8

II = CI = 8/8 = 1

1° case

Coincidence Time [min]	B	C	D	E
B	.	10	50	dir
C	10	.	dir	10
D	50	dir	.	50
E	dir	10	50	.

C_{MIN} = 8

Number of connections = 4

II = CI = 4/8 = 0.5

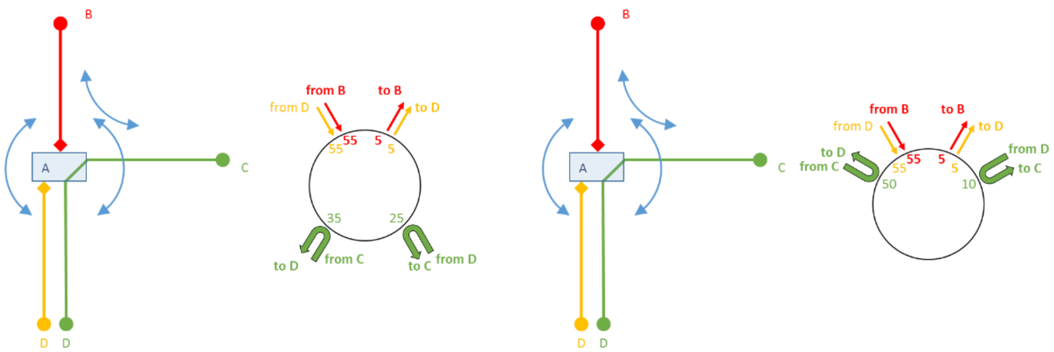
2° case

Figure 27 - Ideal "clocks" for an "X" shape node (second scenario)

The planning of the ideal "clock" for this second scenario is the result of a trade-off between the dwelling time of the C-D railway service and the maximization of the number of good relations. In the first case, the IntegroSKOPIO© value is the best (equal to one) because all the links are satisfied with a connection time of ten minutes for all relations ("integral node"), but, the train running along the C-D relation has a dwelling time of twenty minutes, penalizing a lot this relation, favouring, instead, the integration in this interchange node. Vice versa, the second case minimizes the dwelling time for both services, making worse the integration level: only the relation to and from C have a very good connection time (10 minutes), while the relation to and from D a very bad one (50 minutes). To solve this trade-off, it is fundamental to know the demand for each relation: if it is very high only for one relation (for example to and from C), the second case is preferable; otherwise if all relations have a very high demand, it could be useful to integrate in the best way the two services, even if the dwelling time becomes greater (as it happens in the first case). Nevertheless, if the demand on the relations to integrate is high, this means that the passengers that want to continue the trip on the C-D relation on the even and uneven directions are not so many, consequently the total weighted average time per passenger, considering both the connection and the dwelling time, can be quite low, reaching, the optimum for the whole system.

5.4 Interchange nodes with a “Y” shape

This typology of interchange node is very common in which two services have a railway stretch in common (see figure 28).



Connection Time [min]	B	C	D
B	.	30	10
C	30	.	dir
D	10	dir	.

C_{MIN} = 4

Number of connections = 2

II = CI = 2/4 = 0.5

1° case

Connection Time [min]	B	C	D
B	.	15	10
C	15	.	dir
D	10	dir	.

C_{MIN} = 4

Number of connections = 4

II = CI = 4/4 = 1

2° case

Figure 28 - Ideal "clocks" for a "Y" shape node

Supposing an hourly frequency for all services, the planning of an integrated network has two objective functions: the first is the maximization of the connections and the second is the frequency overlap on the segment A-D, realizing a headway of thirty minutes between the two traffic products (represented with the green and yellow colour in the above figure). Generally, there is not a solution able to satisfy both the objective, consequently the result of the problem is a trade-off solving. In the first case, the frequency overlap concept is stressed, but, the number of good connections is two over four making the IntegroSKOPIO© value equal to one half. The second one minimizes the total connection time, bringing near the arrival and the departure times of the three involved services, improving the IntegroSKOPIO© value up to one, neglecting the constraint related to the frequency overlap. At the end, the planner has to choose if it will be more useful to have two services on the A-D line equally spaced or to integrate in the best way the services.

How to choose the best solution? The first case is to be preferred if the transport demand on the B-C relation is lower than that on the A-D railway segment (it is legitimate to think that there are other stations between A and D), having a regular and a great frequency on the A-D railway segment (one train every 30 minutes). The second case is preferable when the demand on the B-C relation is so high that it is more useful to integrate these two services than having a double of the frequency on the A-D connection. Obviously, it could happen that the solution showed in the first case is more difficult to implement due to the presence of particular constraints in the other nodes where the arrival and the departure of one traffic product is bound by another one.

The aim of this quick overview is to provide the basic knowledge to design the "clock" of the stations according to the amount, functions and specialization of the approaching traffic products and to the morphology of the interchange node, trying to maximize the integration level. It is possible to move from very easy schemes with at most two merging railway lines with only two services to very difficult ones where, in addition to the increasing of the amount of tracks and in coming and out coming trains, there are many constraints to respect, such as the incompatibility among routes, overlapping of the frequencies, minimum number of available tracks to allow the stop of the rolling materials and so on. Furthermore, the difficulty increases if the station is inside a very complex network system in which the planning of an integrated network must consider all the aspects and constraints coming from each element of the railway infrastructure (lines and stations). Consequently, the design of an integrated regular interval timetables can be defined as the individuation of the best structured system in relation with the constraints reducing the amplitude of the solutions domain. The design choices can be:

- the most appropriate solution, if the amount of the free degrees of the problem is greater than the number of the constraints, in this case the solving criteria must be choice according to the targets to achieve;
- the definition of the constraints to remove, if the amount of the free degrees of the problem is lower than the number of the constraints, in this case it is necessary to define a ranking for the constraints.

6. The interchange node of Bologna Centrale

The Bologna Centrale station is the main railway station of the city of Bologna and it is the fifth station in Italy after those of Roma Termini, Milano Centrale, Torino Porta Nuova and Firenze Santa Maria Novella in terms of amplitude (78000 square meters) and amount of yearly passengers (about 58000000 travellers). Instead, it is the second in terms of daily number of arriving and departing trains (about 800). The figure 29 shows the topological structure of the interchange node of Bologna: the different colours represent the railway lines arriving in Bologna Centrale station. In the north part there are:

- the purple line, linking the city of Bologna to Venice, crossing other important cities such as Ferrara, Rovigo and Padova;
- the yellow link to Verona;
- the blue line arrives at Milano, crossing the city of Modena, Reggio Emilia, Parma, Piacenza and Lodi (located in Lombardia region);
- the green one coming from Casalecchio, an interchange node for two lines, one from Porretta Terme, managed by RFI, the other from Vignola, managed by FER (Ferrovie Emilia-Romagna);

In the south part there are:

- the Adriatic railway line linking Bologna to Ancona and Bari, crossing the cities of Faenza, Forlì, Cesena and Rimini;
- the blue line represents the connection between Bologna and Florence through Prato;
- the grey one is the local railway line to Portomaggiore, managed by FER.

The dotted red line represents the high-speed and high capacity line from Florence to Milan, totally built underground: nowadays, thanks to the Venice ramification opening, the high-speed trains flow is completely separated by the regional and the long-haul one, having an own railway station, called Bologna AV, located below Bologna Centrale.

Finally, the brown line is the railway belt of Bologna, used by the freight trains reaching Bologna Interporto on the line to Venice and Bologna San Donato, bypassing the passenger station.

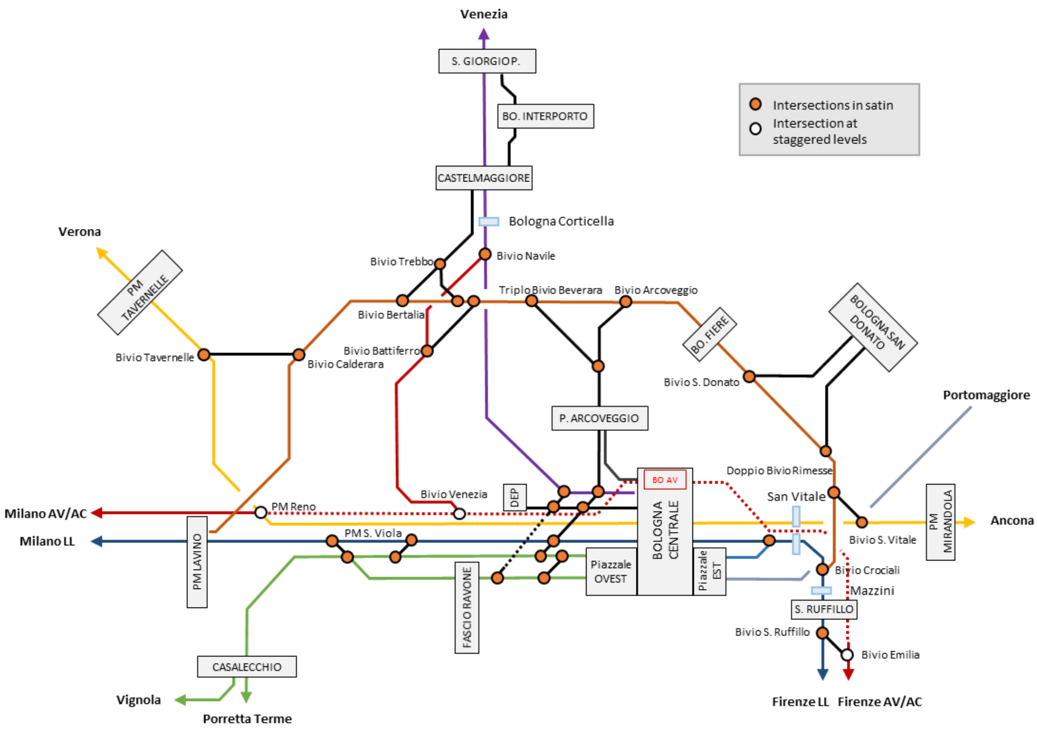


Figure 29 - Topological structure of Bologna's interchange node

As it is possible to see from the above figure, the railway line from Venice ends at Bologna Centrale, in the upper tracks of the station (tracks number ten and eleven); the green one from Casalecchio at "Piazzale Ovest", which represents the terminal for all services coming from the north; the line from Portomaggiore, instead, has the "Piazzale Est" as its terminal. Moreover, the railway line from Verona has its natural continuation on the Adriatic line (represented by the yellow colour); while the line from Milan goes on the historical line to Florence (the blue one). Therefore, the Bologna Centrale station is at the same time a crossing and a terminal interchange node. The high-speed line enters the node at PM Reno from the north, liaising the Verona railway line through an intersection at staggered levels, and at Bivio S. Ruffillo from the south, linking the railway line to Prato through an intersection in satin. The high-speed trains, coming from Venice, leave the historical line near Castelmaggiore (at "Bivio Navile"), across an intersection in satin, using the new ramification to join the underground high-speed station of Bologna at "Bivio Venezia", through an intersection at staggered levels.

6.1 The railway traffics

In a weekday, about 800 trains[2] enter and exit from the interchange node of Bologna. This is due to the strategic position that the station has in the whole Italian railway infrastructure, since there are nine different railway lines merging in the railway node of Bologna coming from the Adriatic coast, Portomaggiore, Venice, Verona, Milan (historical line), Milan (high-speed line), Casalecchio, Prato and Florence (high-speed line). Regional trains, linking the city of Bologna with the surrounding area, make up the 54% of the total railway traffic; the 9% represents the percentage of long-haul trains; the high-speed railway traffic is the 27% of the total one, including the trains of the two main Italian railway undertakings (Trenitalia and Nuovo Trasporto Viaggiatori) and, finally, the last 10% includes freight trains.

6.1.1 Regional service

It represents the greatest percentage with respect to the whole railway traffic, with, on average, 450 regional trains that, every day, approach the station of Bologna. Only the 10% crosses the node: this data is quite fundamental, showing how much important the railway node of Bologna is with respect to the whole Emilia-Romagna region. The figure 30 provides an overview of the regional railway traffic:

[2] The data are relative to the 2017 winter scheduling

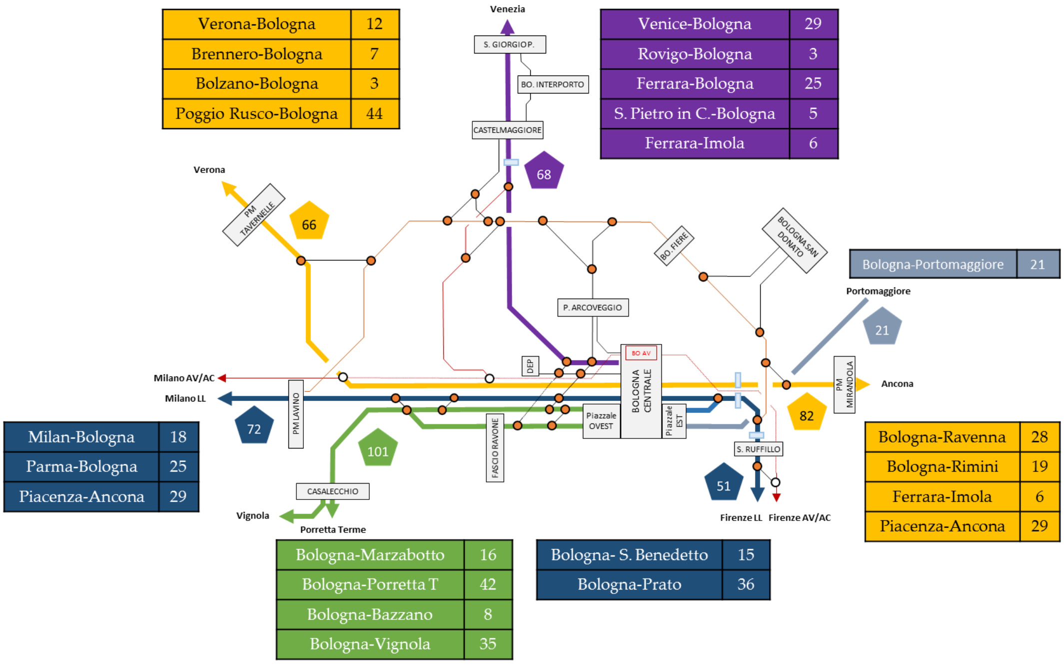


Figure 30 - Regional services

All the traffic running along the railway line to Verona, Casalecchio and Prato is made up by terminal trains; the main crossing railway regional services are the Piacenza-Ancona and the Ferrara-Imola ones: the first is more relevant because links Piacenza (in the north-west to Rimini in the south-east part of the region, touching all the provincial capitals except Ferrara. The railway line to Casalecchio has the biggest amount of trains and it is interested by only regional trains to Porretta or Marzabotto and to Vignola or Bazzano (this line is managed by FER). Then there are the lines to Rimini, Milan, Venice, Verona and Prato. High-speed trains also run the Venice and Verona lines, while the other by long haul one.

6.1.2 Long haul services

It represents the lowest percentage and it includes InterCity, Euro City, Euro Night and Frecciabianca trains. About the eighty percent of the trains crosses the railway node: the main service links the cities of Turin and Milan to those located along the Adriatic coast. The next figure, shows, briefly, these data:

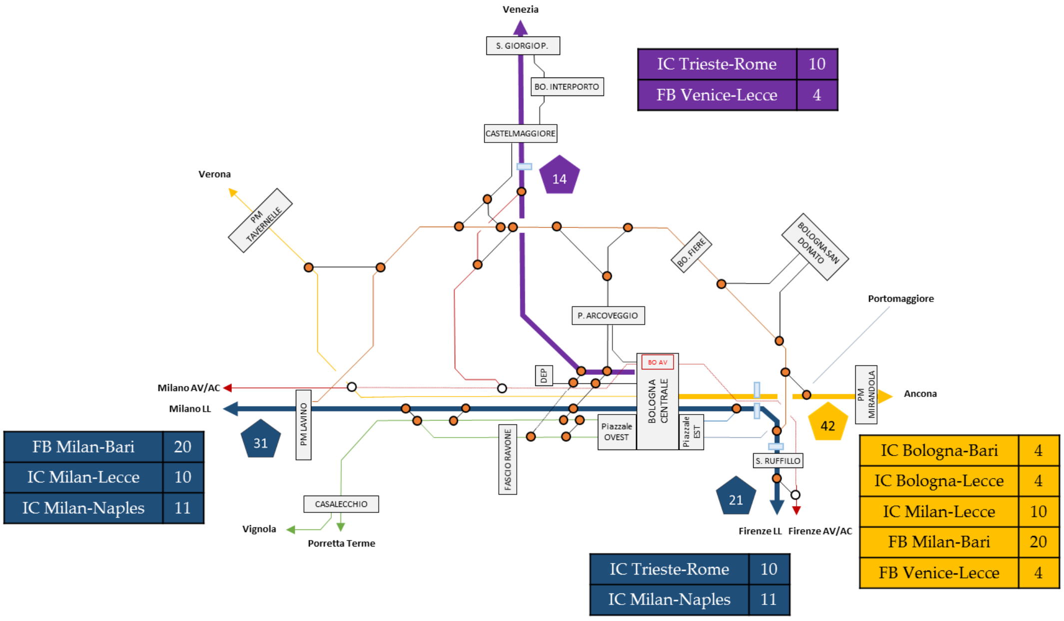


Figure 31 - Long haul services

The biggest amount of trains run along the Adriatic line to reach the cities in the south of the Italy, coming from the north of the country and from Venice: in both situations, the trains do not continue on the natural prolongation of their tracks, so as it occurs for the services coming from Trieste to Rome. The situation is different for the long-haul trains that reach the city of Rome and Naples from Milan. At the end, an important assessment could be made: this kind of railway supply is significant along the Adriatic corridor, because a high-speed line does not serve the east Italian coast, as it happens on the other side of the country, and, for this reason, this is the unique service capable to connect very distant cities between them, such as Milan and Bari. Finally, the cities of Verona and Venice do not have a good long-haul railway supply for the Adriatic corridor, so an interchange at Bologna Centrale is needed: in the next paragraphs, it will be possible to evaluate how this kind of integration is not satisfied.

6.1.3 High-speed services

They include those services that run, partially or totally, along a high-speed line. Infect, there are those trains travelling along the HS axis between Turin-Milan-Rome-Naples or those that use only the first segment from Naples or Rome to Bologna to reach Venice and Verona across the historical line. The following figure, shows, the high-speed railway traffic in the interchange node of Bologna:

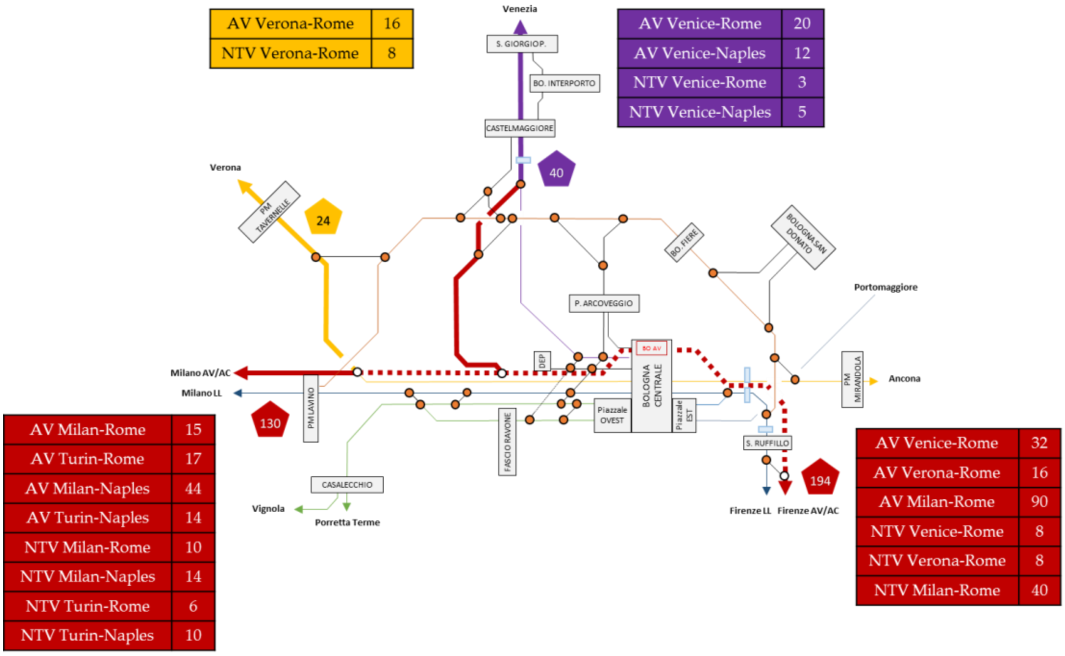


Figure 32 - High-speed services

This kind of service is constantly growing: according to the 2017 winter scheduling, the high-speed trains represents the twenty-seven percent of the total railway traffic in the node of Bologna. About the 65% of the trains crosses the station to reach the cities of Milan and Turin, the 20% the city of Venice and the last 15% the city of Verona and Bolzano. Until the month of December, the trains to Venice were forced to stop in the surface station: now, thanks to the opening of the new ramification, also these can stop in the underground station. This implies a complete separation of the regional and long-haul flows from the high-speed railway traffic (the unique case in Italy) and, therefore, this gives the possibility to optimize the capacity of the surface station to improve and increase the performances of the local services.

7. The actual scenario in the Bologna's interchange node

Nowadays, according to the 2017 winter scheduling, about 700 passenger trains crosses the railway node of Bologna: the regional service represents the most important slice of the cake in terms of daily traffic, followed by the high-speed and by the long-haul trains. The aim of this chapter is to give information about the different traffic products circulating in this node in terms of standardisation, functions and specializations and how it is possible to classify them according these parameters.

7.1 The structure of the railway services

The first step to evaluate the level of the integration is to identify all possible traffic products: they differ each other according to their standardisations, functions and specializations. For example, it is possible to have a railway service with a periodic timetable, but the stops are not always the same, or a service which scheduling changes continuously over the day or a service running along a line but the terminal, the stops and the timetable vary. According to these assessments, it could be useful defining a ranking to classify each single traffic product:

- A_SPOT: the service is strongly irregular with occasional trips, where the stops and the timetable are variable, so as the terminals;
- B_NON CAD: the service is no more irregular, the terminals are fixed but the timetable and the stops are still variable;
- B_CAD NON-SIMM: the service is no more irregular, the terminals are fixed so as the timetable (the arrival and the departure minutes in one station are always the same), but the system is no symmetric and the stops are variable (this means that it can have a periodic timetable in one terminal and no in the other because the running times are different);
- B_CAD SIMM: the service has the same characteristics of the previous one, but, now, it is symmetric too;
- C_NON CAD: the service has fixed terminals and stops (the running time is always the same), but the timetable is not regular;
- D0_CAD SIMM: the service provides periodic trips where the stops and the terminals are always the same and the timetable is periodical and symmetric (the trains leave and arrive continuously at the same minute) and the programmed travel time never changes (pure system);
- D1_CAD SIMM: the service is very similar to the previous one but, sometimes, the stops can change and the running time can be a little bit different;

- D2_CAD NON-SIMM: the service has the same characteristics of the previous ones but the timetable, in despite of it is constant, it is not symmetric.

The following table provide a briefly recap:

Terminals	Stops	Timetable	Service structure
Variables	Variables	Variables	A
Fixed	Variables	Variables	B
Fixed	Fixed	Variables	C
Fixed	Fixed	Periodic	D

Table 2 - Service structures

7.2 Analysis of the traffic products in the node of Bologna

To analyse the actual scenario in the interchange node of Bologna, the data referred to all the railway traffic on any workday were collected in order to identify, corridor by corridor, the different traffic products approaching the railway station of Bologna, trying to classify them according the ranking defined in the above table.

Corridor	Origin	Destination	Stop	Class	Total Trains	Traffic Product	Service Structure
Bologna-Verona	Poggio Rusco	Bologna	Terminal	REG	20	REG Poggio Rusco-Bologna	D0_CAD SIMM
	Bologna	Poggio rusco	Terminal	REG	20		
	Verona	Bologna	Terminal	RV	11	RV (Brennero/Bolzano)/Verona-Bologna	D1_CAD SIMM
	Bologna	Verona	Terminal	RV	11		
Bologna-Venezia	Ferrara	Bologna	Terminal	REG	17	REG (Rovigo)-Ferrara-Bologna	B_CAD NON SIMM
	Bologna	Ferrara	Terminal	REG	17		
	San Pietro C.	Bologna	Terminal	REG	3	REG S Pietro C-Bologna	B_CAD NON SIMM
	Bologna	San Pietro C.	Terminal	REG	2		
	Venezia	Bologna	Terminal	RV	14	RV Venezia-Bologna	D1_CAD SIMM
	Bologna	Venezia	Terminal	RV	14		
Bologna-Piacenza	Parma	Bologna	Terminal	REG	19	REG Parma/Modena-Bologna	B_CAD SIMM
	Bologna	Parma	Terminal	REG	19		
Bologna-Casalecchio	Bologna	Porretta Terme	Terminal	REG	28	REG Bologna-Porretta/Marzabotto	D2_CAD NON SIMM
	Porretta Terme	Bologna	Terminal	REG	28		
	Bologna	Vignola	Terminal	REG	20	REG Bologna-Bazzano/Vignola	D2_CAD NON SIMM
	Vignola	Bologna	Terminal	REG	21		
Bologna-Prato	Bologna	San Benedetto SCP	Terminal	REG	22	REG Bologna-S.Benedetto SCP/Prato	D1_CAD SIMM
	San Benedetto SCP	Bologna	Terminal	REG	23		
Bologna-Ravenna	Bologna	Ravenna	Terminal	REG	19	REG Bologna-Ravenna/(Rimini)	B_CAD SIMM
	Ravenna	Bologna	Terminal	REG	16		
Bologna-Rimini	Bologna	Rimini	Terminal	REG	6	REG Bologna-Rimini	B_NON CAD
	Rimini	Bologna	Terminal	REG	6		
Bologna-Portomaggiore	Portomaggiore	Bologna	Terminal	REG	11	REG Bologna-Portomaggiore	B_CAD NON SIMM
	Bologna	Portomaggiore	Terminal	REG	10		
Ferrara-Imola	Ferrara	Imola	Crossing	REG	5	REG (Ferrara/San P.C.)/Bologna-Imola/Rimini	A_Spot
	Imola	Ferrara	Crossing	REG	5		
Piacenza-Ancona	Piacenza	Ancona	Crossing	RV	17	RV Piacenza/Bologna-Rimini-Pesaro-Ancona	D2_CAD NON SIMM
	Ancona	Piacenza	Crossing	RV	18		

Table 3 - Traffic product and service structure of the regional service

The table number 3 shows the entire regional traffic approaching the railway station of Bologna corridor by corridor, defining if they are terminal or crossing trains, the kind of the class (REG or RV according to the classification provided at the beginning of this paper), the total number of trains running per day and, finally, the service structure. This gives, immediately, an overview on the whole system: most of the traffic products have a periodic timetable, which is, generally, a priori condition to try to build an integrated network, even if, in most cases, the scheduling is not symmetric, implying connection times different per direction. The worst situation is related to the REG (Ferrara/San P.C.)/Bologna-Imola/Rimini traffic product which service structure is A_SPOT because it is made up by occasional trips where the terminals are not always the same (sometime, it is Ferrara or San Pietro in Casale from the north and it is Imola or Rimini from the south), so as the timetable. It is important to focus the attention on the REG Bologna-Rimini traffic product: despite it links two main cities, the service is not structured with an irregular timetable and the stops are not always the same. Finally, all the others traffic products have a periodic timetable, even if it is, quite often, not symmetric.

Corridor	Origin	Destination	Stop	Class	Total Trains	Traffic Product	Service Structure
Verona-Roma	Verona	Roma	Crossing	ES*	10	AV Bergamo/Bolzano/Verona-Roma/Napoli	D2_CAD NON SIMM
	Roma	Verona	Crossing	ES*	10		
	Verona	Roma	Crossing	ES*	4	NTV Bergamo/Bolzano/Verona-Roma/Napoli	D2_CAD NON SIMM
	Roma	Verona	Crossing	ES*	4		
Venezia-Roma	Venezia	Roma	Crossing	ES*	18	AV Trieste/Venezia-Roma/Napoli	D1_CAD SIMM
	Bologna	Venezia	Crossing	ES*	17		
	Venezia	Roma	Crossing	ES*	4	NTV Trieste/Venezia-Roma/Napoli	D1_CAD SIMM
	Bologna	Venezia	Crossing	ES*	4		
Milano-Bari	Milano	Bari	Crossing	ES*	10	FB Torino/Milano-Adriatica	D2_CAD NON SIMM
	Bari	Milano	Crossing	ES*	10		
Milano AV-Roma AV	Milano	Roma	Crossing	ES*	15	AV Torino/Milano-Roma/Napoli STANDARD	D2_CAD NON SIMM
	Roma	Milano	Crossing	ES*	15		
	Milano	Roma	Crossing	ES*	10	AV Torino/Milano-Roma/Napoli RINFORZO FAST	D2_CAD NON SIMM
	Roma	Milano	Crossing	ES*	10		
	Torino	Roma	Crossing	ES*	6	AV Torino/Milano-Roma/Napoli VIA PORTA GARIBALDI	D2_CAD NON SIMM
	Roma	Torino	Crossing	ES*	6		
	Milano	Roma	Crossing	ES*	13	NTV Torino/Milano-Roma/Napoli STANDARD	D2_CAD NON SIMM
	Roma	Milano	Crossing	ES*	12		

Table 4 - Traffic product and service structure of the high-speed service

The table 4 provides the list of the high-speed services approaching the interchange node of Bologna. The most important link is the Rome-Milan one, served by different traffic products, managed by Trenitalia and by Nuovo Trasporto Viaggiatori. The first traffic product is called "standard" and it stops both at Firenze SMN and Bologna AV; the second is the reinforcement of the "fast" which has Bologna AV as unique stop; the third, with the lowest supply, don't arrive at Milano C.le but at Milano Porta Garibaldi to go on to Turin; the last one is the "fast" link because it don't stop during its run (it is not reported in the above because it provides only the services stopping at Bologna). However, all the services have a periodic timetable, even if only the link Venice-Rome has a symmetric scheduling.

The figure 33 gives a general overview of the interchange of Bologna, focusing on the railway lines merging the station.

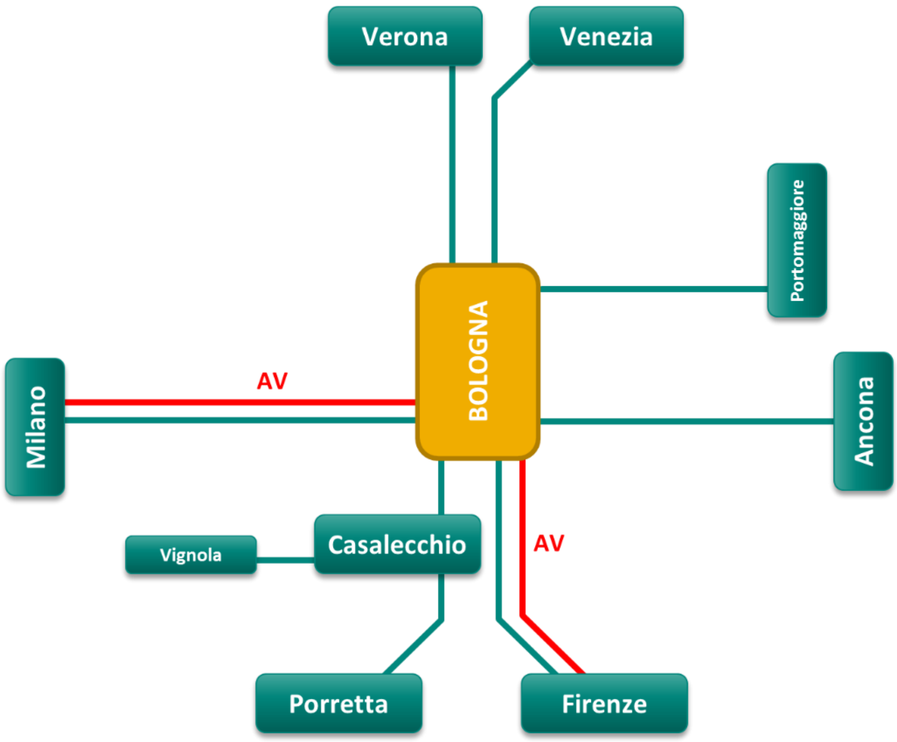


Figure 33 - Overview of the railway node of Bologna

The following picture give, corridor by corridor, a graphical representation of all circulating traffic products. The biggest red circles represent the stations belonging to the first hierarchical level, the white one to the second; the stations of the third level are depicted by pink circles and finally, the yellow ones those appertaining to the fourth. The dotted circles represent those stops that are not made by all the runs.

7.2.1 Traffic products on the Adriatic corridor

Figure 34 - Traffic products on the Adriatic corridor

This is one of the most crowded corridor all over Italy, with about 150 trains per day running along it, belonging to all four hierarchical levels (ES*, IC, RV and REG). Consequently, the different traffic products have dissimilar specializations, functions and standardizations and this implies, mostly, that the running trains have different commercial speeds, reducing, very much, the regularity and the reliability of the services. Moreover, the standardization level of the regional traffic products is very low: this means that the amount and the stations themselves changes trip by trip, making the traffic product a little regular. Therefore, a possible intervention scenario could be the harmonization of the local and of the long-haul trains until Rimini, trying to improve the quality of the rail service making the regional traffic products more regular and avoiding that they have to give the double right of way to the long-haul trains. The interchange nodes are: Castel Bolognese (line to Ravenna), Faenza (to Ravenna and to Florence), Rimini (to Ravenna) and Falconara Marittima (to Rome).

7.2.2 Traffic products on the Venice corridor

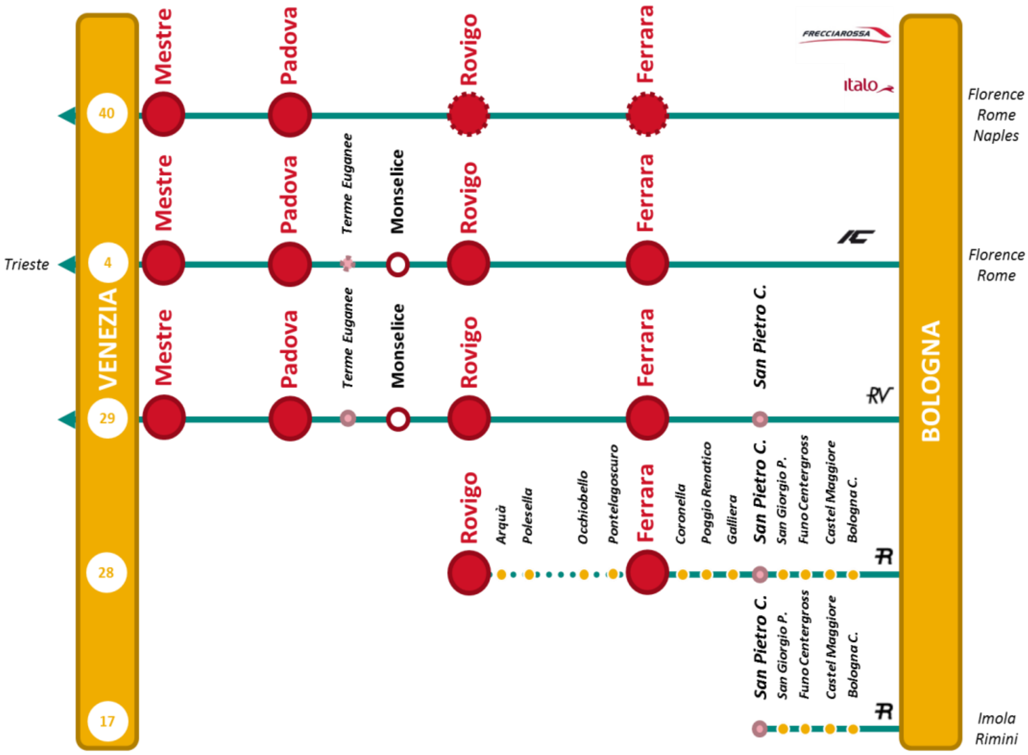


Figure 35 - Traffic products on the Venezia corridor

More than one hundred trains per day run along this corridor: in this case, also, there are the all the categories for each hierarchical level. However, all the traffic products are more regular than the previous situation, with a very good level of standardisation, even if the functions of the IC and the RV services are very similar. Moreover, the number of interchange nodes is very high: Ferrara (line to Ravenna), Rovigo (to Chioggia and to Verona), Monselice (to Verona), Padova (to Verona, Treviso and Belluno) and Mestre (to Treviso, Trieste and Udine). This could be make very difficult to plan an integrated network due to the several constraints to take into account.

7.2.3 Traffic products on the Verona corridor

Figure 36 - Traffic products on the Verona corridor

Less than one hundred trains per day running along this corridor and, differently from the previous two situations, nevertheless the high-speed traffic to Verona will increase in the next year. There is not the railway service related to the second hierarchical level, because, all the municipalities located near the railway line, are not poles so big to require this kind of service. The interchange nodes are Poggio Rusco (lines to Ferrara and to Suzzara), Nogara (to Mantova, Rovigo and Monselice) and Isola Della Scala (to Monselice and Rovigo).

7.2.4 Traffic products on the historical line to Milan

Figure 37 - Traffic products on the historical line to Milan

The figure 37 shows all the traffic products on the historical line to Milan. It is interested by a railway traffic similar to that on the Adriatic corridor, where the service specialization is related to all the four hierarchical levels. The long-haul one connects the main poles on the north of Bologna to Milan, while the regional one links all the municipalities each other. The traffic products are strongly standardised and the functions of the different services are very clear. There are several interchange nodes, due to the various connections with the FER network: Modena (lines to Sassuolo, Suzzara and Mantova), Reggio Emilia (to Sassuolo, Guastalla, Ciano d'Enza), Parma (to La Spezia and Cremona) so as Fidenza and, finally, Codigoro (to Cremona).

7.2.5 Traffic products on the Casalecchio corridor

Figure 38 - Traffic products on the Casalecchio corridor

There are only two regional trains running along this railway line with stations of the fourth hierarchical level. They share a little segment from Bologna to Casalecchio Garibaldi and, then, one goes on to Porretta Terme (this line is managed by RFI), while the other to Vignola, managed by FER. Obviously, the standardisation level is very high. There are not interchange nodes, so the network integration planning does not have to consider this kind of constraints.

7.2.6 Traffic products on the historical line to Florence

The next figure (number 39) represents the railway traffic on the historical line to Florence: there are only two traffic products. The first serves the stations of the second hierarchical level as Prato and Firenze Rifredi (these trains do not stop at Firenze SMN), the second those of the fourth. The standardisation level is very good, so as the function of each traffic product is very clear. The interchange nodes are Prato (lines to Pistoia) and Firenze Rifredi (lines to Pisa, Siena and Empoli).

Figure 39 - Traffic products on the historical line to Florence

7.2.7 Traffic products on the Portomaggiore corridor

The figure 40 depicts the regional traffic on the Portomaggiore corridor: the hierarchical level is unique, since this service is purely a local and a suburban one. Only the station of Portomaggiore is an interchange node, where it is possible to reach Ferrara and Ravenna.

Figure 40 - Traffic product on the Portomaggiore corridor

7.2.8 Traffic products on the high-speed axis

The last picture (number 41) shows the traffic products on the high-speed and high-capacity Italian lines and they are divided according to their functions and to which railway undertaking they belong. Trenitalia offers different services on the Rome-Milan connection (standard, fast and reinforcement of the fast as it has already mentioned before), a periodic service between Venice and Rome with all stops and one between the Italian capital and Verona (16 runs according to the 2017 winter scheduling). Nuovo Trasporto Viaggiatori provides a fast link between Rome and Milan (not represented so as for Trenitalia) and a standard service with all stops. Moreover, it guarantees relations between Rome and Venice and between Rome and Verona (nowadays there are only eight runs, but this number is increasing). A lot of trips start from Naples, and some, along the Rome-Milan connection, end up in Turin. The services are all regular with a high level of standardisation. Finally, each node is, of course, an interchange node.

Figure 41 - Traffic products on the Italian high-speed axis

8. The integration level in the Bologna's interchange node

The aim of this section is to provide to the readers the main results coming from the evaluation of the integration level in the railway node of Bologna. At first, to calculate it, the specializations, the standardisations and the functions of the different approaching traffic products are necessary to know. All this information can be obtained in the previous chapter. In addition, to measure the integration level, the relations between the different traffic products are fundamental to understand: for example, if between two railway services the integration occurs at Bologna or in another station, how much large the potential demand basin is with respect to an O-D relation and with respect to the node of Bologna. This means to calculate the role that this interchange node plays in the integrated network planning for all these traffic products. Therefore, at the beginning, it is necessary to analyse how the different traffic products are coupled each other and what is the importance of Bologna's node in these connections.

8.1 The railway node of Bologna

The following table is the interchanges matrix of Bologna's station, according to the nowadays railway supply, showing for each corridor and for each hierarchical level where the interchange is needed. For example, many of them occur at Bologna, generally, between those relations belonging to different corridors and different hierarchical levels. Some relations are served by direct railway services as it happens for the stations of the first, second and third hierarchical level on the Adriatic corridor and on the historical line to Milan and as it occurs for the cities served by the high-speed trains. Finally, there are those relations which are not interesting to study the integration level in Bologna because or the interchange occurs elsewhere (the blue cells) or they include stations of the same hierarchical level of the same railway corridor. Finally, to recap, the main target is to study the integration between:

- traffic products of the same hierarchical level belonging to two different railway lines (e.g. Verona-Bologna AV – Bologna-Bari LH);
- traffic products of different hierarchical level and railway line (e.g. Venezia-Bologna RV – Bologna-Casalecchio REG),

- traffic products of the same railway line but having a different function (e.g. Verona-Bologna AV – Bologna-Poggio Rusco REG).

The relations which are not interesting for the study are between:

- traffic products of the same railway line and same hierarchical level where there is a direct link (e.g. Rimini-Bologna REG – Bologna-Imola REG);
- traffic products of different railway lines where the interchange occurs elsewhere (e.g. Porretta Terme-Casalecchio REG – Casalecchio-Vignola REG);
- relations served by direct services (e.g. Roma-Milano HS, Piacenza-Ancona RV).

	LIVELLO	MI/(TO)	FI/RM/(NA)	Milano LL				Adriatica				Venezia				Verona			Firenze LL		Casalecchio	Portomaggiore
LIVELLO		0°	0°	1°	2°	3°	4°	1°	2°	3°	4°	1°	2°	3°	4°	1°	3°	4°	2°	4°	4°	4°
MI/(TO)	0°	no	dir	dir	dir	dir	Bo	dir	Bo	Bo	Bo	dir	Pd	Bo	Bo	dir	Bo	Bo	Fi	Bo	Bo	Bo
FI/RM/(NA)	0°	dir	no	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	dir	Bo	Bo	dir	Bo	Bo	FI	Bo	Bo	Bo
Milano LL	1°	dir	Bo	no	dir	dir	dir	dir	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	Bo	Bo	Bo
	2°	dir	Bo	dir	no	dir	dir	Bo	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	Bo	Bo	Bo
	3°	dir	Bo	dir	dir	no	dir	Bo	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
	4°	Bo	Bo	dir	dir	dir	no	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
Adriatica	1°	dir	Bo	dir	Bo	Bo	Bo	no	Rn	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
	2°	Bo	Bo	dir	dir	dir	Bo	Rn	no	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
	3°	Bo	Bo	dir	dir	dir	Bo	Bo	dir	no	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
	4°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	dir	no	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo
Venezia	1°	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	no	dir	dir	Bo	dir	Bo	Bo	dir	Bo	Bo	Fe
	2°	Pd	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	no	dir	Ro	Pd	Pd	Bo	dir	Bo	Bo	Fe
	3°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	dir	no	dir	Bo	Bo	Bo	Bo	Bo	Bo	Fe
	4°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Ro	dir	no	Bo	Bo	Bo	Bo	Bo	Bo	Fe
Verona	1°	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	Pd	Bo	Bo	no	dir	Bo	Fi	Bo	Bo	Bo
	3°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Pd	Bo	Bo	dir	no	dir	Bo	Bo	Bo	Bo
	4°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	no	Bo	Bo	Bo	Bo
Firenze LL	2°	Bo	Fi	dir	dir	Bo	Bo	Bo	Bo	Bo	Bo	dir	dir	Bo	Bo	Fi	Bo	Bo	no	dir	Bo	Bo
	4°	Bo	Fi	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	dir	no	Bo	Bo
Casalecchio	4°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	no	Bo
Portomaggiore	4°	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Bo	Fe	Fe	Fe	Fe	Bo	Bo	Bo	Bo	Bo	Bo	no

Table 5 - Interchange matrix of Bologna

Then, the following table shows the interchange index in terms of percentage corridor by corridor:

INDICE DEGLI SCAMBI [%]	MILANO AV	ROMA AV	Milano LL	Adriatica	Venezia	Verona	Firenze LL	Casalecchio	Portomaggiore
MILANO AV	0.00	0.00	0.10	0.70	0.67	0.40	0.33	1.00	1.00
ROMA AV	0.00	0.00	0.80	0.90	0.78	0.60	0.17	1.00	1.00
Milano LL	0.10	0.80	0.00	0.23	0.80	0.76	0.60	1.00	1.00
Adriatica	0.70	0.90	0.23	0.09	0.90	0.90	0.90	1.00	0.30
Venezia	0.67	0.78	0.80	0.90	0.00	0.56	0.78	1.00	0.35
Verona	0.40	0.60	0.76	0.90	0.56	0.10	0.70	1.00	0.60
Firenze LL	0.33	0.17	0.60	0.90	0.78	0.70	0.00	1.00	1.00
Casalecchio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
Portomaggiore	1.00	1.00	1.00	0.30	0.35	0.60	1.00	1.00	0.00

Table 6 - Interchange index matrix of Bologna C. le

Each single cell represents the percentage of the interchanges between the two railway lines occurring in the station of Bologna and its aim is to provide a priori knowledge on the role of this interchange node in the connection of two different corridors. High values, depicted by red cells, represent those relations that need, very often, an interchange at Bologna. Vice versa, low values match those O-D relations belonging to two different railway lines that don't require an interchange at Bologna because it occurs elsewhere or they are direct linked. For example, to reach the Casalecchio corridor from any origins, an interchange at Bologna is mandatory, so as in the opposite direction. Focusing on the high-speed line, the link with Rome needs a lot of interchanges at Bologna, unlike the connection with Milan, since, many of them happen in other stations, mainly for the connections with the Verona and Firenze LL corridor. An important result is the following: excluding the high-speed railway services that cross the station of Bologna, all the other traffic products are terminal, except the long-haul trains and the RV Piacenza-Ancona, implying, therefore, a lot of interchanges, as the table shows and, finally, an accurate network integration planning in order to satisfy all the relations. Obviously, there will be other parameters to consider to weight which relations are the most important to match such as the transport demand, but, at the beginning, without this kind of data, the above table represents the unique way to understand, with the actual supply, which relations need strongly a great integration.

8.2 Integration level measuring with IntegroSKOPIO© for single modules

The aim of this paragraph is to provide a practical application of the KPI IntegroSKOPIO© in order to evaluate the actual integration level between the high-speed trains to and from Rome and Milan and the long-haul and regional services, useful to reach the cities and the municipalities in the Emilia-Romagna region. The calculation considers all the train belonging to the carrier service, in this case all the high-speed trains, and those to the feeder service that, in function of the hierarchical level of the considered station, can vary. Obviously, the supply of the feeder service decreases according to the level of the taken into account stop, because the amount of stopping trains will be lower. The computation considers all the possible stations, subdividing them according to the railway supply: infect, in the following pages, for each station, there is a list of the others having the same characteristics in terms of stopping trains. The evaluation of the number of good connections is made considering a minimum connection time equal to ten minutes and a maximum one equal to twenty-five minutes. Ten minutes is the minimum time used in the biggest stations, while twenty-five is the maximum according to this paper, considering a frequency of the feeder service of one train every hour, for which, having a connection time greater than twenty-five minutes means a very bad level of integration.

Before studying the integration level with the high-speed axis, it is useful to know how much big the potential demand basin for each direction in the surrounding area of the station is. This allows to understand how much important the integration among the different traffic products is and how many potential passengers are directly involved in this process. To analyse the amplitude of these basins, the actual railway supply was considered and, for each O-D relation, the fastest link. Therefore, planning an efficient integrated network means improving the quality and the attractiveness of the service and increasing the percentage of the railway modal share. The following pictures individuate the segment demand along each corridor interested in having good connection time at Bologna, considering the possible connections with Rome and Milan.

8.2.1 Potential demand: connections with Rome

The target of the following picture is to provide an overview on the amplitude of the potential demand basin directly involved in having a good connection time at Bologna with the high-speed trains to and from Rome. It is quite easy to understand the influence that the node of Bologna has on possible exchanges for the high-speed trains from and to Rome: the blue areas include all the stations that are reachable only through an interchange at Bologna. For example, on the Adriatic corridor, all the stations located after Pesaro, have a faster link with Rome passing through Falconara Marittima, while for the stations of Isola della Scala and Buttapietra it is more convenient interchanging at Verona, as well as for the localities north of Piacenza at Milano C.le and for the municipalities near Padova and

Venice. Therefore, to evaluate the integration level, only the stations included in the blue areas will be considered.

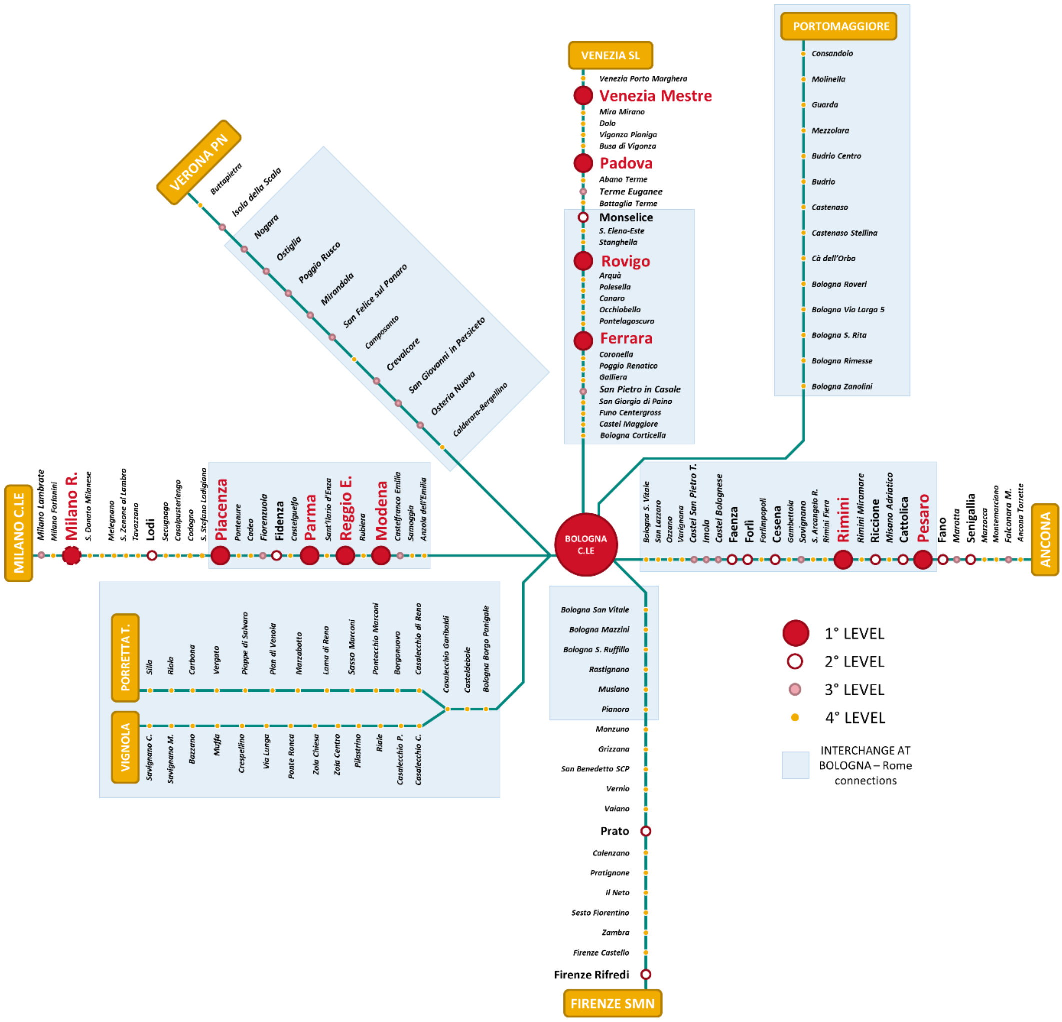


Figure 42 - Potential demand segment with Rome

8.2.2 Potential demand: connections with Milan

The same considerations are made with the high-speed trains to and from Milan: obviously, the amplitude of the potential demand basins is lower than that considered for Rome. This is due to the relative proximity of the city of Milan with the Emilia-Romagna region and due to different long-haul and regional trains that, directly, link Milan with the municipalities along the Milano LL and Adriatic corridor. Infect, on the first railway line only Castelfranco Emilia, Samoggia and Anzola dell'Emilia have the fastest link to Milan passing through Bologna, while on the second, only the localities until Rimini. Moreover, also the basins on the Verona and on the Venice corridor are smaller: the first up to Poggio

Rusco and the second up to Rovigo; since the quickest relations are those for which the exchange occurs at Verona and Padova. Finally, unlike the others, the basins along the historical line to Florence is larger up to Prato.

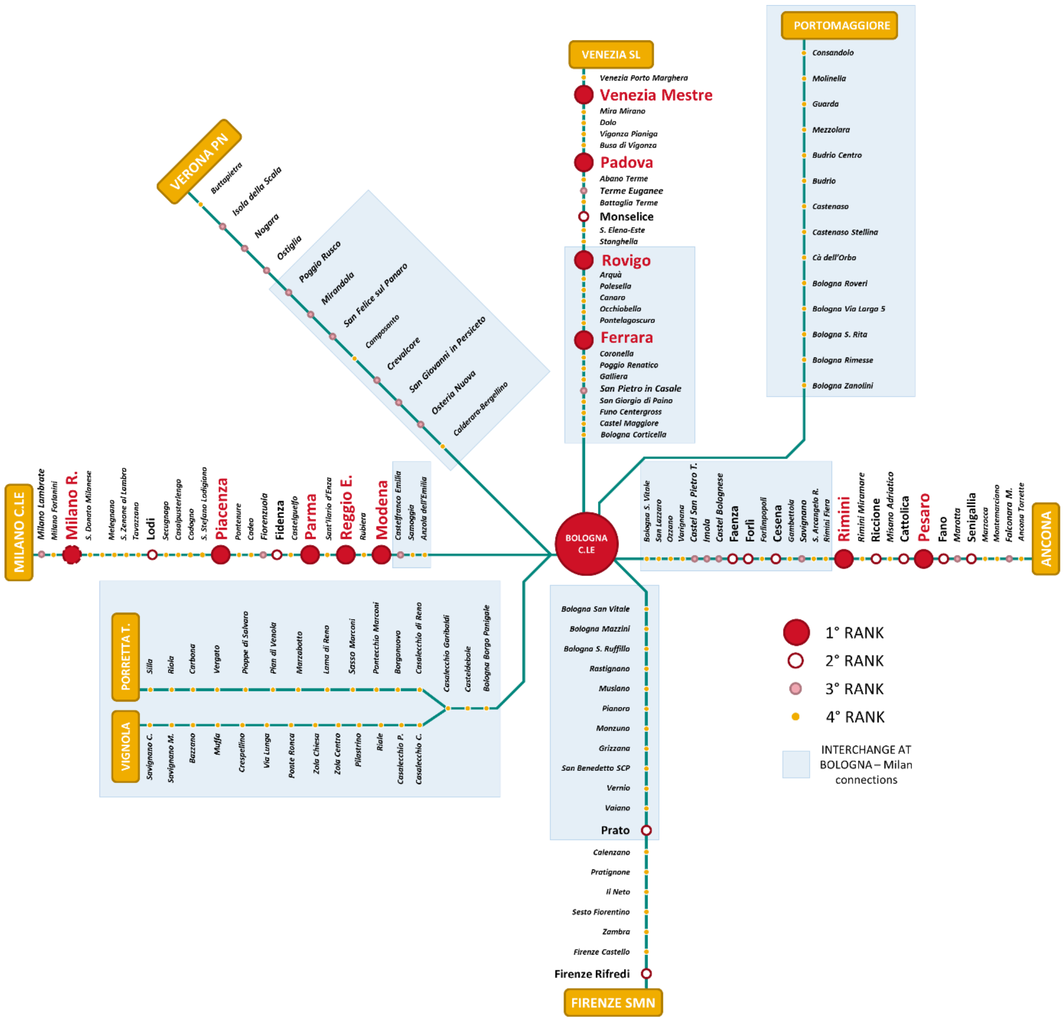


Figure 43 - Potential demand segment with Milan

Now, focusing only on the stations included in the basins for the connections with Rome and Milan, the next paragraphs will provide the results obtained with the KPI IntegroSKOPIO© for single modules, to evaluate, station by station, the integration level at Bologna C.le. Only for the Adriatic corridor, the charts reporting the results will be provided as an example for all the others, while, at the end, a chart depicting the final outcome corridor by corridor will be presented.

8.2.3 Integration level with the Adriatic corridor

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Rimini and Pesaro of themselves,
- Cesena of Faenza and Forlì;
- Cattolica of Riccione;
- Imola of Castel San Pietro Terme and Castelbolognese;
- Savignano of itself;
- Ozzano dell'Emilia of Bologna San Vitale, San Lazzaro di Savena and Varignana;
- Gambettola of Forlimpopoli and S. Arcangelo di Romagna;
- Misano Adriatico of Rimini Miramare.

The results collected, with respect to the connections with Rome, are, globally, quite good, considering both the even and uneven direction. The best link in terms of time coordination is the Rome-Misano Adriatico, even if it has one of the lowest integration index due to the little railway supply for this station. However, this situation is widely diffused because there are, every day, about 120 trains to and from Rome, so much considering the feeder services. The IntegroSKOPIO© value could be improvable for the Roma-Rimini and vice versa connection, taking into account that this station has the best railway supply (it is a first level stop so as Pesaro). The worst result is referred to the Roma-Gambettola relation, with only two connections over the seven daily trains leaving from Bologna, instead the opposite direction has one of the best value in terms of time coordination.

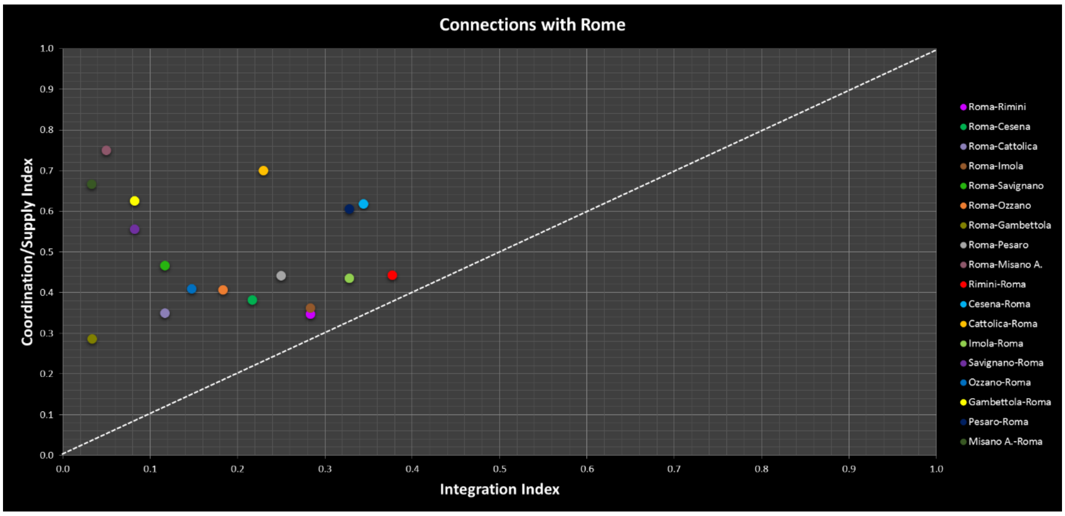


Figure 44 – IntegroSKOPIO© between the Adriatic corridor and Rome

Considering the connections with Milan (see figure 45), good results are related to the uneven direction to Cesena, Gambettola and Savignano sul Rubicone: this means that the traffic products are not symmetric at Bologna, causing different connection times for the two directions. The link between Imola and Milan gives an IntegroSKOPIO© value located on the boundary of the possible domain, this because the supply of the feeder and the main service is quite the same. Finally, very bad results describe the behaviour of the even relation to Savignano and Gambettola, with zero good connections and the Ozzano dell'Emilia-Milan and vice versa with respectively three and four relations over more than twenty trains for the feeder service.

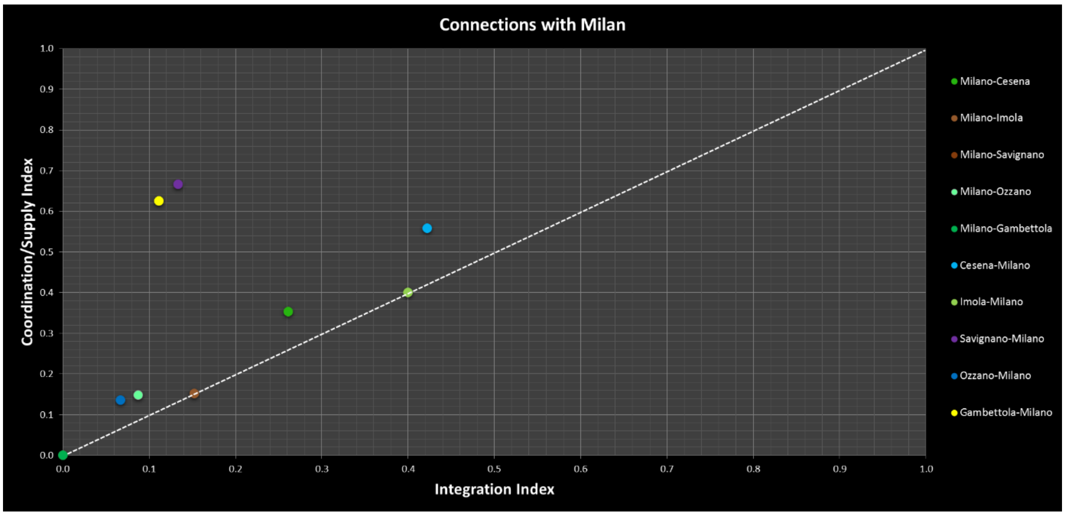


Figure 45 – IntegroSKOPIO© between the Adriatic corridor and Milan

8.2.4 Integration level with the Venice corridor

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Padova of Venice;
- Rovigo, Ferrara, Monselice, Terme Euganee, San Pietro C. of themselves;
- San Giorgio di Piano of Bologna C., Castelmaggiore and Funo C.;
- Poggio Renatico of Galliera and Coronella,
- Polesella of Pontelagoscuro, Occhiobello, Canaro and Arquà.

With respect to the connections with Rome, very good results are related to the station of Polesella, even if the railway supply is very low. However, the integration level is, globally satisfactory, considering all possible origins and destinations. Nevertheless, the amount of connections could be improved for the main cities such as Ferrara and Rovigo, where, the only four direct links per day with Rome are not sufficient. Also in this case, the main problem is the big difference between the supply of the carrier and that of the feeder one.

Differently from the previous considerations, the integration level with the high-speed trains to and from Milan is quite low, where, everywhere, the number of good connections is always less than the half of the maximum one. Even, the coordination index is zero for the relation Milan-Polesella and vice versa and equal to 0.13 for the Rovigo-Milan one.

8.2.5 Integration level with the Verona corridor

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Nogara of Ostigia and Isola della Scala;
- Poggio Rusco of Osteria Nuova, San Giovanni P., Crevalcore, San Felice SP, Mirandola;
- Calderara of Camposanto.

Unlike the other two corridors, the integration level between Rome and the traffic products running along this railway line is quite satisfactory, with not acceptable values only for the even and uneven direction with Nogara. The results obtained for the other stations are a little bit greater, even if, only thirteen connections over thirty-three possible ones cannot be considered as the target in a network integration planning. The nearness of the results symbolize that the traffic products are quite symmetric. Finally, also in this case, all the integration indices are very low.

The unique relations taken into account to study the integration level with Milan are those for Poggio Rusco and Calderara, because the others are outside the potential demand basins with respect to Bologna. They are well integrated each other, with a coordination index very high, considering the previous examples, as well as the integration one. A possible improvement of the whole service could include an increasing of the feeder traffic product supply.

8.2.6 Integration level with the historical line to Milan

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Modena, Piacenza, Fidenza, Castelfranco Emilia, Fiorenzuola, Lodi and Casalpusterlengo of themselves;
- Parma of Reggio Emilia;
- Rubiera of Anzola dell'Emilia, Samoggia and S. Ilario d'Enza
- Cadeo of Castelguelfo and Pontenure.

Focusing on this railway line, the most important results coming from the evaluation of the integration level with the high-speed service to and from Rome. It is possible to observe how the values assumed by the IntegroSKOPIO© KPI are not homogeneously distributed in the chart, moving from very low values as for the Rome-Rubiera relation to the Fiorenzuola-Rome one with the highest number of good connections with respect to the supply of the feeder service. Other acceptable results describe the efficiency of the Fidenza-Rome and the Castelfranco Emilia-Rome links. In terms of integration index, the best connections are the Parma-Rome and the Modena-Rome ones, where, both the coordination time and the supply (both are first level station) of the feeder services are respectable. However, the differences between the even and uneven directions attest that the traffic products are not symmetric: for example, the link Parma-Rome counts thirty-six good connections, while the Rome-Parma one only twenty, at equal feeder service supply (fifty-nine trains). Finally, the collected data show how the integration for this corridor works quite well, but there are many possibilities to improve the whole railway system.

The examined relations with Milan are only four, since many of them are directly linked or have an interchange in another station. Verily, Castelfranco Emilia and Rubiera have a direct traffic product to and from Milan too, but the fastest solution contemplates the exchange at Bologna. In spite of everything, the number of good connections is enough low.

8.2.7 Integration level with the Casalecchio corridor

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Casalecchio Garibaldi of Bologna BP and Casteldebole;
- Marzabotto of Casalecchio R, Borgonuovo, Pontecchio M, Sasso M. and Lama di Reno;
- Porretta Terme of Pian di Venola, Pioppe S, Vergato, Carbona, Riola and Silla;
- Bazzano of Casalecchio C, Casalecchio P, Riale, Pilastrino, Zola C, Zola C, Ponte Ronca, Via Lunga, Crespellino and Muffa;
- Vignola of Savignano M and Savignano C.

According to the potential demand basins, all the stops belonging to these two corridors have to change at Bologna to go on to Milan and Roma and vice versa. Therefore, at the beginning, it will be more important to have a great integration level for the traffic products running on these railway lines. Focusing on the connections with Rome, the time coordination is, generally, quite good, especially with respect to the links Roma-Vignola and Roma-Bazzano (a coordination index greater than 0.7), even if the integration one is less (the feeder supply is only twenty trains per day, unlike the sixty between Rome and Bologna). This is, instead, quite important for the relation with Casalecchio Garibaldi (forty-nine trains per day), since both the traffic products to Vignola and Porretta Terme run the segment between Casalecchio G. and Bologna. Differently, the opposite directions among Vignola and Bazzano to Rome have a lower coordination index, due to the absence of symmetry. The same occurs for Porretta Terme and Marzabotto, since the uneven routes are better integrated than the even one.

The connections with the chief town of the Lombardia region are not well integrated, where, the relation Milano-Porretta Terme does not have good connections. So, the main problem related to this railway line is the completely lack of time coordination between the two traffic products, which are not symmetric too.

8.2.8 Integration level with the historical line to Florence

First, it could be useful to provide the list of the stations having the same features in terms of daily stopping trains. Each station is representative of:

- Firenze Rifredi and Prato of themselves;
- Sesto Fiorentino of Firenze Castello, Zambra, Il Neto, Pratignone and Calenzano;
- Vernio of Vaiano;
- San Benedetto SCP of Bologna SV, Bologna M, Bologna R, Rastignano, Musiano, Pianoro, Monzuno and Grizzana.

Focusing on the connections with Rome, the unique relation interesting to study is that from and to San Benedetto, since many localities located along this corridor are reachable interchanging at Florence. Despite of there is only one traffic product involved in the integration process, its quality is enough unsatisfactory, with a clear lack of time coordination.

Considering some possible connections with Milan, the amplitude of the potential demand basin is larger than that of Rome and, for this reason, the measuring of the integration level is extended up to Prato. However, the greatest number of considered train does not help an improving of the time coordination, which is still very low, or, in some cases, it is worse than before, especially on the link joining Milan to Prato and vice versa. It is legitimate to underline that this relation is served by three direct traffic products per direction, so, the interchange at Bologna is not always useful, but this solution is no the fastest. Focusing on the link to and from San Benedetto, the integration and the coordination indices are greater than the values obtained considering the connections with Rome, thanks to, on one side, a better time coordination at Bologna, with respectively twelve and seven connections in the uneven direction and the same in the opposite one, and on the other to a lower supply of the carrier service from and to Milan.

8.2.9 Integration level with the Portomaggiore corridor

Differently from the previous cases, the station of Portomaggiore is representative of all others, since there is only one traffic product circulating on this line. The results are enough good for Rome in both directions (the coordination indices are higher than 0.6), satisfactory for the link Milan-Portomaggiore, unacceptable for the contrary relation (only three connections over sixteen). In both cases, the collected data are located on the left of the chart, since the railway supply of the feeder service is very low considering that of the main one.

8.2.10 Integration level in the interchange node of Bologna

Finally, to conclude the measuring of the integration level using the KPI "IntegroSKOPIO© for single modules", the following chart provides the results for each corridor considering the connections with the Italian high-speed axis between Rome and Milan. The computation was made calculating for each possible origin and destination the supply of the two involved services and the number of good connections at Bologna, considering all the stations of each corridor and belonging to the potential demand basin. So, if the previous considerations provide a punctual representation of the integration level station by station with the high-speed trains, now, to recap, the next one offers a global view corridor by corridor. Focusing on the connections with Rome, the railway lines that are better integrated are the Portomaggiore corridor and the Milano LL one (for the second only the uneven direction). Moreover, this line has the best value in terms of integration index. Good results coming from the evaluation of the integration level with the Casalecchio and the Venice corridors and for the relations between the Adriatic line and Rome. The worst result concerns the link with the historical line to Florence, which result, can be quite reasonable taking into account the narrow amplitude of the demand basin. However, the outcomes related to the Verona corridors are not satisfactory, especially if the high level of standardization of the traffic products on this line was considered, as well as the for the Adriatic and Milano LL corridors coming from Rome.

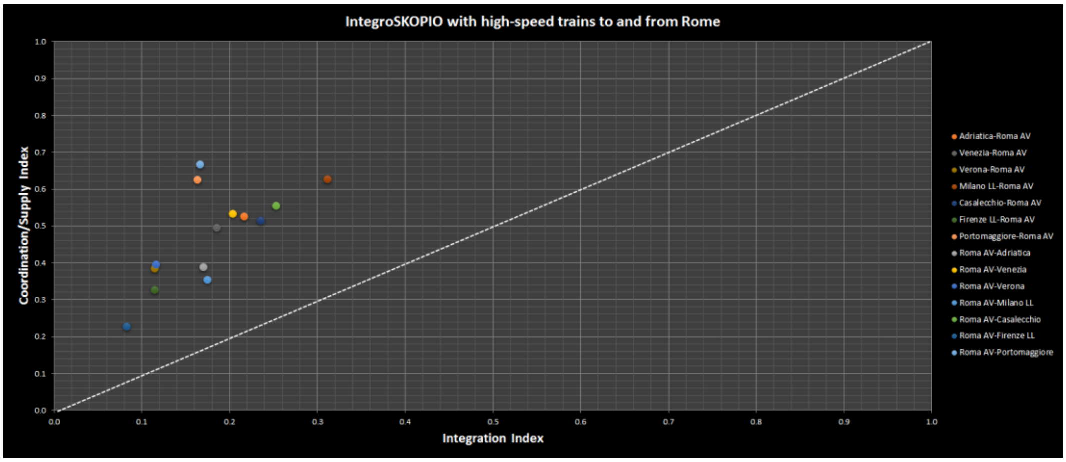


Figure 46 - Integration level with the high-speed trains to and from Rome

Globally, the integration level with the high-speed trains to and from Milan is lower, with many relations above the 0.5 value for the coordination index, except the relations with the Portomaggiore and Adriatic railway line coming from Milan. Paradoxically, the worst connection is that from the Portomaggiore line to Milan, with a coordination index equal to 0.18, so low considering that the opposite direction has the second-best value in this special ranking. There is more uniformity in the outcomes for the links with the Milano LL and the Venice corridors but a big lack of time coordination: if for the first this result could be enough acceptable considering that only three stations are included in the potential demand basin and that are directly linked with Milan too; for the second it is substandard, taking into account that two main cities are within the demand basin as Ferrara and Rovigo, as well as other many municipalities. Finally, the integration level is better with the Verona corridors for the both directions than the connections with Rome.

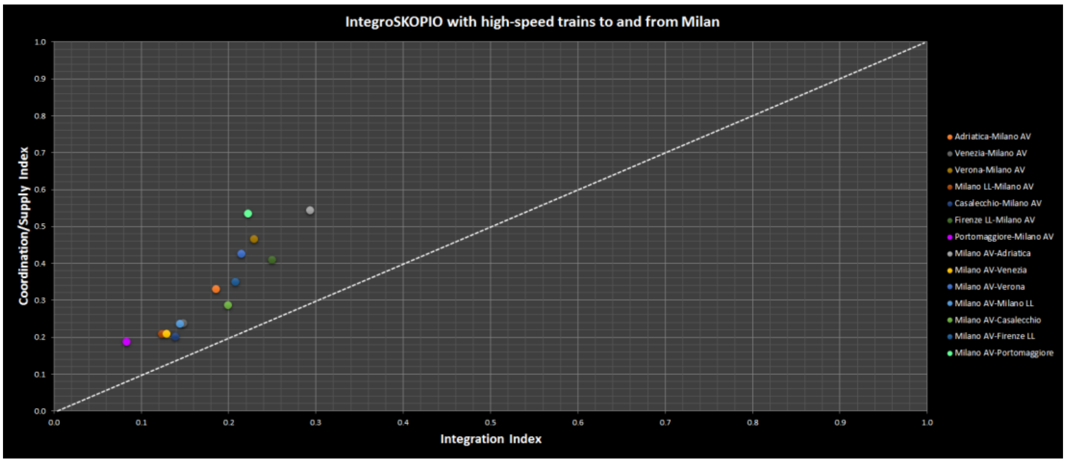


Figure 47 - Integration level with the high-speed trains to and from Milan

8.3 Integration level measuring with IntegroSKOPIO© for structured systems

The previous paragraphs provide a first practical application of the KPI IntegroSKOPIO© to evaluate the performances of the integration between the high-speed trains on the Milan-Rome axis and all the railway lines approaching the station of Bologna. Now, in the following pages, the results are calculated through the "IntegroSKOPIO© for structured systems", focusing our attention on the "clock" supply of the station of Bologna, considering all the different traffic products and their periodical timetables. In this case the estimation of the integration level is no more punctual as in the previous case, but, now, it is computed from a system point of view where its defined structure allows to understand how the "clock" of the station works hour by hour. The main target, now, it is no more to understand how many connections there are relation by relation and which the feeder and carrier service supplies are, but to calculate for a specific hour, how many relations are linked through a good connection time over all possible ones. Of course, the possible domain includes only those connections requiring an interchange at Bologna, excluding all the other, according to the table 5. The traffic products considered are those listed in the table 3, for the regional services, and in table 4 for the high-speed trains with periodic timetables.

8.3.1 The "clock" supply of the station of Bologna

The knowledge about the structure of the railway services approaching the interchange node of Bologna allows to build the "clock" supply of the station. The "clock" does not refer to one particular hour, but it includes the arrival and the departure minutes of all traffic products with a periodical timetable: this means that the "clock" represents what happens every hour. Therefore, all the not-structured services are not considered in the evaluation of the integration level as, instead, it happens using the "IntegroSKOPIO© for single modules". Infect, the main target of this new calculation is to understand if the implemented structure of the system well works or not hour after hour. The following picture points out the "clock" of all station of Bologna: the arcs represent the dwelling times while the arrows the arrivals and the departures and for each of them there is the relative minute. The red arcs represent the high-speed traffic products and the long-haul services between the north and the Adriatic coast; while the several regional ones through different colours. According to the previous consideration about the construction techniques of a "clock", it is possible to observe that many regional traffic products have the arrival and the departure or around the 00 minute or around the 30 minute, but they are not always located in the right clock face, penalizing both the capacity of the whole station and the efficiency of the transport system due to the high time spent at terminus. Finally, there is the most railway traffic in the lower part of the "clock", especially in the high-speed station, but the possibilities to make a good connection between services is low due to their positioning.

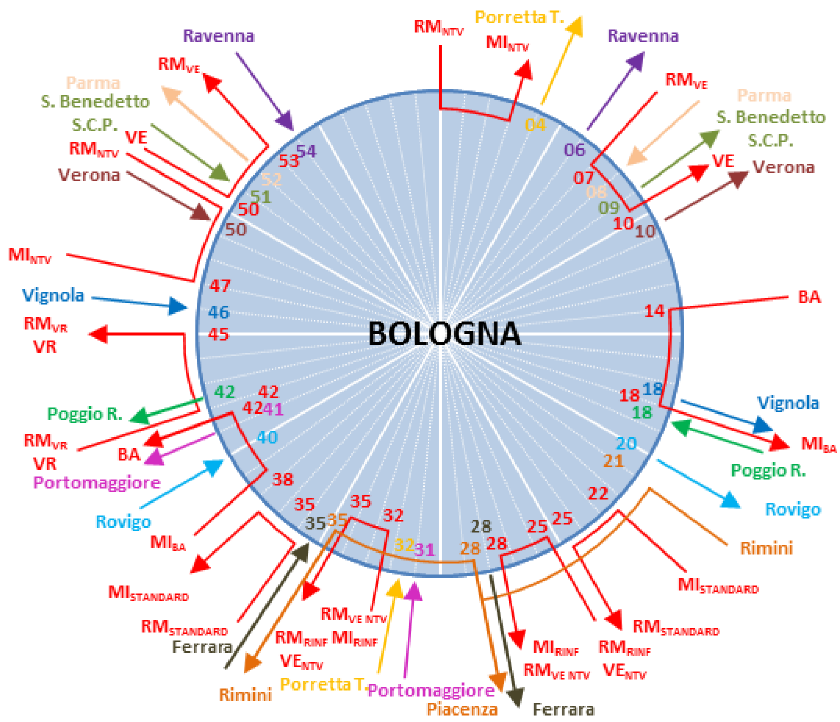


Figure 48 - "Clock" supply of Bologna's interchange node

Now, the "clock" allows to calculate the connection time matrix: for each relation, there is the time difference between the arrival of one train and the departure of the other. The matrix excludes automatically those relationships that or don't require any interchange (direct links) or it occurs in another station. It is obvious how the station of Bologna is not an exchange node among the high-speed trains, except for the relation between the HS trains from Verona and Venice to Bari and vice versa, so as it is fundamental for the regional traffic products and amid them and the high-speed ones.

	RM_{RINF}	RM_{ST}	MI_{RINF}	MI_{ST}	RM_{VE}	RM_{VR}	VE AV	VR AV	BA	MI_{BA}	PR	Ptm	FE	Sben	Vig	Pru	Pte	RA	VE RV	VE RV	PC	AN
RM_{RINF}	0	0	0	0	0	0	0	0	0	0	27	16	3	44	53	17	39	41	45	55	3	10
RM_{ST}	0	0	0	0	0	0	0	0	0	0	17	6	53	34	43	7	29	31	35	45	53	60
MI_{RINF}	0	0	0	0	0	0	0	0	0	0	0	9	56	37	46	10	32	34	38	48	0	0
MI_{ST}	0	0	0	0	0	0	0	0	0	0	0	19	6	47	56	20	42	44	48	58	0	0
RM_{VE}	0	0	0	0	0	0	0	0	0	0	45	34	21	2	11	35	57	59	3	13	21	28
RM_{VR}	0	0	0	0	0	0	0	0	0	0	10	59	46	27	36	60	22	24	28	38	46	53
VE AV	0	0	0	0	0	0	0	0	52	0	2	51	38	19	28	52	14	16	20	0	38	45
VR AV	0	0	0	0	0	0	0	0	60	0	10	59	46	27	36	0	22	24	0	38	46	53
BA	0	0	0	0	0	0	56	31	0	0	38	27	14	55	4	28	50	52	56	6	0	0
MI_{BA}	0	0	0	0	0	0	0	0	0	0	0	3	50	31	40	4	26	28	32	42	0	0
PR	27	17	0	0	45	37	2	37	34	0	0	33	20	1	10	34	56	58	2	12	0	27
Ptm	4	54	57	7	22	14	39	14	11	47	21	0	57	38	47	11	33	35	39	49	57	4
FE	60	50	53	3	18	10	35	10	7	43	17	6	0	34	43	7	29	31	35	0	53	60
SBen	44	34	37	47	2	54	19	54	51	27	1	50	37	0	27	51	13	15	19	29	37	44
Vig	49	39	42	52	7	59	24	59	56	32	6	55	42	23	0	56	0	20	24	34	42	49
Pru	17	7	10	20	35	27	52	0	24	60	34	23	10	51	60	0	46	48	0	0	10	17
Pte	3	53	56	6	21	13	38	13	10	46	20	9	56	37	0	10	0	34	38	48	56	3
RA	41	31	0	0	59	51	16	51	48	0	58	47	34	15	24	48	10	0	16	26	34	0
VR RV	45	35	38	48	3	55	20	0	52	28	2	51	38	19	28	0	14	16	0	0	38	45
VE RV	55	45	48	58	13	5	30	5	2	38	12	1	0	29	38	0	24	26	0	0	48	55
PC	7	57	0	0	25	17	42	17	14	0	0	13	60	41	50	14	36	38	42	52	0	7
AN	14	4	0	0	32	24	49	24	21	0	31	20	7	48	57	21	43	0	49	59	7	0

Table 7 – Connection time matrix in Bologna's station

Before evaluating the integration level, it is necessary to define the connection time range, for which one connection can be regarded acceptable or not. For the minimum value, the next paragraphs will show how it was computed, while for the maximum, a value of twenty-five minutes was considered, according to the reflections mentioned before.

8.3.2 Evaluation of the minimum connection time

Planning an integrated network means to improve the performances of the whole system at equal railway supply, trying to make closer the arrivals and the departures of the different traffic products in order to increase the attractiveness of the service, minimizing the waiting time for the passengers or maximizing the number of good connections. Obviously, there are many constraints to consider such as the minimum transfer time for the movements in the station, the turnaround time at terminus for the terminal trains between one arrival and the next departure, the headway between two services running along the same route or the incompatibility of two or more arrivals or departures at the same time. In addition, there are the symmetry and the minimum rolling material constraints to consider too. In this sub-paragraph, the topic related to the transfer time will be dealt with.

The station of Bologna has a C shape: looking from the top (see figure 49), on the left there is the "Piazzale Ovest", on the right the "Piazzale Est", in the middle the surface tracks from the number 1 to the 11, just outside the station there is the bus square, terminal for many urban buses and, four hundred meters from the main building, the extra urban buses terminal. Finally, twenty-three meters below ground there is the high-speed stations. with four tracks (16-17-18-19).

Figure 49 - Map of the Bologna's station

The transfer time depends on several factors. The main ones are:

- the size of the stations and so, the number of lifts, escalators and speed walks;
- the level of information and so, how much easy collecting the information on the track to reach is;
- the age of the passenger and if he has a suitcase with him.

The "Piazzale Ovest" is located within the main building and it is directly connected to all services provided by the station. It is very easy to collect information related to the high-speed station and to the surface tracks. The "Piazzale Est" is quite distant from the main building: about three hundred meters separate it to the main entrance of the station. Here, the information is not well delivered and the entrance is without lifts and escalators. The underground tracks are reachable through lifts, stairs and escalators, even if they are not so close to the surface. The following table offers the transfer time in the station of Bologna, collected manually in a workday in the peak hour, assuming that the user does not have any experiences of the place.

[Minutes]	Surface Tracks I-VII	Surface Tracks VIII-XI	Piazzale Ovest	Piazzale Est	High-Speed Tracks	Bus Square	Bus Terminal
Surface Tracks I-VII	1	2	3	7	9	3	11
Surface Tracks VIII-XI	2	1	4	9	8	4	12
Piazzale Ovest	3	4	1	7	10	2	10
Piazzale Est	7	9	7	1	14	5	3
High-Speed Tracks	9	8	10	14	1	12	19
Bus Square	3	4	2	5	12	1	7
Bus Terminal	11	12	10	3	19	7	1

Table 8 - Transfer times in Bologna's station

8.3.3 Evaluation of the minimum connection time between traffic products

In the integrated network planning process, it is mandatory to define a minimum connection time to guarantee between the arrival of one train and the departure of another. It is the sum of the transfer time and the safety margin, which aim is to ensure the reliability of the connection according to the different punctuality levels. This second term will be treated in the chapter 11. This sub-paragraph deals with the computation of the minimum transfer time to move from one train to another: for each, according to the M53 document, it is possible to know the track in which the railway service stops. The following tables shows, for all traffic products, the frequency with which the stop occurs in a specific zone of the station, according to the previous description.

				Bologna Centrale				Bologna HS
Corridor	Traffic Product	Origin	Destination	Surface Tracks I-VII	Surface Tracks VIII-XI	Piazzale Ovest	Piazzale Est	HS Tracks
Verona	REG Poggio Rusco-Bologna	Poggio Rusco	Bologna	8%	8%	83%		
Verona	REG Poggio Rusco-Bologna	Bologna	Poggio Rusco	9%	9%	83%		
Verona	RV Verona-Bologna	Verona	Bologna	33%	7%	60%		
Verona	RV Verona-Bologna	Bologna	Verona	29%		71%		
Venezia	RV Venezia-Bologna	Venezia	Bologna		100%			
Venezia	RV Venezia-Bologna	Bologna	Venezia		100%			
Venezia	REG Ferrara-Bologna	Ferrara	Bologna	12%	88%			
Venezia	REG Ferrara-Bologna	Bologna	Ferrara	29%	71%			
Venezia	REG S Pietro C - Bologna	San Pietro C.	Bologna	33%	67%			
Venezia	REG S Pietro C - Bologna	Bologna	San Pietro C.		100%			
Milano LL	REG Parma-Bologna	Parma	Bologna	20%	20%	60%		
Milano LL	REG Parma-Bologna	Bologna	Parma	13%		88%		
Milano LL	REG Milano-Bologna	Milano	Bologna		14%	86%		
Milano LL	REG Milano-Bologna	Bologna	Milano	100%				
Casalecchio	REG Bologna-Vignola	Vignola	Bologna			100%		
Casalecchio	REG Bologna-Vignola	Bologna	Vignola	5%		95%		
Casalecchio	REG Bologna-Porretta	Porretta	Bologna			100%		
Casalecchio	REG Bologna-Porretta	Bologna	Porretta			100%		
Firenze LL	REG Bologna-Prato	Prato	Bologna	5%			95%	
Firenze LL	REG Bologna-Prato	Bologna	Prato	5%	11%		84%	
Firenze LL	REG Bologna-S.Benedetto SCP	S.Benedetto SCP	Bologna	13%			88%	
Firenze LL	REG Bologna-S.Benedetto SCP	Bologna	S.Benedetto SCP		13%		88%	
Adriatica	RV Bologna-Ancona	Ancona	Bologna		100%			
Adriatica	RV Bologna-Ancona	Bologna	Ancona		100%			
Adriatica	REG Bologna-Rimini	Rimini	Bologna	15%	85%			
Adriatica	REG Bologna-Rimini	Bologna	Rimini		100%			
Adriatica	REG Bologna-Ravenna	Ravenna	Bologna	6%	88%		6%	
Adriatica	REG Bologna-Ravenna	Bologna	Ravenna		100%			
Adriatica	REG Bologna-Imola	Imola	Bologna		100%			
Adriatica	REG Bologna-Imola	Bologna	Imola		100%			
Adriatica	REG Bologna-Faenza	Faenza	Bologna	100%				
Adriatica	REG Bologna-Faenza	Bologna	Faenza		50%		50%	
Portomaggiore	REG Bologna-Portomaggiore	Bologna	Portomaggiore				100%	
Portomaggiore	REG Bologna-Portomaggiore	Portomaggiore	Bologna				100%	
Verona-RM AV	AV Verona - Roma/Napoli	Verona	Roma					100%
Verona-RM AV	AV Verona - Roma/Napoli	Roma	Verona					100%
Venezia-RM AV	AV Venezia-Roma/Napoli	Venezia	Roma					100%
Venezia-RM AV	AV Venezia-Roma/Napoli	Roma	Venezia					100%
Venezia-Adriatica	FB Venezia-Lecce	Venezia	Lecce	50%	50%			
Venezia-Adriatica	FB Venezia-Lecce	Lecce	Venezia	100%				
Venezia-Adriatica	REG Ferrara-Imola	Ferrara	Imola		100%			
Venezia-Adriatica	REG Ferrara-Imola	Imola	Ferrara	80%	20%			
Venezia-Firenze LL	IC Trieste-Roma	Trieste	Roma	100%				
Venezia-Firenze LL	IC Trieste-Roma	Roma	Trieste	100%				
Milano LL-Adriatica	FB Torino/Milano-Adriatica	Milano	Bari	100%				
Milano LL-Adriatica	FB Torino/Milano-Adriatica	Bari	Milano	100%				
Milano LL-Adriatica	IC Torino/Milano-Adriatica	Torino	Bari	100%				
Milano LL-Adriatica	IC Torino/Milano-Adriatica	Bari	Torino	80%	20%			
Milano LL-Adriatica	RV Milano/Piacenza-Adriatica	Piacenza	Ancona	89%	11%			
Milano LL-Adriatica	RV Milano/Piacenza-Adriatica	Ancona	Piacenza	100%				
Milano LL-Firenze LL	IC Torino/Milano-Napoli/Salerno	Torino	Napoli	100%				
Milano LL-Firenze LL	IC Torino/Milano-Napoli/Salerno	Napoli	Torino	100%				
Milano AV-Roma AV	AV Torino/Milano-Roma/Napoli	Milano	Roma					100%
Milano AV-Roma AV	AV Torino/Milano-Roma/Napoli	Roma	Milano					100%

Table 9 - M53 document of Bologna's station

The difference percentages represent how much time one traffic product stops in that area of the station: it is obvious how all the high-speed trains stop at the tracks of the HS station.

The "Piazzale Ovest" acts as a terminal for several traffic products such as the REG Poggio Rusco-Bologna, REG Parma-Bologna, REG Vignola-Bologna, REG Porretta Terme-Bologna: these are all railway services coming from the north. Instead, the REG Bologna-San Benedetto, REG Bologna-Prato and the REG Bologna-Portomaggiore end their run at "Piazzale Est". Finally, other terminal traffic products such as those coming from the Venice corridor terminus at the upper tracks (VIII-XI), as well as those arriving from the Adriatic line. Finally, all the crossing services stop in the first tracks (I-VII). Now, knowing both the transfer times needed to move within the station and the stop rails of all trains, it is possible to evaluate the minimum transfer time among traffic products considering the worst situation, and so the combination that involves the most transfer time (see the below table).

MINIMUM TRANSFER TIME AMONG TRAFFIC PRODUCTS	REG Poggio Rusco-Bologna	RV Verona-Bologna	RV Venezia-Bologna	REG Ferrara-Bologna	REG San Pietro in C-Bologna	REG Parma-Bologna	REG Milano-Bologna	REG Bologna-Vignola	REG Bologna Porretta T.	REG Bologna-Prato	REG Bologna San Benedetto	RV Bologna-Ancona	REG Bologna-Rimini	REG Bologna-Ravenna	REG Bologna-Imola	REG Bologna-Faenza	REG Bologna-Portomaggiore	AV Verona-Roma/Napoli	AV Venezia-Roma/Napoli	FB Venezia-Lecce	REG Ferrara-Imola	IC Trieste-Roma	FB Torino/Milano-Adriatica	IC Torino/Milano-Adriatica	RV Milano/Piacenza-Adriatica	IC Torino/Milano-Napoli/Salerno	AV Torino/Milano-Roma/Napoli
REG Poggio Rusco-Bologna	4	4	4	4	4	4	3	4	4	9	9	4	4	4	4	9	9	10	10	3	4	3	3	4	3	3	10
RV Verona-Bologna	4	4	4	4	4	4	3	4	4	9	9	4	4	4	4	9	9	10	10	3	4	3	3	4	3	3	10
RV Venezia-Bologna	4	4	1	2	1	4	2	4	4	9	9	1	1	1	1	9	9	8	8	2	2	2	2	2	2	2	8
REG Ferrara-Bologna	4	4	2	2	2	4	2	4	4	9	9	2	2	2	2	9	9	9	9	2	2	2	2	2	2	2	9
REG San Pietro in C-Bologna	4	4	2	2	2	4	2	4	4	9	9	2	2	2	2	9	9	9	9	2	2	2	2	2	2	2	9
REG Parma-Bologna	4	4	4	4	4	4	3	4	4	9	9	4	4	4	4	9	9	10	10	3	4	3	3	4	3	3	10
REG Milano-Bologna	4	4	4	4	4	4	3	4	4	9	9	4	4	4	4	9	9	10	10	3	4	3	3	4	3	3	10
REG Bologna-Vignola	4	3	4	4	4	3	3	3	1	7	7	4	4	4	4	7	7	10	10	3	4	3	3	4	3	3	10
REG Bologna-Porretta T.	4	3	4	4	4	3	3	3	1	7	7	4	4	4	4	7	7	10	10	3	4	3	3	4	3	3	10
REG Bologna-Prato	9	7	9	9	9	7	7	7	7	9	9	9	9	9	9	9	7	14	14	7	9	7	7	9	7	7	14
REG Bologna-San Benedetto	9	7	9	9	9	7	7	7	7	9	9	9	9	9	9	9	7	14	14	7	9	7	7	9	7	7	14
RV Bologna-Ancona	4	4	1	2	1	4	2	4	4	9	9	1	1	1	1	9	9	8	8	2	2	2	2	2	2	2	8
REG Bologna-Rimini	4	4	2	2	2	4	2	4	4	9	9	2	2	2	2	9	9	9	9	2	2	2	2	2	2	2	9
REG Bologna-Ravenna	9	7	9	9	9	7	7	7	7	9	9	9	9	9	9	9	9	14	14	7	9	7	7	9	7	7	14
REG Bologna-Imola	4	4	1	2	1	4	2	4	4	9	9	1	1	1	1	9	9	8	8	2	2	2	2	2	2	2	8
REG Bologna-Faenza	3	3	2	2	2	3	1	3	3	7	7	2	2	2	2	7	7	9	9	1	2	1	1	2	1	1	9
REG Bologna-Portomaggiore	9	7	9	9	9	7	7	7	7	9	9	9	9	9	9	9	1	14	14	7	9	7	7	9	7	7	14
AV Verona-Roma/Napoli	10	10	8	9	8	10	9	10	10	14	14	8	8	8	8	14	14	1	1	9	9	9	9	9	9	9	1
AV Venezia-Roma/Napoli	10	10	8	9	8	10	9	10	10	14	14	8	8	8	8	14	14	1	1	9	9	9	9	9	9	9	1
FB Venezia-Lecce	4	4	2	2	2	4	2	4	4	9	9	2	2	2	2	9	9	9	9	2	2	2	2	2	2	2	9
REG Ferrara-Imola	4	4	1	2	1	4	2	4	4	9	9	1	1	1	1	9	9	8	8	2	2	2	2	2	2	2	8
IC Trieste-Roma	3	3	2	2	2	3	1	3	3	7	7	2	2	2	2	7	7	9	9	1	2	1	1	2	1	1	9
FB Torino/Milano-Adriatica	3	3	2	2	2	3	1	3	3	7	7	2	2	2	2	7	7	9	9	1	2	1	1	2	1	1	9
IC Torino/Milano-Adriatica	3	3	2	2	2	3	1	3	3	7	7	2	2	2	2	7	7	9	9	1	2	1	1	2	1	1	9
RV Milano/Piacenza-Adriatica	4	4	2	2	2	4	2	4	4	9	9	2	2	2	2	9	9	9	9	2	2	2	2	2	2	2	9
IC Torino/Milano-Napoli/Salerno	3	3	2	2	2	3	1	3	3	7	7	2	2	2	2	7	7	9	9	1	2	1	1	2	1	1	9
AV Torino/Milano-Roma/Napoli	10	10	8	9	8	10	9	10	10	14	14	8	8	8	8	14	14	1	1	9	9	9	9	9	9	9	1

Table 10 - Minimum transfer times among traffic products

The red cells depict the worst results, with a minimum transfer time greater than ten minutes and all of them are related to the displacement from the "Piazzale Est" to the HS station. The yellow ones individuate those relations which transfer time is between six and ten minutes and, finally, the green colour those relationships requiring less than six minutes, as it occurs in most of cases.

8.3.4 Computation of the integration level

At the end, there are all the data needed to evaluate the integration level in the interchange node of Bologna. The “clock” supply provides the arrival and the departure minutes of all traffic products with a periodical timetable and, thanks to this information, it was possible to build the connection time matrix among all possible directions. Then, matching this matrix with that reporting the minimum transfer times to move from one traffic product to another, the computation of the amount of good connections is possible, considering, also, a maximum time of twenty-five minutes. The following table includes all the results:

- the red cells represent those connections that require an interchange at Bologna, but the connection time does not respect the constraints of the minimum and the maximum time;
- the green one underline those relationships effectively integrated.

	RM_{RINF}	RM_{ST}	MI_{RINF}	MI_{ST}	RM_{VE}	RM_{VR}	VE AV	VR AV	BA	MI_{BA}	PR	Ptm	FE	Sben	Vig	Pru	Pte	RA	VE RV	VE RV	PC	AN
RM_{RINF}	0	0	0	0	0	0	0	0	0	0	27	16	3	44	53	17	39	41	45	55	3	10
RM_{ST}	0	0	0	0	0	0	0	0	0	0	17	6	53	34	43	7	29	31	35	45	53	60
MI_{RINF}	0	0	0	0	0	0	0	0	0	0	0	9	56	37	46	10	32	34	38	48	0	0
MI_{ST}	0	0	0	0	0	0	0	0	0	0	0	19	6	47	56	20	42	44	48	58	0	0
RM_{VE}	0	0	0	0	0	0	0	0	0	0	45	34	21	2	11	35	57	59	3	13	21	28
RM_{VR}	0	0	0	0	0	0	0	0	0	0	10	59	46	27	36	60	22	24	28	38	46	53
VE AV	0	0	0	0	0	0	0	0	52	0	2	51	38	19	28	52	14	16	20	0	38	45
VR AV	0	0	0	0	0	0	0	0	60	0	10	59	46	27	36	0	22	24	0	38	46	53
BA	0	0	0	0	0	0	56	31	0	0	38	27	14	55	4	28	50	52	56	6	0	0
MI_{BA}	0	0	0	0	0	0	0	0	0	0	0	3	50	31	40	4	26	28	32	42	0	0
PR	27	17	0	0	45	37	2	37	34	0	0	33	20	1	10	34	56	58	2	12	0	27
Ptm	4	54	57	7	22	14	39	14	11	47	21	0	57	38	47	11	33	35	39	49	57	4
FE	60	50	53	3	18	10	35	10	7	43	17	6	0	34	43	7	29	31	35	0	53	60
SBen	44	34	37	47	2	54	19	54	51	27	1	50	37	0	27	51	13	15	19	29	37	44
Vig	49	39	42	52	7	59	24	59	56	32	6	55	42	23	0	56	0	20	24	34	42	49
Pru	17	7	10	20	35	27	52	0	24	60	34	23	10	51	60	0	46	48	0	0	10	17
Pte	3	53	56	6	21	13	38	13	10	46	20	9	56	37	0	10	0	34	38	48	56	3
RA	41	31	0	0	59	51	16	51	48	0	58	47	34	15	24	48	10	0	16	26	34	0
VR RV	45	35	38	48	3	55	20	0	52	28	2	51	38	19	28	0	14	16	0	0	38	45
VE RV	55	45	48	58	13	5	30	5	2	38	12	1	0	29	38	0	24	26	0	0	48	55
PC	7	57	0	0	25	17	42	17	14	0	0	13	60	41	50	14	36	38	42	52	0	7
AN	14	4	0	0	32	24	49	24	21	0	31	20	7	48	57	21	43	0	49	59	7	0

Table 11 - Integration level evaluation for Bologna's station

Finally, counting the amount of satisfied relations over all the possible ones, the KPI “IntegroSKOPIO© for structured systems” provides the following outcomes. The level of integration is very low considering both all possible relations and only among the regional ones, the most important from the point of view of the commuters that need to have a daily interchange at Bologna. Moreover, there is a clear lack of route integration between the trains from Verona and Venice and those to Bari and vice versa, since there are not direct links and Bologna represents the unique possible point to realize an interchange. Focusing on the links with the high-speed trains, the integration with Rome is simple to create, because there are every hour four different traffic products arriving and leaving, but, in spite of everything, this value could be greater just for these considerations, taking into account that three of them arrive and leave very close each other, without creating a frequency integration. Moreover, the integration level with Milan can be improved too, because a value equal to 0.3 is not acceptable, but, unlike Rome, there are only two traffic products per hour.

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.274
INTEGROSKOPIO HS	0.273
INTEGROSKOPIO REG	0.281
INTEGROSKOPIO to Rome HS	0.786
INTEGROSKOPIO from Rome HS	0.857
INTEGROSKOPIO to Milan HS	0.300
INTEGROSKOPIO from Milan HS	0.300

Table 12 - Integration level at Bologna Centrale

9. Integration level on the Italian high-speed axis

In this chapter, the estimation of the integration level with the KPI “IntegroSKOPIO© for structured systems” of the stations located along the Italian high-speed axis will be provided. The same considerations made before for the station of Bologna are still valid, where, the minimum connection time taken into account is ten minutes. The considered stations are: Torino Porta Nuova, Milano Centrale, Venezia Santa Lucia, Firenze Santa Maria Novella and Roma Termini. For each of them, at the beginning, the railway system structure was studied, to understand, before, which are the traffic products with periodical timetables and, then, to build the “clock” of the station. Finally, through the connection matrix, the integration level will be measured, according to three values: the first is related to a global evaluation, considering all possible connections, excluding those between the high-speed services; the second to the integration level between the regional traffic products and the high-speed trains and, finally, the third measures the goodness of the time coordination among only regional services. The following figure shows the “clocks” supply of the five considered stations:

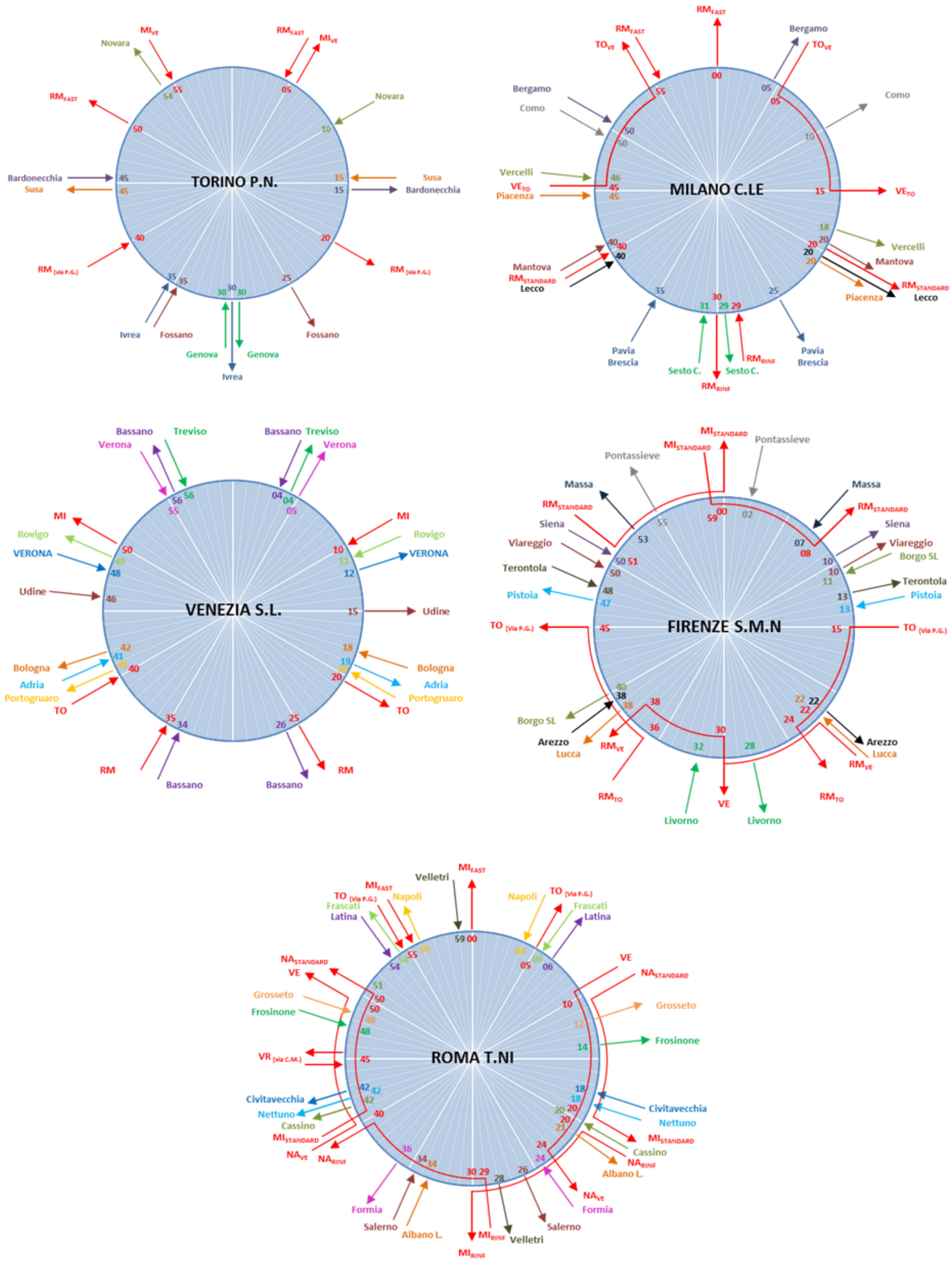


Figure 50 - "Clock" supply of the five high-speed stations

9.1 Integration level at Torino PN

It is the main station of the city of Turin, and the third in Italy with respect to the amount of daily and yearly passengers. It accommodates about 450 trains per day, considering the high-speed trains to and from Milan, Rome and Naples, the regional ones, even if the most regional railway traffic arrive and leave from the station of Torino Porta Susa, and, finally, it acts as terminal for various international railway services.

The railway traffic product RM (via P.G.) indicates those trains bypassing Milano C.le stopping at Milano Porta Garibaldi and Milano Rogoredo. From the leaving point of view, there is a frequency integration between the two high-speed traffic products to Rome, unlike the opposite direction and the connections with Milan, ensured by the traffic product MI_{VE} (leaving at the minute 05) and by the RM_{FAST} one (leaving at the minute50). Except the regional service to and from Novara, all the others leave and arrive in the lower part of the "clock".

Excluding the relations among the high-speed trains and between themselves, the integration level is quite good, especially amid the regional services, improvable with respect to the HS traffic products. The last table recaps the results:

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.348
INTEGROSKOPIO HS	0.306
INTEGROSKOPIO REG	0.400

Table 13 - Integration level at Torino Porta Nuova

9.2 Integration level at Milano C.le

It is the main station of the city of Milan, the second in terms of daily and yearly passengers after Roma Termini, and it is one of the most important in the international scenario. Moreover, it is the third from the point of view of the railway traffic, which is made up by high-speed trains managed by Trenitalia and Nuovo Trasporto Viaggiatori for all of Italy, by regional services operated by Trenitalia and Trenord, and by the direct links with the Milano Malpensa Airport. Finally, it is the terminal station for the international service for Nice, Marseilles and for the Switzerland and a stop for the night connections between Venice and Paris. Most of the regional traffic products, belonging to the suburban system of the Lombardia region, terminus at Milano Porta Garibaldi, the second station of the city. All the traffic products are homogeneously distributed throughout the "clock", except the first clock face where only the high-speed train to Venice from Turin and the regional ones to Bergamo and Como leave. The main HS traffic products to Rome (the RM_{FAST} and the RM_{RINF}) are not symmetric, so as the links to Bergamo, Piacenza and Vercelli. All the arrivals of the regional trains occur in the left side of the clock, favouring a good connection with Rome through the RM_{FAST} traffic product leaving at 00 minute, as well as for the opposite direction, but not with Florence and Bologna, reachable the first only with the standard traffic product (leaving at 20 minute) and the second with the RM_{RINF} too (departing ten minutes later). Due to the particular shape of the "clock", the connections with Rome and Turin are favoured at the expense of connections between regional trains. Nevertheless, considering all the HS service, the KPI IntegroSKOPIO© provides a low value, because all the connection times with Florence, Bologna and Verona do not satisfied the time constraints. To improve the performances of the "clock", the arrivals and the departures of the regional trains and that of the $RM_{STANDARD}$ traffic product should be close to the minute 00, compatibly with the infrastructural and network constraints.

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.247
INTEGROSKOPIO HS	0.333
INTEGROSKOPIO REG	0.111

Table 14 - Integration level at Milano Centrale

The above table emphasises the better results with respect to the high-speed services unlike among the regional ones. Globally, the integration level is quite low.

9.3 Integration level at Venezia SL

It is one of the main stations of the city of Venice, the unique located within the historical island centre. It is the tenth Italian railway node for accommodated passengers. It is directly linked with the station of Venezia Mestre, just outside the old town, where all the railway lines merge. The railway traffics connect the city with Rome, Naples and Milan through high-speed services, while the regional ones with the surrounding area, such as Verona, Brescia, Trieste, Padova and Bassano del Grappa. Finally, international trains arrive from Paris, Wien, Munich and Geneva. The "clock" supply of the station shows as all the traffic products are homogeneously distributed throughout the clock, but the arrivals and the departures do not occur, quite often, in the right clock face, penalizing the integration level very much. There is a frequency integration between the two high-speed services with Milan and Turin. Most the traffic products are symmetric. It is obvious how the different traffic products are not well integrated each other, both considering the high-speed and the regional trains. This is a clear representation of how the timetable is designed without a system vision, but as if the individual traffic products are independent each other. All the results are showed in the following table:

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.198
INTEGROSKOPIO HS	0.148
INTEGROSKOPIO REG	0.236

Table 15 - Integration level at Venezia Santa Lucia

9.4 Integration level at Firenze SMN

It is the main station of the city of Florence, the fifth Italian one considering the amount of yearly passengers. It is one of the busiest stations in Italy, with a daily number of trains equal to about 600. The traffic is both regional, with links with all the municipalities located in Toscana region, all managed by Trenitalia and national, with high-speed trains to Rome, Naples, Bologna, Milan and Venice, while, the connections with Verona cross through the station of Firenze Campo di Marte. The "clock" is quite full, with many regional traffic products arrivals and departures located in the upper part, but no in the exact clock face; while the high-speed ones, excluded the standard service, in the lower side. The national services are all symmetric, except the standard link between Rome and Milan, as well as many regional ones, but the incorrect positioning along the "clock" aggravates the integration level, especially in the regional field. Infect, the connections with the high-speed traffic products seem quite good, especially with respect to the connections with Rome, even if, three different services guarantee this relation. Instead, only the standard product ensures a direct link with Milan, making, for this reason, necessary to connect with it most regional trains as possible, as well as for the link with Venice.

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.281
INTEGROSKOPIO HS	0.317
INTEGROSKOPIO REG	0.233

Table 16 - Integration level at Firenze Santa Maria Novella

9.5 Integration level at Roma Termini

It is the main station of the city of Rome and of Italy and the unique railway node near the old town. It is the most important in terms of daily and yearly passengers so as in terms of railway traffic: infect about 850 trains, every day, approach the station of Roma Termini, which is the fifth in Europe in terms of users. It is the terminal for five over eight regional railway lines that make up the suburban railway system of the Metropolitan City of Rome and for the Leonardo Express, which links the city with the Leonardo da Vinci airport. All the high-speed trains from Naples, Milan, Venice and Verona stop in this station and, some of them in the second station of the capital, which is Roma Tiburtina. The "clock" is very full, where more or less one event per minute occurs: the regional traffic products are located all over throughout the "clock" and this explains clearly how much difficult planning an integrated network in a big station as Roma Termini is, considering all the possible constraints that can influence the final results. There is a frequency integration between the traffic products to Civitavecchia and Grosseto in order to ensure a train every thirty minutes with the port. Focusing on the high-speed traffic products, there are many similarities with the "clock" of Milano Centrale: infect the fast, its reinforcement and the standard services arrive and depart always at the same minute. For the calculations of the global integration level, some links between high-speed traffic products were considered too, such as those between the city of Naples and the fast link with Milan, with Turin and Verona. This last connection is very important since these two towns are not directly linked.

Actual Scenario	
GLOBAL INTEGROSKOPIO	0.247
INTEGROSKOPIO HS	0.250
INTEGROSKOPIO REG	0.254

Table 17 - Integration level at Roma Termini

The table shows how there are not big differences between the regional and the HS services and that the integration level is, globally, quite low.

9.6 Integration level in the high-speed stations

The integration level in the high-speed stations is, everywhere, quite low and this attests how the problem related to the integration is particularly widespread in Italy. There are essentially two reasons:

- the first concerns the fact that the integration problem is not largely treated in Italy, nevertheless its main role in the design of a transport system. The integration allows connecting each other different localities, cities or areas in the easiest and in the quickest way at equal transport supply. This can improve the attractiveness and the efficiencies of the whole system.
- the second takes into account the difficulties related to the planning of an integrated network due to the presence of many constraints. Moreover, reaching the best result in one station can imply its unreachability in other interchange nodes, making fundamental the definition of some criteria to evaluate which relations are more interesting to connect than the others.

The following chart recaps the results of this chapter:

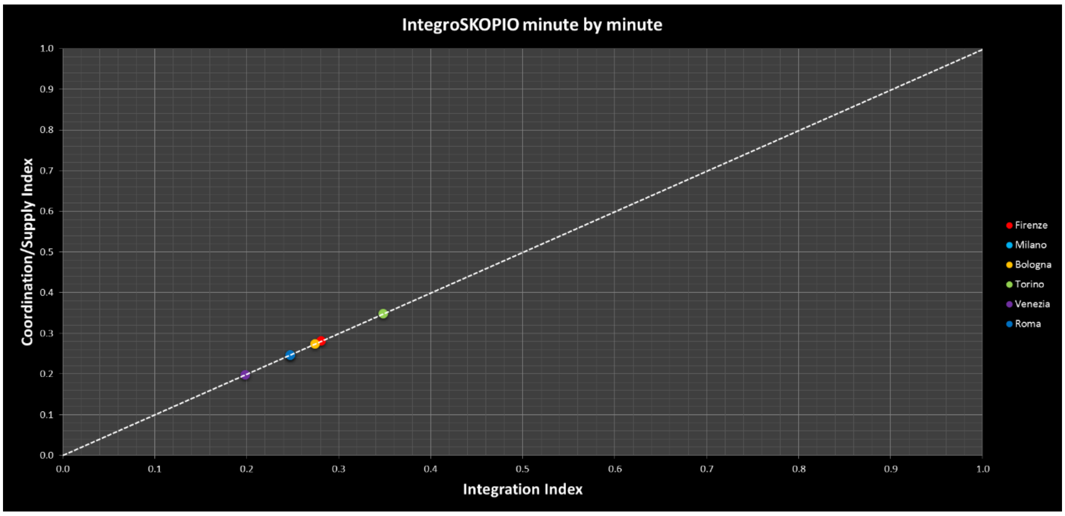


Figure 51 - Integration level in the high-speed stations

10. Train-bus integration level

This chapter provides the results coming from the evaluation of the integration level, considering an intermodal transport mode, made up by a train and a bus. The obtained outcomes have been calculated both with the "IntegroSKOPIO© for single modules" and with the "IntegroSKOPIO© for structured systems". The first when the buses don't have periodical timetables and so when the structure of the feeder service is traditional, while the second, when it is structured with periodical timetables and the arrivals and the departures are always the same. Both urban and extra urban runs have been considered. The assessment of the integration level focuses its attention on four stations along the Adriatic railway line, one for each hierarchical level, to evaluate how the road feeder service is integrated with the railway carrier one. The bus lines taken into account are those stopping or in the square of the station, both if they are crossing and terminus, or in the bus terminal quite close the stations and reachable in few minutes on foot. In all cases, a range connection time between the ten and the twenty-five minutes is considered when the time period of the leaving traffic product is greater or equal to one hour, a range between five and fifteen minutes in case of it is equal to thirty minutes. Lower time period ensures always at least one connection. The stations are:

- Rimini, for the first hierarchical level;
- Cattolica, for the second hierarchical level;
- Imola, for the third hierarchical level;
- San Lazzaro di Savena, for the fourth hierarchical level.

10.1 Train-bus integration level at Rimini

This is the main of the city of Rimini, with about 5000 passengers per day (2007) and it is a stop for all long-haul traffic products, and the terminal for different regional trains. In the adjacent square, many urban and extra urban buses stop, as well as in the terminal located about 300 meters from the station. The considered railway and road traffic products are:

Traffic Product	Train	Level
FB Torino/Milano-Adriatica	FB	1
	FB	1
IC Bologna-Adriatica	IC	2
	IC	2
REG (Bologna)/Ravenna-Rimini/(Ancona)	REG	4
REG Castelbolognese-Rimini	REG	4
RV Piacenza/(Bologna)-(Pesaro)/Ancona	RV	3
	RV	3

Bus Traffic Product	Level
Linea 2 San Giuliano-Caduti di Marzabotto	U
	U
Linea 8 Italia in Miniatura-Rimini GROS	U
	U
Linea 14 Rimini Sauro-Case Pradese	U
	U
Linea 15 Rimini Sauro-La Zingarina	U
	U
Linea 16 Rimini FS-Santa Cristina	U
Linea 18 Rimini FS-Rimini Ospedale DX	U
Linea 19 Rimini FS-Rimini Ospedale SX	U
Linea 3 Rimini FS-Ospedaletto	E
Linea 4 San Mauro Mare-Rimini Tribunale	E
	E
Linea 7 Rimini FS-Cerasolo	E
Linea 20 Rimini FS-Coriano	E
Linea 124 Rimini FS-Morciano	E
Linea 90 Rimini FS-Savignano FS	E
Linea 160 Rimini FS-Novafeltria	E
Linea 160/ Rimini FS-Villa Verrucchio	E
Linea 170 Rimini FS-Mercatino Conca	E

Table 18 - Traffic products at Rimini

Matching all the schedules, the integration level for each bus line is the following depicted by the chart:

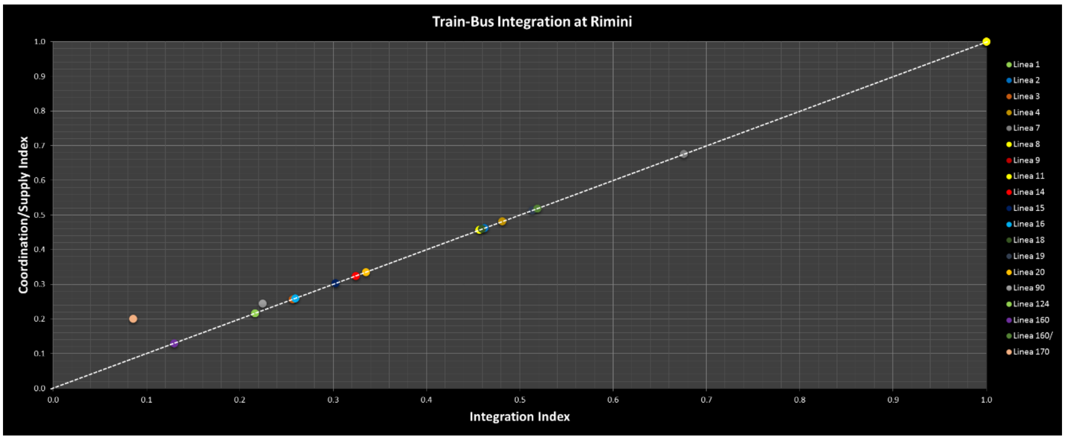


Figure 52 - Integration level at Rimini

The integration level can be, globally, improvable, specifically for those bus lines having a periodical timetable and represented by the circles positioned on the 45 degrees inclined line. This means that the structure of the whole system does not work in the best way. The lines 1, 9 and 11 have an integration and coordination/supply index equal to one, since they have a frequency greater than two buses per hour and this means that at least there is one good connection and their supply is higher than that of the railway transport mode.

10.2 Train-bus integration level at Cattolica

It is the unique station of the municipality of Cattolica, but also it serves other localities such as Gabicce Mare and San Giovanni in Marignano. It is the stops for the IC and for the regional trains. The bus terminal accommodates three extra urban lines:

Traffic Product	Train	Level
IC Torino/Milano-Adriatica	IC	2
	IC	2
RV Piacenza/(Bologna)-(Pesaro)/Ancona	RV	3
	RV	3
REG Rimini-(Pesaro)/Ancona	REG	4
	REG	4

Bus Traffic Product	Level
Linea 125 Cattolica Autostazione-Riccione C. Studi	E
Linea 130 Pesaro-Gradara	E
	E
Linea 44 Cattolica FS-Mercatale	E
Linea 47 Cattolica FS-Urbino	E
Linea 134 Cattolica FS-Morciano	E

Table 19 - Traffic products at Cattolica

Considering these traffic products and many other services having a traditional composition of the schedule, the integration level is:

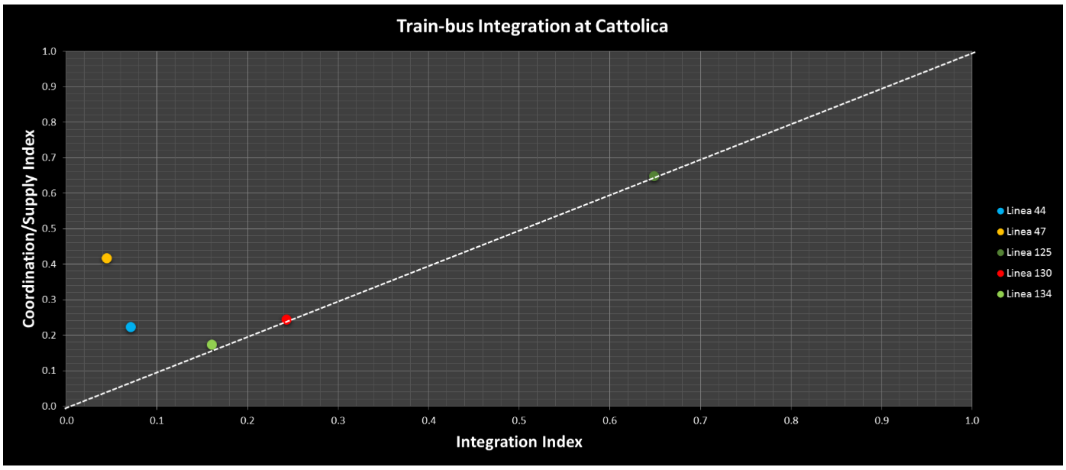


Figure 53 - Integration level at Cattolica

The charts shows as the integration level is low, with a clear lack of time coordination for at least three bus lines; better is the coordination index for the line 47, even if its supply is very low with respect that of the railway transport mode. The result for the line 125 is good, with the two indices greater than 0.6. Also in this case, an improvement of the time coordination is preferable.

10.3 Train-bus integration level at Imola

It is the unique station of the municipality of Imola and it is the terminal for different regional services from and to Bologna and a stop for the RV Piacenza-Ancona. The square just in front of the entrance of the station is the stop for several urban bus lines, while the bus terminal, spaced about three hundred and fifty meters, accommodated different extra urban runs. The traffic products of both transport modes are reported in the following table:

Traffic Product	Train	Level
REG (Piacenza)/Bologna/Ravenna-(Rimini)	REG	4
	REG	4
RV Piacenza/(Bologna)-(Pesaro)/Ancona	RV	3
	RV	3

Bus Traffic Product	Level
Linea 9 Imola Stazione - Pedagna Ovest	U
Linea 1 Imola Ospedale Nuovo - Porta dei Servi	U
	U
Linea 3 Rivazza - Pedagna Ovest	U
	U
Linea 4 Imola GP - Imola dalla Chiesa	U
	U
Linea 101 Imola Autostazione - Bologna Autostazione	E
Linea 136 Imola Autostazione - Z.I. Quaderna	E
Linea 140 Imola Autostazione - Monte Catone	E
Linea 141 Imola Autostazione - Castel del Rio	E
Linea 142 Imola Autostazione - Piancaldoli	E
Linea 150 Imola Autostazione - San Prospero	E
Linea 151 Imola Autostazione - Lugo	E
Linea 153 Imola Autostazione - Conselice	E
Linea 157 Imola Autostazione - Medicina	E
Linea 160 Imola Autostazione - Zello	E

Table 20 - Traffic products at Imola

Now, the integration level can be evaluated: the chart stresses how there was a clear lack of time coordination, making the whole transport system unattractive. The line 136 as a coordination/supply index equal to zero, this means that this bus line does not even have a good connection with the railway field. The bus number 142 has a good time coordination (0.5) but its supply is quite modest, unlike the line 101, which has an integration level a little bit greater too. All the results located in the lower part of the chart are referred to extra urban lines: this is quite important because this shows how the surrounding area is not well integrated with the local railway system.

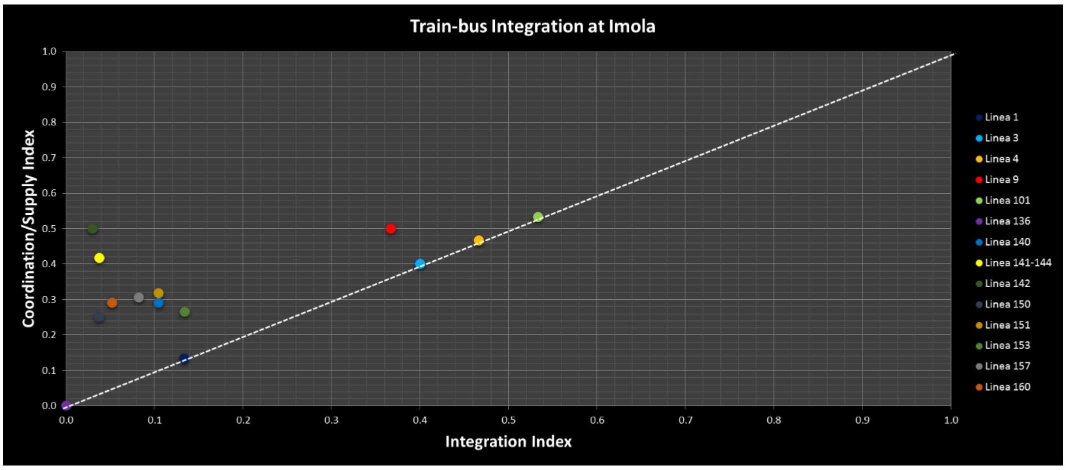


Figure 54 - Integration level at Imola

10.4 Train-bus integration level at San Lazzaro di Savena

It is the unique station of the locality of San Lazzaro di Savena, few kilometres outside the city of Bologna and only regional trains stop here. Only three bus lines ensure the intramodality:

Traffic Product	Train	Level
REG (Piacenza)/Bologna/Ravenna - (Rimini)	REG	4
	REG	4
REG Ferrara/(San P.C.) - Imola/(Rimini)	REG	4
	REG	4

Bus Traffic Product	Level
Linea 19 San Lazzaro di Savena - Casteldebole	E
Linea 124 San Lazzaro di Savena - Ponticella	E
Linea 124\ San Lazzaro di Savena - Ospedale Bellaria	E

Table 21 - Traffic products at San Lazzaro di Savena

The integration level is the following, taking into account that the line 19 has a frequency of four buses per hour:

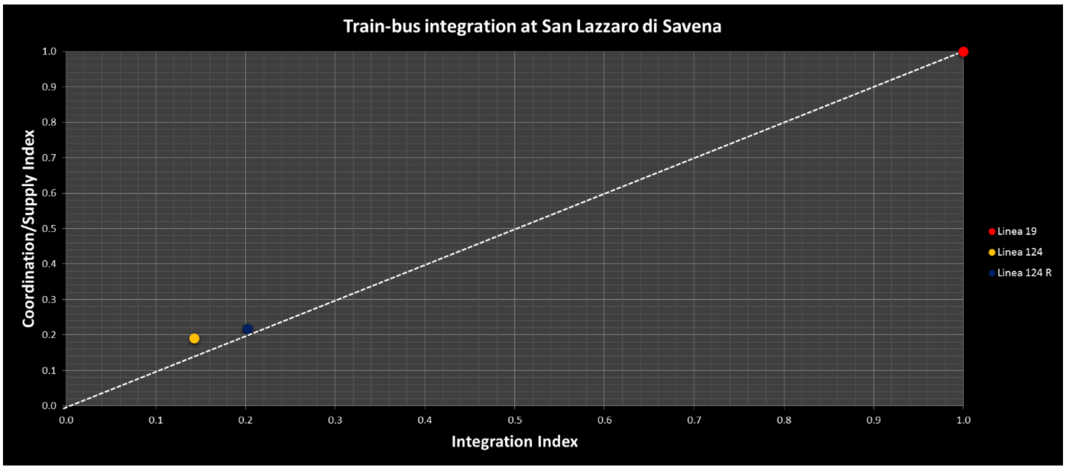


Figure 55 - Integration level at San Lazzaro di Savena

The integration level is globally low, with a coordination index lower than 0.2.

10.5 Train-bus integration level: final results

Finally, it is possible to compare the outcomes obtained for each stop to understand how the train-bus integration works station by station. The following table provides the two indices for each stop and then the chart a graphical representation. To obtain these results, the entire road and the railway field supply was considered and the relative number of good connections is the result of all acceptable matches between the two transport modes

Railway line	Station	Integration	Supply
Adriatica	Rimini	0.489	0.500
	Cattolica	0.206	0.330
	Imola	0.197	0.356
	San Lazzaro di Savena	0.448	0.487

Table 22 - Integration level for four stations on the Adriatic corridor

The table shows how the station of Rimini has the best integration level considering both the indices: the amount of good connections is the half of all those possible ones and, moreover, the total feeder service supply is enough balanced with respect to that of the carrier one. The outcomes related to the station of San Lazzaro di Savena are little bit influenced by the high frequency of the line 19, considering that the other two lines are not well integrated. Finally, the remaining two stations have modest results: the integration indices are about 0.2 and so only the twenty percent of the stopping trains have a good connection with the road transport mode; instead, focusing on the feeder services, there is at the same time both a lack of time coordination and a lack of good transport supply.

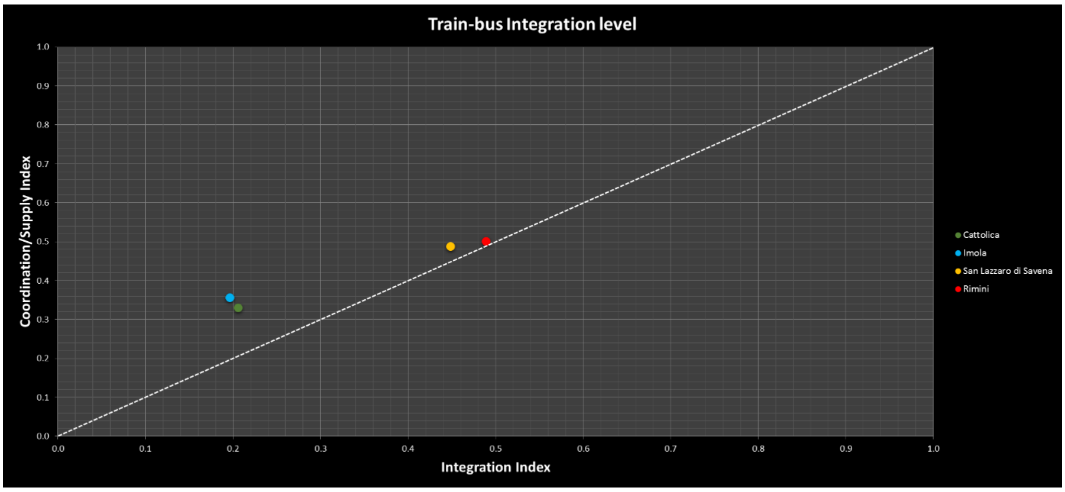


Figure 56 - Integration level for four stations on the Adriatic corridor

11. Computation of the optimum connection time

The timetable is an important factor of modal choice: it determines the spatial and the temporal accessibility of a transport mode as well as the speed, representing the train or the bus performances for each O-D relation, which influence the time factor that is usually considered, together with the price, the main parameter of the modal choice. Therefore, the timetable impacts on the attractiveness of the services offered for the potential train passengers: the timetable quality is associated to the possibility of optimizing the community time factor and improving, at equal fares, the modal share in favour for the train. In an integrated network planning process, the definition of the timetable of the different traffic products plays a fundamental role in order to define the best value of the connection time both to ensure the maximum number of good connections and to minimize the total waiting time of the passengers. Excluding all the constraints that influence the design of an integrated transport network, the connection time must be, at least, greater than the maximum transfer time, needed to the users to move within the station from one track to the other. The transfer time represents, also, the minimum possible connection time: supposing that the arriving traffic product is on time, the waiting time for the departure of the second service is zero, because the passengers reach its track when it is going to leave. Instead, when the arriving traffic product is not on time, the connection is lost. For this reason, the design of the interchange time must consider on one side the transfer time, which is a physical parameter and always constant for each relation and on the other side a safety margin, to be added to the first, which aim is to ensure the reliability of the connection according to the different punctuality levels.

11.1 Estimation of the optimum safety margin

In the connection time planning process, the minimum time has to be defined between the arrival of one train and the departure of another one or of a bus, in case of an intermodal interchange. This minimum time depends on the transfer time and on the safety margin. Of course, the programmed connection time could be greater than the optimum one due to the presence of the boundary constraints, which may not always make us design an optimal connection. Instead, if this planned time is lower than the minimum one, this means that there are many possibilities to lose the connection. Thus, the main target of this chapter is to explain a method to define the optimum time for each single relation, trying to minimize the total waiting time of the passengers. The connection time is the sum of:

$$T_{CONNECTION} = T_{TRANSF} + M$$

where T_{TRANSF} is the transfer time and M the safety margin, to be calibrated with respect to the distribution delays of the arriving traffic products.

If the train is on time:

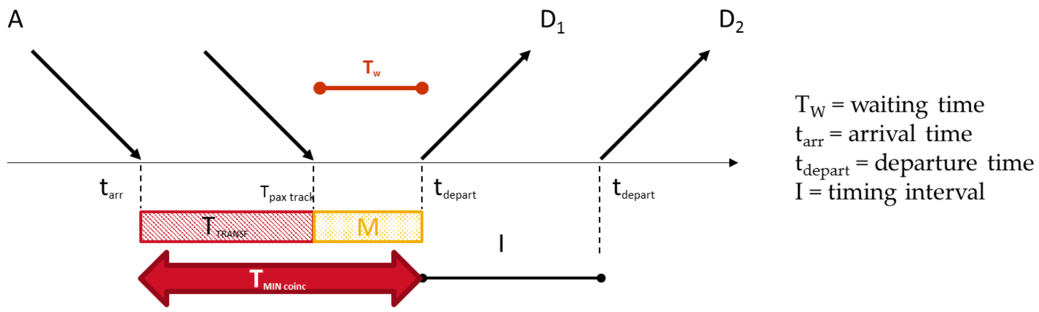


Figure 57 - Representation of a punctual arrival

the waiting time is equal to the safety margin. In this case smaller is the safety margin, lower will be the total waiting time of the passengers.

Instead, if the train is on delay, two possible situations can occur, depending on the value of the planned safety margin and on the value of the delay:

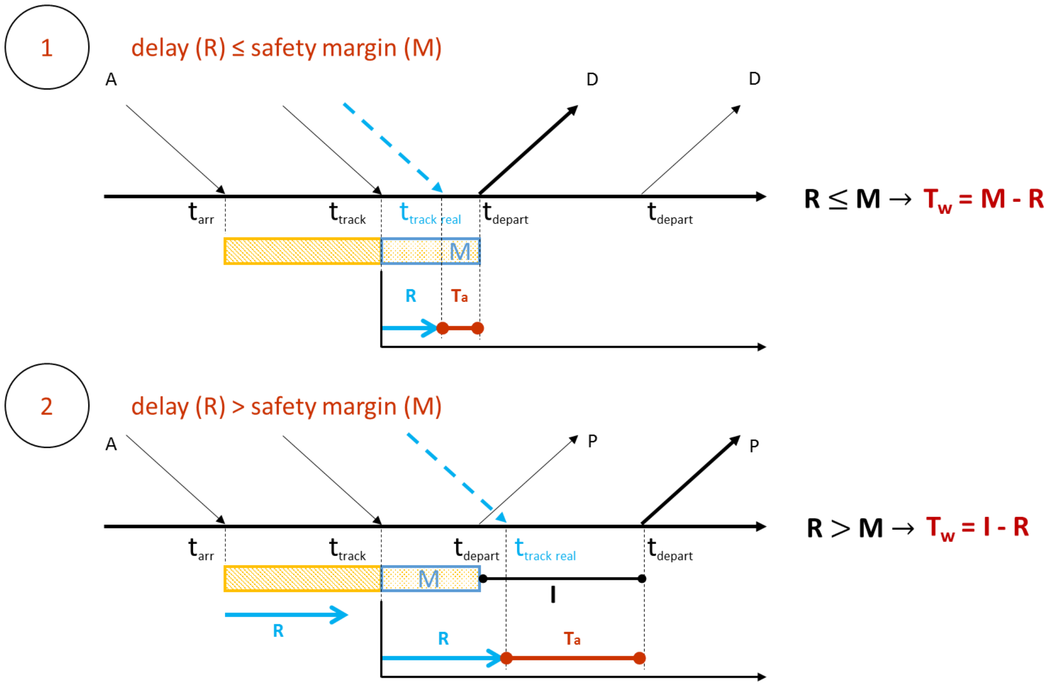


Figure 58 - Representation of a delay arrival

The role of the safety margin is to ensure the reliability of the connection: when the delay is lower than "M", as the first situations represents, the connection is not lost, and the waiting time is the difference between M and R. When the delay is higher, the safety margin is not able to satisfy the reliability of the connection and it is lost: in this second case, the waiting time is the difference between the time period and the delay itself, because the passengers have to wait for the second available train. Therefore, according to the value of the delay, the value of the optimum safety margin (MOTT), which minimizes the total waiting time, varies. Nevertheless, the delay is not constant, and for this reason MOTT must be calibrated according to the delays distribution of the arriving traffic product, minimizing the total waiting time. This is a variable depending on the delay distribution and on the time period of the leaving traffic product. In the following pages, a deterministic and a stochastic distribution of the delays will be considered.

11.1.1 Deterministic distribution of the delays

Supposing that the coming train has a delay of five minutes in the 80% of the cases and ten minutes in the remaining ones, the waiting time can go from a maximum equal to I-R to a minimum that is obtained when:

- the MOTT is equal to the highest delay (10') in case of low frequencies:

- the MOTT is equal to the lowest delay (5′) in case of high frequencies.

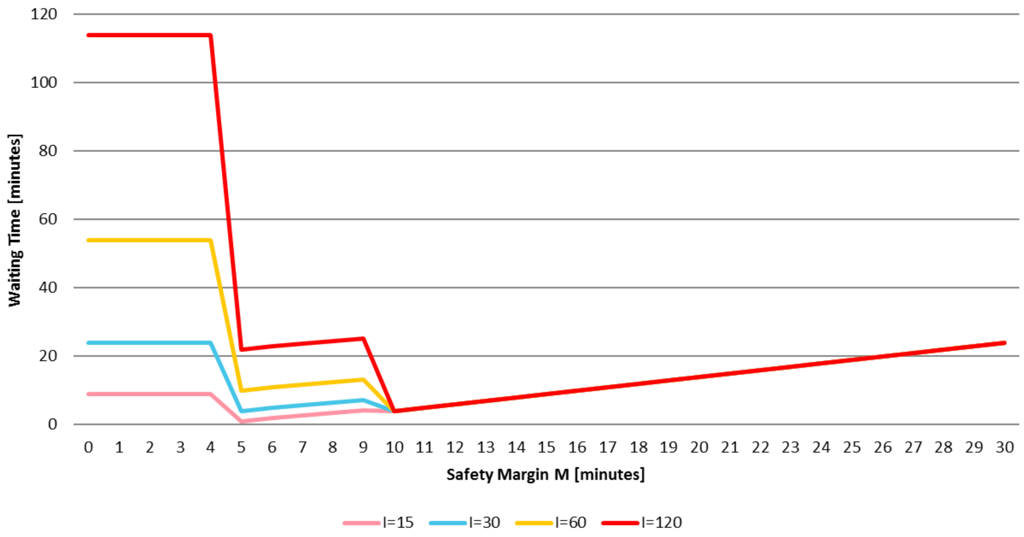


Figure 59 - Distribution of the waiting time with the lowest delay

Supposing, now, the opposite scenario, with the highest delay of ten minutes for the 80% of the cases and five minutes for the remaining ones, the waiting time can go from a maximum equal to I-R to a minimum that is obtained when the MOTT is equal to the highest delay.

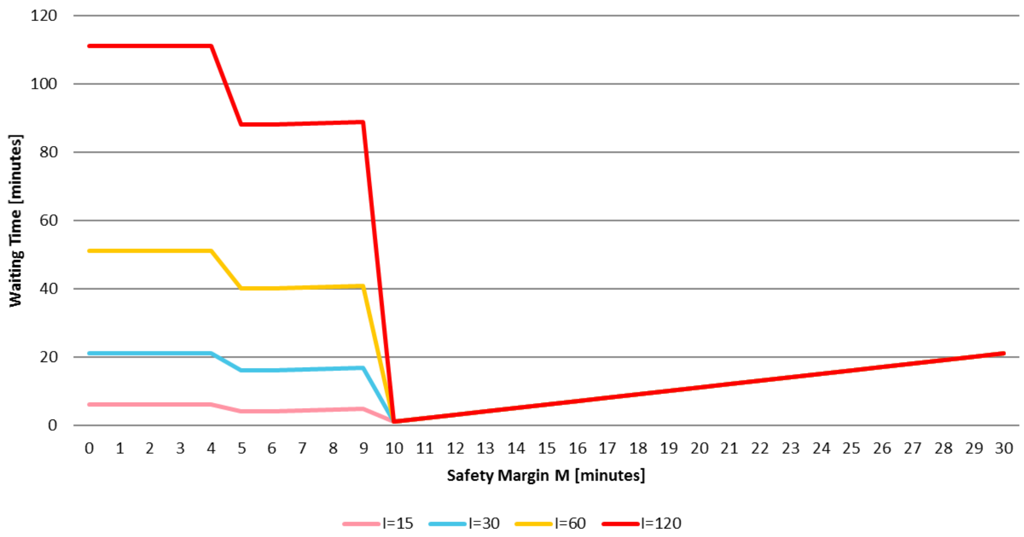


Figure 60 - Distribution of the waiting time with the highest delay

Therefore, these two charts show as the time period influences deeply the optimization of the safety margin because missing the connection means to wait very much for the next available service and, thus, the choice of the MOTT affects the total waiting time. A connection planned with a safety margin value lower than M_{OTT} are not reliable, but, at the same time, very high values can imply greater waiting times, unless there are some boundary constraints imposing this condition.

11.1.2 Stochastic distribution of the delays

Now, it was supposed that the delays are distributed with a normal-type probability function: the distribution is influenced by the average and by the standard deviation of the delays. The top of the curves represents the expected values of the distribution and so the value that has the greatest probability to occur, while the standard deviation influences the shape of the curves and it represents how much the collected data related to the delays are closer to the average. Considering a constant standard deviation and a variable value for the average delay, if this value increases, the shape of the normal-type distribution does not change, but they shift along the average delay axis: the expected value is greater, while the delays distribution is the same. The service is less punctual, but the regularity does not change.

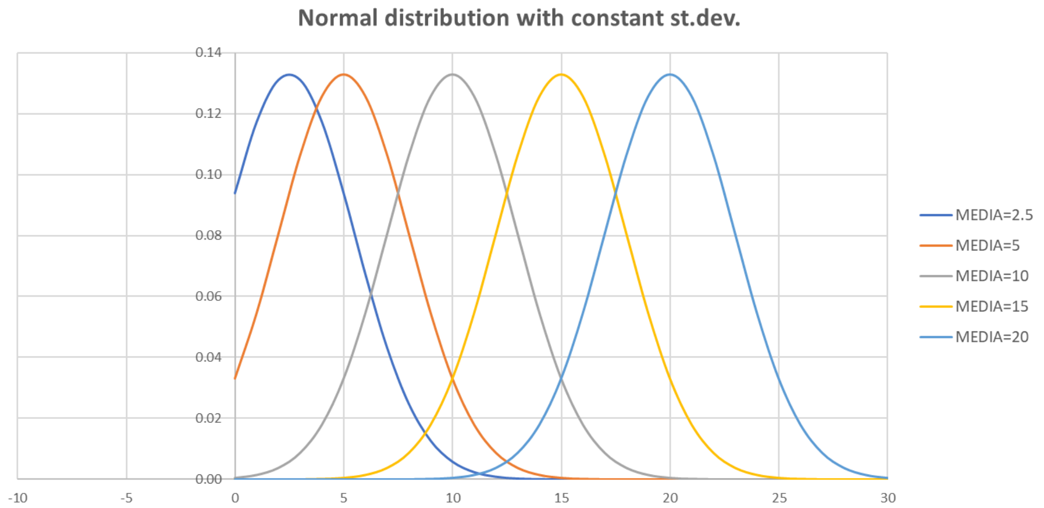


Figure 61 – Normal distribution curves with constant st.dev

Now, the average delay remains constant while the standard deviation is variable: the shape changes with respect to the increasing of the dev.st implying that, at equal expected value, the curves have longer and longer tails and, so, the extreme values of the delay have a chance of ever-greater happening. The service will be more and more irregular.

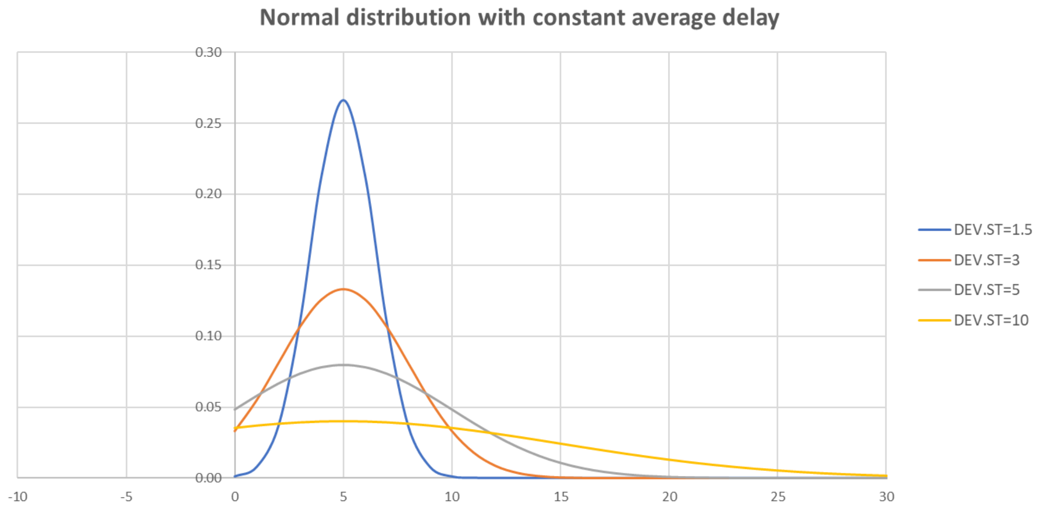


Figure 62 - Normal distribution curves with constant average delay

In both cases, the waiting time is a function of the optimum safety margin, of the delays distribution and of the frequency of the leaving traffic product:

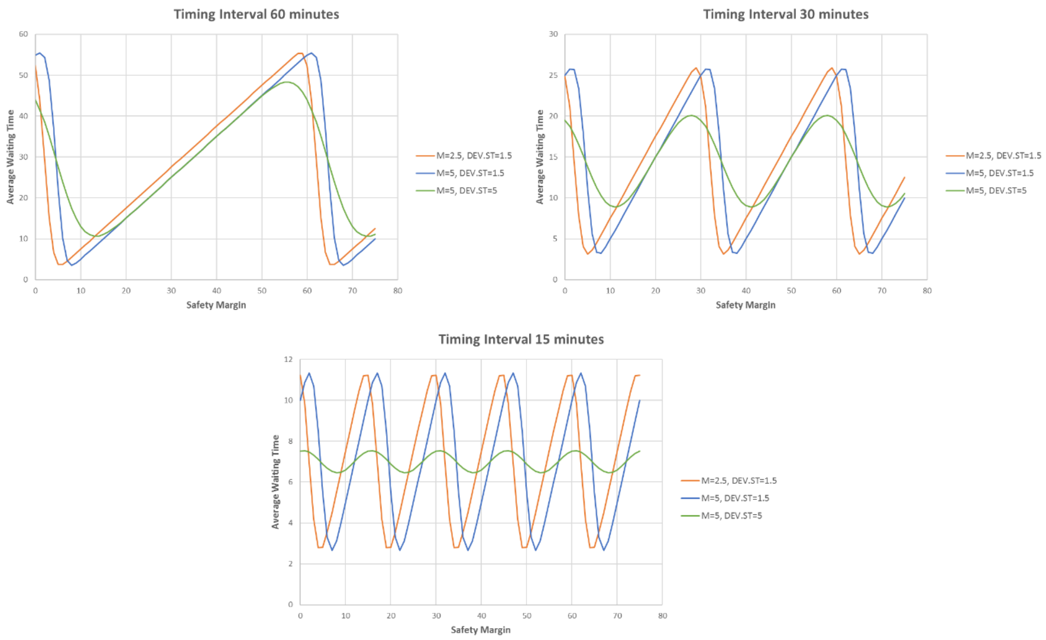


Figure 63 - Distribution of the average waiting time

- at equal time period, the waiting time curve shifts along the safety margin axis if the average delays increase and the dev.st is constant, instead, when it rises, and the expected value is the same, the oscillations of the curves are lower. This means that in the first case the MOTT increases but the waiting time is the same (service less punctual), while in the second both the safety margin and the waiting time are higher (service less punctual and less regular);

- if the distribution does not change and the time period increases the safety margin is higher as well as the fluctuations of the curves are wider: this means that the difference between the maximum and the minimum waiting time is greater and greater because the leaving traffic product is less frequent and to ensure the reliability of the connection a higher M_{OTT} is needed

In all cases, the waiting time as a periodicity equal to the time period of the leaving service. Therefore, the value of the M_{OTT}, which minimizes the total waiting time, depends on the frequency of the second service and on the delays distribution. There are four possible cases:

CASE 1	CASE 2
Low average delay value and low dev.st	Low average delay value and high dev.st.
The arriving traffic product is **punctual** and **regular**: the M_{ott} assumes the minimum value and it depends exclusively on the expected value. **THE BEST** case	The arriving traffic product is **on average punctual** but **irregular**: the M_{ott} is higher and it has to take into account the extremal values of the delay which probability to occur is greater
CASE 3	**CASE 4**
High average delay value and low dev.st.	High average delay value and high dev.st.
The arriving traffic product is **not punctual** but **regular**: the M_{ott} assumes greater values than the case 1 since the higher expected value requests wider connection times	The arriving traffic product is **not punctual** and **irregular**: the delays assume values very different each other and the M_{ott} is the highest to take into account the greater dispersion of the delays. **THE WORST** case

Table 23 - Punctuality and regularity of the services

At the end, changing contextually the average delay, the standard deviation of the distribution and the time period of the leaving service, for each possible case, the value of the M_{OTT} can be calculated. This value is obtained considering several cases, through a heuristic method, as the following abacuses report:

Safety Margin		AVERAGE				
I=60 min		2.5	5	10	15	20
ST.DEV	1.5	6	9	13	18	23
	3	8	11	16	21	26
	5	11	13	18	23	28
	10	15	18	23	28	33

Safety Margin		AVERAGE				
I=30 min		2.5	5	10	15	20
ST.DEV	1.5	5	8	13	18	23
	3	7	9	14	19	24
	5	8	11	16	21	26
	10	9	11	17	22	27

Safety Margin		AVERAGE				
I=15 min		2.5	5	10	15	20
ST.DEV	1.5	4	7	12	2	7
	3	5	8	13	3	8
	5	6	8	13	3	8
	10	8	9	9	10	10

Table 24 - Abacuses for the MOTT evaluation

These abacuses provide the different values of the optimum safety margin for all cases: the inputs are the average and the standard deviation of the delays of the arriving traffic products and the time period of the departing one. Some considerations can be made:

- when the standard deviation is constant, with higher values of the time period and of the average delay, the MOTT increases to take into account the greater waiting time for the second available train in case of the planned connection is lost.
- when the expected value is constant, with higher standard deviations the MOTT increases to consider the long tails of the delay distribution and so that the extreme delay events have a greater probability to occur.
- when the time period is constant, long tails of the distributions implies higher values for the MOTT, as well as in case of an increase of the expected value, because, in case of a missed connection, low frequency railway service involves a great waiting time. Therefore, in this case, it will be preferable to wait a little bit more to take the planned connection, instead, in case of high frequency services, missing the it does not let very high waiting times for the second available transport means.

Finally, the optimum safety margin cannot be never greater than the time period, otherwise the connection with the previous train is planned. In conclusion, the MOTT defines the minimum interchange time ensuring the minimum waiting time and, contextually, the greatest possible reliability of the connection. Infect, the MOTT does not guarantee the highest level of reliability (one hundred percent of the case to take the connection), otherwise in this case it will be necessary define another value of the safety margin which will be equal to the highest collected delay, but, the waiting time is no more the minimum.

11.2 Analysis of a real case: REG Poggio Rusco-Bologna

A real case will be provided to show how it is possible to calculate the optimum safety margin. For the REG Poggio Rusco-Bologna all the arrivals at Bologna C.le are collected considering the 6:00 a.m.-7:00 p.m. range hour for five weekdays. The results are reported in the below table: the column "Events" counts the occurring times of the specific delay (e.g. for 27 times the traffic product arrives on time at Bologna).

Delay	Events	Normal %	Real %
0	27	9.9	36.0
1	16	11.7	21.3
2	10	12.4	13.3
3	7	12.0	9.3
4	3	10.5	4.0
5	4	8.3	5.3
6	2	6.0	2.6
7	2	3.9	2.6
8	2	2.3	2.6
9	0	1.2	0.0
10	0	0.6	0.0
11	1	0.2	1.3
18	1	0.0	1.3

AVERAGE	2.133
ST.DEV	3.202

Table 25 - Delays of the REG Poggio Rusco-Bologna

Then, the average and the standard deviation of the delays are computed. The actual scenario has a connection time of seventeen minutes considering a possible relation with the high-speed trains to Rome and with a transfer time of ten minutes, the waiting time is of seven. According to the delay distribution, the average waiting time per arriving train is eight minutes and, globally, the 5.33% of the connections have been missed. Instead, calculating the MOTT through the "Risolutore" tool of Excel using this specific distribution for the delays and having as objective function the minimization of the average waiting time, the solution provides a MOTT equal to eight minutes. Therefore, the connection time will be one minute longer, but the average waiting time per arriving train is 7.4 minutes with a probability to take the connection of 97.3%. The last scenario wants to reach the maximum reliability of the interchange: it is quite evident as the safety margin of 18 minutes ensures on one side a probability to take the connection of 100%, but on the other side the average waiting time is the maximum. Therefore, the MOTT provides the best value capable to solve the trade-off between the reliability of the connection and the average waiting time.

Real case		Simulated case-Minimum waiting time		Simulated case-Maximum reliability	
Timing Interval	60	Timing Interval	60	Timing Interval	60
Transfer Time	10	Transfer Time	10	Transfer Time	10
Safety Margin	7	Safety Margin	8	Safety Margin	18
Supplied coincidence time	17	Coincidence time	18	Coincidence time	28
Total feeder trains	75	Total feeder trains	75	Total feeder trains	75
Average waiting time [min]	8.0	Average waiting time [min]	7.4	Average waiting time [min]	15.8
Not missed coincidences	94.67%	Not missed coincidences	97.33%	Not missed coincidences	100.00%

Table 26 - Real case and simulated one results comparison

The same solution is supplied by the abacuses provided in the previous paragraph: infect, for the REG Poggio Rusco-Bologna are known the average delay (2.1 min) and the standard deviation (3.2) of the delays as well as the time period of the high-speed train to Rome (60'). Therefore, choosing the correct abacus, the outcome is obtainable matching the row of the st.dev equal to three and the column of the average equal to 2.5 minutes. The obtained result is exactly eight minutes, the same gained through the "Risolutore" tool of Excel.

DATA REG Poggio Rusco-Bologna	
Timing Interval HS train to Rome	60 min
Average delay for the range 6:00 a.m. -7:00 p.m.	2.13
Standard deviation	3.20

Safety Margin		AVERAGE				
I=60		2.5	5	10	15	20
ST.DEV	1.5	6	9	13	18	23
	3	8	11	16	21	26
	5	11	13	18	23	28
	10	15	18	23	28	33

Table 27 - Utilization of the abacus

Finally, considering that, the traffic products are symmetric, and that the connection time must be equal in both directions, the greatest M_{OTT} between the even and uneven route will be used to build the right connection for each relation.

12. Railway demand analysis in Emilia-Romagna region

The aim of this chapter is to illustrate the results coming from the evaluation of the transport demand in Emilia-Romagna. At the begging, all the regional traffic products have been analysed to understand which the regional railway supply is and which localities are directly connected each other. Then, thanks to the computation of an O-D matrix with the data obtained from the 2015 Istat census, some preliminary considerations about the mobility analysis have been possible.

12.1 Definition of the regional traffic products

The regional railway infrastructure is managed by Rete Ferroviaria Italiana and by Ferrovie Emilia Romagna. The first has more than two thousand of kilometres, subdivided into conventional and high-speed lines, reserved to only HS trains from Rome to Milan and vice versa. About the four percent of the total network is not electrified. Finally, the entire regional network connects 144 stations each other, belonging to 94 different municipalities. The FER operator controls about 360 km of railway line which is totally with a single track; more than the sixty percent is not electrified and the interconnection with the national railway network occurs in eight nodes which are Bologna, Ferrara, Modena, Reggio Emilia, Parma, Suzzara, Poggio Rusco and Portomaggiore. The following picture depicts the regional network:

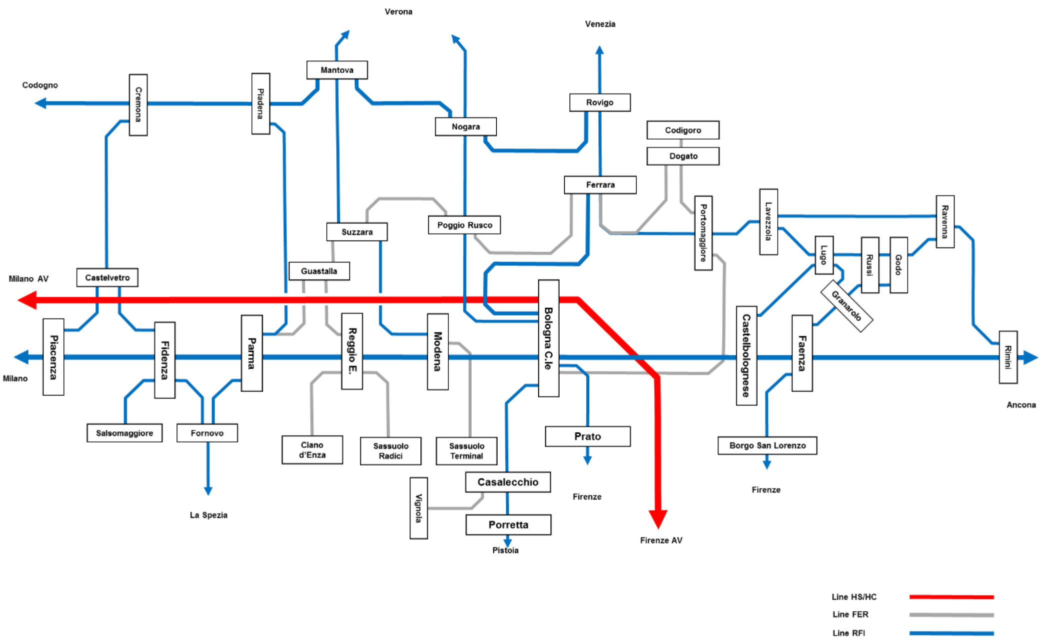


Figure 64 - Railway network in Emilia-Romagna region

The passenger service is managed by three different railway undertakings, considering only the regional and interregional traffic products. The first is the national one, which controls most of the traffic products running inside the region along the RFI lines. The second railway undertaking is TPER (Trasporto Passeggeri Emilia-Romagna) which manages different traffic products both on the national and on the FER network: some of them arrive and leave from the station of Bologna and, excluding the service to and from Portomaggiore, travel on the national line and, with Trenitalia (TI), TPER ensures the passenger service. All the other traffic products, totally running across the FER network, are directly managed by TPER. The last one is Trenord, which controls only three traffic products concerning interregional trips. The following table summarizes all the regional traffic products external to the interchange node of Bologna:

Node	Railway line	Traffic product	Origin	Destination	RU
PIACENZA	Milano-Piacenza	REG Milano GP/Milano Certosa-Piacenza	Milano	Piacenza	TRENORD
			Piacenza	Milano	TRENORD
	Voghera-Piacenza	REG Voghera-Piacenza	Voghera	Piacenza	TRENORD/TI
			Piacenza	Voghera	TRENORD/TI
FIDENZA	Fidenza-Salsomaggiore	REG Fidenza-Salsomaggiore	Salsomaggiore	Fidenza	TI
			Fidenza	Salsomaggiore	TI
	Cremona-Fidenza	REG Cremona-Fidenza	Cremona	Fidenza	TI
			Fidenza	Cremona	TI
PARMA	Brescia-Parma	REG Brescia-Parma	Brescia	Parma	TRENORD
			Parma	Brescia	TRENORD
	Suzzara-Parma	REG Suzzara-Parma	Suzzara	Parma	TPER
			Parma	Suzzara	TPER
	Parma-Borgo Val di Taro	REG Parma-Borgo Val di Taro/Pontremoli/La Spezia	Parma	Borgo Val di Taro	TI
			Borgo Val di Taro	Parma	TI
REGGIO EMILIA	Reggio Emilia-Guastalla	REG Reggio Emilia-Guastalla	Guastalla	Reggio Emilia	TPER
			Reggio Emilia	Guastalla	TPER
	Reggio Emilia-Ciano d'Enza	REG Reggio Emilia-Ciano d'Enza	Reggio Emilia	Ciano d'Enza	TPER
			Ciano d'Enza	Reggio Emilia	TPER
	Reggio Emilia-Sassuolo	REG Reggio Emilia-Sassuolo Radici	Reggio Emilia	Sassuolo	TPER
			Sassuolo	Reggio Emilia	TPER
MODENA	Modena-Carpi	REG Modena-Carpi	Carpi	Modena	TI
			Modena	Carpi	TI
	Modena-Mantova	REG (Bologna)/Modena-Mantova	Mantova	Modena	TI
			Modena	Mantova	TI
	Modena-Sassuolo	REG Modena-Sassuolo Terminal	Modena	Sassuolo	TPER
			Sassuolo	Modena	TPER
FAENZA	Faenza-Firenze	REG Faenza-Borgo San Lorenzo/(Firenze SMN)	Borgo San Lorenzo	Faenza	TI
			Faenza	Borgo San Lorenzo	TI
	Faenza-Ravenna	REG Faenza-Ravenna	Faenza	Ravenna	TI
			Ravenna	Faenza	TI
	Faenza-Lavezzola	REG Faenza-Lavezzola	Faenza	Lavezzola	TI
			Lavezzola	Faenza	TI
RIMINI	Rimini-Ancona	REG Rimini-(Pesaro)/Ancona	Rimini	Ancona	TI
			Ancona	Rimini	TI
	Rimini-Ravenna	REG Ravenna-Rimini	Ravenna	Rimini	TI
			Rimini	Ravenna	TI
	Rimini-Castelbolognese	REG Castelbolognese-Rimini	Castelbolognese	Rimini	TI
			Rimini	Castelbolognese	TI
RAVENNA	Ravenna-Castelbolognese	REG Ravenna-Castelbolognese	Castelbolognese	Ravenna	TI
			Ravenna	Castelbolognese	TI
	Ravenna-Ancona	REG Ravenna-Pesaro/(Ancona)	Ravenna	Pesaro	TI
			Pesaro	Ravenna	TI
	Ravenna-Ferrara	REG Ravenna-Ferrara	Ferrara	Ravenna	TPER
			Ravenna	Ferrara	TPER
FERRARA	Ferrara-Codigoro	REG Ferrara-Codigoro	Ferrara	Codigoro	TPER
			Codigoro	Ferrara	TPER
	Ferrara-Suzzara	REG Ferrara-Sermide/(Poggio Rusco/Suzzara)	Sermide	Ferrara	TPER
			Ferrara	Sermide	TPER
	Ferrara-Venezia	REG Venezia-Ferrara	Venezia	Ferrara	TI
			Ferrara	Venezia	TI

Table 28 - Regional traffic products in Emilia-Romagna

12.2 Mobility analysis in Emilia-Romagna

The study takes into account the data provided by the 2015 Istat Census related to the measuring of all systematic movements declared on a weekday between all Italian cities considering all possible transport modes. Obviously, it focuses its attention only on those movements that have at least the origin or the destination in Emilia-Romagna region. At the end, the evaluation of all movements, related to all transport modes and so the definition of the potential demand for each O-D relation is possible:

Total O-D relations	35.476	
Total movements	2.330.777	
Movements within the municipalities	1.421.233	61%
Movements between municipalities	**909.544**	**39%**

Table 29 - Analysis of the demand

Of course, the movements between municipalities are those more interesting to evaluate the demand more suited to the use of the train. All the municipalities have been clustered according to their railway station and according to the railway network that they belong to. The clustering considers the following four attributes for each origin or destination:

- RFI ER: it includes all the regional municipalities with at least one RFI station in their territory;
- External RFI: municipalities outside the Emilia-Romagna region with at least one RFI station in their territory;
- FER: municipalities without a RFI station but with at least one FER station in their territory;
- No connection: municipalities without a RFI and a FER station in their territory.

According to this clustering, it was possible to calculate the potential demand for each possible macro-relation:

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	298.623	15.369	26.335	92.330	432.657
External RFI	19.638	-	1.568	2.610	23.816
FER	47.991	2.200	21.945	24.147	96.283
No connection	214.939	6.542	35.301	100.006	356.788
Captivation	581.191	24.111	85.149	219.093	909.544

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	32,83%	1,69%	2,90%	10,15%	47,57%
External RFI	2,16%	0,00%	0,17%	0,29%	2,62%
FER	5,28%	0,24%	2,41%	2,65%	10,59%
No connection	23,63%	0,72%	3,88%	11,00%	39,23%
Captivation	63,90%	2,65%	9,36%	24,09%	

Table 30 - Potential demand for each macro-relation

The results showed by the above tables are very important because they attest how the potential demand in this region is splitted between the different clusters. The first table provides the numerical collected data, while the second their percentage with respect to the total one: the biggest potential demand moves along the relation between municipalities with at least one RFI station; then the second value describes how many users reach the RFI stations from localities without any one as well for the opposite direction. In addition, the percentage related to the movements among those localities without any kind of station is quite great (11%). Then there are the links joining the RFI localities to the FER ones and vice versa and the connections between these and the cities not reachable by train. The relation among external municipalities is not considered because it does not have place in Emilia-Romagna. The last column and row defines the generation and the captivation of each cluster: for example, the RFI towns generate about the fifty percent and attract more than the sixty percent of all the potential demand of the region. Therefore, this tables show which could be the total demand along the regional railway network. For example, the relations between RFI or RFI and FER or between FER municipalities are those more suitable to be run by train, because they can be direct link or at most with interchanges only within the same transport modes. Instead, the relations between RFI or FER municipalities with those without any kind of station request at least one intermodal interchange, penalizing a little bit the performances of the railway modal share, favouring the road one. Finally, the worst connections from a railway point of view are those between municipalities without any kind of station: in this case at least two intermodal exchanges are needed in the origin and in the destination node. In this last case, the running time will be very high and generally, the road transport mode will be more attractive than the railway one. For these reasons, to evaluate how much the railway modal share can improve its performances, the last described kind of connection will be neglected. Thus, the possible development scenarios tell us that:

- the 37% of the potential demand can move along the RFI network;
- only 2% along the FER network;
- the potential integration between the two railway networks can involve the 9% of the total demand;
- the 35% are interested to reach a municipality with a RFI station and so the regional transport can improve its performances through a better integration between the road mode and the RFI network;

- the 7% has the same characteristics of the previous point, but the integration is related to the FER network;
- the last 11% needs at least a double intermodal interchange, which makes the railway mode less attractive.

Nevertheless, not all these data are entirely indicative, since most of RFI municipalities are also the biggest cities of the region and, also, this network is quite ten time longer than the other and, so, the previous percentages con be a little bit misleading: infect, the FER network can be seem, immediately, much less attractive then the RFI one. Therefore, to well understand these percentages, it is necessary to appreciate the total population directly linked to the RFI or FER network or to count how much the possible O-D couples are for each cluster and, finally, the average number of movements per day.

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	2.912	1.997	674	4.066	9.649
External RFI	2.298	-	228	882	3.408
FER	846	498	332	1.238	2.914
No connection	8.096	2.093	1.406	7.562	19.157
Captivation	14.152	4.588	2.640	13.748	35.128

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	103	8	39	23	172
External RFI	9	-	7	3	18
FER	57	4	66	20	147
No connection	27	3	25	13	68
Captivation	194	15	137	58	405

Table 31 - Average movements per day

Hence, the first table defines the number of possible O-D relations and the last, which result is the ratio between the potential demand and the O-D couples, the number of possible movements per day. The aim is to stress which is, effectively, the transport intensity for each macro-relation. For example, all the demand on the relation FER-FER is 21495, about ten times lower than that on the RFI-RFI one, but, considering the number of O-D couples, the average number of movements per day is 66 against the 103 of the other, which is more than the half. This means that RFI-RFI relations are more loaded than the FER-FER ones, but they are quite the same in terms of total movements and so comparable each other.

Now, focusing only on the railway modal share, the following results have been obtained:

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	31.163	4.190	426	600	36.379
External RFI	5.297	-	71	96	5.464
FER	4.103	170	727	88	5.088
No connection	7.517	859	241	109	8.726
Captivation	48.080	5.219	1.465	893	55.657

O/D	RFI ER	External RFI	FER	No connection	Generation
RFI ER	10%	27%	2%	1%	8%
External RFI	27%		5%	4%	23%
FER	9%	8%	3%	0%	5%
No connection	3%	13%	1%	0%	2%
Captivation	8%	22%	2%	0%	6%

Table 32 - Railway modal share

The first table depicts the actual railway modal share in Emilia-Romagna for each macro-relation, while the second the relative percentage. The best values are related to the relation between the RFI municipalities in Emilia-Romagna and those located outside: this is quite reasonable because these connections cover very long distances and in most case, the links are direct and, so, the railway becomes the most attractive transport mode. The percentage related to the movements inside the region between RFI stations is quite low and this result is quite strange considering how much diffused the RFI network is in Emilia-Romagna. The main reasons could be linked or to the inefficiency of the passenger service or to the lower performances of this transport mode with respect to the road one. Infect, to well appreciate these results, it will be useful to understand the average distance covered by the users for each RFI-RFI relation: if it is quite low, the fact that this value is quite small is enough clear; otherwise, an improving of the local railway system could attract many and many passengers. In the first case, infect, the users prefer to cover short distances by bus or by car or, in some circumstances, by bike, because the train is less attractive; otherwise in the second, the railway mode might be more likable due to the longer distances and so, if this case is prevailing, the railway undertakings have to understand why this percentage is so low. The same considerations can be valid for the analysis of the railway modal share on the relations between RFI and FER municipalities and those among the last ones: the first has, globally, a percentage around the 11%, while the second about 3%. This big difference can be explained taking into account the possible movement basin: the relation FER-FER involves, generally, small localities located along the same railway line for which the distances are little and the road mode more useful; otherwise at least one interchange is needed in the RFI nodes. Instead, the relation FER-RFI links the provinces to their capitals, which attract every day, many people for several reasons and in this case, the train can ensure a direct, comfortable and less expensive service. Finally, these tables want to stress how much the integration influences the modal choice. Focusing only on the column and on the row related to the municipalities without any kind of stations, the railway modal share is very and very low and, sometimes, equal to zero, except the link with the RFI stations outside the region. This means that an increasing of the number of transhipments makes the local railway transport less and less attractive. The main reasons could be related to the inefficiency of the integration, making an increase of the waiting times in the interchange node penalising so much the total running time or to a clear lack of local transport supply or to a fairly common idea for which a double train-bus exchange is a priori inconvenient, preferring the use of the private car. Finally, this last picture shows, numerically, all the data collected on the transport demand analysis in the Emilia-Romagna region:

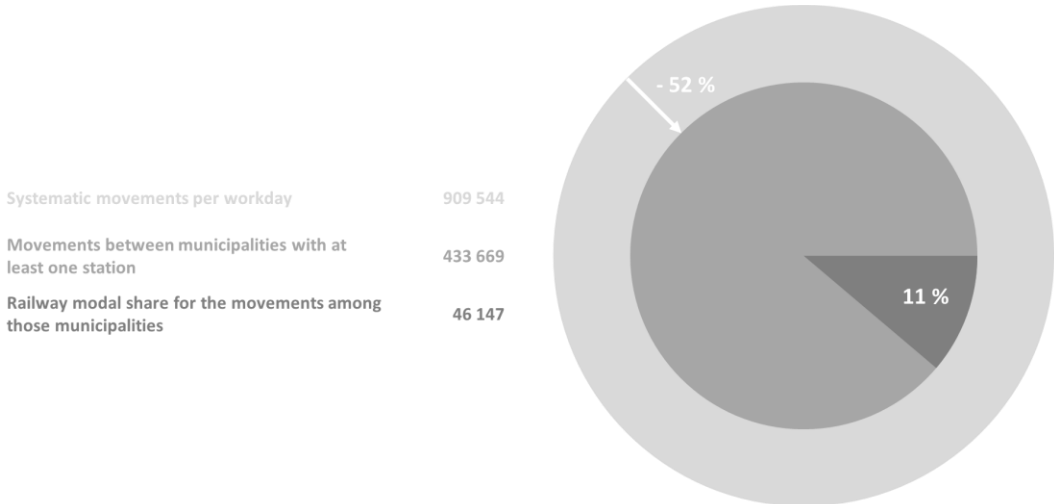


Figure 65 - Demand analysis results

The image illustrates at first the data related to all systematic movements occurring in this region, then those between the municipalities belonging to the cluster to have at least one station in the own territory and, finally, all the movements completed by train. The circles on the right represent, graphically, the results where the railway modal share is a little slice of the cake both considering the external circle and, overall, the internal one, which indicates the real potential demand of the railway mode.

12.3 Potential demand with respect to the interchange node of Bologna

This paragraph focuses its attention on the interchange node of Bologna and on the railway lines approaching the station. At the beginning, the potential demand along all the corridors and that to and from Bologna is analysed, to evaluate which railway lines are more loaded and, subsequently, the relative modal share. At the end, the last outcome concerns the potential demand for each traffic product considering all possible relations that the interchange node of Bologna can create, as well as the direct links with this station.

O/D	Bologna	Ferrara	Piacenza	Poggio Rusco	Porretta	Portomaggiore	Prato	Ravenna	Rimini	Vignola	Generation
Bologna		3632	2537	3203	880	2230	1234	237	6515	6991	27459
Ferrara	11279	6853	419	1091	80	795	221	135	697	758	22328
Piacenza	5571	261	28121	1233	48	77	85	23	297	2753	38469
Poggio Rusco	6717	1034	2589	6051	87	177	109	15	332	1472	18583
Porretta	3656	154	143	265	2952	54	429	5	164	1894	9716
Portomaggiore	6714	1868	162	309	34	2261	207	89	1687	277	13608
Prato	4666	151	107	142	1253	157	498	9	708	703	8394
Ravenna	1278	234	132	18	8	77	24	7590	7716	53	17130
Rimini	15718	546	475	357	45	1199	587	4097	44108	578	67710
Vignola	11497	571	3132	1005	603	197	245	27	508	6827	24612
Captivation	67096	15304	37817	13674	5990	7224	3639	12227	62732	22306	248009

O/D	Bologna	Ferrara	Piacenza	Poggio Rusco	Porretta	Portomaggiore	Prato	Ravenna	Rimini	Vignola	Generation
Bologna		177	679	96	153	65	32	62	574	64	1902
Ferrara	2142	725	49	13	10	13	20	33	77	24	3106
Piacenza	2278	25	4067	19	1	8	29	6	95	27	6555
Poggio Rusco	1306	41	31	301	5	4	11	8	47	5	1759
Porretta	1184	13	23	12	436	4	26		23	239	1960
Portomaggiore	928	130	20	9	2	294	12	17	53	10	1475
Prato	606	17	23	12	91	2	45	5	35	32	868
Ravenna	803	125	18		4	3	14	441	310	6	1724
Rimini	4244	49	114	36	5	16	47	372	3584	19	8486
Vignola	482	19	68	6	40		4	9	53	175	856
Captivation	13973	1321	5092	504	747	409	240	953	4851	601	28691

O/D	Bologna	Ferrara	Piacenza	Poggio Rusco	Porretta	Portomaggiore	Prato	Ravenna	Rimini	Vignola	Generation
Bologna		5%	27%	3%	17%	3%	3%	26%	9%	1%	7%
Ferrara	19%	11%	12%	1%	13%	2%	9%	24%	11%	3%	14%
Piacenza	41%	10%	14%	2%	2%	10%	34%	26%	32%	1%	17%
Poggio Rusco	19%	4%	1%	5%	6%	2%	10%	53%	14%	0%	9%
Porretta	32%	8%	16%	5%	15%	7%	6%	0%	14%	13%	20%
Portomaggiore	14%	7%	12%	3%	6%	13%	6%	19%	3%	4%	11%
Prato	13%	11%	21%	8%	7%	1%	9%	56%	5%	5%	10%
Ravenna	63%	53%	14%	0%	50%	4%	58%	6%	4%	11%	10%
Rimini	27%	9%	24%	10%	11%	1%	8%	9%	8%	3%	13%
Vignola	4%	3%	2%	1%	7%	0%	2%	33%	10%	3%	3%
Captivation	21%	9%	13%	4%	12%	6%	7%	8%	8%	3%	12%

Table 33 - OD relation along the railway lines to Bologna

The first table shows the potential demand corridor by corridor considering both the direct links with Bologna, both those requesting a transhipment in this interchange node and those running along the same railway line, which are outside the station of Bologna. The following one reports the effective railway demand and the last the relative percentage. The most important values are related to the movements towards Bologna with significant peaks for the Ravenna, Piacenza and Porretta Terme corridors. Moreover, this last railway line generates, in terms of percentage, the greatest value, even if the total demand is lower than two thousand. Besides, the modal share is not so high considering the movements along the same corridor, with values generally around the ten percent and this can be well explained taking into account the average length of the travel. The lowest percentages concerns to the railway line to and from Vignola, with a captivation and generation values around the three percent. A deep analysis about the regional demand with respect to the node of Bologna can be made with the following representation, where the demand is splitted in:

- direct links, which groups all the users which travel does not request any kind of transhipment;
- not direct links, which focuses on those travellers which movement is characterised by an interchange in the station of Bologna.

For each cluster, the potential and the real demand is studied:

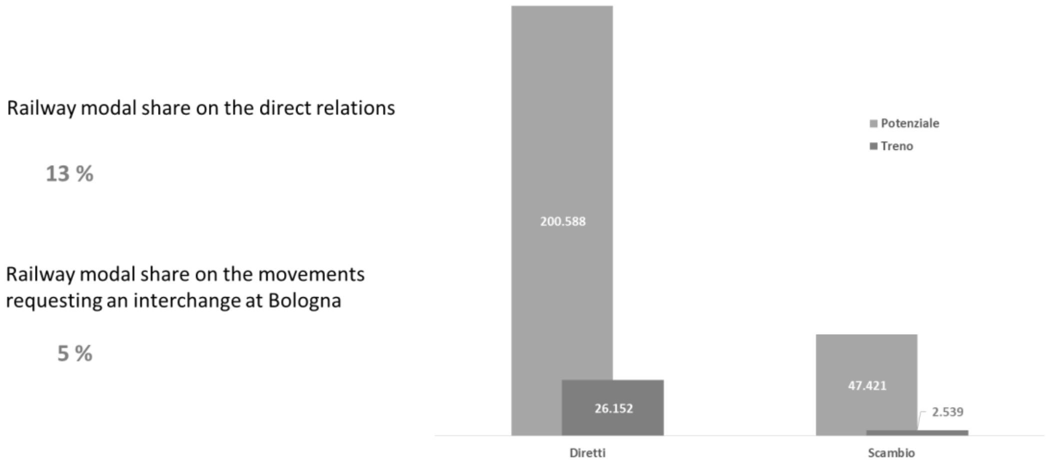


Figure 66 - Potential integration among the railway lines at Bologna

The figure stresses how much low the railway modal share is with respect to both the direct links and the not direct ones. The first column reports all the users which travel is without exchanges: the potential demand is very and very high, about two hundred thousand, but only the thirteen percent of those use the train. In this case, the length of the trip covers an essential role in the modal choice of the people. The second column represents the total demand which travel is characterised by an interchange in the station of Bologna: the demand is about five times lower, and the railway modal share is only five percent. This means that the users prefer to use another transport mode rather than an integrated railway transport. This big difference underline which are the potentials of a good design of an integrated transport network. This implies to revisit the regional "clock" supply of the station of Bologna, trying to improve the performances of the local public transport increasing not only the railway supply but also, especially, the integration level in this station. According to the actual traffic products, this last matrix shows the potential demand, interested in reaching the station of Bologna or in having an interchange.

			Poggio Rusco	Verona RV	Ferrara	San Pietro in C.	Venezia RV	Parma	Piacenza	Porretta T.	Vignola	San Benedetto	Imola	Ravenna	Rimini	Ancona	Portomaggiore	NODO DI BOLOGNA
			REG	RV	REG	REG	RV	REG	RV	REG	REG	REG	REG	REG	REG	RV	REG	
Poggio Rusco	REG	Verona			1019	890	219	2611	1958	639	1498	109	277	295	334	139	177	6812
Verona RV	RV				816	696	221	2314	1818	350	981	79	79	191	227	109	112	4291
Ferrara	REG	Venezia	1100	596				406	280	476	764	224	594	741	705	291	538	11424
San Pietro in C.	REG		833	439				216	122	335	565	175	420	452	471	156	308	7755
Venezia RV	RV		351	223				208	267	165	248	63	181	310	250	144	237	4424
Parma	REG	Milano LL	1253	951	258	214	85			474	2797	85	171	201	284	193	77	5505
Piacenza	RV		752	676	164	125	104			225	1862	53	112	136	218	173	51	3627
Porretta T.	REG	Casalecchio	700	189	475	214	158	520	207			622	399	420	464	163	172	10562
Vignola	REG		1016	317	575	515	84	3161	2316			245	417	450	514	215	197	11829
San Benedetto	REG	Prato	145	31	151	130	24	99	66	1839	716		686	696	723	122	158	4727
Imola	REG	Ravenna/ Adriatica	308	130	437	374	85	267	175	322	522	543					1169	12726
Ravenna	REG		343	181	560	410	329	417	332	362	592	580					1250	14485
Rimini	REG		356	171	544	428	161	429	342	350	578	587					1223	15838
Ancona	RV		151	101	229	145	111	371	342	123	207	111					460	7292
Portomaggiore	REG	Portomaggiore	309	143	994	663	360	159	97	162	280	207	1600	1661	1715	531		6810
NODO DI BOLOGNA			3234	951	3708	3325	567	2543	1548	4845	7136	1256	5886	6166	6670	2222	2256	

Table 34 - Potential demand for each traffic product at Bologna

In the following chapter, an ideal "clock" of the station of Bologna will be provided, computing with the demand data of this table.

13. Optimization of the "clock" supply

The optimization of the "clock" supply is the last topic treated by this work, which focuses its attention, primarily, on the mathematical formulation which is behind an optimization process of the schedule of different traffic products with periodical timetable. Then the chapter will provide an ideal representation of a good "clock" supply of the interchange node of Bologna, explaining which the differences with the actual one are, which the obtained improvements consist in and focusing on the limitations of the final outcome.

13.1 Mathematical formulation of the "clock" supply optimization process

The optimization is a process which aim is to modify some variables of one system in order to make it able to work more efficiently. Generally, it is quite difficult to obtain the optimum solution for the whole system, because, often, there are some trade-offs to be solved and, so, an improvement of one function of the system could produce worsening for the others and so on. Therefore, the most important aim of an optimization process is to find that solution which satisfies most of the components of one system, if many, solving, in this way, the trade-off. The solution research will be easier in case of the system is made up by only one component and the found solution represents the optimum too. Hence, the first step consists in defining the objective function, which deals with a minimization or a maximization of a function. In case of there are more than one objective functions, it is necessary to attribute to each of them a weight in order to make aware the process about the importance of each of them. Then, there is the definition of the variables and so what the problem has to modify in order to reach the optimum. Nevertheless, it is not possible to solve an optimization process without defining the constraints: they are essential in this kind of problem which aim is to limit the amplitude of possible solutions domain. Of course, the formulation of the constraints represents a crucial step in an optimization problem, since if they limit so much the domain, there could be the possibility that the problem is not able to provide any kind of solutions capable to satisfy all the constraints. According to our purpose, the optimization problem can have two different objective functions, which are:

1. $O.F.: Number\ of\ good\ connections = MAX$
2. $O.F.: Total\ waiting\ time = MIN$

So, the first problem is related to a maximization process, where the variables must be optimized to maximize the amount of good connections. The second one is, instead, a minimization process where the optimum of the system has to minimize the total waiting time. The two problems have two different objective functions, but their meaning is quite the same: both of them want to improve the integration level, the first directly by maximizing the number of good connections, the second, indirectly, minimizing the total waiting time and, so, making the arrivals and the departures closer each other. The formulation could be a little bit different if the potential demand for each relation is known:

1. $O.F.: Potential\ demand\ with\ good\ connections = MAX$
2. $O.F.: Average\ weighted\ waiting\ time = MIN \qquad \sum_{ij} \frac{F_{ij} \times T_{ij}}{F_{ij}} = MIN$

Where F_{ij} represents the passenger flow on the relation “i” and “j”, while T_{ij} is the connection time for the relation “i” and “j”.

Now, the variables to take into account are the arrivals and the departures minutes of all traffic product making up the whole railway supply with a periodical timetable. In this case, the definition of the clock allows knowing the entire railway structure of the interchange node for all hours of the day.

$Variables = Arrival\ and\ departure\ minutes$

The last, but no the less important, step is to understand which the constraints that rule the whole optimization process are. For example, without the minimum connection time constraints, with the second objective function, the best provided solution will be that for which the arrivals and the departures occur all at the same time with a waiting time equal to zero. In this case, it is quite evident how this is no possible since on one side, there is always a transfer time to consider and on the other, the infrastructural constraints for which some traffic products have the routes incompatible each other and the simultaneous arrival and departure are not allowed. The main constraints are related to the:

- variables: $D_i = integer; A_i = integrer; 0 \leq D_i < 60; 0 \leq A_i < 60$
- connection time: $D_{j,r} - A_{i,r} \geq C_{min} \quad D_{j,r} - A_{i,r} \leq C_{max}$, where "j" indicates the leaving traffic product and "i" the arrival one and "r" the sub-set of all relations that need to be connected in this specific interchange node. The second formulation is useless in case the minimization of the total waiting time;
- symmetry: $D_{i,s} + A_{i,s} = 60\, min$, where "i" is relative to all stopping traffic products belonging to the subset "s";
- dwelling time: $D_{i,c} - A_{i,c} = T_{dw}$, where T_{dw} is the dwelling time and "c" is the sub-set of all traffic products crossing and stopping in the station;
- turnaround time at terminus: $D_{i,t} - A_{i,t} \geq T_{Rmin}$, where T_{Rmin} defines the minimum needed turnaround time and "t" the sub-set of all terminus traffic products;
- minimum headway: $A_j - A_i \geq T_{Hmin} \quad D_j - D_i \geq T_{Hmin}$, where T_{Hmin} defines the minimum headway for trains moving along the same track;
- incompatibility among routes: $A_j - A_i \geq T_I \quad D_j - D_i \geq T_I$, where T_I represents the interdiction time between the two incompatible routes run by the traffic products "i" and "j";
- frequency of the same traffic product: $A_{j,tp} - A_{i,tp} = I \quad D_{j,tp} - D_{i,tp} = I$, where "i" and "j" are two different trains belonging to the same traffic product "tp" having a time interval lower than sixty minutes.
- frequency on the same railway corridor: $A_{j,rc} - A_{i,rc} = I \quad D_{j,rc} - D_{i.rc} = I$, where "i" and "j" represents two different traffic products belonging to the sub-set "rc"

including all those sharing an entire or a segment of a railway corridor which aim is to create a frequency integration on the common line;

- rolling material: $\frac{2*T_p+T_{DTOT}}{I} \leq N_{MAX}$, where N_{MAX} defines the maximum number of rolling materials available for the railway undertaking, T_P is the running time per direction and T_{DTOT} the total dwelling time at terminus;
- station capacity: the total amount of stopping and/or terminus trains at the same time must to consider the total number of available tracks of the station;
- commercial aspects related to the needs of the railway undertakings, of the infrastructure manager and of the customer;
- technical aspects: a new timetable in one station implies different schedules in all others which have specific constraints to respect.

This mathematic formulation shows how much complex the optimization of the timetable in one station is, due to the various and many constraints to take into account: some of them are purely related to the passenger service such as the respect of the frequency; others are related to the integration planning as the minimum and maximum connection time and the symmetry; as well as those associated to the infrastructure and to the railway circulation and so on. Generally, it is quite impossible to satisfy all of them at the same time, so the introduction of some trade-offs is needed in order to define which constraints are more important than the other to be fulfilled.

13.2 Ideal "clock" supply in the interchange node of Bologna

This part will provide a graphical representation of an ideal "clock" for the station of Bologna. It is ideal because the obtained timetable focuses only on this interchange node, representing a possible achievable result, but it does not consider some constraints related to right of way on those lines with only one track, or to the restrictions on the high-speed lines between the different traffic products or the limitations due to the timetables in other nodes of the regional and national network and so on. Therefore, the main target of this representation is only to provide a hypothetic scenario which aim is to improve the integration level in this node by respecting the constraints related to the minimum and maximum connection time, to the minimum headway and to the route incompatibility, to the dwelling time and to the symmetry, to the minimum turnaround time and to the frequency on the same railway corridor both among trains of the same traffic products and trains of different ones. In this last case, the frequency integration is supposed valid even if the arrivals and the departures are not spaced exactly of the time interval but, also, of a value very close to it.

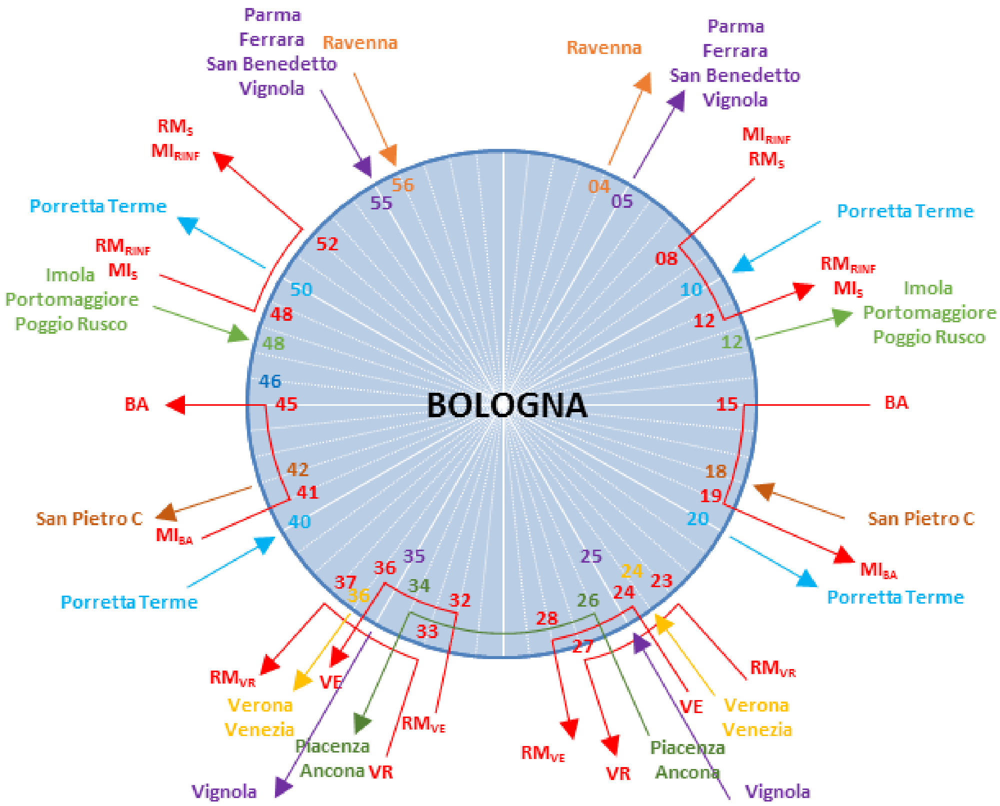


Figure 67 - Ideal "clock" for the interchange node of Bologna

Focusing only on the regional services, it is possible to observe, immediately, how they are all located in the upper part of the "clock", with a minimum headway of six minutes for those trains arriving and leaving along the same track and a minimum turnaround time of eight minutes for the regional train to Ravenna. All of them are symmetric and take into account the constraints related to the incompatibility of the incoming and outcoming routes according to the actual infrastructural plan of the station. Moreover, all of them have good connections with the high-speed trains to and from Milan and Rome: their arrivals and departures are not positioned around the minute 00, because the minimum connection time has to consider the great distance between the ground station and the underground one. To maximize the integration level with them, the even and uneven direction of the standard and the reinforcement of the fast traffic products have the same timetable.

Instead, in the lower side, there all the other regional services which have different functions but the same railway line of the others in the upper one: their aim is to create a frequency integration as well as for the Vignola and Porretta Terme traffic products which schedules are spaced of fifteen minutes to respect this constraint on the Bologna-Casalecchio segment. Additionally, the high-speed services with Venice and Milan with the standard specialization are spaced of about thirty minutes to respect the frequency integration with the city of Florence. Besides, the Venice and the Verona HS trains have, in this way, a good connection with the long-haul traffic product with Bari, as well as for the opposite direction. The following tables provide the results on the integration level both for the actual scenario and the optimized one:

Actual scenario		**Ideal scenario**	
Potential regional demand	80838	Potential regional demand	90106
Fulfilled demand	28170	Fulfilled demand	56071
Percentage	34.8%	Percentage	62.2%
Average connection time/pax	13.52	Average connection time/pax	15.41
Average connection time/rel	31.57	Average connection time/rel	30.18
Average waiting time/pax	29.73	Average waiting time/pax	23.68
Average waiting time/pax	10.44	Average waiting time/pax	13.69
GLOBAL INTEGROSKOPIO	26.6%	GLOBAL INTEGROSKOPIO	36.3%
REGIONAL INTEGROSKOPIO	28.1%	REGIONAL INTEGROSKOPIO	48.8%
Connections to Rome HS	64.3%	Connections to Rome HS	100.0%
Connections from Rome HS	78.6%	Connections from Rome HS	100.0%
Connections to Milan HS	30.0%	Connections to Milan HS	72.7%
Connections from Milan HS	30.0%	Connections from Milan HS	72.7%

Table 35 - Actual and ideal scenario

First of all, there is an important difference in the evaluation of the potential demand: this because in the first scenario there is not a standardised regional traffic product between Bologna and Rimini, instead, in the ideal one, according to the new framework agreement, the RV Bologna-Ravenna (no stops up to Castelbolognese) and the REG Castelbolognese-Rimini have both a hourly frequency and, this timetable computation considers a route integration of these two traffic products at Castelbolognese. Besides, the REG Bologna-Imola has a suburban function, with all intermediate stops. The improving of the fulfilled potential demand is very significant, with more than 50000 users with a good regional connection. The result related to the average connection time per passenger is referred to the satisfied relations and the ideal scenario is about two minutes bigger, while the same per relation concerning all possible ones are equal (about thirty minutes). One of the most important outcome shows how the average waiting time per passenger related to all possible relations is about twenty-three minutes, six minutes lower than that of the actual scenario, which highlights how all the traffic products are better integrated. Vice versa, the same correlated to only fulfilled relations is three minutes longer (thirteen against ten). The KPI IntegroSKOPIO© shows, clearly, how the integration improves its performances, both in the regional and in the long-haul field, where all the local traffic products have, always, at least one good connection time with the high-speed trains to Rome while this percentage is of seventy-two with Milan. This difference is due to the fact that, each hour, four HS trains link Bologna to Rome and vice versa, unlike the two ones to and from Milan.

14. Conclusions

This work shows, completely, which is the role of the integration in the whole transport system, capable to increase its performances, the attractiveness and the efficiency at equal transport supply. First, the integration topic is strictly related to the structure of the system: if it structured, where all the traffic products have an own and precise standardisation, function and specialization in the whole transport scenario with a periodical timetable, it is possible to realize an integrated transport network to connect in the best way all the services. All the traffic products, belonging to different transport modes, have a specific grid, which is repetitive over the time: this let to propose the same transport supply hour by hour, increasing so much the quality of the transport system. The two introduced key performance indicators, "IntegroSKOPIO© for single modules" and "IntegroSKOPIO© for structured systems", allow calculating the integration level in each interchange node, considering also different transport modes. The obtained results show clearly as the integration is an important problem in the Italian railway network and the reasons are different:

- the integration topic is little stressed in Italy, where generally other issues are considered more important, such as the speed and the running time for the direct relations or links including only big poles capable to generate the greatest railway demand, without focusing on the potentiality of an integrated system involving many regional services;
- even if the latest transport plans highlight how the role of the integration is essential to improve the performances of the entire system, its planning is generally very complex. There are a lot of constraints to take into account to design an optimal integrated network and many are the actors in the decision-making process which goals can be completely different;
- the knowledge about this topic is not widespread and clear, making its implementation more and more difficult.

The first chapters explain theoretically, what the integration is, which is its role in a transport system, which is the importance of having a structured service by focusing on the most important issues such as the spatial and the temporal integration, the property of the different traffic products and the main parameters to define the grid of a transport service. The problem of the integration is stressed in the central part by defining the IntegroSKOPIO© indicators to evaluate the integration level in different interchange nodes, underlining how it does not have many senses having very fast direct links if the exchange requires high waiting times. The importance of a great integrated transport network is also stressed at the end, analysing the potential demand in the Emilia-Romagna region, focusing at first, on the railway modal share and then which could be the future one through a better management of the local railway transport, especially in the interchange nodes. Finally, the problem related to the optimization is treated in the last chapters, where the complexity of planning an integrated transport network is underlined and, generally, it is the result of different trade-offs. Nevertheless, some of these trade-offs are unsolvable, making the integration design even more complex. Moreover, the definition of a method to evaluate the optimum connection time shows how it is not so easy to determine the minimum time capable to provide at the same time the minimum waiting time and the maximum reliability of the connections.

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