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Designing Railway Service

Implementing an Efficicent and Effective Model in Rome and Lazio

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Abstract

This thesis investigates the possibility of addressing Rome and Lazio mobility problem improving the regional railway service. The mobility analysis of both city and region, indeed, demonstrates the existence of a generalized mobility problem, that has different effects depending on the analysis scale but that is a constant over all the context. The complex nature of the study frame suggests that the most suitable solution to address the mobility problem of the area is to improve the regional railway service network, thus, this dissertation investigates how to increase the quality and attractiveness of Lazio's railway service.

In order to define how the service can be improved, after a detailed analysis of the mobility status, based on quantitative data and interpretation, there is a quantitative and qualitative investigation of the so-called Swiss model, using both transport and mobility methods, arguing that it is the service model that more increase the attractiveness of railway services.

Successively, its implementation in the studied context is proposed, designing the new railway service of Rome and Lazio taking into account not only the Swiss model principles but also other empirical concepts derived by the author's internship experience in the railway service office of Regione Lombardia, in Milan. Furthermore, it is also analysed the realization process, going through the Italian administrative tools necessary to implement the new service. Hence, not only it is analysed how to design a service railway network but also how to realize it.

In conclusion, this thesis analyses how to implement an effective and efficient service model, derived by the Swiss model, in Rome and Lazio in order to address their mobility problem.

Keywords

Railway Service Desing | Railway Planning | Rome | Lazio | Mobility System | Travel Behaviour | Mobilities Turn | Integrated Regular Interval Timetables | Uniform Clock Headway | Timetable Design | Service Levels | Interchange Nodes | Interchange Stations | Rolling Stock | | Fares Integration | Branding | Wayfinding | Swiss Model | Tendering | Gross Cost Contract | Net Cost Contract | Unbundling

Index

Introduction

Nowadays, the world is under pressure due to the environmental crisis. Many states and cities around the world declared during 2019 the climate emergency. Among the many reasons behind this environmental problem, there is mobility. Transport indeed generates a significant amount of CO_2 emissions in the atmosphere, however, some modes of transport are more responsible than others, such as cars. In the US, indeed, about a third of carbon emissions from energy use are generated by road transportation (Duranton & Turner, 2011). Consequently, in the last years, even before the climate emergency declaration, many cities around the world started to take action in order to switch towards more environmentally-friendly modes, encouraging citizens to avoid car usage. In fact, the massive presence of cars into urban environments does not only increase the pollution level but requires a lot of space that people are starting to pretend back, in order to use it for human-size activities. Hence, different measures in cities around the world have been adopted, like free-cars days or investments on cycling infrastructure, pedestrianization and public transit (Nieuwenhuijsen & Khreis, 2016).

Due to the same reason for the rest of the western world, also in Rome, and its region, Lazio, there is a mobility problem. This problem can be approached from different scales, but in the past, a comprehensive approach which takes into account both the urban and the regional scale has never been proposed. The various plan or project proposed and approved for Rome in the last years (Roma Mobilità, 2019), indeed, have often been focused only on new infrastructures, especially metro and tramways. Differently, the projects and plan that took into account the railway as a resource for the city (Rome Municipality, 2008; Mantuano 2015) were always related to the urban and metropolitan area, always avoiding the regional scale. Differently, those plans relative to the regional dimension of the railway service (RFI, 2018) were not taking properly into account the urban scale. This multifaced nature of the railway, that makes it potentially relevant to the urban, metropolitan, regional and national scale, is the reason why the railway system is suitable to address a multi-scalar problem regarding a complex context as the Roman can be. Thus, in order to fill a gap in the literature, this thesis investigates the implementation of a new railway passenger service model in Rome and Lazio. This dissertation will not only describe this service model, but it wants to be a guideline to apply the new service to the context, using the empirical knowledge learned by the author during his internship to design the possible future service network and analyse how to realize it.

Behind the need for a new service model, there is the lack of mobility present in Rome and its region. Rome counts 2.8 million inhabitants in the urban area (1,287 km^2) and about 4.6 million inhabitants in the metropolitan area (5,352 km^2). It is the capital of Italy but also of the region

Lazio, that counts a total of about 5.8 million inhabitants over 17,232 square kilometres. As regards to the mobility problems, Rome is the second city in the world for hours lost in congestion and contemporary has a low public transport modal share, especially if compared to other similar European cities. Consequently, it is arguable that both the public transit system and the road network failed to meet the mobility demand of the city and its population. Similarly, the situation in the rest of Lazio is far off: the public transport modal share is on average low and the congestion problems are substituted by pollution problems. Hence, to improve mobility in both the city and the region, it is necessary to improve one of the mobility systems that affect both Rome and Lazio: the road network or the public transport network. However, motorized private transport it is proved to be inefficient compared to public transport, especially when looking at railways. Besides, as demonstrated by Duranton and Turner (2011) that data analysed of city-level traffic in the continental US between 1983 and 2003 confirming the researches of Antony Downs of 1962 and 1992, the more roads are built, the higher congestion will be, thus any road implementation would not solve the mobility problem. Differently, the railway network is the only other infrastructure that, if properly implemented, could address the regional mobility problem in the most efficient way.

The objective of this thesis is to implement an effective railway passenger service to Lazio's railway network in order to improve the overall quality of mobility in the region and to offer an explanation on how to do it. Literature, suggests that the best railway passenger systems in terms of effectiveness, and thus transported passengers, are those where the so-called *'integrated regular interval timetables'* (IRIT) are applied (Finger at al. 2014). This thesis will explain the theory behind the service model based on IRIT, and then will apply it to the Roman context, explaining the process of implementation and the resulting planned service. Besides, there will be also an explanation on how to realize the planned service, investigating the governance and the policies needed to do so. In this project, the mobility problem of both Rome and Lazio will be addressed looking into ***'how can Lazio's railway passenger service be implemented, considering the mobility perspective, in order to increase its quality and attractiveness in comparison to other modes?'***. In relation to this, I will also address the following subquestions:

1. *'Is there a mobility problem in Rome and Lazio?'*
2. *'How to plan an efficient and effective railway service?'*
3. *'How to implement the previously described model in Lazio?'*

The beginning of the thesis comprehends the introduction and the methodology, where the various methods used to write this text have been described. This dissertation is mainly a mix of different theories, from the classical transport theory to the mobilities turn, and empirical experience made by the author during its internship in Lombardia region into the office which manages the regional railway service.

Part 1 will present the context analysis followed by the problem formulation. It answers the question ‘Is there a mobility problem in Rome and Lazio?’ and will argue for the presence of a problem as well as offering as a solution to work with a specific regional mobility system which is multi-scalar: the railway. The first chapter of part 1, describes the city of Rome and its region, talking about the geography, the demography and the infrastructures of the area. Successively, in chapter 1.2, there is a detailed analysis of the mobility in Rome and a general analysis of that in Lazio, focusing the attention of the reader on the mobility problems and their consequences, like congestion and pollution. Next, a consideration of how the mobility shapes the city and the region is presented and, in chapter 1.3, it is explained why it is necessary to intervene on a regional mobility system to solve its mobility problem and why the railway system should be chosen. Finally, the regional railway system is critically analyzed to understand its status and its potentialities.

Part 2 analyses all the theory necessary to understand the solution proposed in part 3 for Lazio’s mobility problems. This part answer the question ‘how to plan an efficient and effective railway service?’. The first chapter is about the state of the art of both transportation and mobilities theory, that are the basis to understand the successive chapters. 2.2, indeed, describes the principles behind the so-called Swiss model, a supply-based service model built on the concept of integrated regular interval timetables, and other policies that can improve its effectiveness. After that, two case studies where the model has been applied, are presented: Switzerland’s and Lombardia’s cases, outlining the effect of the model on passenger’s number.

In part 3 the solution described previously is applied to Lazio’s railway network. The question answered here is ‘how to implement the Swiss model in Lazio’, or in other words, ‘how is the theory explained in part 2 applicable to the context described in part 1?’. This is the design part of the thesis, where the author designs the future railway service model taking into account the theories and the data previously analysed. Along with the design, there is also the process of model implementation that is explained throughout, adding here other concepts learned during the author’s internship necessary to the model implementation and design. The first chapter describes these principles and the long-term scenario, that is the first step towards the model realization and the main design part. Nextly, chapter 3.2 explains the administrative instruments required by the public authority to implement the model and how to use those to design a short-term scenario and how to realize it. Successively, in chapter 3.3, the reasons behind the necessity for public tendering to assign the service to a train operating company are explained, along with the theory necessary to design a tendering process as efficiently as possible, while, chapter 3.4 and 3.5 are about additional policies that could be applied to the model to make it more effective and efficient, like branding policies and transport oriented development policies.

Finally, part 4 will present the conclusion. There, the thesis' parts are summarized, the main findings outlined and a small focus on the possible future researches related to this topic is made. Indeed, many topics mentioned here, like the wayfinding system or the branding theories, could be researched in detail in relation to railway service planning.

Methodology

This chapter will explain the methods used to write this thesis analyzing the research design, the type of knowledge used in it and finally, a brief reflection about the knowledge and method used.

This dissertation is mainly divided into three parts:

1. Context analysis.
2. Theory of the model.
3. Model implementation in the analysed context

The context analysis is fundamental to set the spatial frame of the work. In this part are indeed analysed the intervention area and scale using mixed methods. On the one hand, indeed, lots of quantitative data regarding, for instance, the mobility in the context has been analyzed, on the other hand, qualitative analysis along with interpretative analysis has been made, as for instance regarding the infrastructural context. In relation to the railway network, for instance, not only it has been analysed the network extension in terms of kilometres, but also the network shape and capacity.

The theory of the model, similarly, has been written interpreting and analyzing many different sources, from both the quantitative and qualitative perspective. Scientific papers have been analysed to understand why a model could be better than others and which features define it, along with publications and plans of public authorities. Besides, quantitative data helped to understand the potentialities of the model. This part represents the first answer to the research question. If into the context analysis indeed it is explained in detail Lazio's railway network, here there is the first answer to the '*how implement it*' question. It is indeed argued here that the model object of this part has implemented the quality and attractiveness of railway service, in comparison to other modes, in all the contexts where it has been applied.

Finally, as regards the model implementation into the analysed context, it completes answering the research question designing the railway service in Lazio's context applying the model's theory. Hence, it is the design part of the thesis that put together the knowledge acquired in the previous parts to design a new service model for Rome. In addition to the theoretical background, here, empirical knowledge has an important role. To the theory, it is indeed added the working experience made by the author during its internship in the railway service office of Lombardia Region. As a result of the design, many schemes and maps have been produced, to better understand the effect of the model in the context.

As context analysis is meant the study of the context in order to understand its features, peculiarities and issues to frame the project area and to understand the effect that the context has on the topic. The mobility of an area, for instance, is deeply influenced by the geographical characteristics of that place, but also from its history and administrative organization. Thus, to answer the subquestion 'is there a mobility problem in Rome and Lazio', the context has been analysed from different perspectives. Firstly, the geographical dimension, studying statistical data (ISTAT, 2019) and the regional physical and political maps. Next, an infrastructural overview is presented, investigating the infrastructural data (Regione Lazio, 2015; Assoaeroporti, 2019; RFI, 2020b). Presented the context, in the following chapter, its mobility is analysed using quantitative data (Roma Mobilita, 2019 & 2020; Musso, 2009 & 2013;) along with the consequences that it has in terms of congestion (INRIX, 2018), pollution (Legambiente, 2020), urban development (Tocci et al., 2008), and population growth (Spinosa, 2015).

As theory of the model, it is meant the theoretical principles that together form the model, along with the basic transport and mobility theory that is behind those. The first chapter, indeed, is a brief overview of the classical transport and mobility theory (Mohoring, 1972; Makie et al., 2003; Ponti et al., 2010; Stagni, 2012; Vuk, 2019; Urry, 2000 & 2007, Sheller & Urry, 2006; Vannini, 2010). Successively, the model itself is explained, examining papers and books related to its principles (Borza et Horváth, 2014; Finger et al., 2014; Johnson et al., 2006; Regione Lombardia, 2001, 2004a & 2004b) and to some policies that can increase its effectiveness (Regione Lombardia,2001 & 2004b; Vuchic, 2005; Gibson, 2009; Zenker & Braun, 2010; Viganò, 2014; Spinosa, 2017). Finally, the last chapter of this part is dedicated to analysing the effect that the application of the model had in Switzerland (Kräuchi, 2004; Rail Gazette International, 2005; Keller et al., 2008) and Lombardia (Regione Lombardia, 2001, 2004a, 2004b & 2015; Il Cittadino, 2019).

Model implementation in the analysed context is part 3 of the thesis where the theory is applied to the given context. In addition to this, it is also explained how to realize the model into the administrative context, using the empirical knowledge of the author. Thus, the first chapters of this part, explain the design process behind the model implementation and show the design results, producing several maps and several scheme lines. Into the design process, there are not only the theoretical principles investigated into the model theory but also other principles, here explained, that come from the author's internship experience. Hence, the first half of part 3 is the design part where the theoretical and empirical knowledge is applied to the context. The second part, it is also based on the author's experience and it looks through the service's realization process. Here, indeed, the administrative tools of the Italian context (RFI, 2018 & 2020a; Regione Lazio, 2018), are analysed and the model applied to those (Consalvi & Bassi, 2019).

It is so arguable that this thesis, considering the diverse kind of sources and the different scale of investigation that moves continuously from the detail to the general, follows the hermeneutic philosophy (Mantzavinos, 2018). The hermeneutic philosophy of science is fundamental to change the analysis perspective without losing the comprehensive sight: on the one hand, the same topic applied on different scales, on the other, different topic applied to the same main issue.

Furthermore, the interpretative method typical of hermeneutic school can be considered as the main approach of this thesis, that tries to interpret the reality to understand how the theoretical model could be improved in the defined context. This work indeed is built 'fusing two different horizons' the knowledge previously acquired by the author, that brings to the Gadamer's concept of prejudice, and the knowledge acquired writing this thesis. This dissertation is indeed a synthesis of the academic knowledge acquired by the author during its bachelor, of the empirical knowledge learned during its internship, the knowledge of the papers, the books analysed to write this thesis, and the maps and the data interpreted. The design and the map produced by the author are the results of this synthesis but those are themselves tools used to interpret the results of the fusion between the prejudice (the before knowledge) and the object of interpretation (Gadamer, 1960, 1977 & 1983).

However, the value and prejudice into any research process must be used properly. The legitimacy of value in the research process has been theorized in 1995 by Ottar Brox, which developed a model to explain where can be considered legitimate its use and where it is not, inside of a research process. Before explaining the model, it is important to briefly understand the concept of value, that can be social or personal. The environment and the willingness to protect it, for instance, can be considered as a social value, whilst the personal interests and knowledge are personal values. Regardless of the values' nature, Brox's model argues that it is legitimate to use those into the research question formulation, into the explanation, into the practical implication and the feed-back. On the contrary, into the hypothesis development and the data collection and manipulation, it is illegitimate to use the value (Brox, 1995). The hypothesis and the data handling, indeed, must be objective to avoid the confirmatory bias.

Analysing this thesis, it is possible to observe the application of this model. The research question formulation has been made using the background and the previous knowledge of the author, that is from Rome and accumulated railway-related knowledge during its studies and internship. However, the development of the hypothesis and the data collection and handling are based on the sector literature. The so-called Swiss model is analysed throughout the classical research tools, like books and papers., Differently, into the practical implications and the feed-back the value and the before-knowledge of the author play a significant role. They are indeed fundamental for the design part that represents itself the fusion of horizons between the scientific knowledge and the author's values and experience. As stated before, they are added to the scientific knowledge acquired here to achieve the hermeneutic fusion of horizons.

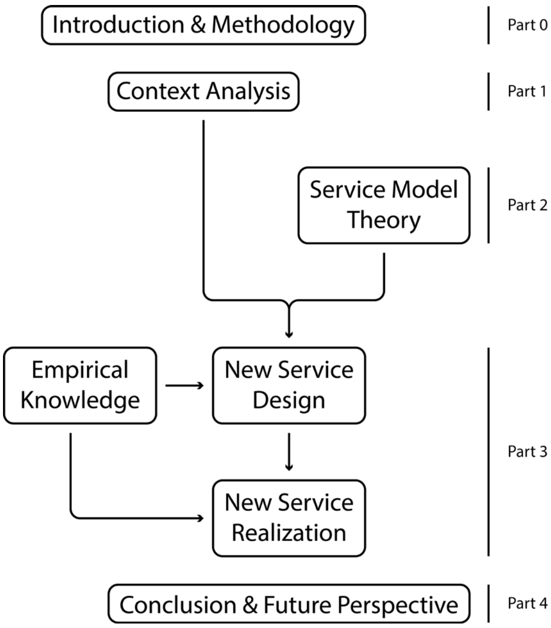


Figure 1 - Methodological Process. Author's drawing

Figure 1a - Rome View. Image downloaded from https://www.visitareromain3giorni.it/weekend-a-roma-dove-andare/

1. The Context: Rome and Lazio

This part of the thesis will provide the reader with the context's elements necessary to understand it. Besides, the context analysis will motivate the choices that will lead to the next part of the thesis. It is indeed the analysis of the context that suggests working with public transit, and especially railway, due to its multi-scalar value.

The first chapter describes the territory from the geographical and demographical point of view. There is a territory's description followed by detailed data about the inhabitants and, successively, a first analysis of the infrastructural network of the region. To conclude, a short but detailed description of the city of Rome is made, because it is the most important city of the region and its characteristics will deeply influence the design.

The second chapter, similarly to the first one, is an analysis chapter. There the mobility data available for the region and Rome are analysed and described, showing a mobility's lack in the overall context. The second and third parts of the chapter, are dedicated to analyzing the consequences of the mobility status, like the pollution generated by it or the influence that mobility had and still has on the urban development.

Successively, the last chapter of this part will start to address a solution to the problem. Understood that to solve a mobility issue it is necessary to work on the mobility itself, in the first section of this chapter it is explained what is a mobility system, and successively, in section two, why it has been chosen to work on the railway system. Finally, in the last section, Lazio's railway system is analysed and described in detail taking into account both infrastructure and timetables, showing the limits of the system, that are outlined in the discussion.

Figure 2 - Trajan's Column, Rome. Image downloaded from https://www.pinterest.it/pin/668151294705251128/

1.1. Context Description

In this chapter, an overview of Lazio geographical characteristics is provided to the reader. Understanding the context is fundamental to comprehend the phenomena that take place there. In the first part, there will be a brief description of the territory's characteristics while the second part will be about population size and geographical distribution among the region's cities. In the third section, a description of the existent infrastructures of the region will be presented and finally, a more detailed description about Rome will be made, briefly describing the city, to provide the reader with the necessary elements to understand the context.

However, before starting Lazio's geographical description, it is pivotal that the reader is aware of Italy's administrative division. Italy is a democratic republic, divided into twenty regions. The State and the Regions can both amend laws, but the regional laws cannot go against national laws. Regions are administratively divided into provinces and metropolitan cities, which in turn comprehend many communes. The biggest among them, are generally divided into smaller municipalities, that is the smallest administrative unit. It is pivotal to understand that this system is hierarchical, and the law of a subordinate can be more restrictive, but it cannot go against those of a higher-order authority (Republic of Italy, 1947). To sum up, the hierarchical division is the following:

1. Republic (Italy)
2. Regions (Lazio, Lombardia, Tuscany, etc…)
3. Provinces and Metropolitan Cities (Rome Metropolitan City)
4. Communes (Rome Commune)
5. Municipalities (Rome's 15 Municipalities)

1.1.1. Territory

Lazio, one of the twenty Italian regions, is situated in the centre of Italy. It has about 5.8 million inhabitants over 17,232,29 square kilometres. It adjoins on the north with Tuscany, Umbria and Marche, on the east with Abbruzzo and Molise and on the south-east with Campania, whilst the west side is all touched by the Tyrrhenian Sea. As regards its physical features, Lazio's territory is hilly for 54% of its size, mountainous for 26.1% and flat for the remaining 19.9%.

Figure 3 - Lazio's Map. Image downloaded from https://viaggifantastici.blogspot.com/2016/

1.1.2. Population and Cities

5,867,097 people live in Lazio. The majority of them, about 4,6 million, live in the metropolitan area of Rome, that takes a bit less than one-third of the overall regional surface, and about 2.8 million of those live in its commune (1,287 km^2). As regards the main cities, in addition to Rome, there are four provincial capitals and other 11 cities with more than 45,000 inhabitants (ISTAT, 2019).

Provincial or Metropolitan Capitals:

1. Rome – 2.8 million inhabitants (metropolitan capital)
2. Latina – 126,746 inhabitants
3. Viterbo – 89,671 inhabitants
4. Rieti – 47,149 inhabitants
5. Frosinone – 46,054 inhabitants

Other Main Cities

1. Guidonia Montecelio – 89,671 inhabitants
2. Fiumicino – 80,470 inhabitants
3. Aprilia – 74,660 inhabitants
4. Pomezia – 63,796 inhabitants
5. Tivoli – 56,472 inhabitants
6. Anzio – 55,101 inhabitants
7. Velletri – 53,250 inhabitants
8. Civitavecchia – 52,716 inhabitants
9. Nettuno – 49,995 inhabitants
10. Ardea – 49,750 inhabitants
11. Terracina – 45,800 inhabitants

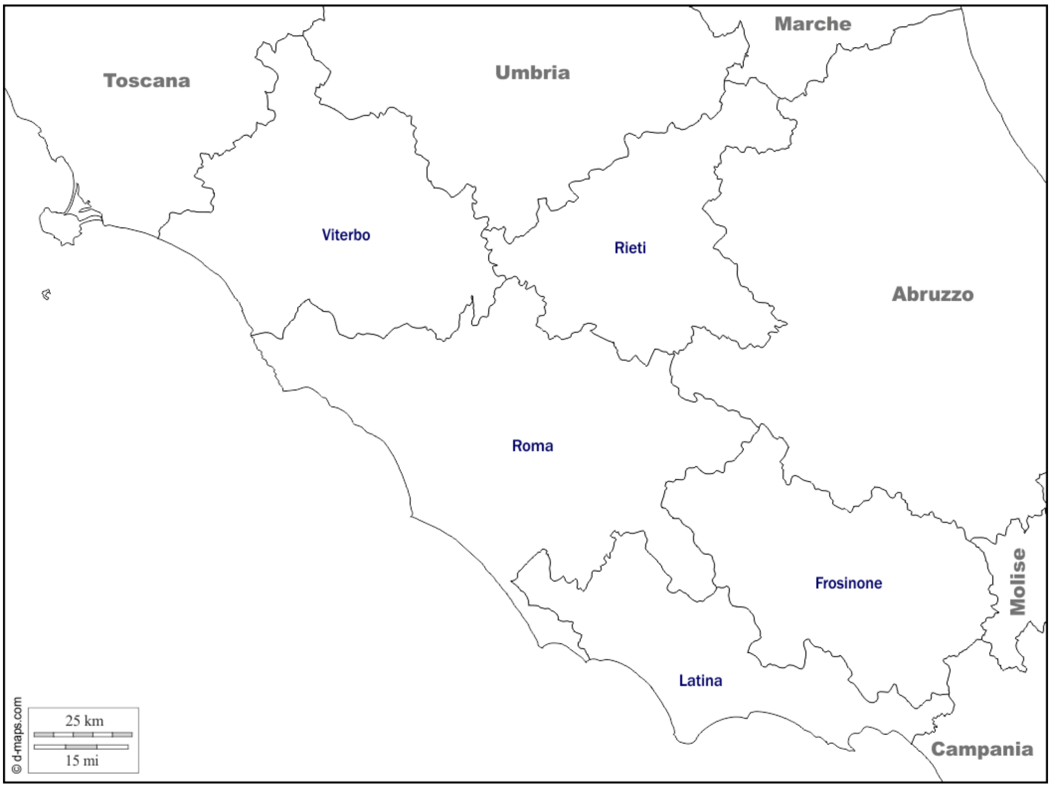


Figure 4 - Lazio's Administrative Division. Image downloaded from https://d-maps.com/pays.php?num_pay=402&lang=it

Figure 5 - Lazio's Main Cities. Image downloaded from https://d-maps.com/pays.php?num_pay=402&lang=it

Those eleven cities, excluding Aprilia and Terracina, are all in the metropolitan area of Rome; hence, it is possible to conclude that the majority of people living in Lazio lives in Rome or in its surroundings, gravitating around Rome.

Figure 6 - Colosseum, Rome. Image downloaded from http://ilturistico.it/wp-content/uploads/2014/06/Fori-Romani-dallalto-2.jpg

1.1.3. Infrastructures

Figure 7 - Lazio's Main Roads. Image downloaded from https://d-maps.com/pays.php?num_pay=402&lang=it

As regards the road network of Lazio, it counts about 8,000 km of roads, of which 545 km of national roads and 470 km of highways (Regione Lazio, 2015) which are shown on the map. The wider lines are highways or dual carriageways whilst the thinner ones are single carriageways. It is evident the radial structure of the network, that support the majority of displacements. Indeed, as it can be seen in figure 8, Rome looks like a black hole attracting everything. In this picture, each arch represents a commuter flow between two different communes. In order to better represent the areas where there is a big number of displacements, each arch has a different intensity of transparency. Thus, denser areas in the map represent not only the zones with the major number of connection between communes but also areas where there is the biggest number of commuters. To make the map readable, the flows made of less than 10 commuters are ignored: even though they represent the 80% of the arches, they are just 9% of commuters.

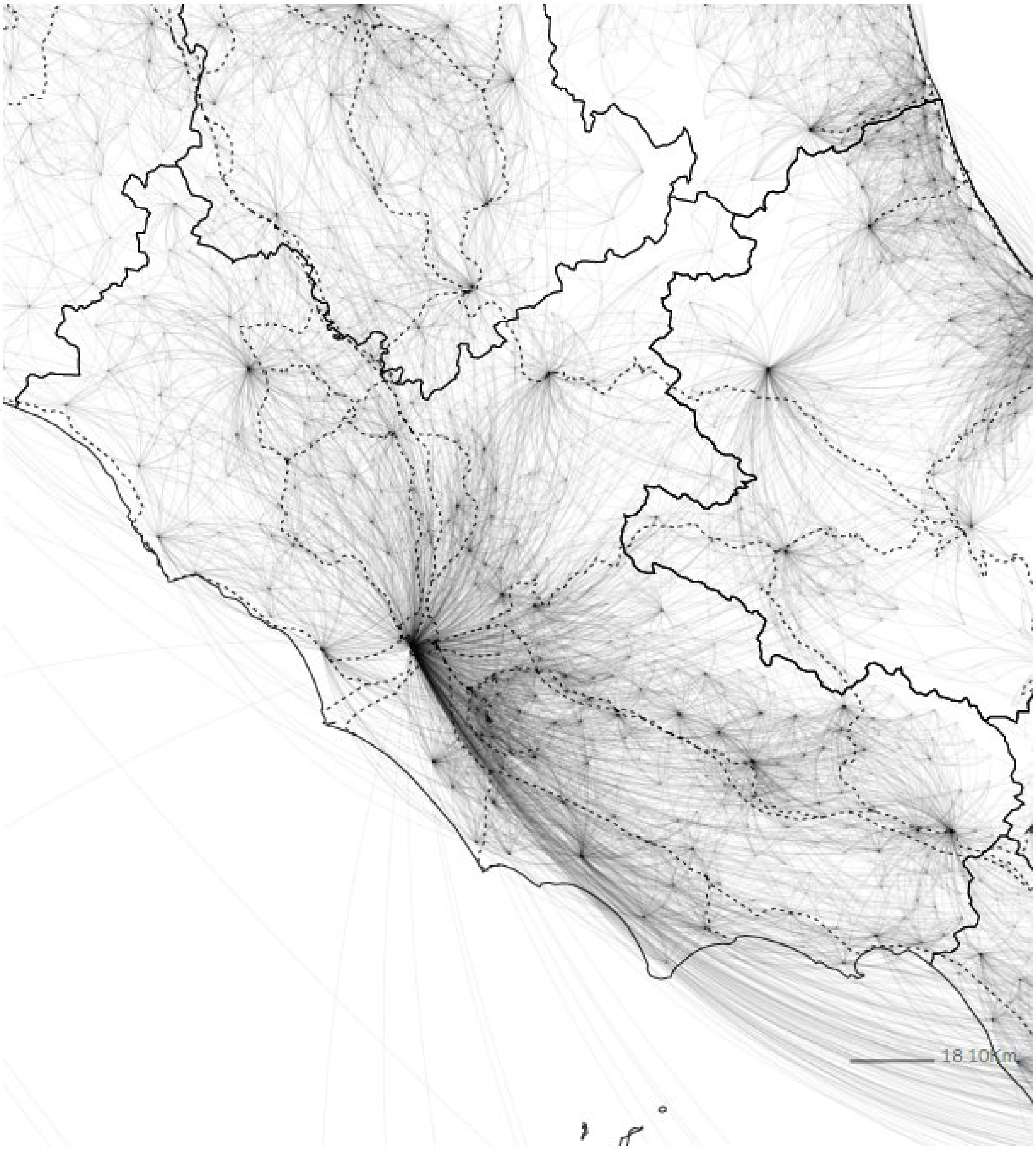


Figure 8 – Commuters' Flows. Image downloaded from http://www.postmetropoli.it/atlante/?p0=F-Mobilita-e-flussi

As regards other infrastructures, as it can be seen in figure 9, the railway network, similarly to the road network is radial respect to Rome and counts 1,319 km and 200 stations (RFI, 2020b). The two main airports are Fiumicino Airport, with about 43 million passengers in 2019 (Assoaeroporti, 2019), and Ciampino Airport; the former is Italy's biggest airport in term of passengers and the ladder is Rome urban airport, with about 5.8 million passengers in 2019. As regards the harbours, excluding those tourists which are present all over the coast, the principal port of Lazio is Civitavecchia, that is used both for passengers and cargo, generally transported by ferry or Ro-Ro vessels. The harbour of Formia, the second of the region, is essentially touristic but it guarantees the link between the continent and Ponza and Ventotene Islands.

Figure 9 - Lazio's Railway Network. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

1.1.4. The City of Rome

In this section, there will be a description of the city of Rome focusing on its urban geography. Considering its population and its commune area, the population density is about 2,200 inhabitants per square kilometre. However, considering that about 44% of the total commune area are green areas (ISTAT, 2011), there are many neighbourhoods where the real density is much higher than the average. Rome commune is divided into 15 municipalities, that have both an administrative and a political office, that represents the people community. Rome has been

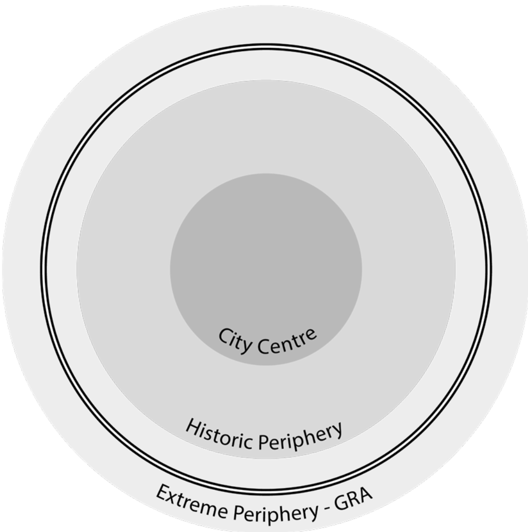


Figure 10 - Rome's Zones. Author's drawing

built the 21st of April of 753 BC, and since then the city's shape has changed innumerable times. Nowadays, after more than 2700 years of history, the city's shape can be simplified dividing it into three main areas; the historic city centre, the historic periphery and the external periphery, as shown in figure 10. As it will be successively explained, the external periphery has grown around the Grande Raccordo Anulare (GRA, literally translated as Great Annular Connection), that is the circular highway that surrounds the city.

1.1.5. Summary

Lazio is the region of Rome and it is situated in the centre of Italy. The majority of its population, 4.8 million people out of 5.6 million, lives in the metropolitan area of Rome, and more than half of this, 2.8 million, in the urban area of the city. The infrastructural networks, both roads and railways, reflect the centrality of Rome, presenting both a radial shape that connect all the cities of the region to its capital. Consequently, especially for the commuters demand, Rome represents the destination of the majority of the displacements, that from all over the region are directed to the capital. Considering this and that 77% of the population lives in Rome's metropolitan area, it is possible to affirm that addressing a regional problem means addressing Rome's problem, and vice-versa.

1.2. Mobility’s Analysis

In this chapter, Lazio’s mobility is analysed, to understand its limits and potentialities. It is important to comprehend that, due to the population distribution, talking about Lazio's problems and addressing those means addressing Rome’s problems. Thus, this chapter will analyze data regarding both Rome and Lazio because, as stated before, about 77% of Lazio’s population is living in Rome’s metropolitan area and about 50% in its urban area (ISTAT, 2011). Hence, analysis and solutions need to be multi-scalar, from the urban to the regional scale. In the first section, there is an analysis of Rome and Lazio displacements data, especially regarding the modal share, to give to the reader an idea about mobility patterns in the study context, whilst the second and third sections are about the consequences generated by the ineffectiveness of mobility demonstrated in the following section.

1.2.1. Modal Share

In this section, there will be an analysis of Rome and Lazio mobility in order to understand how people are on the move in Lazio. As said before, Rome metropolitan population is 4.6 million inhabitants out of 5.8 million regional inhabitants, thus Rome’s problems are Lazio’s problems. Unfortunately, mobility’s data referring to the overall regional situation are not available, as much as the information about Latina and Frosinone provinces, whilst data about Rome commune and metropolitan city are disposable and updated at 2018. However, data shows a trend confirmed all over the country (Beria, 2018): Rome urban area attracts public transit users because is one of the few areas where, thanks to population density and dimension, public transit it is used not only by categories that do not own a private vehicle. Indeed, public transit modal share in Rome’s metropolitan area and in the other two provinces that have available data is lower or comparable to Rome’s commune.

On the one hand, as regards Rome’s mobility, the 2.8 million inhabitants generate 5.3 million displacements per average day, about 58% made by private car or moto, about 21% made using public transit and about 17% walking (Roma Mobilità, 2020). Among the total displacements, 20% are systematic displacement (students and working commuters) whilst 38% are not. As regards the magnitude of displacements, 55% are short: these take less than 30 minutes; in fact, 53% of the total take place inside the same city’s municipality. Finally, talking about the timeframe, 18% of displacements happen between 7:30 and 9:30 whilst 20% between 16:00 and 19:00. Differently, considering the metropolitan area, the data show a decrease in walking and a raise in displacements made by private vehicle. Considering the displacements internal to the metropolitan area but excluding Rome, about 81% of the total is made by private vehicle, whilst about 18% by public transport (Roma Mobilità, 2019). However, if displacements towards Rome's commune data are included, the public transit modal share increase to about 21%, whilst regarding private vehicle it decreases to about 74% (ibid).

On the other hand, as regards mobility in Viterbo's and Rieti's provinces, the modal share data are divided into internal and external displacements. The internal displacements modal share is referred to the displacements among origins and destinations internal to the province, whilst the external displacements modal share regards the displacements that present internal origins and external destinations or vice-versa. Viterbo's province internal displacements are made by car for 74 %, by public transit by 26% (22% bus + 4% train) and walking or cycling by 0.2%. However, the displacements that present the origin or the destination outside the province, that is Rome 41 times out of 100, present a better modal share for public transport. In this case, indeed, the public transit modal share is 47% of which 31% represented by train and 16% by buses, whilst the walking modal share remains constant and private car represents 53% (Musso, 2013). Rieti, differently, does not present train modal share for the internal displacements. The private car has the biggest share, with 62%, whilst the bus represents 18%, as much as the walking and cycling mobility. However, similarly to Viterbo's area, the outgoing displacements (almost 80% of which towards Rome) have a bigger modal share for public transit (40%) where the train represent the 21%, whilst the private car modal share is still the biggest with 59% of the share, with the remaining 1% composed by the other modes, that includes walking and cycling (Musso, 2009).

Lazio's Modal Share Divided by Area				
Area/Mode	Private Vehicle	Public Transit	Walking /Cycling	Others
Rome Commune	58%	21%	17%	4%
Rome Metropolitan City Rome Commune Destinations Excluded	81%	18%	-	1%
Rome Metropolitan City Rome Commune Destinations Included	74%	21%	-	5%
Viterbo's Province Internal	74%	26%	0.2%	-
Viterbo's Province External	53%	47%	0.2%	-
Rieti's Province Internal	62%	18%	18%	2%
Rieti's Province External	59%	40%	-	1%
Frosinone's Province	-	-	-	-
Latina's Province	-	-	-	-

The point here is that, in all these contexts, private car is the main character of the mobility, while public transport is used into Rome and to go to Rome because the longer is the distance, the more convenient is taking the train, as shown by data. However, if Rome commune modal share is compared to Paris, Barcelona or London modal share, it is possible to observe a substantial difference. London presents 48% of public transit modal share, double than Rome, Paris the 63% and Barcelona the 68%, both three times Rome (Mantuano, 2015). In the next section, it will be explained why this difference with the other European cities, and so this lack of public transit mobility, is a problem for Rome and Lazio.

1.2.2. Congestion & Pollution

This chapter is about the main problem related to the mobility's lack presented in Rome and Lazio: congestion and pollution. The difference between Rome public transit modal share and that of other European cities is not enough by itself to state that there is a mobility problem in Rome. If, for instance, the city road network and the parking space of the city had enough capacity to host all the traffic without congestion, there would not be a mobility problem. However, on the contrary, Rome is the second most congested city in the world after Bogotà. Roman citizens have lost, in 2018, 254 hours in congestion (INRIX, 2018). However, people prefer to use the private vehicle over public transport even though the city is one of the more congested in the world. Hence, public transit is not efficient, and neither is private transport. Thus, it is arguable that in Rome there is a mobility problem. As regards, on the contrary, the other Lazio's areas, the congestion is not so problematic, mainly, because of context characteristics. The less population density reduces congestion level, however, the higher usage is still a problem for the pollution levels. Frosinone indeed, in the last 10 years, exceeded the daily PM10 maximum level (50 $\mu g/m^3$) 1000 times, more than 35 days per year, that is the maximum law value, whilst the annual average (40 $\mu g/m^3$) has been overcome 8 years out of 10 (Legambiente, 2020). The author is aware that pollution is not only generated by traffic, nevertheless, if private vehicle modal share is, as it is probable, at least as much as in the rest of the region, it undoubtedly contributes to the pollution issue.

Next section is about another consequence of Rome chronic mobility's lack: the population growth distribution. It is a clear example of how mobility shapes society over time and space.

1.2.3. Urban Development and Population Growth

This section will offer a brief overview of Rome urban development from the eighties until today because the mobility and population growth phenomena that will be later explained find their origins in those years. Secondly, a paragraph will talk about the population growth of the last 10 years and the forecasted for the next 30 years, and finally, a little discussion about the future city shape will be presented.

During the eighties, new unauthorized neighbourhoods around the GRA, the circular highway surrounding Rome, have been built. Trying to offer some services to these new illegal houses, the public authority decided to build new public neighbourhoods close to them, to unify those illegal to the historical periphery of the city (Tocci et al., 2008). Unfortunately, the result of these two interventions has been a disaster on the mobility of the city. The new peripheries, indeed, were adding people on Rome existent radial roads increasing the average distance of urban displacements. The new suburbs were, in fact, far away from the city centre and so a bigger distance needed to be covered. The existent public transit network was not prepared to supply the new demand, thus, during the second part of those years, the public transit modal share decreased by 30% (ibid). Besides, during the first part of the nineties, new shopping centres were built around the GRA and successively new service sector offices have been constructed. The reasons behind this peripheral development around the highway were mainly two: the former economic and the latter related to mobility. Firstly, building at the extreme peripheral is cheaper than building close to the city centre and secondly, the mobility's lack that characterizes the extreme-periphery-to-city-centre commuting is filled by the GRA in the periphery-to-periphery commuting, especially since it has been upgraded with the 3rd lane. However, the magnitude of the peripheral development has saturated the upgraded highway in many of its section, reducing the effectiveness of the peripheral-to-peripheral commuting (ibid).

Thus, in the last 40 years, the city shape changed dramatically, reaching and urbanizing the areas around the highway that surrounds the city. This new shape made the extreme-periphery-to-city-centre commuting too ineffective and started to create new important traffic flows from periphery to periphery, that were more effective and pushed the extreme-periphery development. This development drove to the partial saturation of the new highway, that, however, still has an important impact on the city. In the last decade, indeed, the population of the metropolitan area (Rome excluded) has grown more than the Rome municipal population, registering a growth of 7.5% whilst the city has grown by 4.5% (Roma Mobilità, 2020). The reasons behind this, are probably both economical and related to mobility. The new areas around the GRA have started to attract workers that are probably living not only in those areas but also in the other metropolitan cities because those are cheaper than Rome and the distance house-work comparable, while, the congestion probably inferior (public transport is not an option if the destination is the extreme-periphery). Besides, the growth for the next 30 years forecasts a decrease in Rome commune population and a rise in the metropolitan and regional population, as shown in figure 11 (Spinosa, 2015).

area urbana	provincia	area	01/01/2014	densità	01/01/2020	01/01/2030	01/01/2040	01/01/2050	Δ 14-50	densità
FR01 Anagni-Colleferro	Frosinone/Roma	234.93	57,020	243	58,129	59,119	58,888	57,356	1%	244
FR02 Frosinone	Frosinone	513.00	160,471	313	158,639	154,469	147,380	137,552	-14%	268
LT01 Latina	Latina	533.89	176,533	331	182,591	189,400	192,220	190,553	8%	357
LT02 Terracina	Latina	314.60	75,531	240	82,587	92,605	101,660	109,073	44%	347
LT03 Sezze-Sermoneta	Latina	209.09	40,179	192	43,210	47,731	52,225	56,544	41%	270
LT04 Cori	Latina	103.48	12,245	118	12,243	12,103	11,705	11,057	-10%	107
RI01 Rieti	Rieti	331.26	58,543	177	59,304	59,731	58,861	56,655	-3%	171
RI02 Poggio mirteto	Rieti	88.16	12,894	146	13,587	14,467	15,073	15,341	19%	174
RI03 Forano	Rieti	74.37	9,983	134	10,753	11,841	12,812	13,598	36%	183
RI04 Poggio nativo	Rieti	101.34	9,301	92	9,743	10,314	10,721	10,921	17%	108
RM01 Roma	Roma	1,287.36	2,863,322	2,224	2,865,769	2,837,171	2,748,169	2,600,136	-9%	2,020
RM02 Pomezia-Ardea-Aprilia	Roma	336.77	181,089	538	211,165	260,601	318,443	384,703	112%	1,142
RM03 Marino (Castelli Est)	Roma	179.75	170,743	950	176,774	184,258	188,916	190,321	11%	1,059
RM04 Guidonia-Tivoli	Roma	163.47	151,841	929	162,351	176,721	188,667	197,219	30%	1,206
RM05 Lido di Enea	Roma	115.29	101,946	884	116,885	139,857	163,861	187,677	84%	1,628
RM06 Monterotondo	Roma	106.50	99,089	930	111,087	129,308	147,992	166,256	68%	1,561
RM07 Fiano Romano	Roma	205.74	66,300	322	79,063	101,290	129,584	164,976	149%	802
RM08 Fiumicino	Roma	213.89	74,855	350	88,416	110,054	134,027	159,431	113%	745
RM09 Albano Laziale (Castelli Ovest)	Roma	125.57	109,019	868	114,263	121,051	125,928	128,450	18%	1,023
RM10 Palestrina-San Cesareo	Roma	145.83	75,910	521	85,950	101,474	117,910	134,648	77%	923
RM11 Cerveteri-Ladispoli	Roma	160.27	77,193	482	84,740	95,550	105,494	113,856	47%	710
RM12 Bracciano	Roma/Viterbo	337.51	59,729	177	67,825	80,210	93,048	105,694	77%	313
RM13 Valmontone	Roma	130.00	49,631	382	55,762	65,202	75,171	85,388	72%	657
RM14 Civitavecchia	Roma	122.65	71,591	584	72,608	73,369	72,705	70,545	-1%	575
RM15 Velletri	Roma	118.23	52,956	448	54,259	55,538	55,619	54,406	3%	460
RM16 Formello (Parco di Veio)	Roma	106.51	31,932	300	35,578	40,944	46,139	50,827	59%	477
RM17 Rignano Flaminio	Roma/Viterbo	115.77	17,062	147	19,460	23,313	27,632	32,304	89%	279
RM18 Castel Madama	Roma	148.15	17,860	121	18,818	20,097	21,095	21,732	22%	147
RM19 Montelibretti	Roma/Rieti	185.70	16,461	89	17,349	18,529	19,441	20,011	22%	108
RM20 Genazzano	Roma	100.02	19,811	198	19,944	19,936	19,534	18,730	-5%	187
RM21 Palombara Sabina	Roma	75.80	12,232	161	12,935	13,840	14,488	14,814	21%	195
RM22 Subiaco	Roma	132.42	17,355	131	17,018	16,381	15,457	14,275	-18%	108
VT01 Nepi	Viterbo/Roma	147.38	19,943	135	23,013	28,102	34,182	41,407	108%	281
VT02 Viterbo	Viterbo	436.38	71,712	164	74,623	78,572	81,828	84,389	18%	193
VT03 Civita castellana	Viterbo/Rieti	232.44	35,892	154	37,341	39,112	40,168	40,383	13%	174
VT04 Sutri	Viterbo	139.46	18,469	132	20,311	22,979	25,487	27,669	50%	198
VT05 Montefiascone	Viterbo	199.76	18,824	94	18,939	18,894	18,447	17,597	-7%	88
VT06 Ronciglione	Viterbo	127.52	16,283	128	16,626	16,950	16,928	16,533	2%	130
VT07 Orte	Viterbo	110.69	14,558	132	15,074	15,665	15,935	15,839	9%	143

Figure 11 - Lazio's Demographic Trend (Spinosa, 2015)

The main reason behind this population growth distribution will probably be economical. As theoretically described by Von Thunen with its land-use model of 1826, the city centre and the historic periphery will gain value and will be used for valued activities, probably related to the tertiary and the tourism. Consequently, people will move to the metropolitan area or other regional cities, that will offer cheaper accommodations and better or comparable motility.

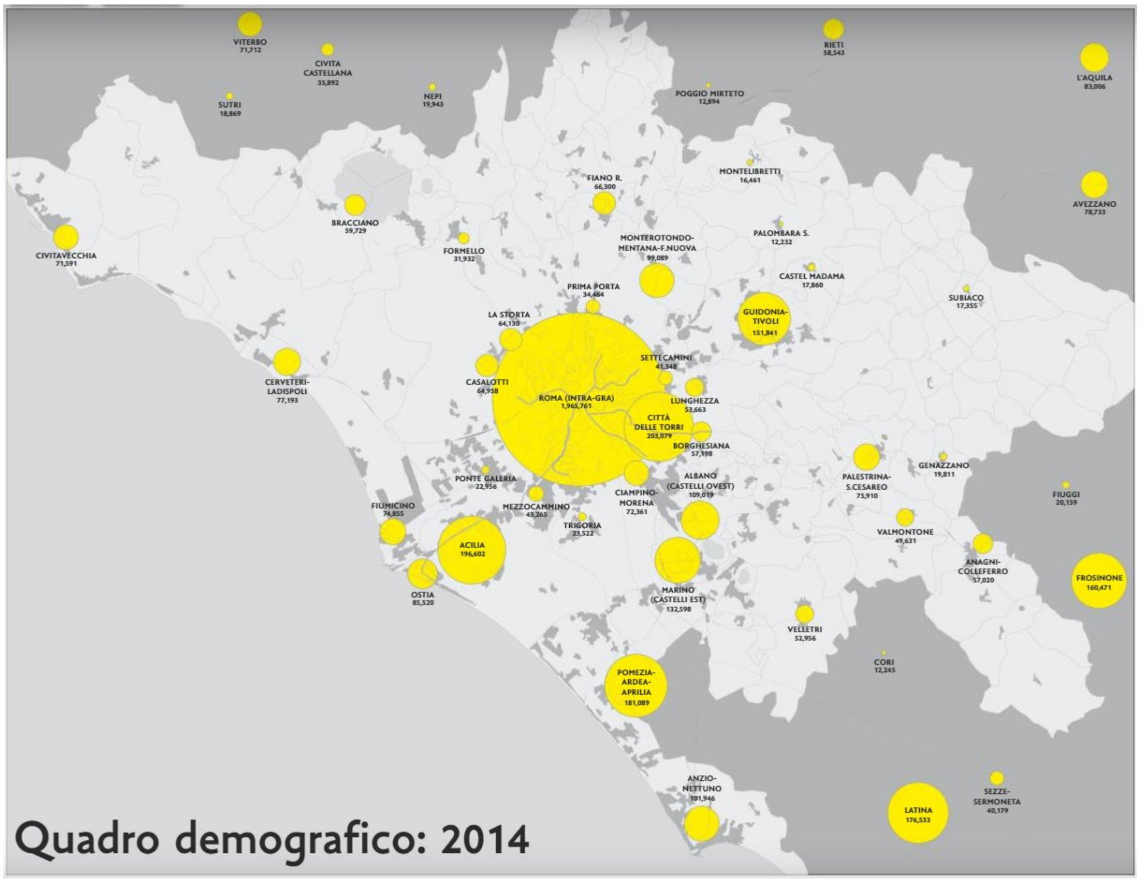
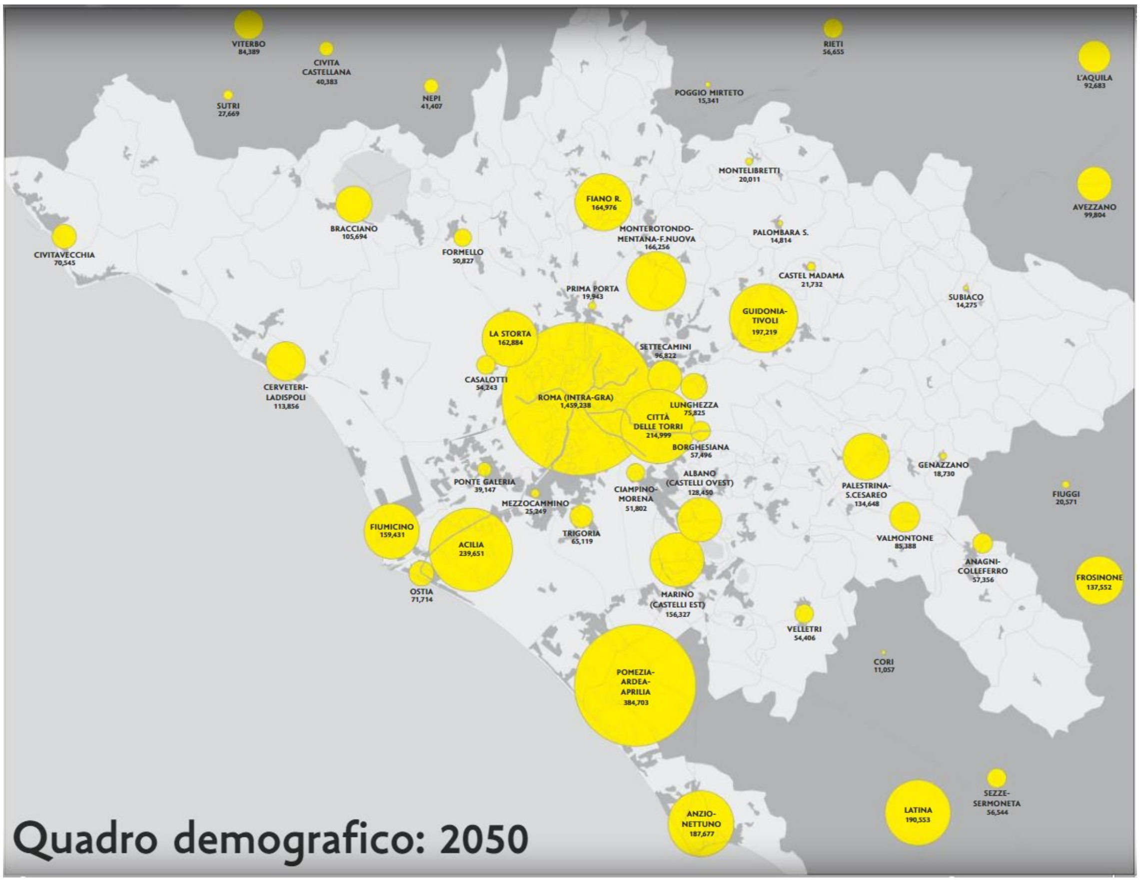


Figure 12 ↑ - Lazio's Population in 2014 (Spinosa, 2015) ///// Figure 13 ↓ - Lazio's Population in 2050 (Spinosa, 2015)



Consequently, it is possible to suppose the main mobility flows that will characterize Rome and its region in the next years. Those will probably be the existent flows but strengthened and enlarged. People working in the historical city, that will offer more jobs than accommodations, will live into the historical city if they can afford it, or in other regional cities, far from Rome. Extreme-periphery-to-city-centre commuting will be less efficient than today, due to the road network situation, whilst the public transport will be effective only on the regional scale, as today data demonstrate, connecting quickly by train Rome city centre and the historic periphery with the other regional cities. This trend will be enforced, as much as the extreme-periphery-to-extreme-periphery commuting. The city around the GRA, indeed, will be consolidated and the tangential flows will increase their magnitude, moving people inside the extreme periphery and to the cities into the hinterland. To sum up, there will be five main groups of flows:

1. Inside the historic city (figure 14).
2. Between the historic periphery and the extreme periphery (figure 15).
3. Inside the extreme periphery along the GRA (figure 16).
4. Between the extreme periphery and the metropolitan area (figure 17).
5. Between the historic city and the regional cities (figure 18).

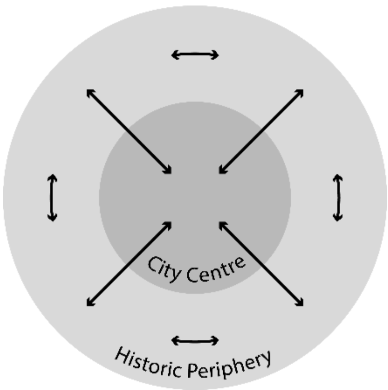


Figure 14 – Author's drawing

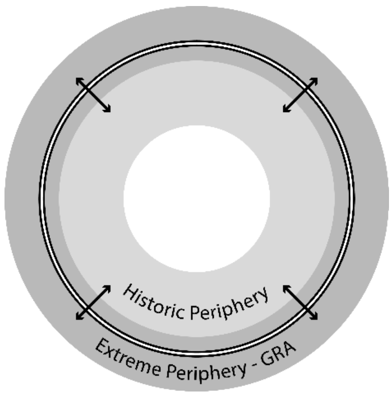


Figure 15 - Author's drawing

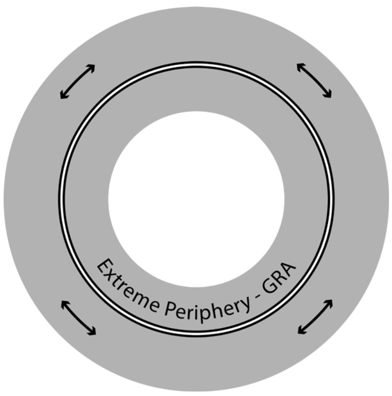


Figure 16 - Author's drawing

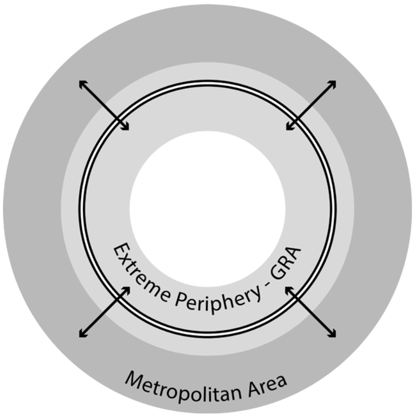


Figure 17 - Author's drawing

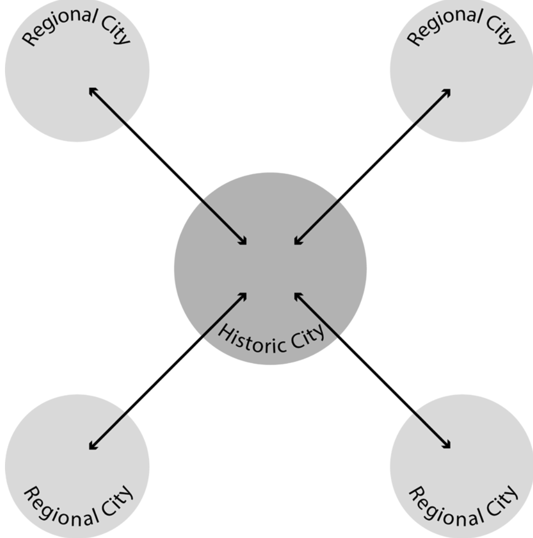


Figure 18 - Author's drawing

1.2.4. Conclusion

In this chapter, the mobility of both Rome and Lazio has been analyzed, outlined the strong relation that the region has with the Capital. Talking about Rome's mobility problem, indeed, due to its population magnitude, means talking about Lazio's mobility problem. The regional data analyzed, confirm the national trend about public transit modal share: it is in the city that it represents a valuable alternative to the private vehicle due to context peculiarities, such as population density and congestion. About half of the displacements that take place in Rome are short, lasting less than 30 minutes and having origin and destination inside the same city's municipality. However, the public transit modal share is low in Rome, especially if compared to other European cities. Besides, this low share is not balanced by an effective road network. Even though the majority of displacements, 58%, are made using the private vehicle, Rome is the second city in the world for hours lost in congestion (254 hours per year per person), showing that even though the private vehicle is not efficient at all, it is preferred to the public transit. This lack of mobility together with urban planning has built a city that relies on the private car, especially in the so-called extreme periphery, that has been developed along the GRA, the circular highway that surrounds the city. The population growth trend states that this phenomenon will continue: the population living in the historic city should slightly decrease whilst the population living in the extreme periphery and into the metropolitan area should raise, as much as the inhabitants of the regional cities, mainly due to economical reason related to the land use.

This analysis is pivotal to understand the problem that this thesis is trying to address: a complex mobility problem that requires a multi-scalar approach. To solve this problem, the author argues that regional mobility needs to be updated, working on a specific mobility system. Into the next chapter, the concept of mobility system will be explained and it will be made a focus on the specific regional mobility system chosen to solve Lazio’s and Rome’s mobility problems: the regional railway system.

Figure 19 - Pantheon, Rome. Image downloaded from https://www.pinterest.it/pin/256283035030552814/

1.3. The Mobility System of the Past for the Future

In order to solve the mobility's lack described in the previous chapter, it is necessary to intervene in the existent systems that support the regional mobility. Among the two main regional mobility systems, the road and the railway network, the author strongly argues that is the railway system that needs to be improved to solve Lazio's mobility problem. In the first section of this chapter, there will be explained the concept of 'mobility system', to understand why one of those will be analysed. Secondly, a section will be used to illustrate the reasons why the railway system has been chosen and to conclude, a deep description of Lazio's railway network will be made, regarding both the infrastructure and the service which today is running.

1.3.1. The Mobility System Concept

This section will provide the reader with a definition of mobility system to understand why one of those will be selected and analyzed to address Lazio's mobility problem. The definition of mobility system has been given by John Urry, in its book '*Mobilities*' (2007): "*These systems make possible movement: they provide 'spaces of anticipation' that the journey can be made, that the message will get through, that the parcel will arrive. Systems permit predictable and relatively risk-free repetition of the movement in question. Systems enable repetition. In the contemporary world these systems include ticketing, oil supply, addresses, safety, protocols, station interchanges, web sites, docks, money transfer, inclusive tours, luggage storage, air traffic control, barcodes, bridges, timetables, surveillance and so on*" (Urry, 2007, pg. 13). Throughout those systems, modern life, characterized by a loss of collective coordination, can be scheduled and rescheduled. The more modern the world is, the more complex the mobility systems that permit a modern lifestyle are. In the 19th century, there have been invented the railway, the national post system and the telegram, in the 20th century, high-speed trains, mobile phones and networked computers have been invented and nowadays the mobile phone has become a smart-phone, that is networked like the computer, and so on (ibid). Thus, to sum up, a mobility system is a system that allows movements of people, goods or informations, and it can be simple or complex, so composed of many different systems.

Consequently, it is pivotal to understand that railways are a complex mobility system, made of many different mobility systems, and those need to be analysed taking into account their complex nature. Railways are not only the tracks and the trains running on those, but also when the trains run, how the circulation is organized on a line, the ticketing systems, the information provided to the users, and so on. Hence, a complete analysis need to take into account all the features of this complex mobility system, as it will be done in this thesis.

1.3.2. Railways VS Roads

In this section, it will be explained why, among the two systems, the railway system has been chosen. The road network and the railway network are the only two mobility systems that allow people and goods movement all over the regional territory. However, between these two, the railway seems to be the system more suitable to solve the mobility problem of both the region and Rome. The main reasons for this choice are three:

1. There is a mobility problem because the regional mobility is based on roads and cars.
2. The railway can intercept the main flows on both regional and urban scale.
3. It is forecasted into the Sustainable Urban Mobility Plan of Rome to increase the Public Transport modal share.

1.3.2.1. Private Vehicle Inefficiencies

As stated in the previous chapter, the mobility problem of Rome and Lazio provokes congestion and pollution. The technological upgrade could solve part of the negative externalities generated by private vehicles, however, some inefficiencies can not be overtaken by technology. The electric engine together with the autonomous driving does not affect congestion and the low efficiency of the car as a transport mode. "*A single lane of limited-access highway carries a maximum of 2,500 vehicles per hour*" (Giuliano & Hanson, 2017) and considering the average passenger transported by a car is 1.2 people (Beria et al. 2012), "*the passenger volume rarely exceeds 3,000 per hour per lane*" (Giuliano & Hanson, 2017). The space, especially into the city, is a limited and high valuable resource, and cars, compared to other modes, require much more space, for both movement and parking. A metro line, for instance, can easily carry more than 30,000 passengers per hour per direction and does not require as much space for parking, because on the one hand, public transit is in motion more hours than a single car, and on the other hand, the space used by public transport to accommodate people is inferior than the space used by the car. Into 5 square-metres, that is the average dimension of a city-car, there can be up to 5 people seating (even though the average is 1.2 passengers per car), whilst, the same space into a train or a bus can accommodate up to 20 or 30 standing people.

1.3.2.2. The Regional Flows and the Existent Planning

The railway Lazio's system, as it is going to be described in section 1.3.3, has a radial shape with Rome in the centre. If the service is properly planned, the railway network can intercept mobility flows on both urban and regional scale. It has been explained that the most frequent relation (54% of displacements) are intra-municipality whilst the other important flows, forecasted to increase, are those on the medium distance among Rome and the other regional city, where the train is already a valid alternative to the private vehicle. As regards the first group of flows, those intra-municipality (even though this can be applicable to many flows inside the historic city), congestion does not affect the railway, that could absorb the demand more effectively than today. Besides, a more effective railway would be compliant with Rome existent planning, that presents the increment of the public transit modal share as one of the main aims (Roma Mobilità, 2015).

1.3.3. Analysing Lazio's Railway System

Until now, this chapter has explained the concept of mobility system and the reasons why among those regional it has been chosen to work on the railway system. The low public transit modal share suggests that the railway system in Lazio has not adapted itself to the 3rd millennium. Railways are a mobility system of the 19th century, however, those can be updated and set up to be one of the mobility systems of the future, not only as high-speed trains but also offering urban and suburban services. In this chapter, Lazio's railway network will be analysed, from the infrastructural (1.3.3.1), the service (1.3.3.2), and the rolling stock perspectives (1.3.3.3), to understand the context and the possible upgrades to do.

1.3.3.1. Infrastructural Analysis

As briefly explained before, Lazio's railway network counts 1,319 km and 200 stations. As it can be observed by the map, the network has an evident radial shape, with all the railways going towards Rome, that is in the central part of the region. Starting from the north-west there are those are the railway on Lazio's territory (RFI, 2020b):

1. Rome – Civitavecchia – Pisa – Genova. It is the northern Tyrrhenian railway, one of the more important in Lazio and it links Rome with Pisa and Genova, passing throughout all the cities on the Tyrrhenian coast. It is a double-track railway over all its itinerary.
2. Rome – Viterbo. It is a regional railway, very important on the urban scale due to the many stations present on the urban section. There, it has two tracks whilst, outside Rome municipality, it is a single-track railway.

3. Rome – Orte – Florence traditional railway. It is the historic Appenninic railway that linked Rome to Florence. However, since the eighties the new high-speed line Rome – Florence has been built and the old line has been dedicated mainly to regional and suburban traffic. It is a double-track railway over all its itinerary.
4. Rome – Florence high-speed railway. It is the Italian most important and congested railway. It is saturated by high-speed trains that run here to go to Milan, the most congested route, but also to Venice and any other city northern than Rome. It is a double-track railway over all its itinerary and the maximum speed is 250 km/h.

Figure 20 - Lazio's Railway Network. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

5. Rome – Avezzano – Pescara. It is a secondary railway that crosses the Appennin connecting Rome to Pescara. It is double-track in the first 15 kilometres and single-track in the rest of the itinerary. It is a typical mountain railway with low speed limits due to the many bends presented all over the itinerary.
6. Rome – Napoli high-speed railway. It connects Rome to Napoli allowing trains running at 300 km/h. Differently from the Rome- Florence high-speed railway, it is not saturated.

7. Rome – Frosinone – Napoli. This railway is one of the most important on the regional scale. It links Rome with Frosinone's area. It is used by both regional trains connecting Frosinone and Cassino with Rome and by interregional trains linking Rome with Isernia and Campobasso. It is double-track over all its itinerary.
8. Rome – Ciampino – Frascati/Velletri/Albano. These are three railways that share a significative section of their route, from Rome to Ciampino. They connect Rome to Ciampino, where there is the second airport of the city, and to the so-called 'Castelli Romani' area (literally translated 'Roman Castles'), one of the most populated areas of the metropolitan city. The shared section is double-track while the rest of each railway is single-track.
9. Roma – Latina – Napoli. Until 2009 it has been one of the main national railways because it was used by trains connecting Rome and southern Italy. It presents double-track and it allows speeds up to 180 km/h. Today it is mainly used by regional traffic and some long-distance trains that do not run on the high-speed network. Linked to it, there are two railways both important on the regional scale, that along with the main line link Rome with Nettuno and Terracina respectively.
10. Rome – FCO. It is very important on both regional and urban scale. It links Rome with its first airport, Fiumicino, but it also has many urban stations. It is double-track over all the itinerary.
11. Viterbo – Orte. It is a secondary railway linking Viterbo with Orte, in the north of Lazio. It is single-track and it does not present much traffic (Trenitalia, 2020).
12. Terni – Rieti – L'Aquila. It is a secondary railway that goes from north-west to south-east along the Apennine mountains. It is a single-track non-electrified railway with few trains per day running on it.
13. Avezzano – Sora. Similarly to the previous railway, is the only other line that does not originate in Rome. It links the Rome – Frosinone – Napoli line with the Rome – Avezzano – Pescara line. It is not electrified and does not present much traffic (ibid).
14. Roma Flaminio – Viterbo. This line is not shown on the map because it is not managed by RFI, the national infrastructural manager, but by the region. It is indeed a regional railway owned by the region, that starts in Roma Flaminio station and ends in Viterbo, close to the RFI station. The line presents double-track in its urban section and the single-track on the rest of the itinerary.

1.3.3.2. Service Analysis

In the previous chapter, the hardware (the infrastructure) of Lazio's railway mobility system has been described. Now, this section will describe the railway service, that is the software installed on the hardware. Analysing a railway network, indeed, does not mean to only analyze its infrastructural characteristics but also its service. The impact of a railway on any area, indeed, does not depend only from its itinerary, but especially from the number of trains which run over it. Firstly, the map of the existent railway service will be described, and finally, the regional timetables will be analyzed.

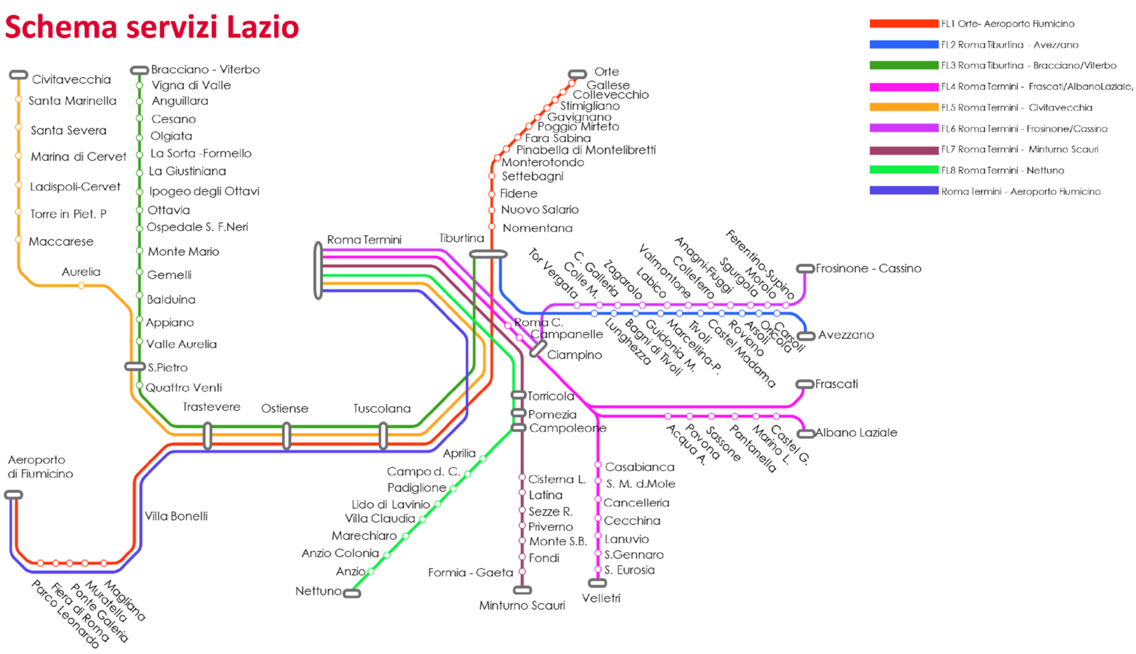


Figure 21 - Lazio's Railway Service. Image downloaded from https://www.trenitalia.com/it/treni_regionali/lazio/informazioni_utili-lazio.html

This map is the official map of the train company (Trenitalia) that runs the service in Lazio. It is observable the organization of the service on all the regional railway that origin in Rome. They are called today FL, the acronym for Ferrovie Laziali (literally: Lazio's Railways), but from 2002 to 2012 they were called FR, the acronym for Ferrovie Regionali (literally: Regional Railways) and from 1990 to 2002 they have been called FM, the acronym for Ferrovie Metropolitane (literally: Metropolitan Railways). However, although the name changed three times in the last 30 years, the lines remained almost the same since the beginning. The last updates are the introduction of line FL8, before a branch of FL7, and the terminus change of FL3 that has been moved from Roma Ostiense to Roma Tiburtina Station (Trenitalia, 2001; Trenitalia, 2003, Trenitalia 2020). The lines' design follows the infrastructure: excluded the first three lines, FL1, FL2 and FL3, all the others depart from Roma Termini station but all of them, except for line FL1, run on a single railway. FL2 runs on the Roma – Avezzano – Pescara railway, FL3 on the Roma – Viterbo railway, FL4 run from Rome to Ciampino and then it presents three branches, one per railway, and so on. Looking at the map, it seems that the services are designed to stop in each station of the line and that the only no-stop service is the line connecting Roma Termini station to FCO airport. Into the next paragraph, some Lazio's timetables will be analysed to understand if the map corresponds to the real services which run on the infrastructure.

Looking at the regional timetables, it is clear that there are significant differences between the map and the timetable. Firstly, the name of the lines exists into the map and the stations, but the timetable refer to them as R trains, that means regional.

Figure 22 is a picture taken from the author the 20/03/2020 in Gemelli Station, Rome. It is observable that the FL3 is the name of the line but the electronic screen does not call the trains FL3 but just regional trains. Furthermore, different trains (it is important to remember that all of them are classified as FL3) have different termini, two different in Rome and four (only three are visible in the picture but FL3 reaches Viterbo) towards Viterbo (Trenitalia, 2020). Hence, there is an attempt to brand the system and create a wayfinding system, but it does not result very effective due to the timetable.

Figure 22 - Departures from Gemelli Station, Rome. Photographed by the author in 2020

Analysing the timetable (figure 23), it is clear that the map simplifies too much the reality. There are indeed some trains, called R as the others, that run from Roma Ostiense to Viterbo skipping many urban stations. Contemporary, other trains run only in the urban section, from Roma Ostiense to La Storta (ibid).

3

Roma -Cesano -Viterbo (FL3)

5 Non sono ammesse le comitive con biglietto scontato.

6 Il servizio di trasporto biciclette è soggetto a limitazione. Per i dettagli consulta le Condizioni generali di Trasporto.
Treno con servizio di trasporto biciclette al seguito del viaggiatore il sabato e nei festivi.

7 Non sono ammesse le comitive con biglietto scontato nei lavorativi escluso il sabato.

8 Si effettua il sabato. Sospeso il 25/4.

9 Il servizio di trasporto biciclette è soggetto a limitazione. Per i dettagli consulta le Condizioni generali di Trasporto.
Treno con servizio di trasporto biciclette al seguito del viaggiatore il sabato fino al 18/4 e dal 2/5.

Km		R 24064 ♿ 2 5	R 7438 ♿ 2 5	R 21942 🚲 ♿ 2 6 7	R 7440 ♿ 2 5	R 7396 ♿ 2 5	R 24066 🚲 ♿ 2	R 24068 ♿ 2 5	R 7442 ♿ 2 5	R 7444 ♿ 2 5	R 7444 🚲 ♿ 2 8	R 21944 🚲 ♿ 2	R 24070 🚲 ♿ 2 7 9	R 7446 ♿ 2 5	R 7448 ♿ 2 5
	Provenienza	■	■	■	■	■	■	■	■	■	■	■	■	Monterot.	■
0	Roma Termini ✈	·	·	·	·	·	·	·	·	·	·	·	·	·	·
	Roma Tiburtina	·	Ⓐ 15.53	16.08	Ⓐ 16.23	·	Ⓒ 16.38	·	Ⓐ 16.53	·	·	† 17.08	·	Ⓐ 17.23	·
	Roma Tuscolana	·	≀ 15.59	16.14	≀ 16.29	·	≀ 16.44	·	≀ 16.59	·	·	≀ 17.14	·	≀ 17.29	·
	Roma Ostiense	Ⓐ 16.02	≀ 16.07	16.22	≀ 16.37	·	≀ 16.52	Ⓐ 17.02	≀ 17.07	Ⓐ 17.17	≀ 17.17	≀ 17.22	✕ 17.32	≀ 17.37	Ⓐ 17.50
1	Roma Trastevere	≀ 16.06	≀ 16.11	16.26	≀ 16.41	·	≀ 16.56	≀ 17.06	≀ 17.11	≀ 17.21	≀ 17.21	≀ 17.26	≀ 17.36	≀ 17.41	≀ 17.54
2	Quattro Venti	≀ │	≀ 16.14	16.29	≀ 16.44	·	≀ 16.59	≀ │	≀ 17.14	≀ 17.24	≀ 17.24	≀ 17.29	≀ │	≀ 17.44	≀ 17.57
5	Roma S. Pietro	≀ 16.12	≀ 16.18	16.33	≀ 16.48	Ⓐ 16.57	≀ 17.03	≀ 17.12	≀ 17.18	≀ 17.28	≀ 17.28	≀ 17.33	≀ 17.42	≀ 17.48	≀ 18.01
6	Valle Aurelia	≀ 16.16	≀ 16.22	16.37	≀ 16.52	≀ 17.02	≀ 17.07	≀ 17.16	≀ 17.22	≀ 17.32	≀ 17.32	≀ 17.37	≀ 17.46	≀ 17.52	≀ 18.05
7	Appiano Proba Petronia	≀ │	≀ 16.25	16.40	≀ 16.55	≀ 17.05	≀ 17.10	≀ │	≀ 17.25	≀ 17.35	≀ 17.35	≀ 17.40	≀ │	≀ 17.55	≀ 18.08
8	Roma Balduina	≀ │	≀ 16.27	16.42	≀ 16.57	≀ 17.07	≀ 17.12	≀ │	≀ 17.27	≀ 17.37	≀ 17.37	≀ 17.42	≀ │	≀ 17.57	≀ 18.11
10	Gemelli	≀ │	≀ 16.30	16.45	≀ 17.00	≀ 17.10	≀ 17.15	≀ │	≀ 17.30	≀ 17.40	≀ 17.40	≀ 17.45	≀ │	≀ 18.00	≀ 18.14
11	Roma Monte Mario	≀ │	≀ 16.33	16.48	≀ 17.03	≀ 17.13	≀ 17.18	≀ │	≀ 17.33	≀ 17.43	≀ 17.43	≀ 17.48	≀ │	≀ 18.03	≀ 18.17
12	Roma S. Filippo Neri	≀ │	≀ 16.36	16.51	≀ 17.06	≀ 17.16	≀ 17.21	≀ │	≀ 17.36	≀ 17.46	≀ 17.46	≀ 17.51	≀ │	≀ 18.06	≀ 18.20
14	Ottavia	≀ │	≀ 16.39	16.54	≀ 17.09	≀ 17.19	≀ 17.24	≀ │	≀ 17.39	≀ 17.49	≀ 17.49	≀ 17.54	≀ │	≀ 18.09	≀ 18.23
15	Ipogeo degli Ottavi	≀ │	≀ 16.42	16.57	≀ 17.12	≀ 17.22	≀ 17.27	≀ │	≀ 17.42	≀ 17.52	≀ 17.52	≀ 17.57	≀ │	≀ 18.12	≀ 18.26
16	La Giustiniana	≀ │	≀ 16.45	17.00	≀ 17.15	≀ 17.25	≀ 17.30	≀ │	≀ 17.45	≀ 17.55	≀ 17.55	≀ 18.00	≀ │	≀ 18.15	≀ 18.29
19	La Storta	≀ 16.34	≀ 16.49	17.04	≀ 17.19	Ⓐ 17.29	≀ 17.34	17.34	≀ 17.49	Ⓐ 17.59	≀ 18.07	≀ 18.04	≀ 18.04	≀ 18.19	≀ 18.40
24	Olgiata	≀ │	≀ 16.52	17.07	≀ 17.22	·	≀ 17.37	│	≀ 17.52	·	≀ 18.11	≀ 18.07	≀ │	≀ 18.22	≀ 18.46
28	Cesano	≀ 16.42	Ⓐ 16.58	17.13	Ⓐ 17.28	·	≀ 17.43	≀ 17.42	Ⓐ 17.58	·	≀ 18.17	≀ 18.13	≀ 18.12	Ⓐ 18.28	Ⓐ 18.53
31	Anguillara	≀ 16.47	·	17.17	·	·	≀ 17.47	≀ 17.47	·	·	·	† 18.17	≀ 18.17	·	·
40	Vigna di Valle	≀ │	·	17.25	·	·	≀ │	≀ │	·	·	·	·	≀ │	·	·
44	Bracciano	≀ 16.59	·	17.31	·	·	≀ 17.59	≀ 17.59	·	·	·	·	≀ 18.30	·	·
49	Manziana-Canale Monterano	≀ 17.05	·	·	·	·	≀ 18.05	≀ 18.05	·	·	·	·	≀ 18.36	·	·
54	Oriolo	≀ 17.11	·	·	·	·	≀ 18.10	≀ 18.10	·	·	·	·	≀ 18.42	·	·
63	Capranica-Sutri	≀ 17.21	·	·	·	·	≀ 18.18	≀ 18.18	·	·	·	·	≀ 18.51	·	·
74	Vetralla	≀ 17.31	·	·	·	·	≀ 18.27	≀ 18.27	·	·	·	·	≀ 19.03	·	·
77	Tre Croci	≀ 17.35	·	·	·	·	≀ 18.31	≀ 18.31	·	·	·	·	≀ │	·	·
87	Viterbo Porta Romana	≀ 17.45	·	·	·	·	≀ 18.42	≀ 18.42	·	·	·	·	≀ 19.16	·	·
88	Viterbo Porta Fiorentina a	Ⓐ 17.48	·	·	·	·	Ⓒ 18.46	Ⓐ 18.46	·	·	·	·	✕ 19.20	·	·

Figure 23 - FL3 Timetable (Trenitalia, 2020)

Looking at the other lines, the situation is similar. On the FL1 (figure 24), for instance, even though all the trains stop on every station, the northern terminus changes continuously and those are not called by name's line, but just regional (R). To sum up, one line name, FL3 for instance, can comprehend different relations or different service types (those will be deeply explained in chapter 2.2).

1

Fiumicino -Roma -Fara Sabina -Orte (FL1)

8 Non sono ammesse le comitive con biglietto scontato.

11 Si accede al servizio unicamente con biglietti a tariffa specifica (di corsa semplice o andata/ritorno). Servizio non compreso nelle tariffe integrate metrebus.

16 Si effettua il 4/4 e il 5/4.

17 Si effettua dal 1/4.

18 Si effettua il sabato e nei festivi. Sospeso nei festivi.

Km		R 22037 21762 🚲 ♿ 2	R 26235 🚲 ♿ R 2 8 11 17	R 21927 🚲 ♿ 2	R 22039 21764 🚲 ♿ 2	R 7417 🚲 ♿ 2	R 34629 ♿ 2 8 16	R 22041 21766 🚲 ♿ 2	R 24063 🚲 ♿ 2	R 24063 🚲 ♿ 2 18	RV 2482 🚲 12 8	R 22043 21768 🚲 ♿ 2	R 7419 🚲 ♿ 2	R 22045 21770 🚲 ♿ 2
	Provenienza	■	Civitavecc.	Bracciano	■	Cesano	■	■	Anguillara	Viterbo	■	■	Cesano	■
0	Fiumicino Aeroporto	Ⓐ 10.42	·	·	10.57	·	≀ 11.12	Ⓐ 11.12	·	·	·	11.27	·	Ⓐ 11.42
5	Parco Leonardo	≀ 10.47	·	·	11.02	·	≀ 11.17	≀ 11.17	·	·	·	11.32	·	≀ 11.47
7	Fiera di Roma	≀ 10.50	·	·	11.05	·	≀ 11.20	≀ 11.20	·	·	·	11.35	·	≀ 11.50
11	Ponte Galeria	≀ 10.53	·	·	11.08	·	≀ 11.23	≀ 11.23	·	·	·	11.38	·	≀ 11.53
17	Muratella	≀ 10.58	C ·	·	11.13	·	≀ 11.28	≀ 11.28	·	·	·	11.43	·	≀ 11.58
19	Magliana	≀ 11.01	i ·	·	11.16	·	≀ 11.31	≀ 11.31	·	·	·	11.46	·	≀ 12.01
22	Villa Bonelli	≀ 11.04	v ·	·	11.19	·	≀ 11.34	≀ 11.34	·	·	·	11.49	·	≀ 12.04
25	Roma Trastevere	≀ 11.09	i │	11.20	11.24	Ⓐ 11.33	≀ 11.39	≀ 11.39	† 11.50	≀ 11.50	·	11.54	Ⓐ 12.03	≀ 12.09
26	Roma Ostiense a	≀ 11.13	≀ t ◖ 11.17	11.24	11.28	≀ 11.36	≀ 11.43	≀ 11.43	≀ 11.54	≀ 11.54	·	11.58	≀ 12.06	≀ 12.13
	Roma Ostiense	≀ 11.16	≀ a ◖ 11.19	11.25	11.31	≀ 11.37	≀ 11.46	≀ 11.46	≀ 11.55	≀ 11.55	·	12.01	≀ 12.07	≀ 12.16
30	Roma Tuscolana	≀ 11.23	≀ v │	11.31	11.38	≀ 11.44	≀ 11.53	≀ 11.53	≀ 12.01	≀ 12.01	·	12.08	≀ 12.14	≀ 12.23
	Roma Termini ✈	≀ ·	≀ e 11.30	·	·	≀ ·	≀ ·	≀ ·	≀ ·	≀ ·	✕ 12.02	·	≀ ·	≀ ·
39	Roma Tiburtina a	≀ 11.30	c ·	11.37	11.45	Ⓐ 11.52	≀ 12.00	≀ 12.00	† 12.07	≀ 12.07	≀ 12.11	12.15	Ⓐ 12.22	≀ 12.30
39	Roma Tiburtina	≀ 11.31	c ·	·	11.46	·	·	≀ 12.01	·	·	≀ 12.13	12.16	·	≀ 12.31
42	Roma Nomentana (binari 1-2)	≀ 11.35	h ·	·	11.50	·	·	≀ 12.05	·	·	≀ ·	12.20	·	≀ 12.35
44	Nuovo Salario	≀ 11.41	i ·	·	11.56	·	·	≀ 12.11	·	·	≀ ·	12.26	·	≀ 12.41
50	Fidene	≀ 11.45	a ·	·	12.00	·	·	≀ 12.15	·	·	≀ ·	12.30	·	≀ 12.45
51	Settebagni	≀ 11.50	·	·	12.05	·	·	≀ 12.20	·	·	≀ ·	12.35	·	≀ 12.50
60	Monterotondo-Mentana	≀ 11.59	e ·	·	12.14	·	·	≀ 12.29	·	·	≀ ·	12.44	·	≀ 12.59
66	Piana Bella di Montelibretti	≀ 12.04	x ·	·	12.19	·	·	≀ 12.34	·	·	≀ ·	12.49	·	≀ 13.04
72	Fara Sabina-Montelibretti	Ⓐ 12.12	p ·	·	12.26	·	·	Ⓐ 12.42	·	·	≀ ·	12.56	·	Ⓐ 13.12
83	Poggio Mirteto	·	r ·	·	12.35	·	·	·	·	·	≀ ·	13.05	·	·
88	Gavignano Sabino	·	e ·	·	12.40	·	·	·	·	·	≀ ·	·	·	·
91	Stimigliano	·	s ·	·	12.45	·	·	·	·	·	≀ ·	·	·	·
96	Collevecchio-Poggio S.	·	s ·	·	12.50	·	·	·	·	·	≀ ·	·	·	·
105	Civita Castellana-Magliano	·	·	·	12.57	·	·	·	·	·	≀ ·	·	·	·
109	Gallese Teverina	·	·	·	13.02	·	·	·	·	·	≀ ·	·	·	·
118	Orte a	·	·	·	13.10	·	·	·	·	·	✕ 12.43	·	·	·
	Destinazione	■	■	■	■	■	■	■	■	■	Foligno	■	■	■

Figure 24 - FL1 Timetable (Trenitalia, 2020)

In all the lines, from FL1 to FL8 it is common to find similar issues. On the contrary, as regards the other unnamed lines on the periphery of the region, the service is much more inconstant presenting just a few trains all over the day (ibid), as it can be observed for the Avezzano – Roccasecca railway.

11

Avezzano -Sora -Roccasecca

a Fermata a: V. Arpino bv. staz
b Fermata a: Piazza Gran Sasso
c Fermata a: Bv. staz. della S.P.63
d Fermata a: Uscita Superstrada per S. Vincenzo.
1 I viaggiatori sono ammessi limitatamente alla disponibilità dei posti.
2 Gli autoservizi sostitutivi non effettuano il servizio di trasporto di bici al seguito
3 Non sono ammessi cani di media e grossa taglia.
4 Il treno potrebbe subire un ritardo in partenza di 15 minuti per attesa coincidenza.

Km		RM161 2 1 2 3	7471 2	7473 2	7475 2	7477 2	7479 2	7481 2	7483 2	PE217 2 1 2 3 4	7487 2 4	PE215 2 1 2 3 4
0	**Avezzano**	·	05.44	06.43	08.45	10.15	12.40	13.59	14.05	16.20	18.46	20.35
9	Capistrello	·	05.53	06.52	08.59	10.24	12.48	14.07	14.14	16.35	18.56	20.50
13	Cupone	·	|	06.58	|	10.30	12.54	14.13	14.20	·	|	·
14	Pescocanale	·	|	07.02	|	10.34	12.58	14.17	14.24	·	19.03	·
17	Canistro	·	06.02	07.06	09.08	10.38	13.02	14.21	14.28	·	19.06	·
20	Civitella Roveto	·	06.08	07.12	09.13	10.44	13.08	14.27	14.34	16.55	19.12	21.10
26	Civita d'Antino-Morino	·	06.16	07.25	09.21	10.56	13.16	14.35	14.42	17.05	19.20	21.20
30	Morrea-Castronovo-Rend.	·	|	07.30	09.26	11.01	13.21	14.40	14.47	17.11	19.25	21.26
33	S. Vincenzo Valle Roveto	·	06.24	07.35	09.31	11.06	13.26	14.45	14.52	17.17	19.30	21.32
36	Roccavivi	·	|	07.39	09.35	11.10	13.30	14.49	|	·	|	·
38	Balsorano	·	06.30	07.42	09.38	11.13	13.34	14.52	14.58	17.23	19.35	21.38
41	Ridotti-Collepiano	·	|	07.47	|	11.18	|	14.57	15.03	·	19.40	·
45	Compre S. Vincenzo	·	|	07.53	|	|	|	15.03	15.09	·	19.46	·
50	**Sora** a	·	06.44	07.59	09.50	11.30	13.52	15.09	15.15	17.40	19.52	21.53
	Sora	Ⓐ 05.16	06.49	08.01	09.51	·	13.53	15.11	15.16	·	19.53	21.53
56	Isola Liri	05.26	06.56	08.08	09.58	·	14.00	15.18	15.23	·	19.59	22.03
0	**Frosinone** a	Ⓐ 06.01	·	·	·	·	·	·	·	·	·	·
60	Arpino	·	07.03	08.15	10.05	·	14.07	15.25	15.30	·	20.06	22.11
63	Santopadre	·	07.07	08.19	10.09	·	14.11	15.29	15.34	·	20.10	·
67	Fontana Liri Inferiore	·	07.14	08.25	10.16	·	14.18	15.36	15.41	·	20.16	·
71	Arce	·	07.20	08.31	10.21	·	14.28	15.42	15.47	·	20.22	22.26
75	Colfelice	·	07.29	08.38	10.28	·	14.35	|	15.54	·	20.29	22.33
80	Roccasecca a	·	07.37	08.45	10.34	·	14.43	15.55	16.02	·	20.36	22.41
	Roccasecca	·	07.38	08.46	10.35	·	14.44	15.56	16.03	·	20.37	22.41
	Piedimonte-Villa S.L.-Aquino a	·	07.46	08.54	10.41	·	14.52	16.04	16.11	·	|	22.51
	Cassino a	·	07.55	09.04	10.52	·	15.01	16.13	16.20	·	20.52	23.03

Figure 25 - Avezzano-Roccasecca Railway Timetable (Trenitalia, 2020)

1.3.3.3. Rolling Stock Analysis

As regards the rolling stock, different types of trains run on Lazio's railway network. The majority of the network is electrified and so it is the majority of the fleet. The rolling stock specifics can be found into the service contract signed between the region and the TOC Trenitalia. However, it is possible to state that generally, being the services not properly classified, neither the trains are made specifically for service typology. The majority of rolling stock is suitable for regional services whilst there is a part of the fleet that is used for the most urban services (FL1 and FL3) but does not present clear urban or suburban specifications. These trains present a higher acceleration than the others, but not high enough to be a proper metropolitan train. Also, they are double-deck trains but the majority of suburban trains, all over Europe, are single-deck trains presenting much more doors per side than those used here. However, the service contract plans to substitute the oldest trains with new rolling stock. Unfortunately, neither this new rolling stock is specifically made for a service type, thus there will be new hybrid trains, suitable both for regional and suburban service but not optimal for any pf these services (Regione Lazio, 2018).

1.3.3.4. Discussion

As it has been described, Lazio's railway network is essentially radial having Rome in the middle. The majority of the railways and all the most important, origins in Rome. Similarly, the train service network has been built following the infrastructure. However, the so-called FL, that should be the service lines name, are not proper lines. The name FL3, for instance, could represent a train going from Rome to Viterbo, skipping the stops in the urban section, or a train that runs only in the urban section. The service model indeed, even though it presents some positive aspects, like the regularity of the timetable (at least on the most important relation), it has many negative aspects: the same line name used for disparate service with different termini generates a lot of confusion in the user and make it impossible to draw a clear service map or an effective branding system. Similarly, having a wayfinding system and a map indicating the name lines but the impossibility to find them on the station screen adds more confusion. Besides, the FL 'brand', although not very effective, it has been used only for train lines originating in Rome, ignoring the other Lazio's railway relations, which on the contrary exist and should be improved because today those are very inconstant, hence almost useless, as it will be explained in part 3. Furthermore, the rolling stock used to run the service is not suitable for the service. Being the service types not properly defined, the rolling stock must be a hybrid, able to execute different tasks decently but not optimally. Thus, even though Lazio's railway service presents some good aspects, like the branding attempt, it is not good enough to be a valid alternative to the private vehicle, especially on the short displacements, and it still needs many upgrades to be a mobility system suitable for the 3rd millennium.

1.3.4. Summing Up

This chapter is pivotal to understand the logic behind this thesis. Here, indeed, it has been explained the concept of 'mobility system' and why it has been necessary to analyze the regional railway network. Among the regional mobility systems that are spread out all over the region and that can have a multi-scalar impact on the overall mobility, the railway system is the most suitable to solve the mobility problems, due to the intrinsic features that make it more efficient than private vehicle under many aspects. Consequently, the railway network has been deeply analysed, looking at the infrastructure, the service and the rolling stock. As a result, the analysis shows that the railway system has some positive aspects but that has not been updated enough to be ready for the mobility challenge of 3rd millennium. The timetables analysis, indeed, has shown that even though the majority of lines have a good timetable structure, this is valid almost exclusively for the peak-hour, or from Monday to Friday. Similarly, the branding system presented have some positive aspects, but because of the line structure it I svery ineffective: FL3, for instance, can mean a train going from Rome Ostiense to Viterbo stopping at every station, or a train with the same itinerary but without half of the stops. Finally, analyzing the rolling stock it is possible to argue that it reflects the chaos of the branding system: being the lines not classified for service type, the trains must be suitable for both suburban and regional services, even though this two services have different features and requires, theoretically, trains with different characteristics.

Hence, the rolling stock today travelling on Lazio's railway network is often an hybrid inappropriate for both the suburban and regional service.

1.4. Conclusion

This part has presented the context to the reader, in order to make it aware of the spatial frame. The first chapter has been a geographical and demographic description of both Lazio and Rome, including an infrastructural focus and a more detailed description of Rome. Successively, there has been a mobility analysis, underlying the lack of mobility presented in Rome due to the inadequacy of both the public transit system and the road network, that generates a loss of time in congestion major than 250 hours per person per year. In chapter 2 there are described also other consequences of this mobility problem, like the pollution or the effects on urban development. Finally, chapter 3, addresses the problem proposing a solution. Firstly, it is explained that being a mobility problem it is necessary to work on one of the regional mobility systems, hence, the concept of mobility system is explained. Consequently, railways are chosen as mobility system to work with due to their characteristics that make them more efficient than roads under many aspects. Hence, in the last part of the chapter, Lazio's railway system is deeply analysed, looking at the infrastructures but also at the timetable and the rolling stock, to understand the type of services that run on the network. At the end of the chapter, there is a discussion where the author states that Lazio's railway service is good but that presents some limits that make it unsuitable to the mobility needs of the 21st century. Into the next part (2), it will argue which are the theoretical and technical features that make a railway system suitable for 3rd millennium, that will be successively applied to Lazio's context (part 3).

2. Railway Service Model Theory

There are many ways to improve the efficiency and the effectiveness of a railway system, but the author believes that the best way is working on the service. The service is the software that makes the hardware working. In railways, this software is generally identified as the timetable. In this part, the theoretical principles behind the Swiss model are explained, to make the reader aware of the potentialities of this model and the reasons why it has worked where it has been applied. However, the reasons why some principles bring to more effectiveness and efficiency are to find into the classical transport theory or the mobilities turn theory. Thus, the first chapter of this part quickly talks about the state of the art of both transport and mobility theory, to provide the reader with the necessary tools to understand the Swiss model, explained in chapter 2. In the beginning, there are the technical features that compose the model, whilst the last parts of the chapter are about policies that are not part of the service model, but that would make it much more effective and efficient. Finally, the model application effects in Switzerland and Lombardia are described, analyzing data from the two contexts.

Figure 27 - Termini Station, Rome. Image downloaded from http://www.vg-hortus.it/images/stories/scritti/montuori_termini/cantiere/19_vista%20aerea%201950.jpg

2.1. Transport and Mobilities Theories

This chapter is about transport and mobility theory state of the art. The aim is to provide the reader with the basic instrument to understand mobility phenomena so that it will be able to understand the logic behind the actions and the strategies presented in the next chapters. The theory described here justify next chapter, where these theoretical principles will be applied into a mobility system. The first section describes the demand function of goods, while the following explains the concept of cost related to mobility: the generalized cost. The third section will explain the Mohring effect, and the last will go beyond the transport theory explaining the mobilities turn.

2.1.1. Demand Function

This section describes the demand function of goods, a microeconomic concept. Even though the demand for a good depends on price, income, utility, habits, etc., in microeconomic theory the function used is simpler: the demand function is the relation between the demanded quantity of a good and its price. Intuitively the higher is the price, the less the market is demanding for that good. To a price P_1 corresponds a consumed quantity q_1, as shown by the diagram (Ponti et al., 2010).

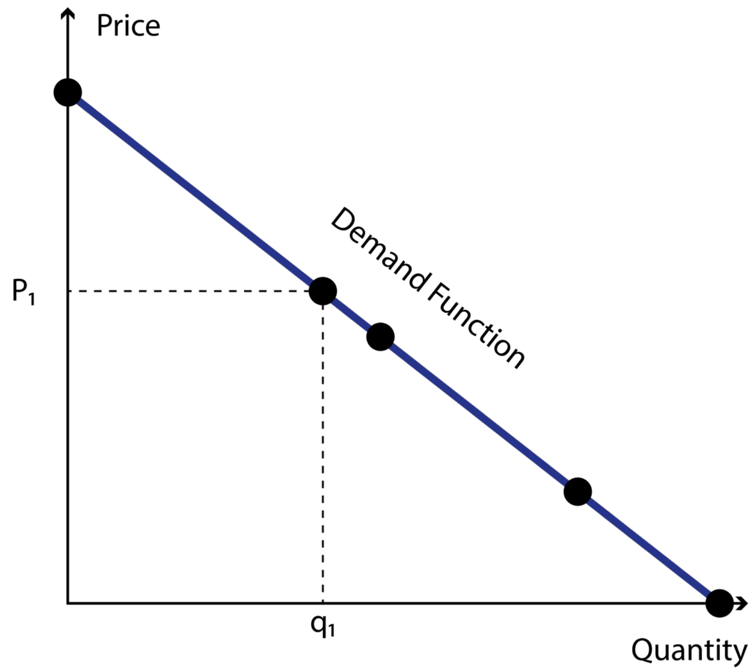


Figure 27 Demand Function. Author's drawing, inspired by Ponti et al. (2010)

If a price variation of a certain good occurs, there will be a movement along the demand curve, whilst variations in other factors, like income, utility, habits, and so on, will shift the function (ibid).

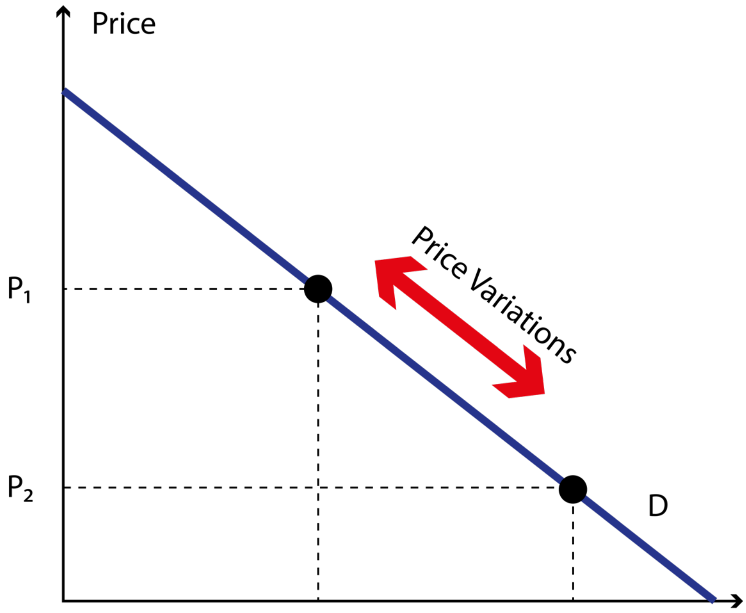
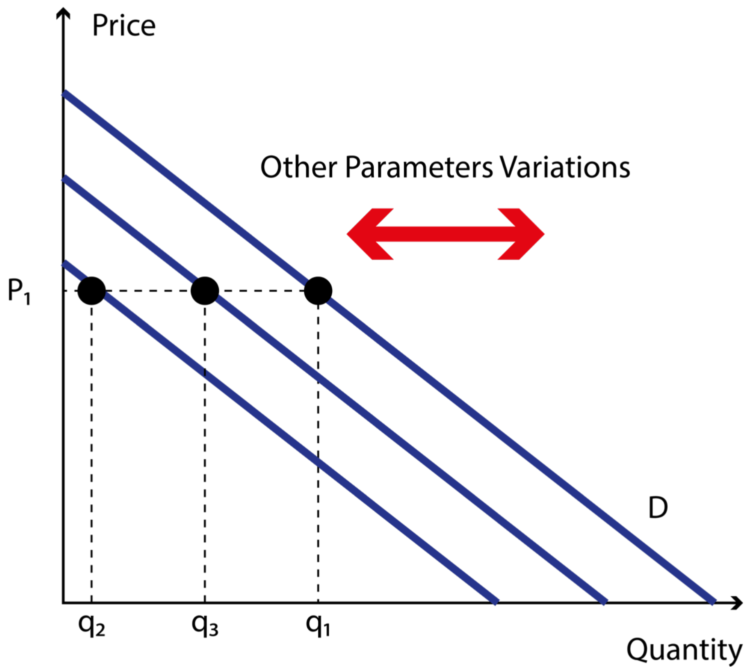


Figure 28 ↑ - Price Variation. Author's drawing, inspired by Ponti et al. (2010)

Figure 29 ↓ - Other Parameters Variations. Author’s drawing, inspired by Ponti et al. (2010)



This function can be easily imported into transport theory. If the journey is considered as the good to buy, the higher is the price, the fewer people will make that trip, and vice-versa. But how can be defined the travel price? Next section will talk about that.

2.1.2. Generalised Cost and Discrete Choice Model

This section describes the generalized cost concept, in its first part, whilst later a small paragraph about discrete choice models is presented.

Generally, for the majority of goods, the demanded quantity, as seen in the previous section, depends on the product price. In transport theory, similarly, the demand function presents the so-called *'Generalised Cost'* (G_C) instead of price. The reason behind this difference is that mobility demand is a derived demand. Travelling "*does not occur for the sake of the journey itself but is only a means to an end,* [thus] *there are accompanying sacrifices. The higher the level of disutility the less travellers would be willing to undertake trips*" (Pienaar, 2002). The disutility or generalized cost is the sum of all the monetary and non-monetary costs of travel. Monetary costs are, for instance, gasoline, tolls, vehicle operating costs, etc., if travelling by car or ticket fare if the journey is made by public transport, whilst, non-monetary costs are travel time, waiting time, discomfort, safety risk and other negative qualitative aspects (ibid). To sum monetary and non-monetary costs it is needed to transform everything into the same measure unit, typically money so that other data, like the value of time, are needed (Goodwin, 1974). The easiest formula to calculate the generalized cost is $\mathbf{G_C} = \boldsymbol{m} + \boldsymbol{\lambda t}$, where m is the amount of money spent, λ is the value of time and t is the travel time (ibid). If more data are available and a better degree of detail wants to be reached, more factors, related to other non-monetary costs, need to be added (Ortuzar, 2011).

Generalised cost is generally used to compare different modes or different trips made with the same mode. In both the situation, even though there is a cheaper option, there will always be someone choosing the more expensive mode. The reason behind this, is simply that reality is more complex than the theory, and each traveller has his own needs and preferences: some people like train more than car while others would take car no matter what (ibid). In order to have an idea about the number of people that will make a trip choice, random utility behavioural models are used. The most common is the so-called logit models, that calculates the probability that a mode will be chosen among the options available (ibid). As expected, the minor G_c will have more users than the others, but very unlikely all the users will choose only one option.

To sum up, it has been stated that the only difference between the demand function and the transport demand function is the use of price in the former and of generalized cost in the ladder. The G_c is the travel cost, so the sum of all the monetary and non-monetary costs, and it is mainly used to compare different transport choices. However, it is not true that all people will use the cheapest option. Because of many different reasons, it is very unlikely that there will be one mode (if comparing different modes) or one road (if comparing the different routes made with the same mode) chosen by everyone. To determine how many people will probably choose an option or another, discrete choice models are used. In any case, generally, the cheaper option will be the most used.

2.1.3. Travel Behaviour

The calculation of generalized cost is strictly related to travel behaviour. In this chapter, dynamics related to travel behaviour are described. In transport world, in order to make transport model and cost-benefit analysis, it is necessary to understand people travel behaviour (that means to calculate their travel generalized cost), to forecast their travel choice. Obviously, having a mathematical model perfectly coherent with reality would mean to have a model per each person, and this is not doable. Thus, engineers divide transport users into categories, in order to forecast more precisely generalized cost and so people choices. For instance, a businessman will have a value of time (VoT) much higher than a student, so that he will probably prefer to take an aeroplane to move because it will be probably the fastest way to transpose to another place, even though it would be the more expensive transport mode. On the contrary, a student, travelling the same distance, would rather take a bus (probably the cheapest mode), even though it would mean to spend many hours on it because it has time, thus a low VoT, but not a lot of money. These categories are just two of the many used to forecast travel behaviour, where differences are not only related to the value of time but to many other factors (anyway, it would not be useful for this paper to go deeper into the categories analysis). However, some travel behaviours do not change because of the user but depending on travel features, like distance and headway. People, no matter who, do not like to wait before taking any modes of transport. It is recognized indeed, that waiting time is on average 2 times the in-vehicle VoT (Vuk, 2019). However, has been realized that depending on the distance travelled, the ratio between the in-vehicle value of time and the waiting value of time changes (Makie et al., 2003). This happens with every mode and the general rule is that the longer is the journey, the less is the waiting time value (ibid).

WALK WAIT	DIST	CAR USER		BUS USER		RAIL USER	
		Walk	Wait	Walk	Wait	Walk	Wait
2	2 miles	2.18	3.68	1.68	2.57	1.28	2.51
5		2.79	4.25	2.15	2.97	1.65	2.90
10		3.37	4.73	2.59	3.31	1.99	3.24
20		4.07	5.28	3.13	3.69	2.40	3.61
2	10 miles	1.72	2.90	1.49	2.29	1.14	2.24
5		2.20	3.35	1.91	2.64	1.46	2.58
10		2.66	3.73	2.30	2.94	1.77	2.88
20		3.21	4.16	2.78	3.28	2.13	3.21
2	50 miles	1.35	2.28	1.32	2.03	1.02	1.99
5		1.74	2.64	1.70	2.35	1.30	2.30
10		2.09	2.94	2.05	2.62	1.57	2.56
20		2.53	3.28	2.47	2.92	1.90	2.85
2	200 miles	1.10	1.86	1.20	1.84	0.92	1.80
5		1.41	2.15	1.53	2.12	1.18	2.07
10		1.71	2.39	1.85	2.36	1.42	2.31
20		2.06	2.67	2.23	2.64	1.71	2.58

Figure 30 - Implied Weights for Walk and Wait Time (Mackie et al., 2003)

Figure 30 shows how to calculate in transport modelling waiting or walking value of time, starting from the in-vehicle value of time. For example, waiting for a train 20 minutes to travel 200 miles (about 320 km) is 2.58 times the in-vehicle VoT, while the same waiting time for a 2 miles trip (about 3,2 km) is 3.61 times the in-vehicle VoT. Even though the modifiers change depending on transport modes, the principle does not: the longer is the journey, the less waiting time counts on

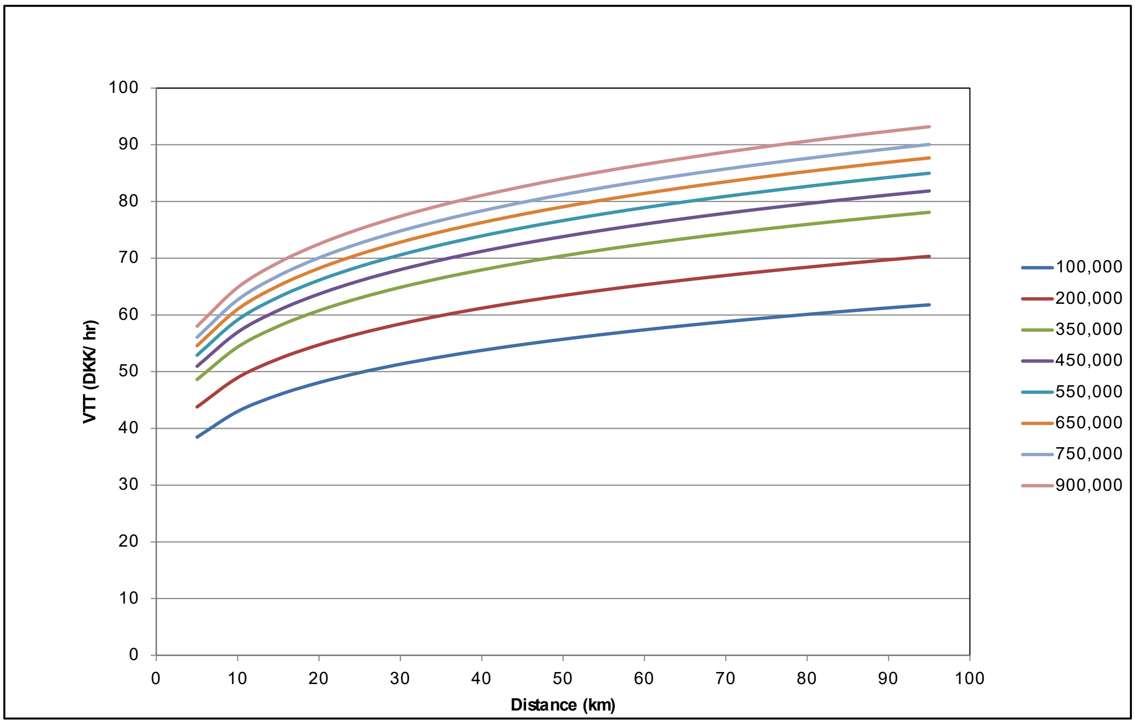


Figure 31 - Home-Work Displacements Value of Time-Distance ratio (Vuk, 2019)

generalized cost calculation (ibid). Contemporary, as regards home-work displacements, it is noted that in-vehicle VoT is directly proportional to distance: as shown by figure 31, the longer is the journey, the higher is VoT (Vuk, 2019).

These model calculations transform into calculation empirical evidence: nobody likes to wait a lot for a short journey as everybody, for a long-distance trip, put more attention to travel time than to waiting time (Stagni, 2012).

To sum up, model theory demonstrates that depending on the journey characteristics, travel behaviour, and so generalized cost, changes. Increasing the journey distance, the relevance of waiting time decrease whilst, on the contrary, the in-vehicle VoT rise.

2.1.4. Mohoring Effect

Another phenomenon affecting travel behaviour is the so-called Mohring effect, named by the American economist who theorized it, Herbert Mohring (1972). Differently from the previous behaviours that depended on travel features, the Mohring effect is based on line characteristics and is only related to public transport, because it is strictly linked to service frequency. If a train line, indeed, presents a rise in demand, there are three possible solutions to absorb that need (Grimaldi & Nistri, 2017):

1. Increase load factor, thus raising the number of passenger on the programmed vehicles;
2. Use bigger vehicles, thus augment the number of place on programmed vehicles;
3. Increase frequency, thus increasing the number of vehicles running on that line.

If choice number three is made, the headway will be reduced, and proportionally the waiting time. Cutting waiting time means to reduce the generalized cost for travel, that will likely bring more users to that line. More users could mean major demand, that can be absorbed in the three ways previously exposed. Obviously, this effect does not tend to infinity, because the lower is the headway, the less G_C is reduced: waiting time is ½ the headway, thus if headway is 60 minutes, value for waiting time is VoT x 60/2, and so on (Mohring, 1972). Thus, for example, if VoT is 30€/h (random value), the trip requires one hour for a 5€ ticket and, as said in previous section, generalized cost = Ticket (€) + Waiting Time x 2VoT + Travel Time x VoT:

- Headway = 60 minutes → Waiting Time Value = 2VoT x 60/2 = 30€ → G_C = 65€
- Headway = 30 minutes → Waiting Time Value = 2VoT x 30/2 = 15€ → G_C = 50€
- Headway = 15 minutes → Waiting Time Value = 2VoT x 15/2 = 7.5€ → G_C = 42.5€

- Headway = 10 minutes → Waiting Time Value = 2VoT x 10/2 = 5€ → G_C = 40€

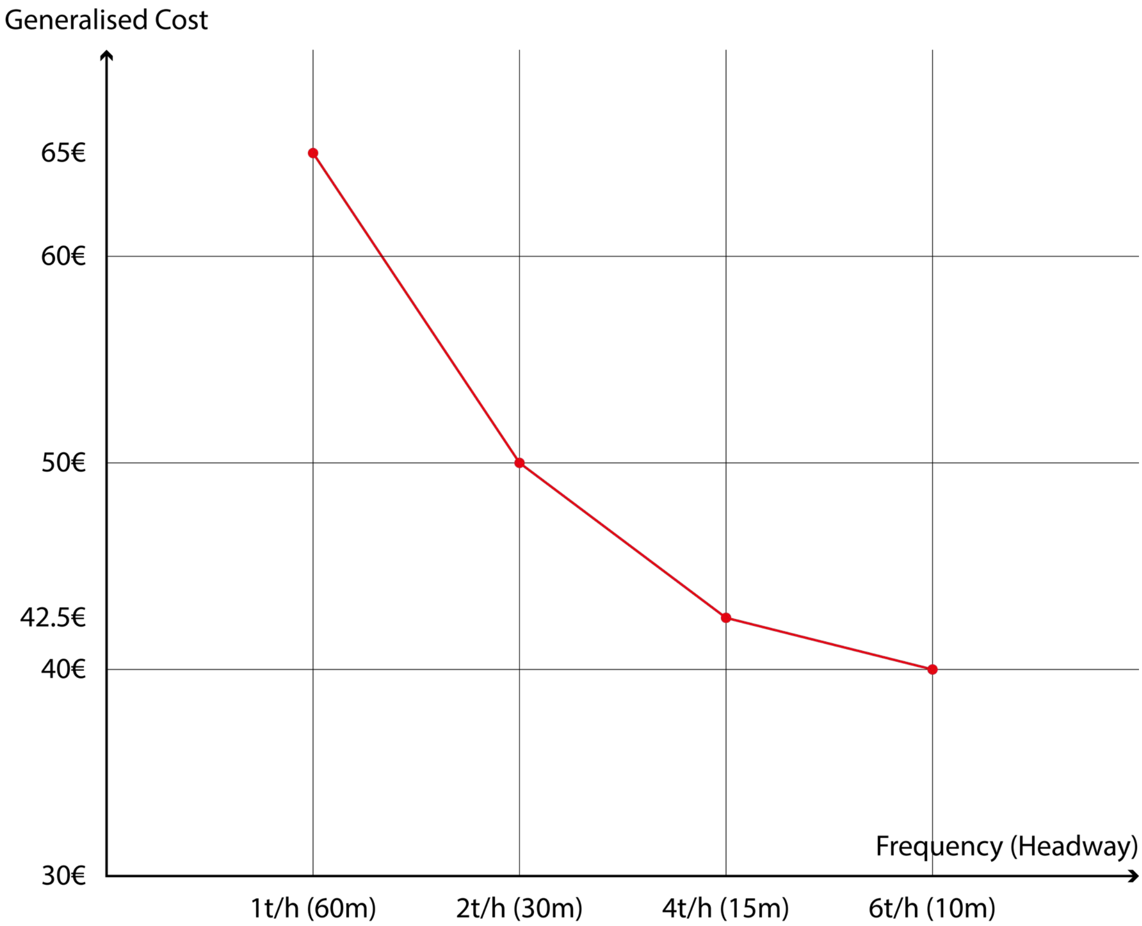


Figure 32 - Mohoring Effect. Author's drawing

Thus, to sum up, the so-called Mohring effect is just the effect of reducing the waiting time. Increasing the mobility demand can bring to a frequency rise, that will reduce G_C and so increase again the demand. However, this effect magnitude does not tend to infinity but decrease each time the headway is reduced, as shown by figure 32.

2.1.5. Mobilities Turn

Until now conventional transport theory based on economical principles has been analysed in order to define the theoretical framework necessary to understand the analysis of next chapter. In this section, differently, the mobility paradigm is described, going beyond the classical transport theory. It is thanks to John Urry that the mobility study changed. He published, indeed, a book titled *'Sociology Beyond Societies: Mobilities for the Twenty-first Century'* (2000) in which he changed the approach to mobilities' study. Transport literature and Mobility literature both investigate movement, but the former consider it just as a technical issue, where people are seen as billiard balls or simple points, whilst the ladder consider it something much more complex and relevant for the individual and the society, that affect many spheres of human life, such as the physical, cultural and economical (Consalvi, 2018b). P. Vannini argues indeed that *"the study of mobilities generally focuses on such phenomena as migration, transport, travel and tourism, the social organization and experience of transportation and communication infrastructures, and regional and transnational flows of capital and material things"* (Vannini, 2010, p.112), or in one sentence, that mobility is much more than going from A to B. In transport theory, mobility is a derived demand and travel time is seen as dead time that needs to be minimized as much as possible, whilst, on the contrary, in mobility theory, mobility is seen as an experience influencing both the mobile users and the contexts in which it takes place and, travel time, is considered as valuable time (ibid).

For instance, during a train journey, a professor can prepare its class or a businessman can have meetings or use its laptop to work. Thus, both for the professor and for the businessman the time spent travelling is valuable (ibid). Data demonstrates that this is not only a theoretical approach but that has empirical prooves. The approximately 600km trip from Roma to Milan was the second European route for air traffic until 2008. In that year, indeed, the high-speed railway linking the two cities has been completed and people started to switch mode. Looking at the theory previously explained, being the travel time by plane inferior to the train journey time, the majority of travellers should have kept using the air connection, but they switched, why? It has not been a matter of money, because prices are similar, but a matter of time quality. Indeed, even though the air connection is faster, into the train, it is possible to use the internet, studying and do many more things than on a plane. Besides, the comfort of the overall travel is major, because it is possible to carry any kind of luggage, there are no check-ins, controls and so on. Consequently, one-third of people using today the train travelling from Rome to Milan, where using the aeroplane and shifted to train (Beria, Grimaldi, 2016). This phenomenon happens all around Europe, with different magnitude, when a new high-speed railway is built: a decrease in the number of planes on the same route occurs (Dobruszkes, Dehon, Givoni 2014).

In addition to the study of what goes on during the movement to the mobile people, the mobility theory focuses its attention also on the immobile elements affected by mobility. Indeed, "*Mobilities [...] entails distinct social spaces that orchestrate new forms of social life around such nodes, for example, stations, hotels, motorways, resorts, airports, leisure complexes, cosmopolitan cities, beaches, galleries, and roadside parks. These are places of intermittent movement constituting for some at least relatively smooth corridors*" (Sheller & Urry, 2006, p.213). This multi-faced approach allows analysing mobility as a flow, from the beginning to the end of the movement, investigating all its aspects and its relations on many different levels. For instance, a metro infrastructure can be analysed from the passenger point of view, looking at the user experience and comfort into the train wagons, but also into the stations, where space is negotiated among passengers and physical structures. Otherwise, the attention could be focused on the relation among the metro infrastructure and its context, because, as stated for instance by Butcher (2011, p. 243-244) regarding New Delhi's metro, "*Metro is responsible for transforming areas near its stations, increasing the sense that the city as a whole is changing as a result of the network*".

To conclude, looking at movement with a mobility turn perspective means to look at the A-B displacement and everything linked with it. As stated by Vannini (2010, p. 114), indeed, *"the mobility turn emphasizes the importance of flows, networks, connections, movements, performances, processes of deterritorialization and reterritorialization, transnational organizations, immobile infrastructures, and even immobile groups. Equally important are mobile culture dynamics such as the emergence of relationships on the move, and the changing meanings of places, times, and social ecologies"*.

Consequently, mobility thinking is a pivotal instrument for this work. It ensures that the analysis made, is not a transport but a mobility study, which comprehend not only the transport aspects, like timetables, but also the mobility aspects, like wayfinding and branding. This perspective permits a comprehensive design that takes the overall mobility aspects into account, improving the work quality and so its positive effect on people life and society.

2.1.6. Conclusion

The theory presented until now is pivotal to the understanding of next chapter. There, indeed, several concepts related to railway planning are described, but they can be fully underhanded only keeping in mind what has been explained here, regarding both the transport and the mobility theory. In fact, the theory presented here needs to be used as a pair of glasses to navigate throughout the next section, that will talk about more detailed topics taking for granted what is written here. The demand function, for instance, is crucial to understand all the mobility phenomenon. However, the generalized cost concept, used to calculate the travel cost in the demand function, must include many other aspects that are not considered by the classical transport theory. This is fundamental to understand why, in the next chapter, it will not be described only the transport theory related to railway service planning, but also other policies needed to make the system attractive for the user. The mobilities turn indeed, enlarge the focus of the classic transport theory, allowing a deeper and more complete analysis of a mobility system and consequently more complete solutions.

Figure 26 - Filisur Station, Germany. Image downloaded from https://www.pinterest.it/pin/568086940501127722/

2.2. The Swiss Model

In the previous chapter, theories related to transport and mobility have been explained to provide the reader with the necessary tools to understand the Swiss model described in this chapter and the reasons behind its success. This chapter will be mainly about the railway's software, the timetables, rather than the infrastructure. However, as many different operating systems exist, given a railway infrastructure, it is possible to design various timetables for it, and the result can be very different. Finger et al. (2014), divide the timetables in different groups, depending on the level of integration and regularity present into the timetable design, as observable in the picture.

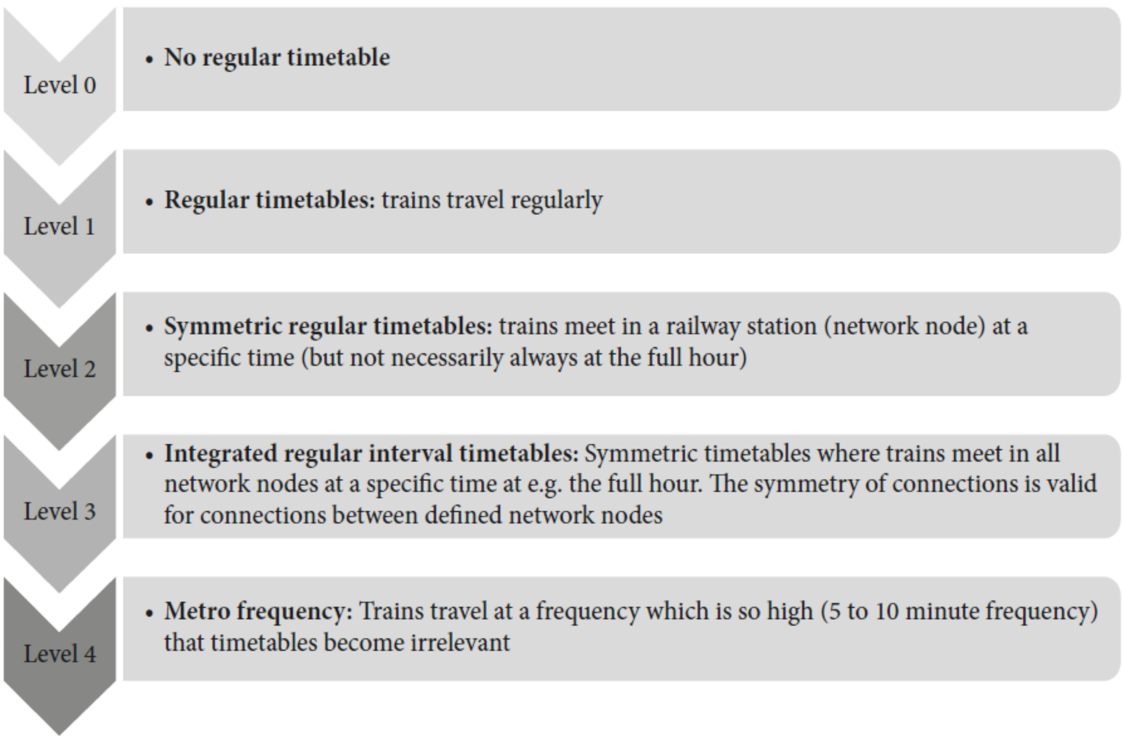


Figure 33 - Timetable Integration Levels (Finger et al., 2014)

Among level 0 models, it is defined by Borza et Horváth the French model, that is a demand-driven service model following the basis of simple business economics. The train indeed, run only when they can be fully loaded, so when the demand matches the offered capacity. In this model, passenger preservation is made investing in expensive rolling stock and infrastructure developments: high-speed trains (TGV) and hyper-modern suburban system (RER) represent indeed the majority of the supply (Borza et Horváth, 2014). Differently, among level 3 systems they define the Swiss model: it is a supply-driven service model that "*takes into account the dominance of overhead in transport (rail in particularly)*" (ibid p. 94). It is based on regular interval timetables and on "*infrastructural upgrades geared to service needs in harmony with the timetable*" (ibid p. 94). Before analysing the technical features of the Swiss model, it is interesting to analyse passengers data of both the French model and the Swiss model, to understand why the second has been chosen for this thesis purpose.

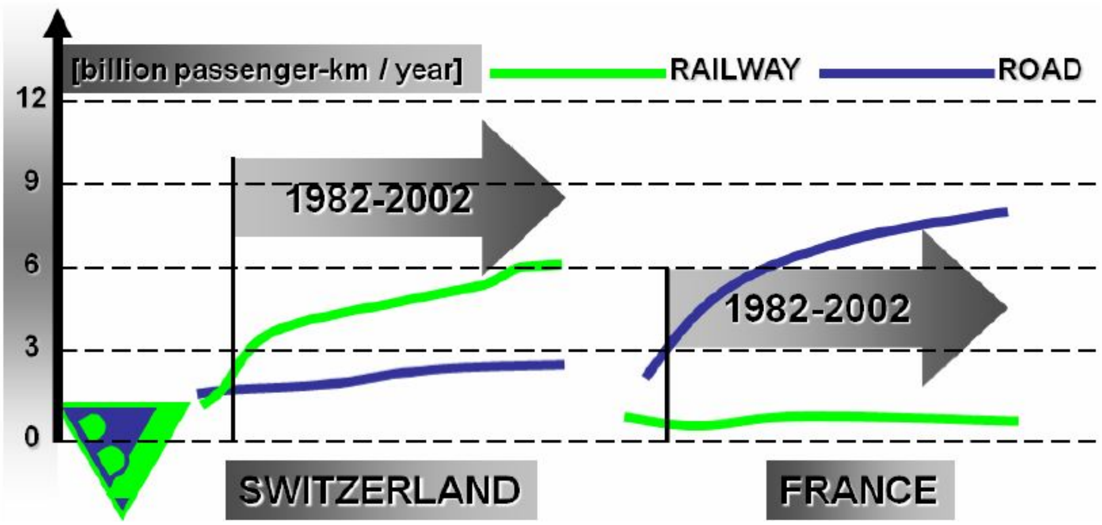


Figure 34 - Passenger-Km/Year in Switzerland and France (Borza et Horvàth, 2014)

The picture shows the effect produced by these two models on passenger number. The Swiss model, over time, captures mobility demand, increasing the number of passengers, whilst the French model presents a constant number of passenger, although the big amount of money required for new infrastructure (ibid).

Thus, this section will describe the principles behind the Swiss model, because it appears to be the most suitable for the aim of this thesis. Next section is about the need for different levels of service, the following regards the necessity of defining lines, then the third talks about the so-called '*uniform clock headway*' or '*regular interval timetable*' and the fourth explains the concept of '*symmetry'* related to the timetables. Successively, there is a section about the rolling stock, to understand its role in the model. After that, the last sections are about the network branding and fares integration, which are not properly related to the timetable design but are fundamental for the system and strictly related to the other concepts explained.

2.2.1. Different Service Levels and Different Categories

The first feature presented by the Swiss model is *"a well-defined hierarchy of services"* (Johnson et al., 2006, pg. 350). This subsection explains what the service level is and why it is needed to have many of them.

A scheduled train running on a railway from A to B is providing a service. However, there could be many trains running from A to B, and they could travel at different speeds and stopping in different towns. For instance, running from A to B on the 40 kilometres length AB railway there could be 4 trains:

- Train 1, that travels during the day 40 km in 60 minutes stopping at every station;
- Train 2, that travels during the day 40 km in 50 minutes stopping at some stations;
- Train 3, that travels during the day 40 km in 40 minutes no stop;
- Train 4, that travels during the night 40 km in 60 minutes stopping at every station.

Four different trains that provide the traveller with four different services that can be differently categorized: the train 3 could be categorized, for example, as express train, while train 4 could be called a night train because it travels only during the night. The types of service can be infinite and can be classified depending on the characteristic that is analysed. Train 1 and 4, indeed, offer the same service in terms of time and stops, but in a different part of the day. A train category identifies a type of service: night train is the category that pinpoints all the trains that travel during the night.

Defined the concept of level service and of train category, it is possible to introduce the categories that are going to be used in our model and that are generally used in the other middle-European railways. However, as it has been said that the category could take into account many different characteristics, it is pivotal to define the technical specifications used here. They are:

1. Distance, meant as the length from the first stop to the ending stop.
2. Commercial Speed, meant as the distance from the origin to the destination divided the journey time, including the intermediate stops.
3. Frequency or Headway. The former is the number of trains that travel a route in a defined time while the ladder is the amount of time that divide one train to another. Hence, if the headway is 15 minutes the frequency is 4 train per hour.

These features define three different train categories that identify three different levels of service. The categories are:

- Suburban Trains (S)
- Regional Trains (R)
- Regio-Express Trains (RE)

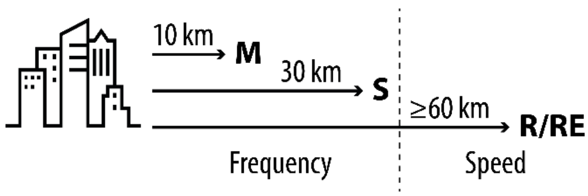


Figure 35 – Distance, Speed and Frequency. Author's drawing

As shown by the previous picture, the distance is the basic element that defines the train category. Commercial speed and frequency, indeed, are function derived by the distance. As it has been also illustrated into chapter 2.1, the importance of speed and frequency are strictly related to the size of the displacement: the longer is the journey, the more important is the speed and the less important is the frequency, whilst, on the contrary, the shorter is the journey, the less important is the speed and the more important is the frequency.

Thus, the suburban trains serve the urban and suburban area of a city within an area with a maximum radius of 30 kilometres. Within these distance from the city centre, the frequency is more important than the commercial speed, and so they have a low commercial speed due to the high number of stations, generally close to each other, where they stop, and high frequency, at least 2 train per hour. Furthermore, due to its urban and suburban nature (they are like a metro that serves the suburban area), the S lines run all day long, at least from 5:00 to 00:00 (Regione Lombardia, 2001).

The regional trains provide service to the main towns of the region, connecting them to the main city and/or with other towns and villages. The distance covered by the R lines is bigger than 30 kilometres and arrives easily to 60 km and more. When a regional line overlaps a suburban line in proximity with the main city, the R does not stop in the suburban stations but goes straight to the main stations of the city, as shown by the following picture. The distance among stations, in this case, is higher than in the suburban linea and so the commercial speed is higher, especially when the overlapping with S lines occurs. Again, here it is possible to observe the distance function: high distance means high speed, but also a frequency that is maximum of 2 train per hours or lower. These lines run generally a few hours less than the S train, generally from 5:00 to 22:00 (ibid).

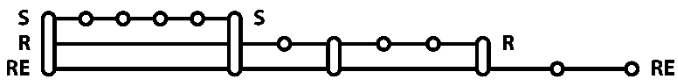


Figure 36 - Train Categories. Author's drawing

Finally, the regio-express services provide fast connection among the main cities and towns of the region and the adjacent regions. They cover high distances, up to a few hundreds of kilometres and so present the higher commercial speed among the three categories, but also the lowest frequency. Generally, there is a RE each hour but sometimes there could even be a headway of 120 minutes. The service period is the same as the R trains, thus from 5:00 to 22:00 (ibid).

To sum up, the first characteristics of the Swiss model is the presence of different categories of trains that correspond to different levels of service. These categories are Suburban, Regional and

Regio-Express and their features are functions derived by the distance from the city centre: the shorter is the journey, the lower is the commercial speed and the higher is the frequency; on the other hand, the longer is the journey, the higher is the commercial speed while the lower is the frequency. The reason behind this need for having different kinds of trains is to answer to different mobility needs and so to capture different mobility flows. A train that tries to capture all the flows, and so that wants to be either suburban and regional train will probably fail in both. The Swiss model provides the citizen with the train that answers his mobility demand: a fast train if he needs to go far, a frequent train if he needs to move around in the urban and suburban area (Stagni, 2012).

2.2.2. Defining Lines

Once established the categories, it is pivotal for the model to define the different lines included in each category. This section describes the features that each line need to present. Setting up the categories is not enough for implementing the model. Under each category, there could be many lines going from different places to different places. For instance, there could be a regional train going from A to B as well as a regional train going from C to D; they are both regional trains but they connect different places. So, to make the network completely legible and recognisable, it is needed something more than just defining train categories.

In order to make the network readable, le lines' service must be standardized in an easy and recurring way. Each line has to be associated with a symbol identifying the line category (S if suburban, R if regional and RE if regio-express) and so its features, a number and eventually with one colour, to make the network as legible as possible. The objective is to make as easy as possible for the user to recognize which line is the best option for each displacement and which kind of service is identified with that symbol. Once the network is legible, it is consequently possible to make it recognisable, creating an identity that could link the network to the territory (Regione Lombardia, 2004a).

Categories	**Suburban**	**Regional**	**Regio-Express**
Lines	S1 S2 S3 S4 S5 S6	R1 R2 R3 R4 R5 R6	RE1 RE2 RE3 RE4 RE5 RE6

Figure 37 - Categories & Lines. Author's drawing

In order to reach the aim of legibility, it is necessary that al the trains running on one line carry out the same service in terms of stops served, first and last stop, and travel time. Besides, also the frequency must be constant during the service period. Eventual demand peak should be absorbed splitting in half the basic headway (more about regular interval timetable into the following section). During the off-peak time, if two lines present part of the route overlapped, it is possible to limit one of them if the demand is particularly low. However, this should be the exception and not the normality (ibid).

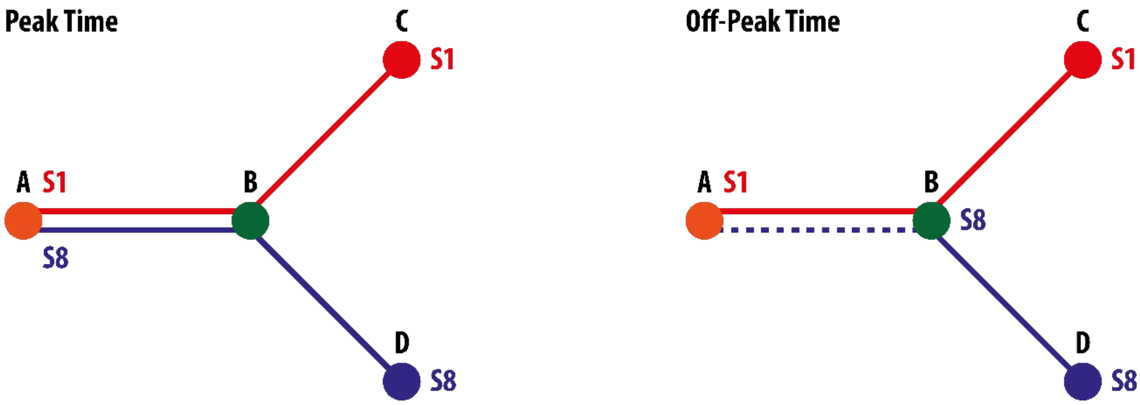


Figure 38 - Peak & Off-Peak Service. Author's drawing

To conclude, it is important to define not only train categories but also train lines that will be uniquely identified, in order to make the network easy to read and to use by the traveller.

2.2.3. Uniform Clock Headway or Regular Interval Timetable

In this section, the reasons behind the necessity of the so-called Regular Interval Timetables (RIT) or Uniform Clock Headways will be described. The first part will explain what is a RIT whilst the second part is focused on the effect produced by it.

It is defined Regular Interval Timetable the timetable based on periodicity, where the departures repeatedly occur with regular interval among themselves all service period long, or in other words, where the headways of the lines are constant. The size of the time interval depends on the line features, generally, due to the reasons explored into the transport theory (section 2.1), short headways are typical of urban and suburban contexts, whilst long intervals are peculiar of regional and long-distance services (Regione Lombardia, 2001). In any case, as regards the headway magnitude, *"if it is longer than 6 minutes, it is desirable to use only values divisible into 60 (7.5, 10, 12, 15, 20, 30, or 60 minutes) known as 'clock headways', because with them the departure time at any one stop falls on the same minutes in each hour"* (Vuchic p. 10, 2005). The magnitude determination depends on four factors (ibid)

1. The physical characteristics of the system, like technology, signalling, degree of safety required, rate of boarding/alighting, departure control at stations, etc. define the maximum capacity of the line, and so the minimum possible headway.
2. Passengers travel time, that, as explained before, defines the passengers' will to wait. Obviously, all the travellers are interested in having short headways due to the high wait that it has on the travel generalized cost, but the shorter is the headway, the higher is the system running cost.
3. Cost operation, that is derived by the headway size.
4. Passenger volume. If a line has a demand for 1000 passenger per hour, it is possible to move them all together with a long train with a thousand seats, or it is possible to carry them with 4 train with 250 seats each scheduled with a 15 minutes regular interval among them.

Consequently, headways are determined as a compromise among the previous 4 factors. Indeed, in the previous example, the decision to have a 15 or 60 minutes headways, both enough for providing adequate transporting capacity, will depend on the possibility of the line to run up to 4 trains per hour, on the cost operation (it is affordable to run 4 trains on that line?) and on the passengers type of travel; if it is an urban line, indeed, 60 minutes headway will probably an unacceptable headway. The consideration of the waiting time is valid even though in off-peak time the utilization ratio of the offered service would be rather low.

The reasons behind the need for this kind of timetable are the effects produced by it. RIT are easy to design: they require the design of only a cycle that then repeats itself over all the service period. For example, if a system is made of several lines, the biggest headway is the only time interval needed to e designed. In a railway were run 3 lines, line 1 (L1) with 15 minutes headway, line 2 (L2) with 30 minutes headway and line 3 (L3) with 60 minutes headway, only 60 minutes of schedule needs to be designed. Once what happens in those 60 minutes interval is established, the service period is built by the systematic repetition of those 60 minutes.

The repetition will grant uniform headways. Those statistically minimize waiting time and provide both regular and incidental users with simple information. If the headway is a value divisible into 60, indeed, it is called Uniform Clock Headway and makes the timetable easy to memorize by the users (Vuchic, 2015). The train will pass at station A always at the same minutes of each hour (Regione Lombardia, 2001). A RIT creates a passenger-friendly, highly available and reliable system (Borza et Horváth, 2010).

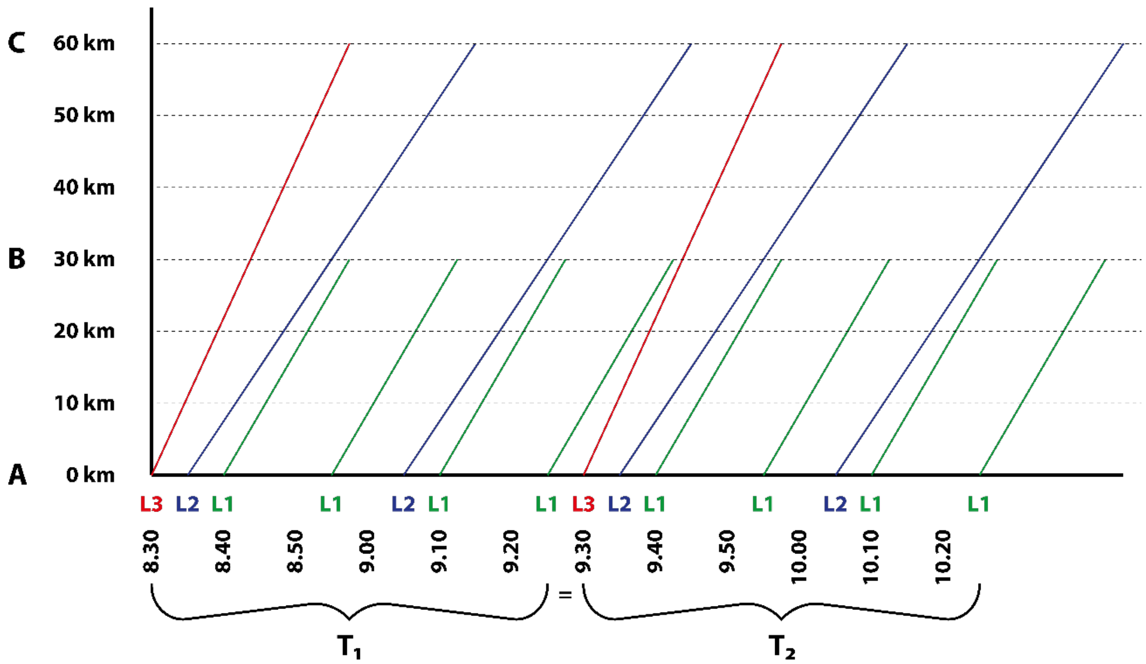


Figure 39 ↑ - Timetable Repetitive Design. Author's drawing

Figure 40 ↓ - BLS Trains. Image downloaded from https://www.railwaygazette.com/news/single-view/view/long-distance-concession-bids-go-in.html

2.2.4. Symmetry and IRIT

The concept of symmetry referred to timetables is simple but it produces very interesting effects. In this section, both the concept of symmetry and its advantages will be described. Theoretically, in every regular interval timetable, departure time and arrival time in a defined place are symmetrical to a distinct and constant temporal point all over the system. In this temporal point, two trains of the same line running in opposite directions cross (Regione Lombardia, 2004a).

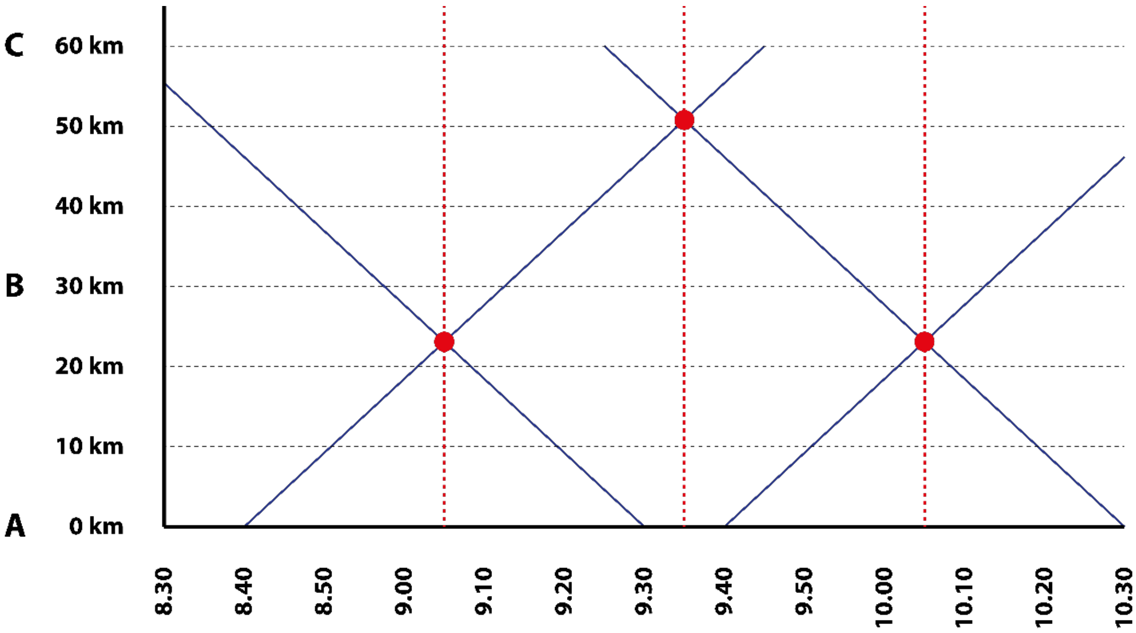


Figure 41 - Simmetry into Regular Interval Timetables. Author's drawing, inspired by Regione Lombardia (2004a)

It is important to understand that this is a result of any RIT but that can be used as a cardinal element to design timetables. When all the timetables are designed with the same minute of symmetry, the effects on the system are very important, mainly for the users; in Europe, this fixed minute is 00. This means, for instance, that the intercity train running from Milan to Venice departs from Milan at minute 05 (of each our in this case, because we are talking about RIT) while the intercity train running in the opposite direction, from Venice to Milan, arrives at Milan at minute 55. This means that the intercity trains running on that line are symmetrical respect to minute 00 (ibid; Johnson et al., 2006).

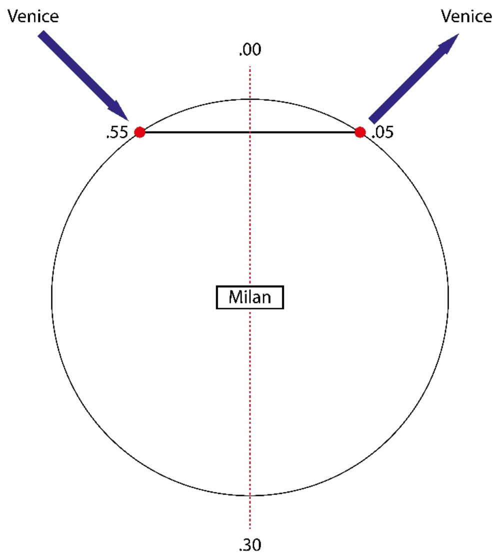


Figure 42 - Symmetrical Arrival and Departure Example. Author's drawing, inspired by Regione Lombardia (2004a)

As stated before, a RIT is by definition symmetrical. Two trains of the same line running in opposite directions meet every x minutes, where x is the half of the headway. Thus, if the symmetry axis passes through minute 00, trains of a line with RIT that presents headway of 60 minutes, will cross at minute 00 and at minute 30. Consequently, if the timetable is designed in order to make the train be at minutes 00 and 30 at stations where more lines intersect, there are all the elements to realize integration among these lines. These stations are so called interchange stations or interchange nodes, not only because probably different railways interchange there but also because the lines' timetables make all trains arriving there contemporary from all directions. This feature can be extended also to other modes, like buses, in order to create an intermodal interchange station.

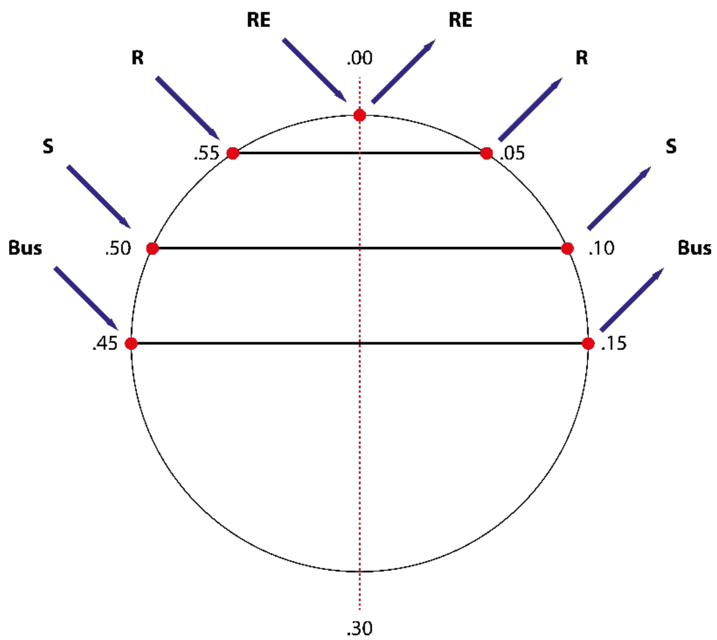


Figure 43 - Interchange Node Example. Author's drawing

In addition to this, the symmetry makes very easy the RIT design. Because of is, indeed, it is needed to design the timetable just in one direction, for instance from A to B, while the opposite direction, from B to A, is automatically made applying the symmetry rule: as shown before, the arriving time of a train in a station is symmetrical to the departure time in the opposite direction at the same station. Thus, if going from A to C there is 10 minutes connection in station B, with a symmetrical RIT there will be a 10 minutes connection in station B also for the return travel (ibid).

In order to make the symmetry works, thus to integrate the regular interval timetables (IRIT), it is required very high system punctuality. In the IRIT, indeed, punctuality is not a consequence but a requirement of the system to make it work properly (Finger at Al., 2014). "*IRITs have the advantage to require a high punctuality but not only for direct connections but also to optimize transfers between trains. Rail systems with IRIT go hand in hand with strong incentives to achieve and sustain high punctuality*" (ibid, pg. 88).

To sum up, symmetry is another fundamental feature of the Swiss model. It is an easy concept that has very important consequences for timetables. It makes them easier to design because it is necessary to build the time schedule only in one direction, while the opposite will be automatically made applying the symmetry rule, and, if used properly, it creates interchange nodes where all the trains (but also other modes) arrive contemporary from all directions. The introduction of a defined symmetry in the RIT makes them Integrated Regular Interval Timetables (IRIT). When the model is based on the IRIT, punctuality becomes a requisite to make the timetables work properly.

2.2.5. Rolling Stock

Many types of rolling stock are used in the rail world. The different feature of the rail line causes the differences among vehicles: a light rail and high-speed railways require, for instance, very different rolling stock (Vuchic, 2007). However, even on the classic railway, there should be different trains, depending on the characteristic of the infrastructure but also on the characteristic of the service. This chapter describes the features necessary to select the right vehicles for a railway network. The main element needed to be taken into account is the train category. Depending on the service type, indeed, there will be needed different train characteristics. In addition to these, the demand magnitude and the railway infrastructural features are the other elements necessary for defining the right train qualities. Those are (Regione Lombardia, 2004b):

- Acceleration, that depends only on the service type. The closest are the stations among themselves, the more important will be the acceleration, in order to minimize the travel time, whilst, on the contrary, the furthest will be the stops, the less important the acceleration will be because other features will be more effective on reducing travel time.
- Doors number and width, which are influenced only by the service type. The more are the doors and their length, the faster access and egress will be. The closest are the stations among themselves, the more important will be access and egress time in order to

minimize the travel time.

- Maximum speed, that depends not only on the service type but also on the infrastructural features. Railways, like roads, present speed limits. For instance, on a line that has 80 km/h as maximum speed will be useless to have high-speed rolling stock; it will be able to run, but only up to 80 km/h. Similarly, for instance, on a railway line with many stations close to each other, even though the speed limit is 200 km/h, it would be useless to use a train that could run up to 200 km/h because, due to the short distance among stations, it will never reach its maximum speed.
- Seats, which are based on service type and on demand magnitude. The former defines the quality of the seats (seating or standing seats), the ladder determines the number of seats. A train line running in an urban and suburban context, where users are on board for a short or medium time, will probably need both seating and standing capacity whilst, a train line running in a regional context, where the average time spent onboard is higher, will probably need as many seats as possible.
- Train dimensions, which rely on both demand magnitude and infrastructural features. Obviously, the higher is the demand, the bigger should be the train, in order to accommodate the passenger, but the maximum dimensions are affected by the infrastructural features of the railway. The maximum height and width are defined by the so-called loading gauge of the line, that is the maximum shape containing the transverse section of each vehicle and ensures that trains can pass safely through tunnels, under bridges and aside platforms (Viganò, 2014) whilst, the length, is defined by the platform length of the line's stations. The maximum vehicle length should not be major than the shortest platform present on the line. Of course, only the platform of the stations where the train stops must be considered.

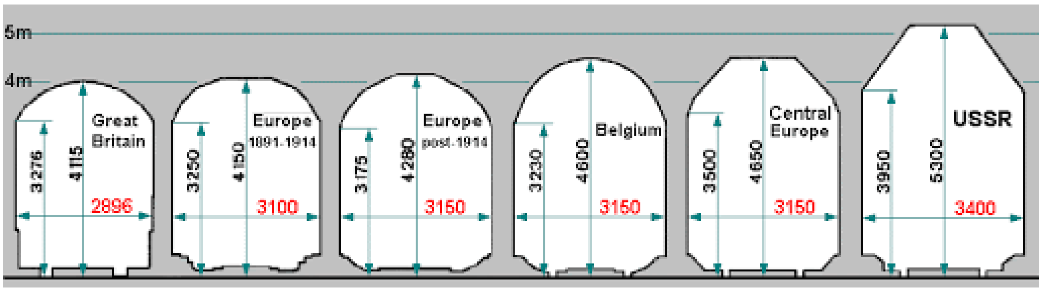


Figure 44 - Different Loading Gauges. Image downloaded from https://www.quora.com/Why-are-British-trains-more-narrow-than-the-Japanese-Shinkansen-despite-both-running-on-the-same-standard-gauge

- Speed class, which is defined by the infrastructural features of the line. It is not this the place where deeply explaining the concept of speed class but, briefly, it is just important to take in mind that railways present different speed classes that depend on the physical characteristics of the line and that are assigned also to the rolling stock. Each class defines a different maximum speed. For example, in Italy, four different speed classes define different maximum speeds (ibid).
    1. Class A, that allows, on rectilinear tracks, a maximum speed of 140 km/h
    2. Class B, that allows, on rectilinear tracks, a maximum speed of 160 km/h
    3. Class C, that allows, on rectilinear tracks, a maximum speed of 250 km/h
    4. Class P, that allows on rectilinear tracks the same maximum speed of class C but on curves a maximum speed that is the maximum speed of class C * 1,18 because this is proper of rolling stock presenting the tilting system, which allows, indeed, higher speeds on curves (ibid).

  Thus, a train classified under class A can reach a maximum speed of 140 km/h and so on. However, not all the railways present all the classes. Main lines present usually class A, B and C, while secondary lines present often just A and B. Train classified under class C can travel on railways without speed class C following the class B speed limits, because, as shown by the picture, the higher class includes the lower (ibid). Consequently, depending on the infrastructural features, it could be necessary to have trains classified as class B or C but also, if the line presents many curves, as class P (class A is generally used by freight trains and locomotives travelling alone).

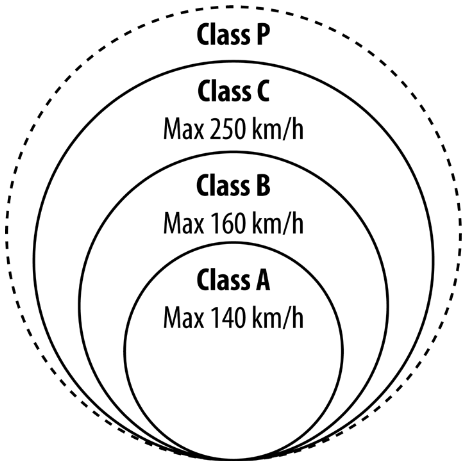


Figure 45 - Speed Classes. Author's drawing

To sum up, thus, it is possible to define the rolling stock features crossing three main elements: type of service, infrastructural characteristics and demand magnitude. Generally, in suburban context trains are similar to underground's trains, with high acceleration, many doors, relatively low speed and many standing seats whilst, on longer distances trains present high speeds and bigger seat capacity (Regione Lombardia, 2004b). This rolling stock differentiation is necessary to improve the quality of the travel. From the mobilities turn perspective, travel time is not a loss, but something valuable. Following this principle, it is important to provide the traveler with a train as suitable as possible to the kind of journey, in order to take advantage of the time spent to travel.

2.2.6. Fares Integration

In this section, the fares integration related to the Swiss model will be explored. The complete theory about transit fares is better explained in chapter 7 '*transit fares'* of Urban Transit – Operations, Planning and Economics, by Vuchic (2005) as regards both the objectives and the requirements that any fares system requires. However, in this section, only the fares policy principles related to the Swiss model will be described.

The first principle is that the fares must include all the train categories present on a route. Being the ticket a linear fare or a zone fare (the former is a ticket valid from location A of the network to point B while the ladder is a fare valid for a zone), it must be usable on all the train categories travelling there, so that the traveller can pick the best travel option. For instance, if from A to B there are both a suburban and a regional train, the ticket must be valid on both, so that the passenger can use them indifferently from the fares perspective (Regione Lombardia, 2001).

The second principle is that this integration must be not only among train categories but also among different modes so that with only one ticket it is possible to use all the modes included in the zone (generally, integrated systems are designed dividing the territory into zones) (ibid). This intermodal integration should not be delimited to public transit, but it must include also car parking and bike parking fares, in order to encourage public transport usage.

Thus, to conclude, in order to maximize the effectiveness of the Swiss model, fares integration policies must be adopted. The fares should include all the modes and all the categories of each mode (suburban trains, regional trains, urban buses, express buses, etc.) in order to incentivize people to use public transit.

2.2.7. Identity and Wayfinding

This last subsection will describe the role of branding and wayfinding in relation to the Swiss model. As stated before in section 2.2.2, once the network is legible (if it is compliant with the theory explained until now it is readable), it is possible to make it recognisable. Making the system identifiable it is fundamental to make it effective: simply, citizens must recognize the system when they make contact with him in order to know where and how to access it. Or in other words, the system needs to be branded. Indeed, "*a brand is by definition a network of associations in consumers' minds*" (Zenker & Braun, 2010, p. 1) that can be spontaneous or actively influenced. Generally, creating an identity starts with a logo (Gibson, 2009). If we see the image of a beaten apple, or even if we just think about it, we immediately imagine smartphones and computers. Similarly, to come back to the mobility field, if we see the logos of the pictures to the right, we instantly think about London underground. Thus, in order to brand the network, it is important to create its image, starting with a logo but completing it with a wayfinding program, that can offer much more substance (ibid).

Figure 46 - London Metro Logo

As explained by David Gibson in '*The Wayfinding Handbook'* (2009), indeed, creating a new branding identity and a wayfinding program together, it is the optimal situation because "*it ensures that all branding elements will be coordinated with the signage and allows the designer to create a more holistic brand experience*" (Gibson, 2009, p. 70). The wayfinding program is needed for orientating the traveller both in the small and in the large scale. The system we are talking about is a railway network, and its accesses are the train stations. This places, sometimes tend to be very complicated and there, people need to find their way to the right platform to catch the right train. "*The wayfinding design provides guidance and the means to help people to feel at ease in their surroundings*" (ibid p. 12), and so it helps to make people feel comfortable in each step of their journey. Similarly, also the overall network needs to be communicated. Into the mobility field, indeed, communication is fundamental: if something is not adequately represented it is not accessible. If it is not accessible, it does not exist (Spinosa, 2017). To effectively communicate the network is necessary a map, in order to allow the user to navigate and orientate itself into the system at large scale. "*This broader involvement, while harder and more expensive to manage, can result in a more widely adopted brand strategy as well as a more coherent and unified public image*" (Gibson, 2009, p. 70), because everything is thought coherently.

To sum up, in order to make the system recognisable, it is pivotal to create a brand identity, together with a wayfinding program. The former is fundamental to improve the effectiveness of the system, letting know to the users where it is accessible and making him think about its features, the ladder, on the other hand, it is fundamental to guide the users throughout the system, both in the large scale, with a map representing the network, and in the small scale, into the stations, throughout the signage.

2.2.8. Conclusion

To summarise, the Swiss model is the service model more adapt to this thesis aim, because in the long term it increases the number of travellers by train. It a supply-driven model, based technically on the concept of different service level and integrated regular interval timetable. These features make the model very user-friendly, granting many advantages for the users because they affect positively travel time and waiting time, so they reduce the generalized cost for travelling:

- Trains belong to different categories in order to supply different demands. There are frequent suburban trains for short or medium displacements and fast regional or regio-express trains for larger journeys.
- Timetables are easy to remember because they repeat themselves. A train of a determined line passes through a station at the same minute of every hour.
- Interchanges at nodes station work in the same way in both directions. If to go from A to C it is needed a 10 minutes connection in B, the return travel will present a connection time of 10 minutes in B.

In order to improve the efficiency of the model, it is necessary to choose the appropriate rolling stock depending on the service type that the train is going to execute, depending on the infrastructural features of the railway and finally, depending on the mobility demand. In addition to this, also other policies are pivotal to the success of the model: the fare integration policy and the branding and wayfinding policies. The former grant an easy ticketing system, the ladder, on the contrary, improve the communication between system and users.

2.3. Study Cases

Into the previous chapter theory about the Swiss model has been discussed, deeply explaining the concept of regular timetable, symmetry and service differentiation. In this chapter, two study cases where the model has been applied are presented. The former is the Swiss case, that will help the reader understand what else is needed, especially from the infrastructural point of view, to make the model work, while the ladder is the Lombardia case. Lombardia (Milan's region) has the only Italian regional railway network where the Swiss model and its principles have been applied. In this case, the focus will be on the results, from the number of users perspective, that this timetable model had there.

2.3.1. Implementing the Swiss Model: Bahn 2000

This section presents a brief description of the Bahn 2000 project, a Swiss railway project that aimed to improve the railway infrastructure in order to take the maximum advantage of the new timetable model. As explained before, integrated regular timetables present as feature the symmetry, a quality that can be used to build interchange stations and so planning the service. It has been also discussed that, into a regular interval timetable with symmetry on minute .00, trains meet at minute .00 and .30, and so that with doubled frequency, they meet at minutes, .00, .15, .30, .45. Consequently, if a train has to pass throughout two nodes, the travel time among interchange stations has to be a bit inferior to 15 minutes or its multiples (30, 45, 60, etc.), or the node will be missed. Missing a node means reducing the effectiveness of the interchange station because some connections are not possible in a reasonable time (if the headway is 60 minutes missing a node could mean having to wait 55 minutes), and so it means making all the model less efficient. The Swiss model planned a 30 minutes headway service among all the major Swiss cities, that would have become the principal interchange station of the railway network. Consequently, the project, approved 5 years after the introduction of IRIT all over the country, in 1987, has got as the main target to make travel time compatible with the model, allowing so travel time a bit inferior of 30 minutes or one hour among the major Swiss cities (Kräuchi, 2004). The motto of the project, indeed, was: '*not as fast as possible, but as fast as necessary*'. The result of this principle is a project that did not plan one or two high-speed railways, but many projects, from small-size to big-size, all over the network, in order to save some minutes, sometimes even two or three, to make the infrastructure ready for the new timetable. In any case, not only the network has been interested but also train stations. Due to symmetry property, into interchange stations, all the trains arrive almost contemporary or in a short time, so it is necessary to have a sufficient number of tracks to accommodate all of them. In 2004 the project was concluded and the new timetable was ready.

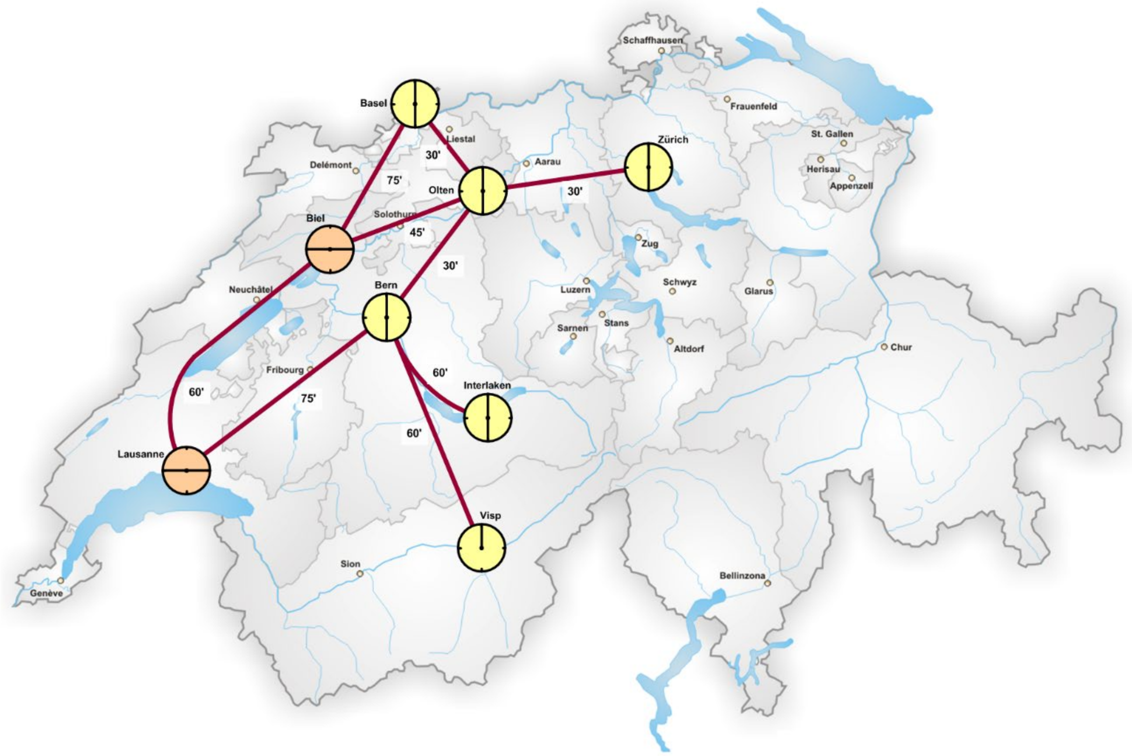


Figure 47 - Interchange Nodes of Swiss Railway Network. Image downloaded from https://it.wikipedia.org/wiki/Ferrovia_2000#/media/File:Knotensystem_Schweiz_mit_LBT_2007.png

The new Bahn 2000 timetable was launched in December 2004 changing the timing of 98% of all Swiss Federal Railways (at that time the only train operator in Switzerland) passenger trains (Rail Gazette International, 2005) but improving the overall railway offer. From 1995 to 2006, the number of tran*km increased by 30%, rising frequencies of long-distance trains about 20% and of regional trains about 16%, whilst, on the contrary, journey time has been reduced by 7% on long-distance connection and by 2% on regional services. As a result, public transport demand augmented significantly. It has been registered a +27.5% (12% of which in 2004-05 with new timetable) of growth, 47% of which related only to the service offered whilst the other 53% to developments in population, income, and so on. As regards modal switch, it can be assumed that around one third switched from private car to public transport, while, comparing the overall traffic growth, data demonstrate that during the period 2006-2005 railway traffic increased more than road traffic (27.5% vs 19%) (Keller et al., 2008).

To sum up, in order to enhance the new service model, based on regular timetable, symmetry and service level division, Switzerland decided to upgrade the overall national network with many projects of many different size, in order to make it possible to travel as fast as necessary to reach interchange stations at the right moment. The fulfilment of the project brought to an increase in transport supply, and consequently to a rise in transport demand, especially on the long-distance journey. In the next chapter the effect of the application of the Swiss model in Lombardia, Milan's region, will be explored.

2.3.2. Exporting the Model: Lombardia's Experience

In the following section, an overview of Lombardia's railway network and service will be presented because it has been the first Italian region (and the only one until now) to apply the Swiss model. Firstly there will be a context description, providing the reader with data regarding

Figure 48 - Italian Regions. Image downloaded from https://d-maps.com/continent.php?num_con=12&lang=it

Lombardia's geography, from territorial extension to population, while nextly, the railway network and service will be illustrated.

Lombardia is an Italian region situated in the central-north part of the Italian peninsula, and its capital city is Milan. The region has an area of about 24'000 km^2, where circa 10 million people live (ISTAT, 2019). To better understand, it can be useful to compare it with Denmark, that is doubled size but hosts half of Lombardia's population. The majority of Lombardia inhabitants live near Milan where there are 4 million people, 1.3 into the city and the rest into the metropolitan area (ibid).

Figure 49 - Lombardia's Main Cities. Image downloaded from https://d-maps.com/pays.php?num_pay=404&lang=it

As regards the railway network, nowadays it measures 2,929 kilometres, of which 227 of high-speed railway, where there are 417 passenger stations (RFI, 2020a; Ferrovienord 2020). In 2002, before the implementation of the Swiss model, passengers transported every day (working day) by the regional trains were about 500,000 (Regione Lombardia, 2004a), whilst in 2018 there were over 800'000 people daily (300,000 during holydays) travelling by train (Il Messaggero, 2019). The reasons behind this growth, +60% in 15 years, are many, and some of them are physiological (population growth, income), as happened in Switzerland, but some credits need to be given to the implementation of the new service model.

The occasion to start the implementation of the Swiss model in Lombardia was the opening in 2004 of the so-called *'Passante Ferroviario'* (lit. Passing Railway), a new urban underground railway that crosses Milan from north-east to south-west.

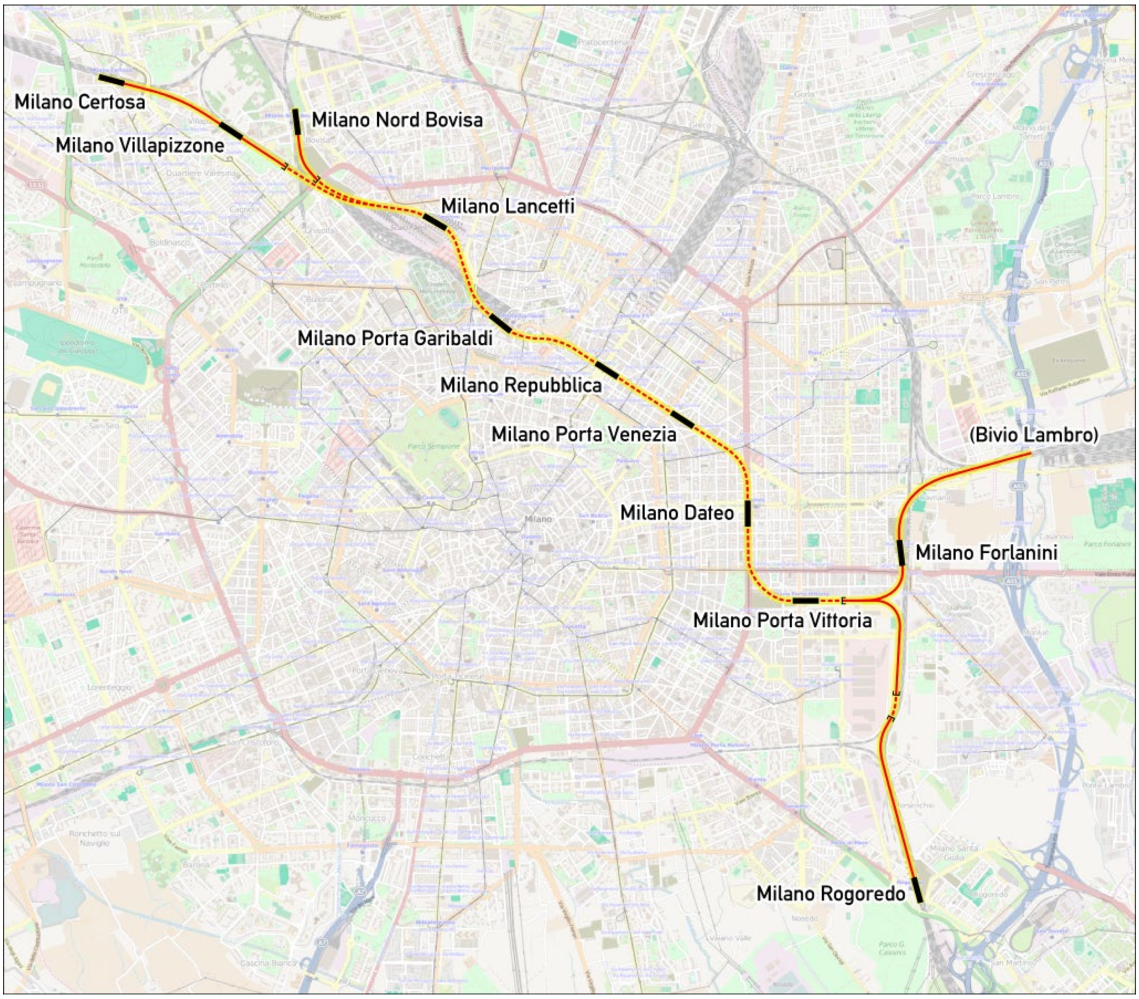


Figure 50 - Passante Ferroviario in Milan. Image downloaded from https://it.wikipedia.org/wiki/Passante_ferroviario_di_Milano#/media/File:Milano_-_mappa_passante_ferroviario.svg

Opening this infrastructure gave to the region the occasion to rethink the overall train service, also pushed by the need for deciding which train would have run in the new tunnel. Thus, the Region, in charge of regional train planning since 2001 reform (Regione Lombardia, 2001), take advantage of the situation aiming to reform all the train service network. Data showed that the majority of people were using the train to go to Milan (65% of all daily displacements), and that half of them were travelling inside Milan's metropolitan area, where roads were and are overcrowded (Regione Lombardia, 2004a). Furthermore, the capacity offered by regional trains was not sufficient to absorb the demand, especially around Milan (ibid), where people were regularly travelling standing. Also, train schedules were built following the classical commuters demand many trains during rush hour, no trains or a few trains during off-peak hours), ignoring the market that was tending (and today even more) towards irregular mobility demand (ibid). On the majority of the network, indeed, timetables were not regular (only about 10%) and when they were, the symmetry principle was ignored, thus no interchange nodes existed (ibid). In order to cope with these problems, contemporary to the *'Passante'* opening, train categories and timetables were revolutionized, introducing suburban lines (along with Regional and Regio-Express lines) that would have travelled into the new infrastructure and redesigning 13 of the 36 railway directrix of Lombardia (Regione Lombardia, 2004b). In December 2004, after an initial period of experimental services, ten new suburban (S) lines were introduced along with the integrated regular interval timetables, that present 30 minutes headway during all service period, and many others, hence introducing effective interchange stations (ibid). As regards the ten new lines, five of them were designed to pass into the new infrastructure, crossing Milan diametrically, starting and ending into the metropolitan area, 4 of them were radial, starting into Milan and, one was a semi-circular line around Milan suburbs.

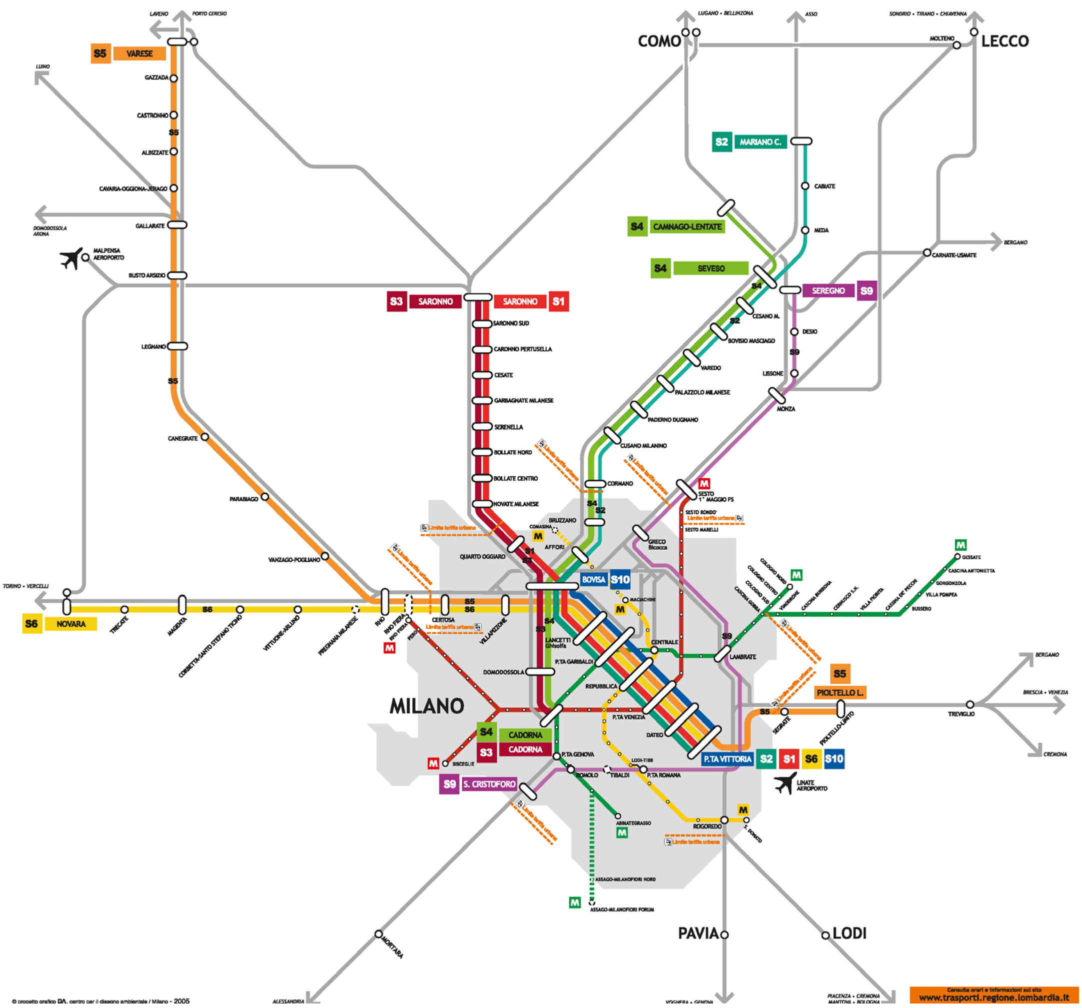


Figure 51 - Suburban Services of Milan, Official Map (2005)

The new model was so much a success that during the following year regular interval timetables were extended to all network and new S lines opened. Coherently with this trend, in 2015 the new Regional Sustainable Mobility Program has been published, where new S lines are planned, not only serving Milan metropolitan area but also other Lombardia's cities suburban areas, as shown by the map, confirming the success of the model and the will of exporting it all around the region (Regione Lombardia, 2015)

Figure 52 - Railway Service Medium-Term Scenario. Zoom on Bergamo and Brescia Area. (Regione Lmobardia, 2015)

To sum up, in 2004 a new infrastructure was built in Milan city, and it offered the occasion to rethink the regional railway service model. New train categories have been established and so new suburban lines designed and old regional lines modified, all of them following the principles of Swiss model, thus integrated regular interval timetable with minute .00 symmetry. The new model was a success in term of passengers growth, and so the region continued to develop it, designing new S lines and planning others around the region, not only around Milan. The increased capacity derived by the new service model contributed to rising passengers' number of 65% in circa 15 years, passing from the 500,000 of 2002 to the 800,000 in 2018 (Il Cittadino, 2019).

2.3.3. Summing Up

Swiss and Lombardia study cases are important to understand the effectiveness of the model in real-world, as much as what is needed to make it effective. Swiss case confirms the necessity for planning the infrastructure following the timetable, in order to improve is effectiveness, while Lombardia demonstrates that the model works also in different contexts. Of course, adaptation to the exterior conditions is fundamental to the success of the model, that in both cases brought growth in passengers of 50% or more. However, this passenger rise needs time, it is not immediate, even though Swiss experience confirms the importance of infrastructure compliance to timetable: as explained before, data show that half of passengers growth occurs after the implementation of 2004 timetable. Lastly, Swiss and Lombardy also demonstrate that the model's implementation is not for free, more money is needed indeed to run the new services, especially if new train categories are introduced.

These experiences have shown the effectiveness of the model in increasing passengers number, thus they explain why this service model has been selected to be applied in Lazio's context. It is, indeed, the best way to improve public transit modal share making it competitive with private transport. The model's features along with the other policies, indeed, transform the railway mobility system of the 19th and 20th century, thought mainly for commuters, to a mobility system made for the citizen of the 3rd millennium, that does not move only to reach the working place (Regione Lombardia, 2001; Roma Mobilita, 2019). As explained in the previous chapter indeed, due to its features, the Swiss model offers to the citizen the most suitable option for the displacements possible by train, making it a valuable choice. In Rome, this will positively affect not only people that today are already taking the train, improving their travel quality but also people that use the road network. The more public transport effectiveness will shift people from private transport to it, but those that will keep using the car will have less congestion on the road, thus also their travel quality will be improved.

Into the next chapter, the implementation of the model in Rome's region will be described, starting from the premises and arriving at the first steps needed for its realization.

2.4. Conclusion

Identified as a solution in the previous part, the Swiss model is the main theme of part 2. In the first chapter, the reader is provided with all the tools necessary to understand the Swiss model, described in detail in chapter 2. The first chapter talks about classical transport theory and mobility theory, that are needed to understand the effect that the model can have and why. The technical features of the model are so explained in chapter 2, along with other policies that will improve the efficiency and effectiveness of the model. Finally, the last chapter includes two study cases where the model has been applied, Switzerland and Lombardia, and the relative passenger's data, demonstrating the effectiveness of the model.

3. Designing and Implementing the Model in Lazio

In the previous part, the Swiss model has been technically analysed, along with its consequences where it has been implemented, in Switzerland and Lombardia. Consequently, now the reader should have all the tools to understand what is proposed in this part and why. Here, indeed, a design exercise is proposed: the Swiss model will be applied in Lazio, looking through all the design and implementation process, from the beginning to the first applicative step. To realize it, it will not only be used the knowledge acquired in the previous chapter, but it will also be added the empirical knowledge earned during its internship experience. The first chapter is dedicated to explaining how to design a long term scenario, the first thing necessary to implement the model. Once the long term scenario is built, as described in chapter two, next step is to design the short term scenario, that describes the first scenario applicable to reality and what is the administrative process to make it real. Completed also the short term scenario, the third chapter describes why and what is needed to tender the new services, while, chapter four talks about the basic elements necessary to effectively brand the service. To conclude, the fifth chapter will be about the future steps, so the actions to do once the new service starts to reach the long term scenario service model and to make it as effective and efficient as possible. Briefly, this chapter will go through the new service network designed by the author and the process needed to realize it.

3.1. Long-Term Scenario Design

"The wind is never favourable to those who do not know where they are going" is a famous sentence from Lucius Annaeus Seneca (4 BC – 65 AD). The author of this thesis strongly argues that this principle is fundamental to successfully plan mobility. Thus, to achieve this thesis main aim, that is to apply successfully the Swiss model in Rome's region, the first thing to do is design the final vision, that is the optimal service model, unobtainable today but possible into the future; in a few words, a *'Long-Term Scenario'*. In this section, indeed, the process of designing a scenario will be broken down. The first thing to do is to analyse the infrastructural context, thus analyzing the regional railway network, because it is necessary to understand the maximum available capacity and to start thinking about interchange stations (3.1.1). After that, taking into account some common sense principles (3.1.2), the new train lines can be designed into detail (3.1.3), and so, finally, the interchange nodes can be defined item by item (3.1.3) and the overall service map presented (Attachment 1).

3.1.1. Infrastructural Context: Capacity Limit and Interchange Nodes

Necessary to design a railway service scenario is the analysis of the infrastructural network. In this section, Lazio's railway network will be critically analysed focusing on its capacity aspects. It is visible from the map (figure 53) that even for railway works the proverb *"All* [rail]*roads lead to Rome"*: all the railways indeed, except for two, origin or finish in Rome. As described in section 2.1, Lazio has 200 stations on 1,319 kilometres of railway network, of which 875 km double-track whilst the rest, 444 km, single-track (RFI, 2020b; ATAC, 2019).

Figure 53 - Lazio's Railway Network. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The number of tracks defines the theoretical maximum capacity, which is a basic element to take into account when lines are designed and frequencies are chosen. The most modern signalling systems developed by RFI (the infrastructure manager) allow the following capacities (RFI, 2020b):

- 2 trains per hour per direction in single-track railway.
- 12 trains per hour per direction in double-track railway with maximum speed higher than 60 km/h.

- 16 trains per hour per direction in double-track railway with maximum speed lower than 60 km/h.

This does not mean that today each double-track railway in Italy can have 12 trains per hour per direction, but that upgrading the technology to its maximum possible today it will allow that capacity. Considering that this is a long term scenario, it is reasonable to consider each track equipped with the best technology available, and so that each double-track stretch of the network can host 12 or 16 trains per hour per direction, that correspond to headways of 5 or 3 minutes.

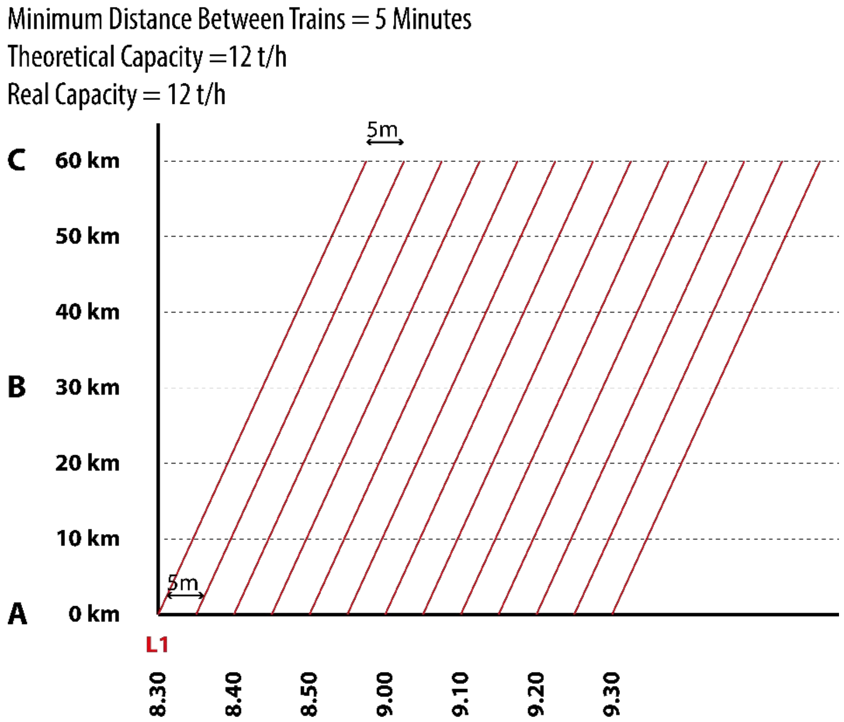


Figure 54 – Timetable Design and Capacity 1. Author's drawing

However, the headway is constant only if trains run at the same speed, but, as said before (section 2.2.1) one of the principles of the Swiss model is service differentiation, that consist of trains presenting different commercial speed. This means that capacity depends on the speed difference among trains. As shown by the picture, indeed, even though a railway can theoretically allow 12 trains per hours, if they present different commercial speed, the real capacity could be dramatically reduced. Being capacity a scarce resource, it is common sense to use it in the most efficient possible way.

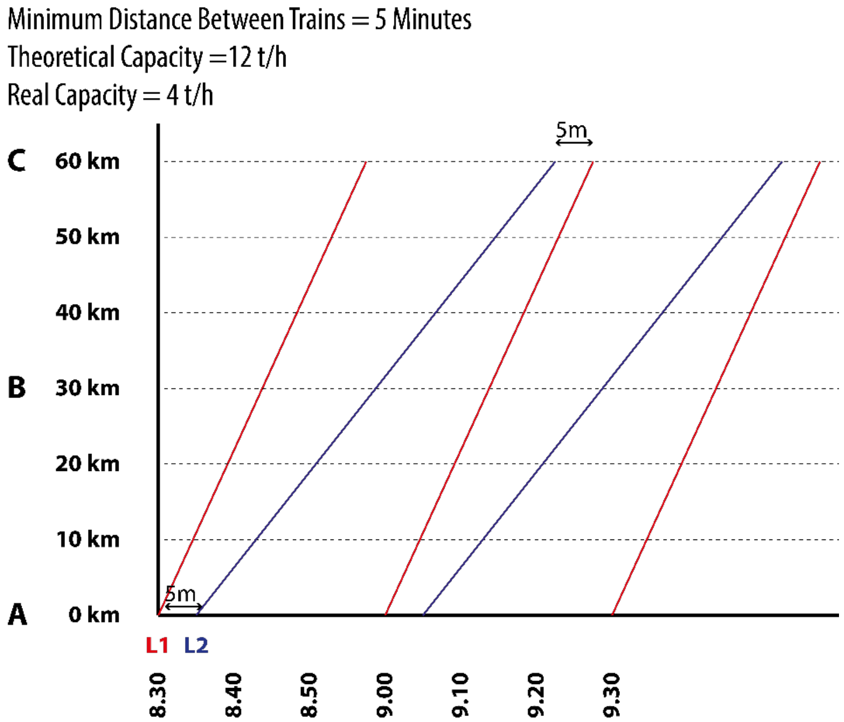


Figure 55 – Timetable Design and Capacity 2. Author's drawing

Thus, during the timetable design, attention is required to avoid different speed as much as possible. If, for instance, there are three service level (S, R and RE) between interchange stations A and B, and 2 service level between C and D (R and RE), it is favourable that R and RE trains will run at the same speed between A and B, in order to maximize line capacity.

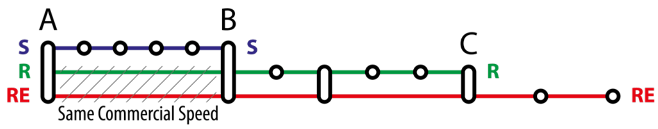


Figure 56 - Commercial Speed and Capacity. Author's drawing

The network needs to be analysed looking for the cardinal elements of the future service network: interchange stations. In order to define the primary nodes, as explained in the previous part, it is necessary to find firstly the stations where two railways physically meet. Secondly, other nodes will be identified were different services meet, thus probably at the terminus of each suburban, regional or region-express line. Lastly, the last group of interchange station will be defined looking at the major city of the region, because even though no different railways or train categories meet, there are probably many urban and suburban buses originating there. The second step could seem incoherent because lines are not yet designed. However, generally, train lines end where the infrastructure ends or in big cities, thus, it is possible to make some hypothesis studying the railway network and the geography of the region.

To sum up, the analysis of the regional railway network is pivotal to design the train service. It is indeed necessary to understand the possible capacity of the infrastructures, that depends on the number of tracks. On double-track railways (875 km of the network) equipped with the most advanced technology can run a maximum of 16 train per hour per direction at low speeds, 12 if the speed is high, and up to two trains per hour per direction on single-track railways (444 km of the network). However, the theoretical maximum capacity explained is related to the best signalling systems that exist but that could not be installed yet. In addition to this, depending on the timetable of the trains running on the line, a line with a theoretical maximum capacity of 12 trains per hour per direction could allow only 4 train per hour per direction due to the different commercial speed of the trains.

3.1.2. Designing Lines Principles

After the infrastructural analysis, other elements need to be taken into account before starting to design the lines. This section, indeed, describes the common sense principles behind lines' design. In addition to what has been explained in the previous chapter (2.2), to design train lines, it is necessary to follow some other non-written rules important to define the network coherently with reality (<u>N.B. the following subsections describe rules that are derived by the experience collected by the author during his job in the railway service office of Lombardia region, that handle the railway service planning in Lombardia, and where he participated to the lines' design process</u>).

Before to start to explain the lines' design principles, it is pivotal to remember what has been explained in section 2.2.1 about different service level or train categories. It has been explained there that the model that is going to be applied requires different service levels, that are suburban, regional and regio-express. Each service level presents some features, that need to be taken into account when the line is designed. As stated before, for instance, suburban lines do not generally go further than 30 km from the city centre, or regional and regio-express trains do not stop in all the stations where suburban trains do. In addition to these, four other factors need to be considered: geometry of lines, existent services, existent planning and, demand magnitude and infrastructure features. In the following paragraphs, these elements will be singularly analysed.

3.1.2.1. The Geometry of Lines.

This principle is as simple as important to design lines. It is pivotal to start by remembering what has been explained in chapter 2.1 so that to go from A to B the majority of people takes the mode that offers the lowest generalized cost for that displacement. It has been also explained how generalized cost depend on journey's distance because generally, the longer is the distance, the

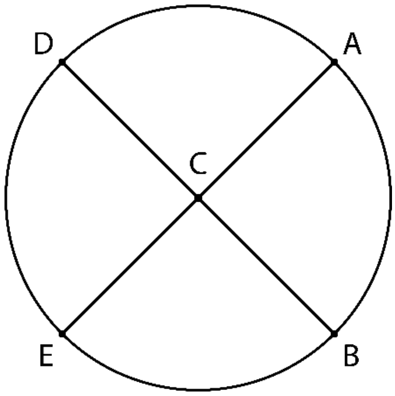
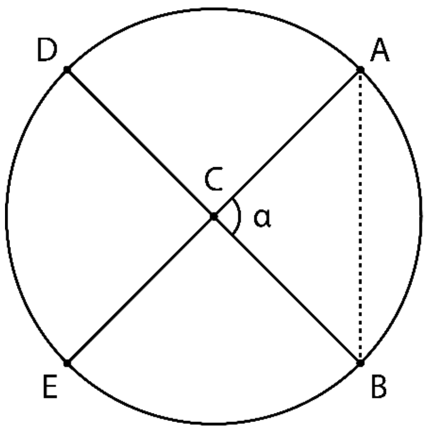


Figure 57 - City Geometrical Simplification. Author's drawing

higher is the time spent to cover it and so VoT changes relatively to distance. Stated this, it is now possible to explain the geometric principle behind lines' design. The majority of geographical urban areas can be simplified as geometrical shapes. The more physical barriers are there, the less the geometrical approximation is accurate, but if there are just a few natural impediments, it is possible to state that usually, cities develop a shape reducible to a circle area or a part of it. For sake of simplicity, from now on, the shape used as city simplification will be a circle crossed by four railways intersecting in the centre (again, just a simple infrastructure network is considered for simplicity's sake). Thus, if that circle area is crossed by railways AC, BC, DC and EC, what is the best service possible considering that each railway is linked to all the others? Direct services from all points to all points passing through C is the best option, but generally, network capacity is limited, thus it is considered a maximum capacity of one train per hour per direction per each railway. Another consideration is that minimizing numbers of forced connection is always good, as connections negatively affect travel generalized cost (nobody likes to change from a vehicle to another). The last simplification to make is that the speed of each displacement is constant, thus increasing distance means increasing travel time and so increasing generalized cost. Considered all this, the service options available are two: two diametrically opposed lines ACE and line BCD or two lines ACB and DCE. The following geometrical analysis demonstrates why two diametrical lines are the best option.



$$\overline{AC} = \overline{BC} = \overline{DC} = \overline{EC} = r$$
$$\overline{AE} = \overline{DB} = 2r$$
$$\overline{AC} + \overline{BC} = \overline{DC} + \overline{EC} = 2r$$
$$\overset{\frown}{AB} = \overset{\frown}{DE} = 2\pi r \bullet \alpha/2\pi = \alpha r$$
$$\overset{\frown}{BE} = \overset{\frown}{DA} = (\pi\text{-}\alpha)r$$
$$\overline{AB} = \overline{DE} = \sqrt{2} \bullet \sqrt{(1\text{-}\cos\alpha)} \bullet r$$
$$\overline{BE} = \overline{DA} = \sqrt{2} \bullet \sqrt{(1\text{-}\cos(\pi\text{-}\alpha))} \bullet r$$

Figure 58 - Arches and Chords Geometrical Features. Author's drawing

As it can be observed in the picture, the distance between point A and points B, D and E, passing throughout the centre C, is the same: 2r. If the distance among point A and the other points is calculated on the arch or the cord, it depends on angle α. On one hand, as regards the chord, if α ≠ 180°, then the chord between two points on a circumference is shorter than 2r and if α is 180°

the chord is the diameter, thus the distance will be 2r. On the other hand, talking about the arch, the distance among two points on a circumference is shorter than 2r if α < 2 radian (that correspond approximately to 115°). In the picture's example, α = 90° if angle ACB or ACD is taken into account, while it is 180° if the angle ACE or DCB are considered. Thus, as regards the distances A-B and A-D, they will be shorter than 2r (that is AC+BC and AC+DC) both considering chord and arch. Taken into account this, if the distance is the only parameter influencing the travel generalized cost, to go from A to B or from A to D, people will probably avoid the train (there will be people taking the train, but only the ones who have no other option), using another mode that will travel along the arch or the chord (it has been assumed that system's speed is constant). On the contrary, the railway option to go from A to E is competitive to the other modes because it covers the shortest route, hence people will consider the train as one of the best options. Consequently, going back to the hypothesis, so that it is better to directly connect A to E and D to B than A-B and D-E, it is true because, even though the distance among the four points is the same, people travelling from A to E or E to B using the train will be probably more than people travelling among the other points using the train (among the other points, as said before, the train will be probably avoided). Thus, it is more rational to provide connection discomfort to the smallest number of people than to the majority of travellers. To sum up, direct diametrical lines are the best option because they provide the majority of travellers with a direct connection, forcing only a few users to change train in the centre. To conclude, it is important to remember that this is a geometrical principle but that reality is much more complex, indeed, for example, city centres are generally congested or reserved to pedestrian, thus the diametrical connection is only possible by train (or by other public transport modes) making it even more convenient than other modes. On the other hand, sometimes, the connection along the arch or the cord is congested, thus passing through the centre (or close to the centre) is better. However, as a general principle to design transport lines, this theory is valid and it will be applied in the following chapter as it has been applied in the lines' design process during the author's internship.

3.1.2.2. Existing Services

This is necessary to take into account only when the new service, like in this case, is going to take place on an existent infrastructure where there is an existing train service. On the contrary, if the infrastructure is new there is no need for this consideration. However, being this a train service model for an entire network, and being very unlikely that new railway networks are built from scratch, it is necessary to analyse and consider the existing services. The cause behind this need is that people consider public transport as an acquired right so that they will not easily accept downgrades. For example, if in train station A pass two trains per hour, it will be easy to double the supply, making four trains run, while on the contrary, it will be very difficult to remove one and let them with just a train per hour, even though there are technical reasons behind it. However, it could be necessary to make unpopular choices, for many reasons. The easiest way to do that is compensating for the loss with something else. For instance, could be more acceptable for people to pass from two trains per hour to one train per hour if the remaining train is considerably faster than before, or if a service provides for one train per hour from A to B, where B is the city's central station, and it is needed to make the line run from A to C, where C is a secondary station of the same city, if the number of trains increases from one to two trains per hour, it will be probable that people will not complain too much, and so that the change will be accepted.

3.1.2.3. Existing Planning

Similarly to the previous reasoning, if present, could be useful to look at the existent planning strategies, to understand how far the long term scenario can go. Maybe they are not compliant with the model, but they could be useful to have an idea of the forecast services. For instance, if today two trains are running from A to B and the planning strategy forecast that tomorrow there will be four, it is possible to consider that four as an acceptable quantity to insert also into our model (although the quality of the train will change, as they could be two suburban and two regional trains), because it is important to remember that scenarios are not utopias, they need to be doable in order to be effective. Similarly, the existing infrastructural plan will provide the planner with an idea of what is going on that front, to understand, again, how far can the scenario go. If for instance, it is already forecasted a megaproject, like a new high-speed railway, it can be useful to consider it into the model, or, on the other hand, some features of the new service model could be justified only if the future high-speed railway project was blocked.

3.1.2.4. Demand Magnitude and Infrastructure Features

In order to not fall into inefficiency or ineffectiveness would be optimal if train lines presented similar demand all along their path. The bigger is the train, the higher is its running cost, thus it would be very inefficient to make travel a train with 1,000 seats with only 150 passengers in rush hour. Consequently, when lines are designed, demand over line needs to be considered to reduce inefficiencies. If demand is low all along the A-C-B line, there is no need for big trains, so it is efficient to have a single line, whilst, if the demand on the C-B part of the line is higher, could be better to have two distinct lines (A-C and C-B), to allow bigger trains where there is high demand and. This needs to be considered also in relation to the infrastructure because sometimes different railways allow different rolling stock, thus, even though the demand would be similar, sometimes is not possible to have a single line. If for instance from A-C-B the demand is balanced, but from A to C the infrastructure allow double-deck short trains while from C to B single-deck long trains, it will not be physically possible to satisfy both demands with just one service, but because of infrastructural features, different lines will be needed.

3.1.2.2. Summing Up

To conclude, when a service network is designed, it is necessary to take into account four different principles:

1. The geometry of lines, in order to provide the major number of travellers with the smallest discomfort.
2. The existent services, in order to design something doable in the future that will not meet many opposers.
3. The existent planning, in order to design a plan coherent with the planned infrastructure or that justify a change in the existent planning.
4. Demand magnitude and infrastructure feature, in order to design effective lines as compliant as possible with the infrastructure.

3.1.3. Lines Description

In this section, the principles explained until now will be practically applied to design a new railway service network in Lazio. Each line will be deeply detailed showing all its characteristics and explaining the reason behind its design. The lines are grouped into three categories and this section will follow this division: firstly, the eleven suburban lines are going to be described, secondly, the thirteen regional and thirdly, the nine regio-express lines. Finally, the overall network is presented and analysed.

3.1.3.1 Suburban Lines

Considering the existent and the planned network, ten lines have been designed to cover the urban and suburban area of Rome, and one to supply the suburban demand around Formia, a city in the south of the region. As regards the Roman lines, the design has taken into account the maximum distance of 30 kilometres from the city (Trenitalia, 2020), the geometry principle, the existent services and the demand magnitude along with the infrastructural features, as shown by the following map.

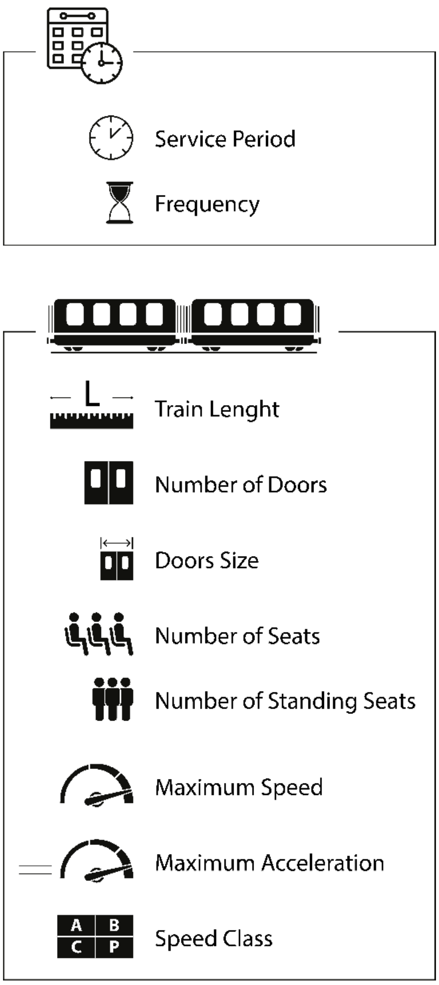


Figure 59 – Icons' Legend. Author's drawing

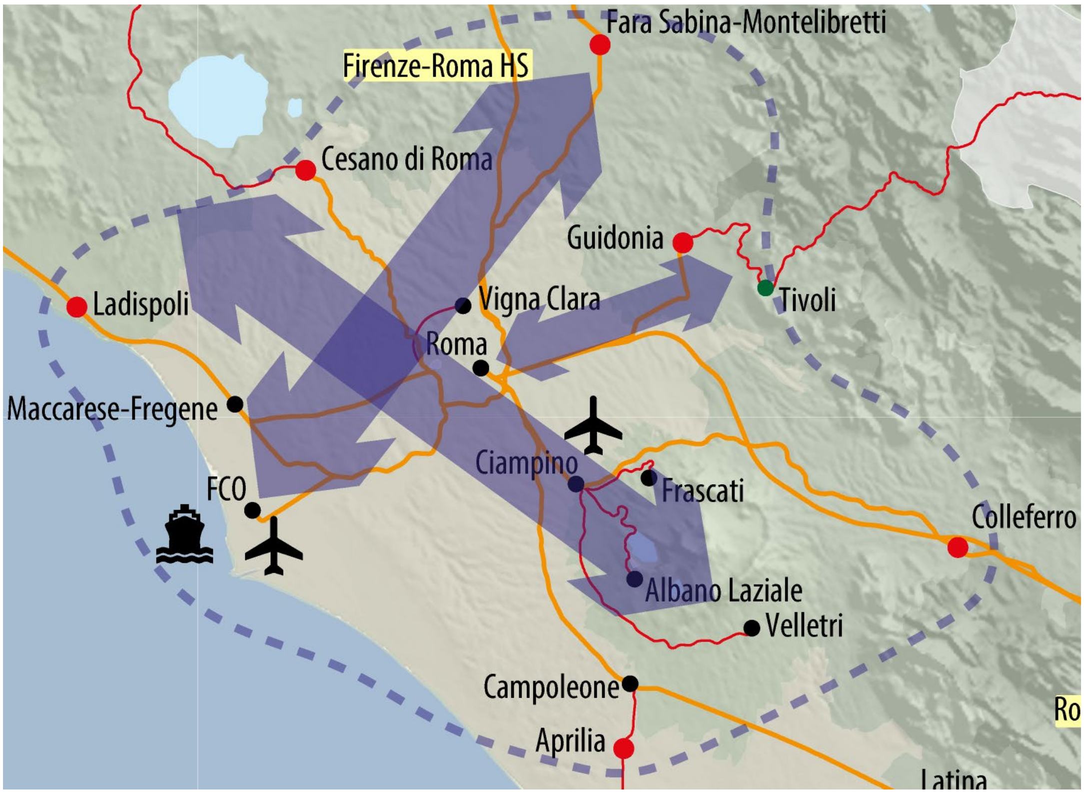


Figure 60 - Suburban Lines Main Trajectories. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The new suburban lines will intercept the mobility flows inside the city of Rome, offering a metro-like service providing the historic city with fast and frequent connections. As explained in part 1, half of Rome displacements are short. It means that to offer a competitive service high frequencies are required. Contemporary, the S lines will connect the historic city with the metropolitan area, avoiding the traffic generated by the external periphery developed around the GRA and so offering a valid alternative to the private vehicle.

The dashed line is the 30 kilometres radius whilst the three arrows represent the general direction of the lines. The smallest arrow represents the only services that do not cross the city because of infrastructural and demand features.

Each line will be described using the same pattern:

1. Line scheme and features.
2. Geographic context.
3. Line description.

The symbols on figure 59 will be used to describe the lines' characteristics.

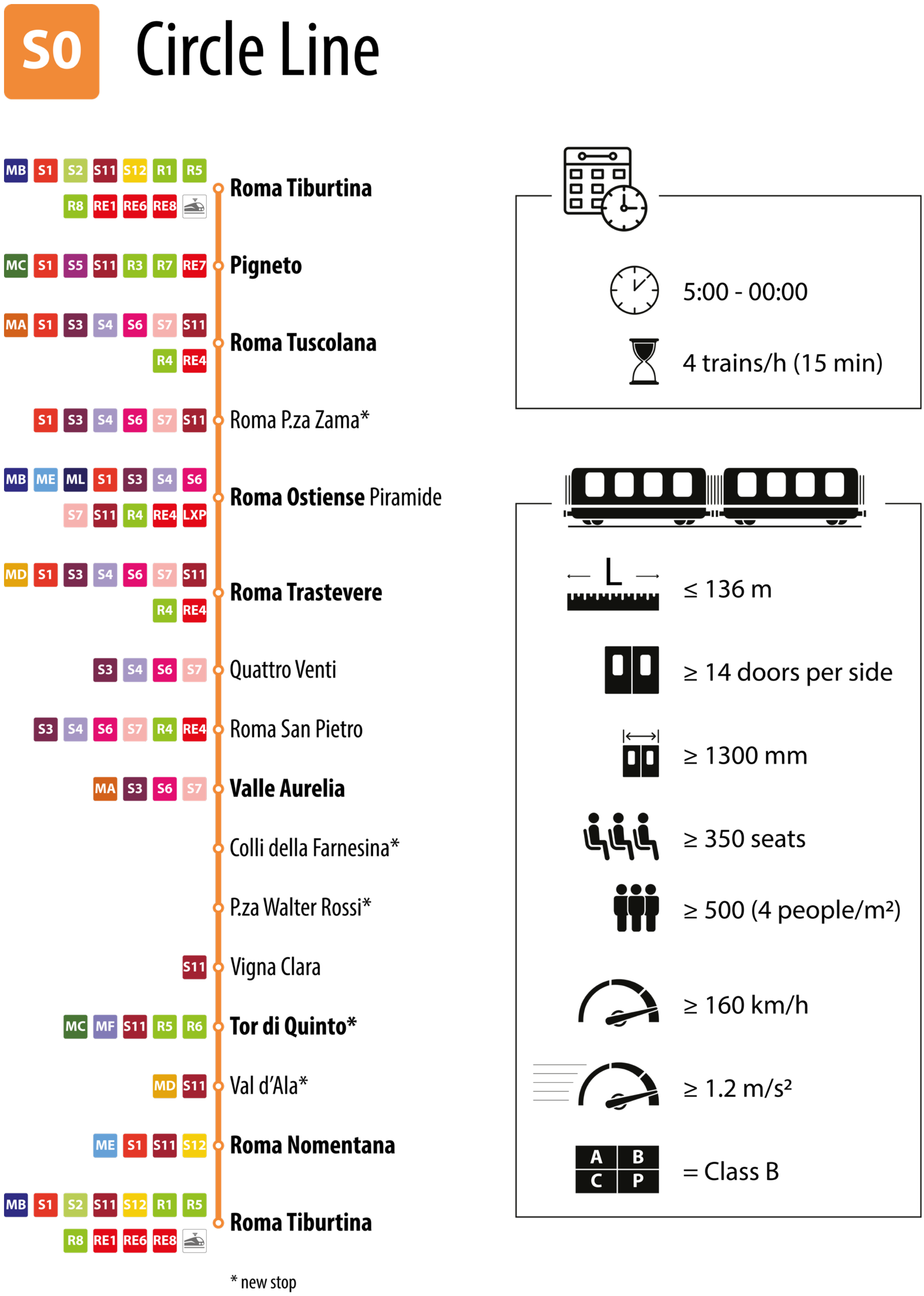


Figure 61 - S0 Line's Features. Author's drawing

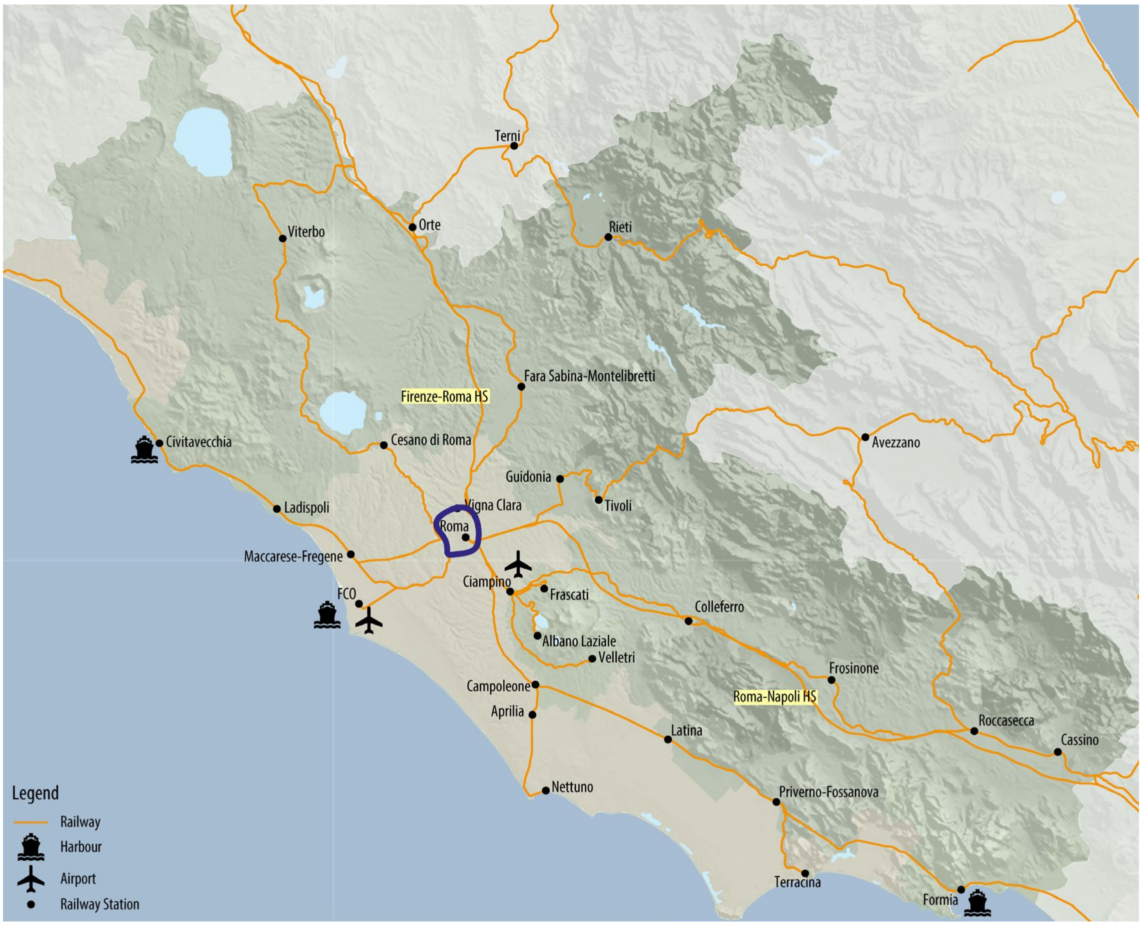


Figure 62 - S0 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The S0 will be the only proper urban line of the network. Indeed, it will not go beyond the commune borders running around the city centre. It will run every 15 minutes from 5:00 to 00:00, using rolling stock similar to that used in metro systems: high acceleration with a high number of width doors. However, considering the demand, about 1000 passengers per hour per direction in the northern part (Mantuano, 2015), the only not shared with other lines, the trains on this line do not need to offer huge capacity. Besides, in the southern part, where demand is considerably higher, the high number of lines makes it unnecessary for this to provide more capacity. As regards the infrastructure, right now the railway is not completed in the northern part but the regional and municipal planning forecast to build it (Roma Mobilità, 2019), thus, if in the short term it will not be possible to have a complete circular line, in the long term it will.

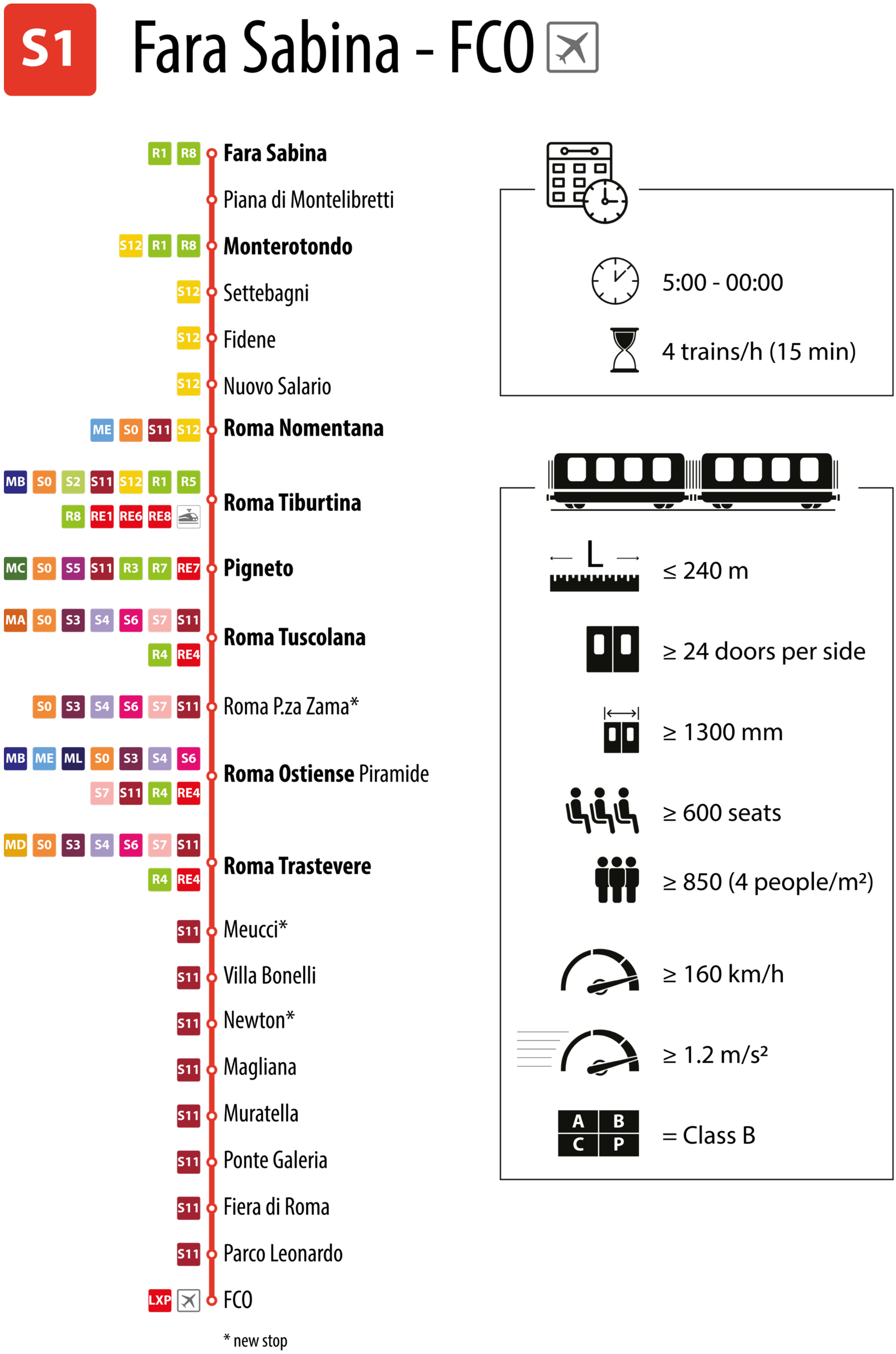


Figure 63 - S1 Line's Features. Author's drawing

Figure 64 - S1 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The S1 line will follow the existent FL1 line in its suburban part, crossing the city from the north-east to the south-west of Rome metropolitan city and connecting it to Fiumicino airport. The frequency will be the same as today but extended to the entire service period, from 5:00 to 00:00 and along with lines S11 and S12, it will provide very low headways (less than 10 minutes) on urban sections, allowing people to use the system as it was a metro. The rolling stock will have the same characteristics of that used for S0, but considering the major demand, it will be longer to offer more places. As regards the infrastructure, the line already exists so it would be not necessary to make any upgrade to realize it, even though more station should be built in the urban section to improve its attractivity providing the line with more access point to the city.

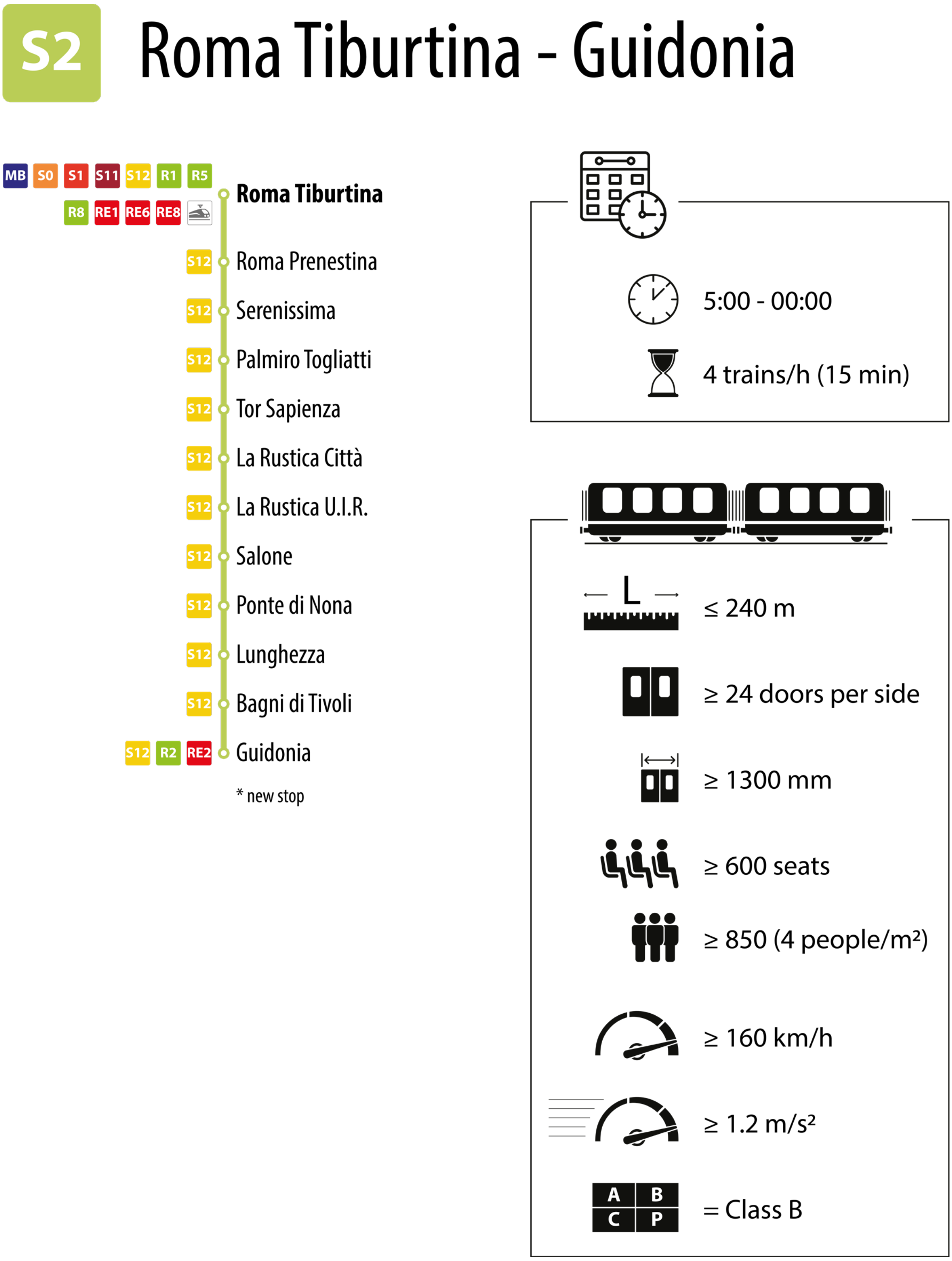


Figure 65 – S2 Line's Features. Author's drawing

Figure 66 - S2 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The S2 line will follow the existent FL2 line going from Roma Tiburtina, the second railway station of the city, to the est suburbs. The line will run with a train every 15 minutes, as already planned by the region (RFI, 2020a) from 5:00 to 0:00 and along with S12, it will provide even better headways in the urban section. As regards the rolling stock it will be the same used for line S1. The infrastructure will be ready by 2021 allowing 10 trains per hour per direction (ibid) and so providing even more capacity than what is needed.

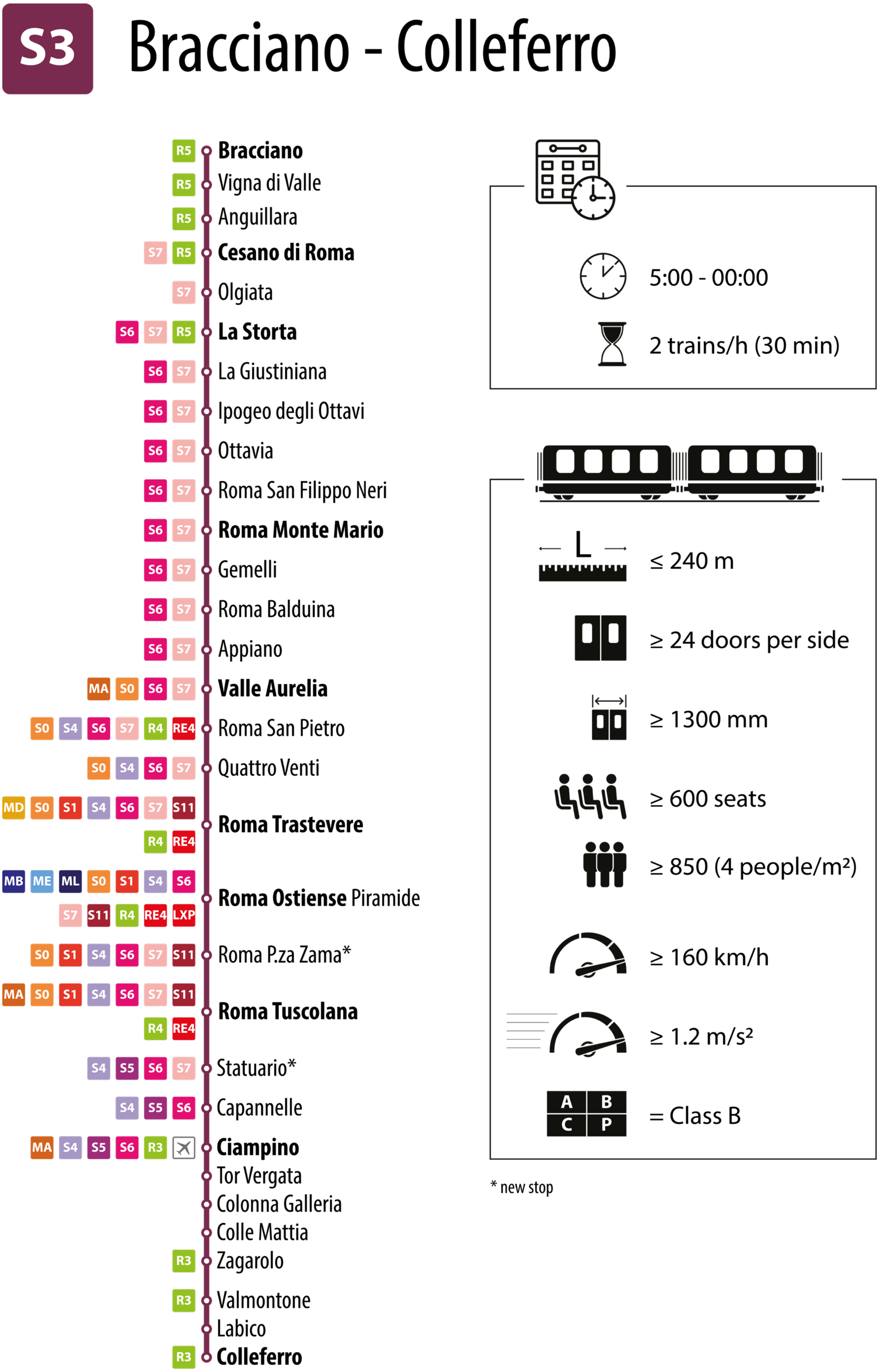


Figure 67 – S3 Line's Features. Author's drawing

Figure 68 – S3 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The S3 is a new line covering part of the existing FL3 and the suburban part of the FL6. It will cross the city from south-est to north-west, connecting these parts of the city to Ciampino airport. As regards the northern section, even though the suburban area ends in Cesano di Roma, today services are connecting Bracciano to the northern-west neighbourhoods of the city, thus, it is appropriate to maintain a train line that directly connects those places. The line will run with a train every 30 minutes from 5:00 to 0:00 and, along with S6 and S7, it will provide 7-8 minutes headways in the urban section. As regards the rolling stock it will be the same used for lines S1 and S2. No infrastructural upgrades are needed to activate this line (RFI, 2020b).

S4 Cerveteri Ladispoli - Frascati

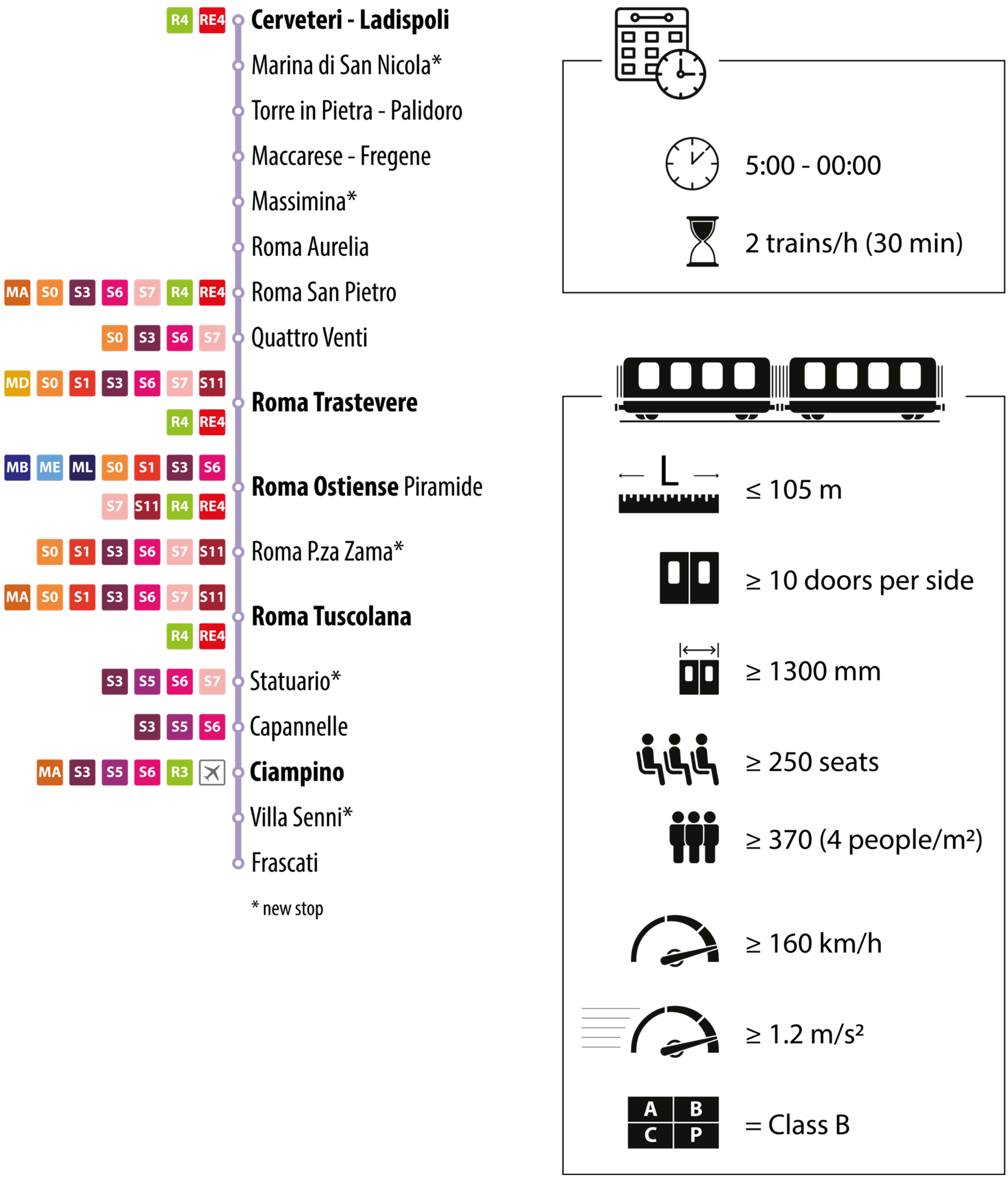


Figure 69 – S4 Line's Features. Author's drawing

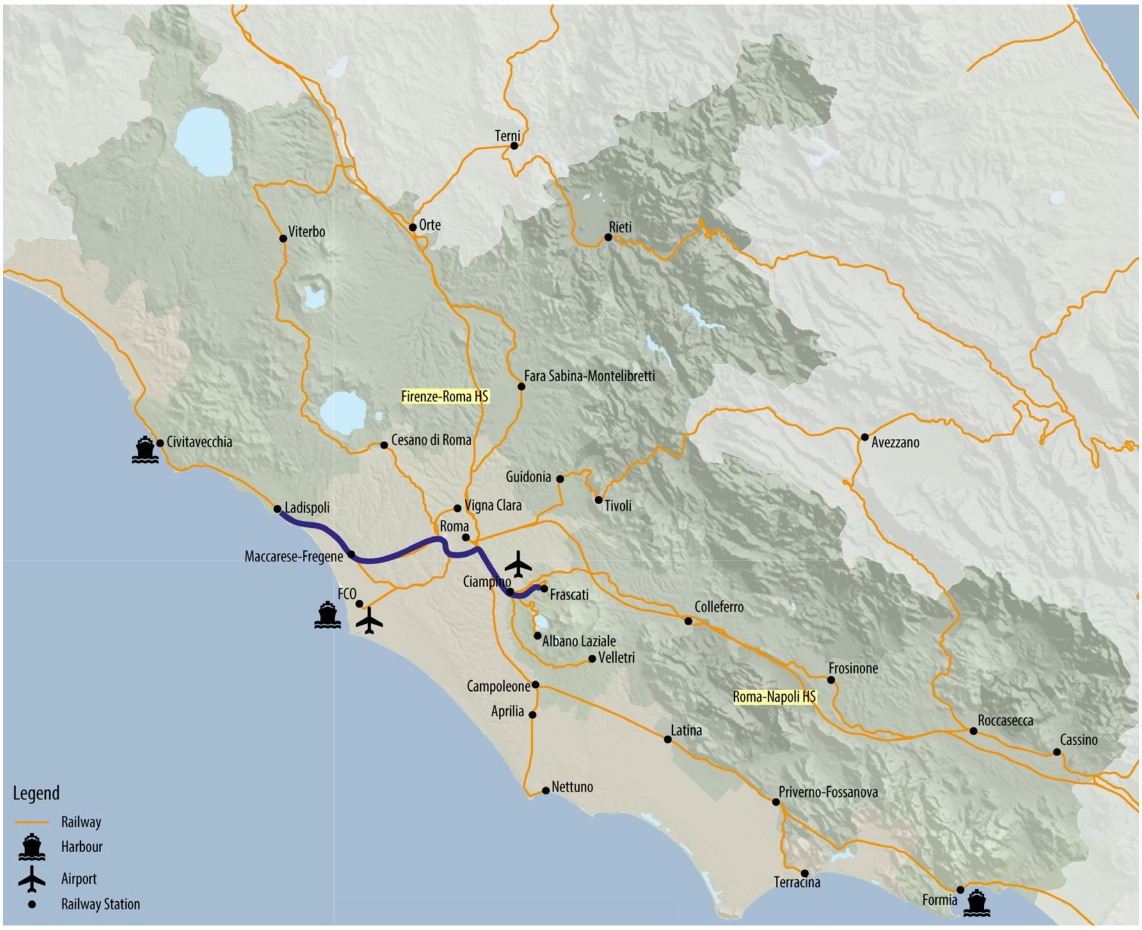


Figure 70 - S4 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

S4 will be the suburban line connecting Frascati to Ladispoli, on the coast, crossing the city from the south-east to the west and passing through Ciampino airport. This line, even though it follows the geometric principle, presents this itinerary mainly due to infrastructural features and demand magnitude. As regards the southern part, indeed, the railway station of Frascati only presents 125 metres platform, allowing only short trains, while, in the west section of the line, the demand is not so high to require big trains, even though, there, platform are bigger. The line will run with a train every 30 minutes from 5:00 to 0:00 using the same rolling stock used for the previous lines but shorter, to fit in Frascati station platforms. About the infrastructure, it is ready in the west part whilst, concerning the southern single-track section, it is planned a new station where trains can cross in order to double the frequency up to 2 trains per hour per direction (RFI; 2020a).

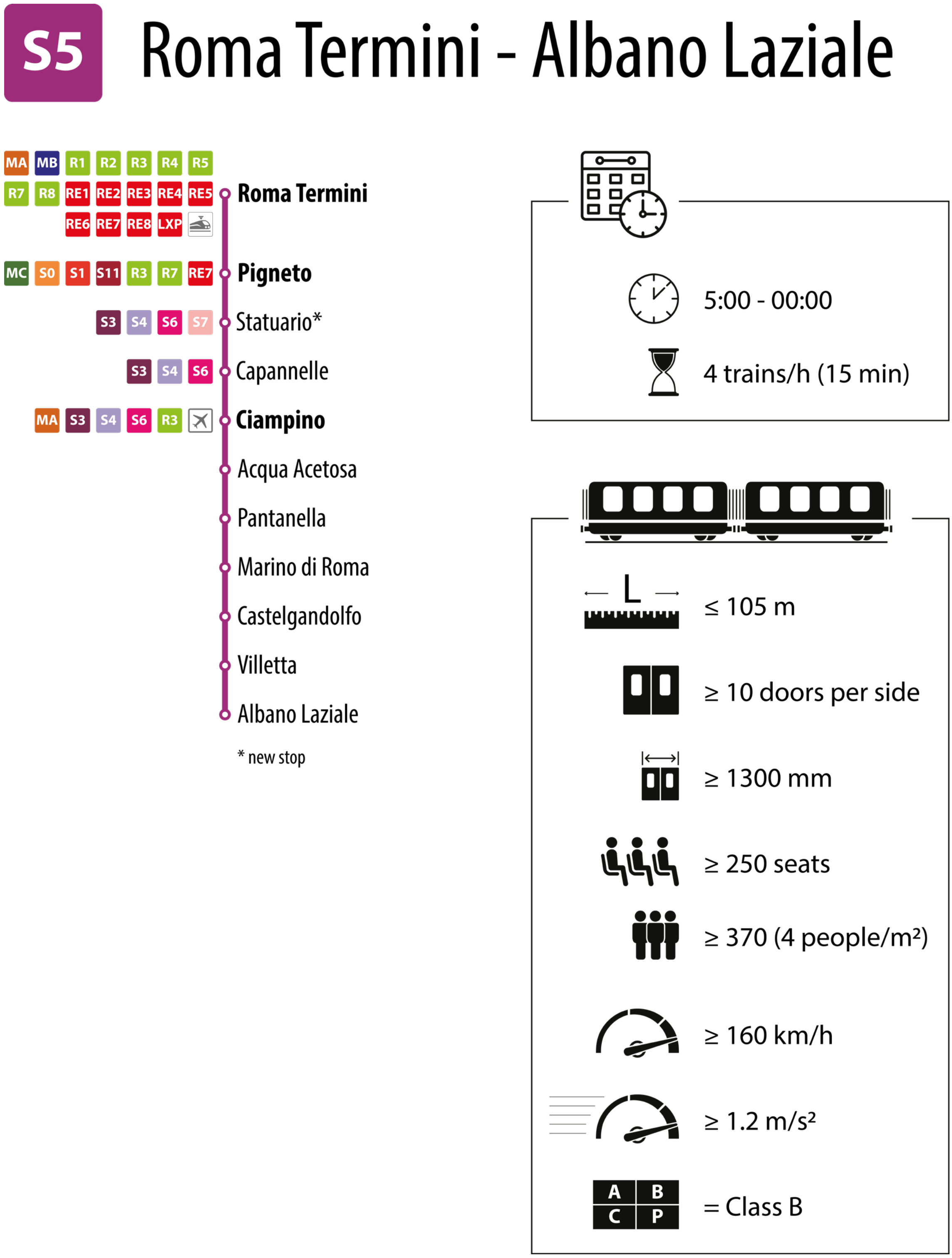


Figure 71 – S5 Line's Features. Author's drawing

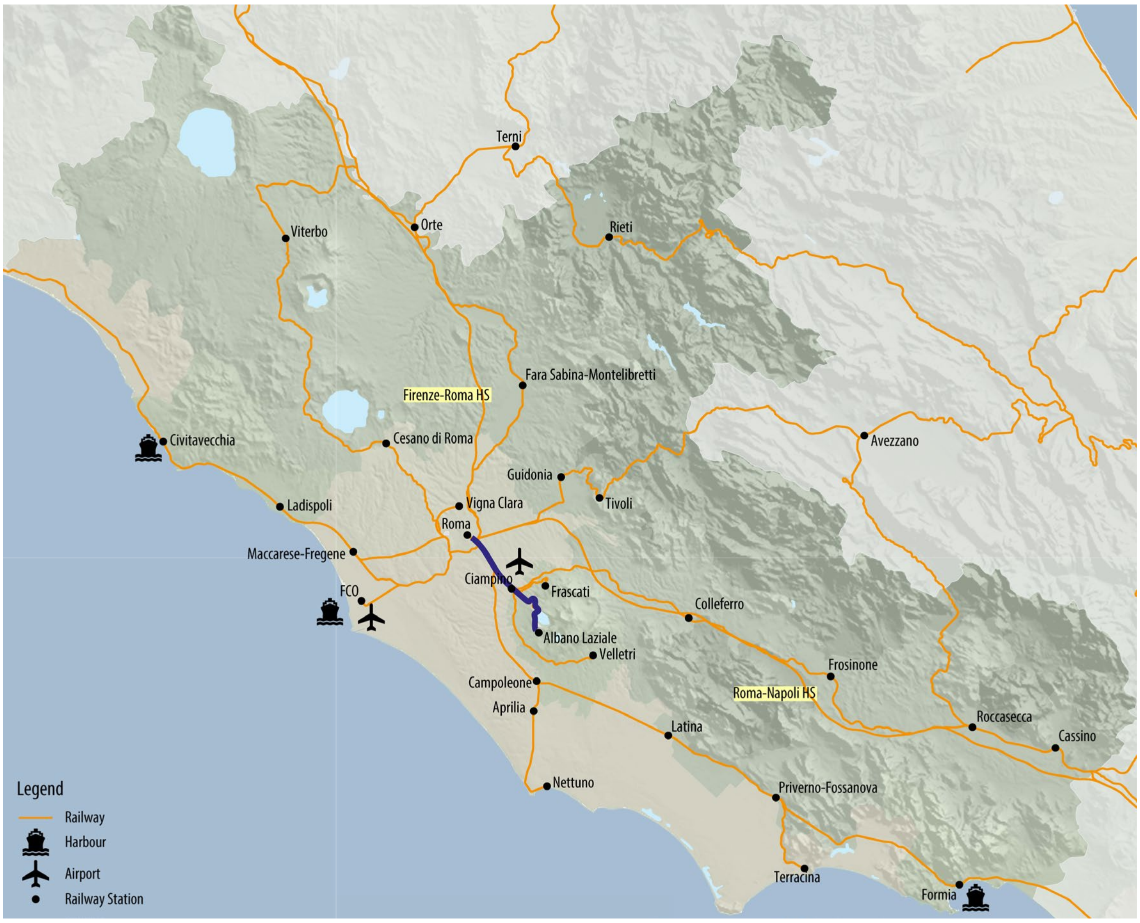


Figure 72 – S5 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The S5 is the only suburban line, along with S2, that will not cross the city of Rome but that will start/end in the city centre. Besides, it will be the only suburban line starting from Roma Termini, the most important station of the city. The reason behind this choice depends again on the demand magnitude and the infrastructure features: this line runs on an old single-track railway, that today allows one train per hour per direction. It is probably possible to upgrade the infrastructure just in some points, where trains will intersect, to allow four train per hour per direction, but, due to context limitations, it will not be possible to double the entire path. This infrastructural limits will make the service not so reliable: considering all those crossing points if a train was delayed, the delay would pass to all the other trains running on that line, and there will not be many possibilities to recover it. Thus, to contain the eventual inconvenience generated by this line, its itinerary must be as short as possible, and so it ends at the central station of the city. In addition to this, this line will guarantee a direct connection from the central station to the second airport in the city, Ciampino. It will run with a train every 15 minutes from 5:00 to 0:00 using the same rolling stock used for the S4 because also here, the platform limits do not allow longer trains (RFI, 2020b).

Figure 73 – S6 Line's Features. Author's drawing

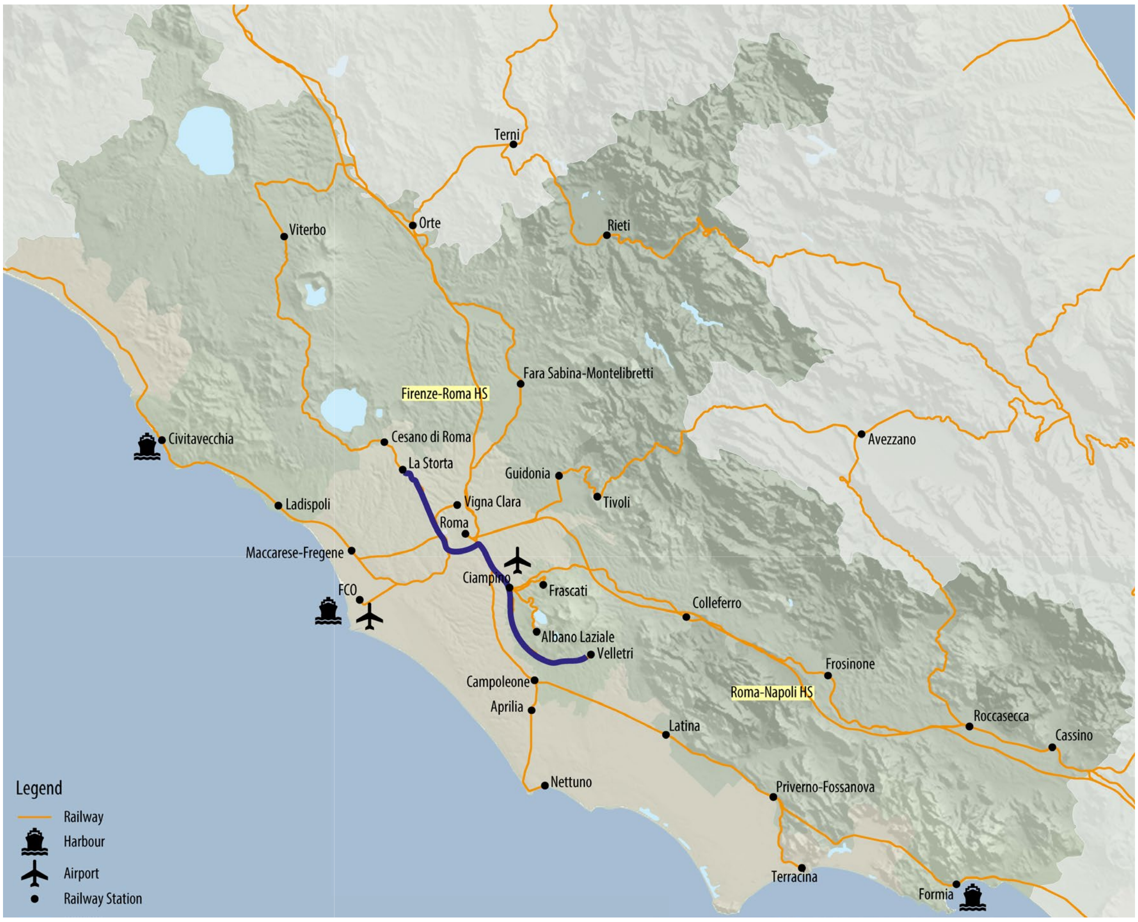


Figure 74 – S6 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

S6 substitutes part of the existing FL4 and the urban part of the existing FL3. It will cross the city from south-est to north-west, connecting these areas to Ciampino airport. As regards the northern section, even though the suburban area ends in Cesano di Roma, the number of trains planned to go further than La Storta is enough to cover the suburban demand, hence the northern terminus will be La Storta. The line will run with a train every 15 minutes from 5:00 to 0:00 and, along with S3 and S7, it will provide 7-8 minutes headways in the urban section, using the same rolling stock of S0, due to infrastructural limits that do not allow long trains on the southern section. The infrastructure (single-track) is not ready to allow the planned frequency but there is enough space to double the track, to allow smoothly four trains per hour per direction.

Figure 75 – S7 Line's Features. Author's drawing

Figure 76 – S7 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

S7 substitutes part of the existing FL8 and the urban part of the existing FL3. It will cross the city from south to north-west. The line will run with a train every 30 minutes from 5:00 to 0:00 and, along with S3 and S6, it will provide 7-8 minutes headways in the urban section. The design of this line has taken into account the geometric principle and the mobility demand, that is high all along the line. Thus, the rolling stock used to run the line every 30 minutes from 5:00 to 0:00 is the same used for S1, the longest possible on RFI lines (RFI, 2020b). The infrastructure does not require upgrades to allow this frequency (ibid).

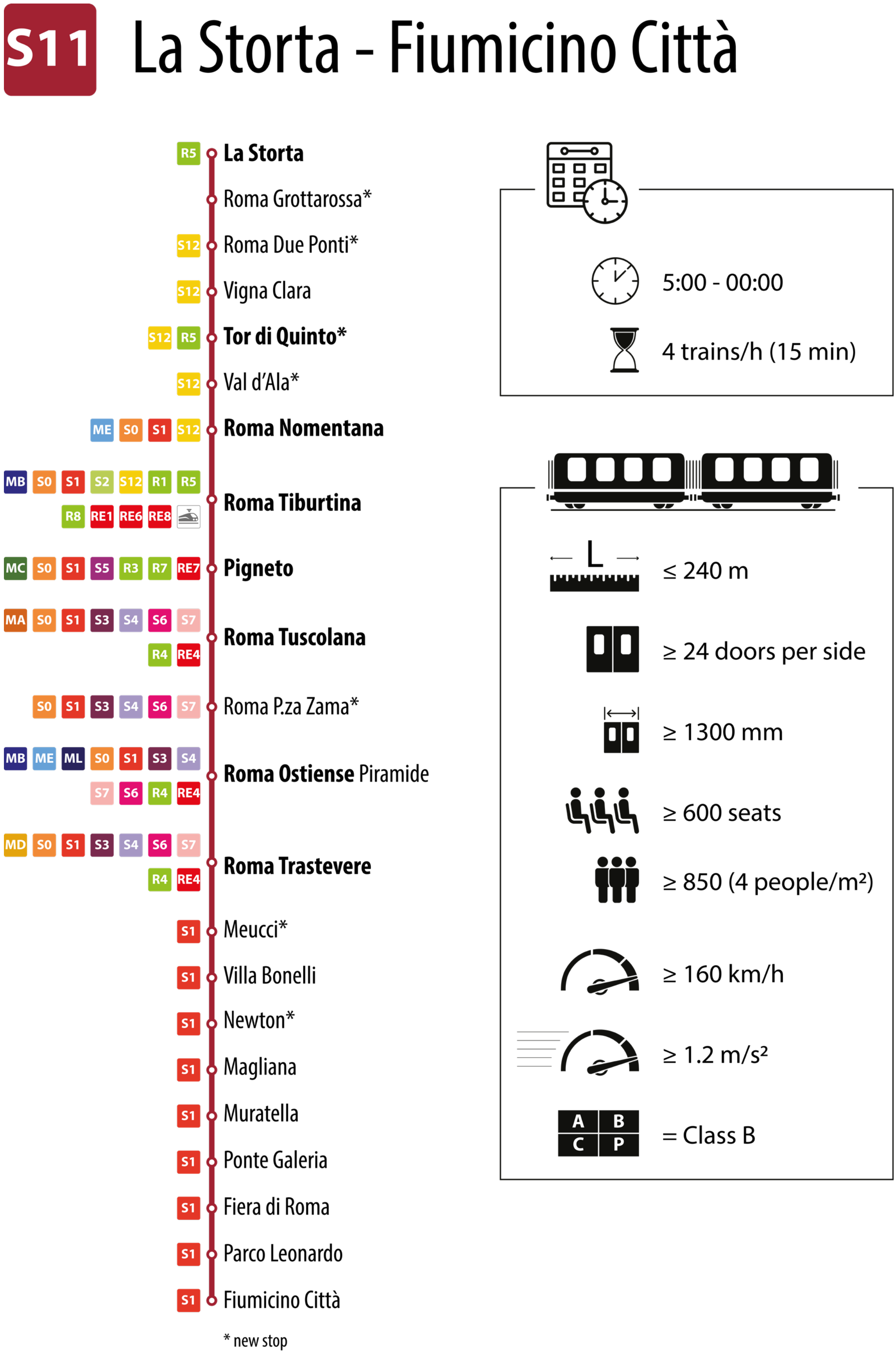


Figure 77 – S11 Line's Features. Author's drawing

Figure 78 – S11 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

S11 is a new line that will overlap the S1 on the southern section whilst will run on a new infrastructure on its northern part. Its design is driven only by the demand magnitude, ignoring the geometric principle. The line indeed goes from the south-west to the east and then turn to the north-west. In the south-western part, it overlaps the S1 to cover the high urban demand that requires high frequencies. Besides, Fiumicino, the city of the FCO airport, does not have an urban station but only the airport one. The metropolitan planning (Roma Mobità, 2019) forecasts the reopening of the old railway that was going to Fiumicino city, but it is not clear which trains should run on it. Thus, the S11 will run from Fiumicino City station towards Rome and then it will turn to the north-west on the completed urban railway ring and then it will turn again north to leave the ring towards its destination, La Storta, where it will exchange with lines S3, S6 and S7. Regarding the northern section, from Vigna Clara station, on the ring, to La Storta, it is necessary to build a completely new underground infrastructure. However, a similar infrastructure is already forecasted by the municipal planning as metro C (Roma Mobilità, 2019). The metro line C is opened in its south-east section, from the suburbs to the city centre, it is under construction in the city centre and it is just planned on the northern part. The northern section of the C line is planned to go from Vigna Clara station to the north-west of the city, in the suburbs. Differently, in the scenario here presented, the line C will stop to Vigna Clara, and a new underground railway will replace the metro and will continue further to reach La Giustiniana station and meet lines S3, S6 and S7. The reasons behind this choice are two: this new infrastructure will be built in a part of the city where there is no a high demand, whilst, the railway where S3, S6 and S7 will run, will need very frequent trains in the urban section, that will occupy the slots today used for the regional trains Rome – Viterbo. Thus, to provide the regional trains with reasonable travel time, they will run on the new infrastructure, where the bigger S11 headways will guarantee slots for them. The S11 will have a frequency of four trains per hour per direction, and it will run from 5:00 to 0:00 using the same rolling stock used for line S1, thus it will offer an urban service proportionated to the mobility demand over all its itinerary.

Figure 79 - Rolling Stock Used for Berlin's S-Bahn. Image downloaded from https://press.siemens.com/global/en/feature/new-trains-berlins-s-bahn

Figure 79a - Reichsbahn Neubau S-Bahn. Image downloaded from https://www.pinterest.it/pin/209487820154231744/

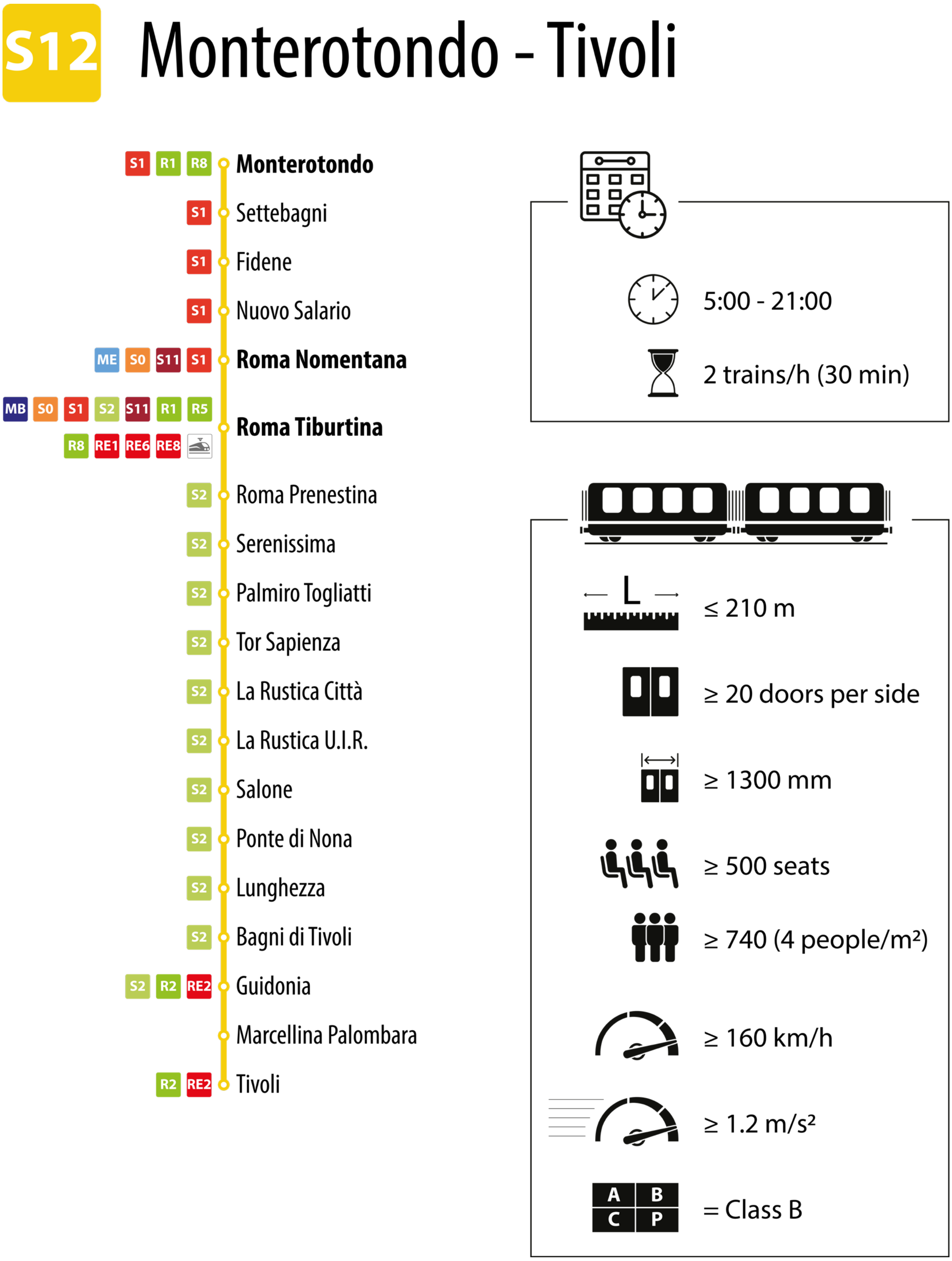


Figure 80 – S12 Line's Features. Author's drawing

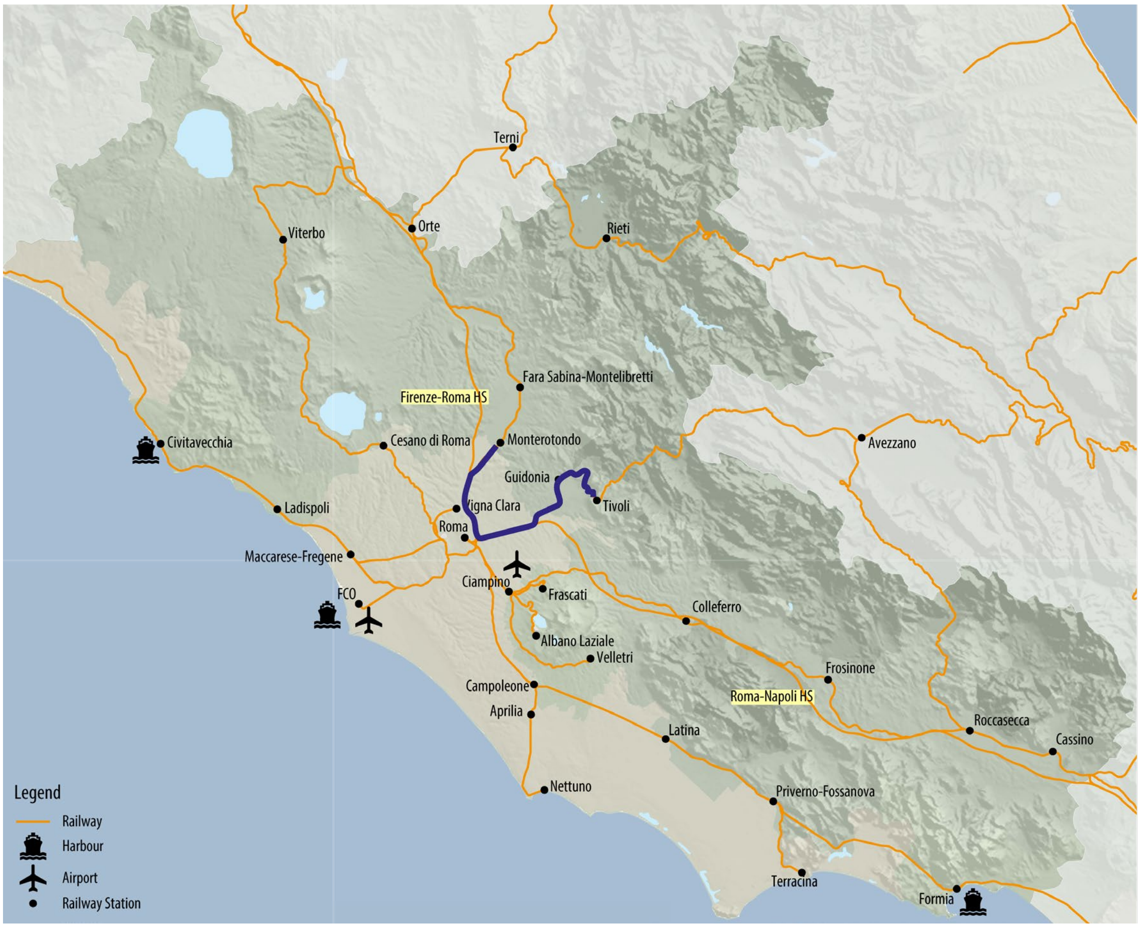


Figure 81 – S12 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Similarly to S11, S12 is another line that does not follow the geometric principle. It will run indeed from the east of the city to the north, almost only in Rome's urban area. The reason behind its design is just the demand magnitude. It is called indeed S12 because it will overlap a part of S1 and S2, to satisfy the demand in those populated areas where 15 minutes headways provided by both S1 and S2 are not sufficient. S12, differently from the other suburban lines, will run from 5:00 to 21:00, because after 21:00 S1 and S2 frequencies are enough to supply the mobility demand. Due to the platform length in Monterotondo, the line will present the same rolling stock used in line S1 but shorter, and it will run every 30 minutes in each direction. The infrastructure does not require any upgrade to run this line (RFI, 2020b).

S70 Gaeta Centro - Minturno Scauri

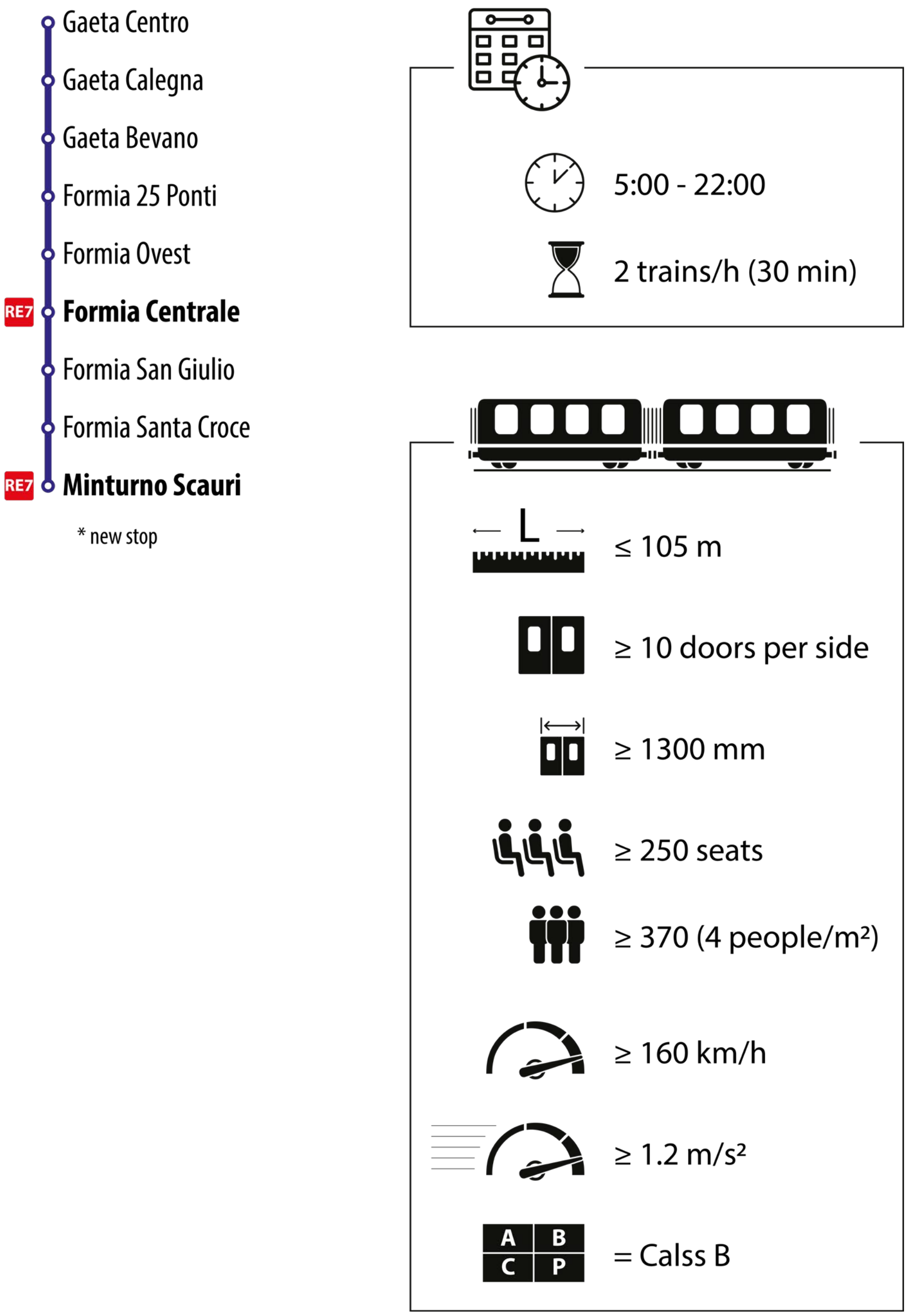


Figure 82 – S70 Line's Features. Author's drawing

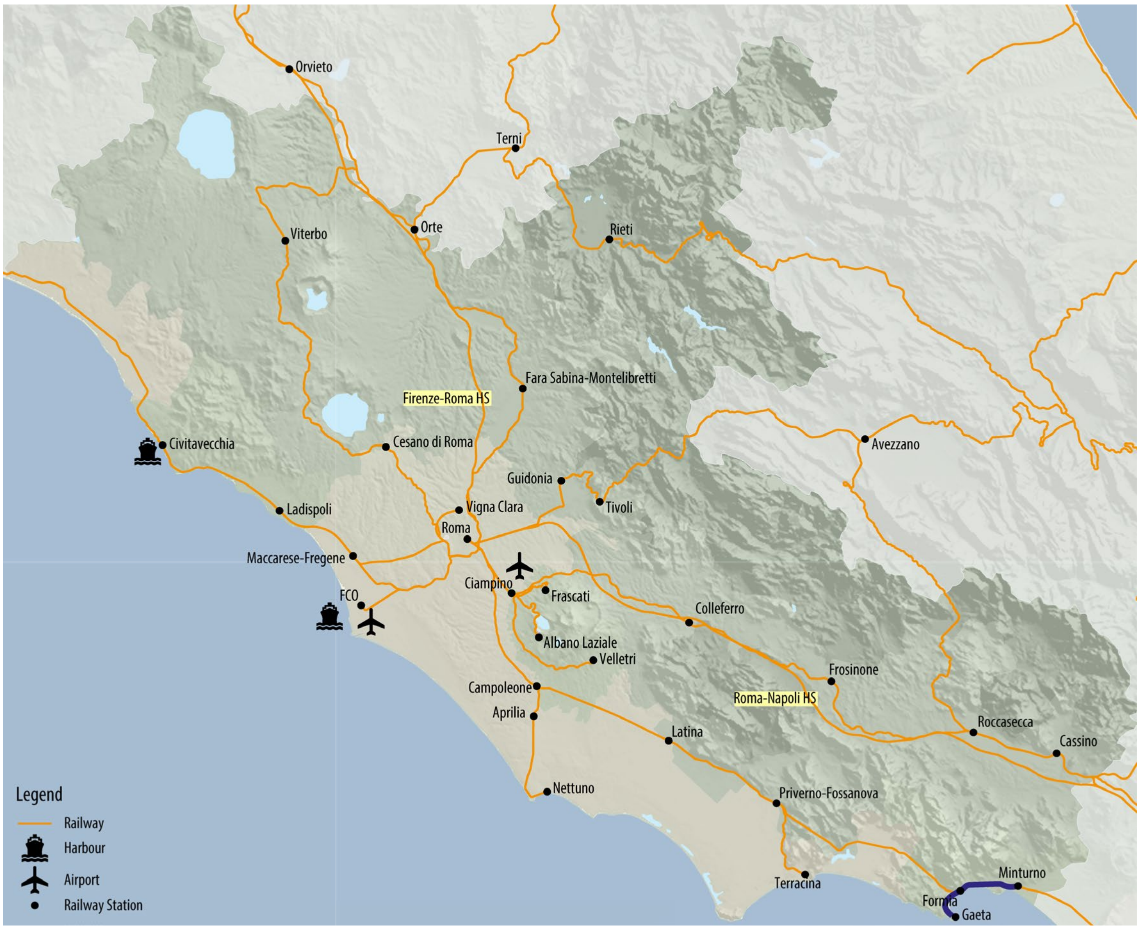


Figure 83 – S70 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The line S70 is the only suburban line that will not run in Rome, although the urban features of the area allow the presence of a suburban line. Formia, Gaeta and Minturno together, indeed, have more than 70 thousand inhabitants (ISTAT, 2019) and they are a very touristic area. Thus, Lazio Region is thinking about reopening the old railway line that was linking Gaeta and Formia and to build new stations between Gaeta and Minturno (Il Faro Online, 2019). Hence, it is planned by this scenario that there will be a train every 30 minutes per direction running from Formia to Minturno from 5:00 to 22:00, using the same rolling stock employed for line S5.

3.1.3.2. Regional Lines

Regional lines, as stated before (2.2.1), link the major cities of the region with the other small and medium towns. Considering Lazio's railways, their structure is essentially radial, with some exceptions represented by the few railways not leading to Rome. The main principles used to design these lines are the analysis of the existent services and the demand magnitude along with the infrastructure features. Hence, all the lines have as a terminus Roma Termini station, except for line R6 that travels on an infrastructure divided by the rest of the network and so starting in Rome from Roma Flaminio station and ending in Viterbo near Viterbo Porta Fiorentina station.

Each line will be described using the same pattern:

1. Line scheme and features.
2. Geographic context.
3. Line description.

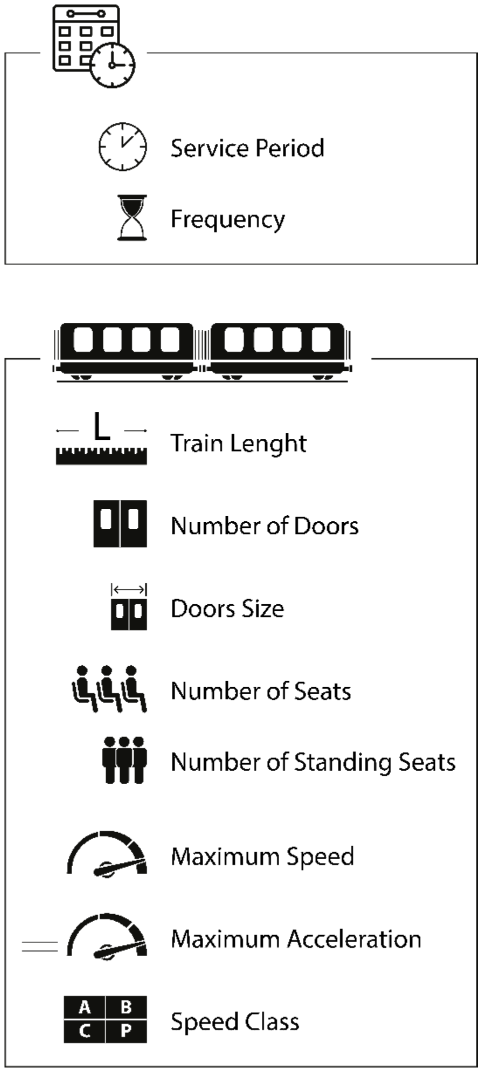


Figure 84 – Icons' Legend. Author's drawing

Figure 85 - German ICE 2, Regio Trains and S-Bahn. Image downloaded from https://www.pinterest.it/pin/795166877946712376/

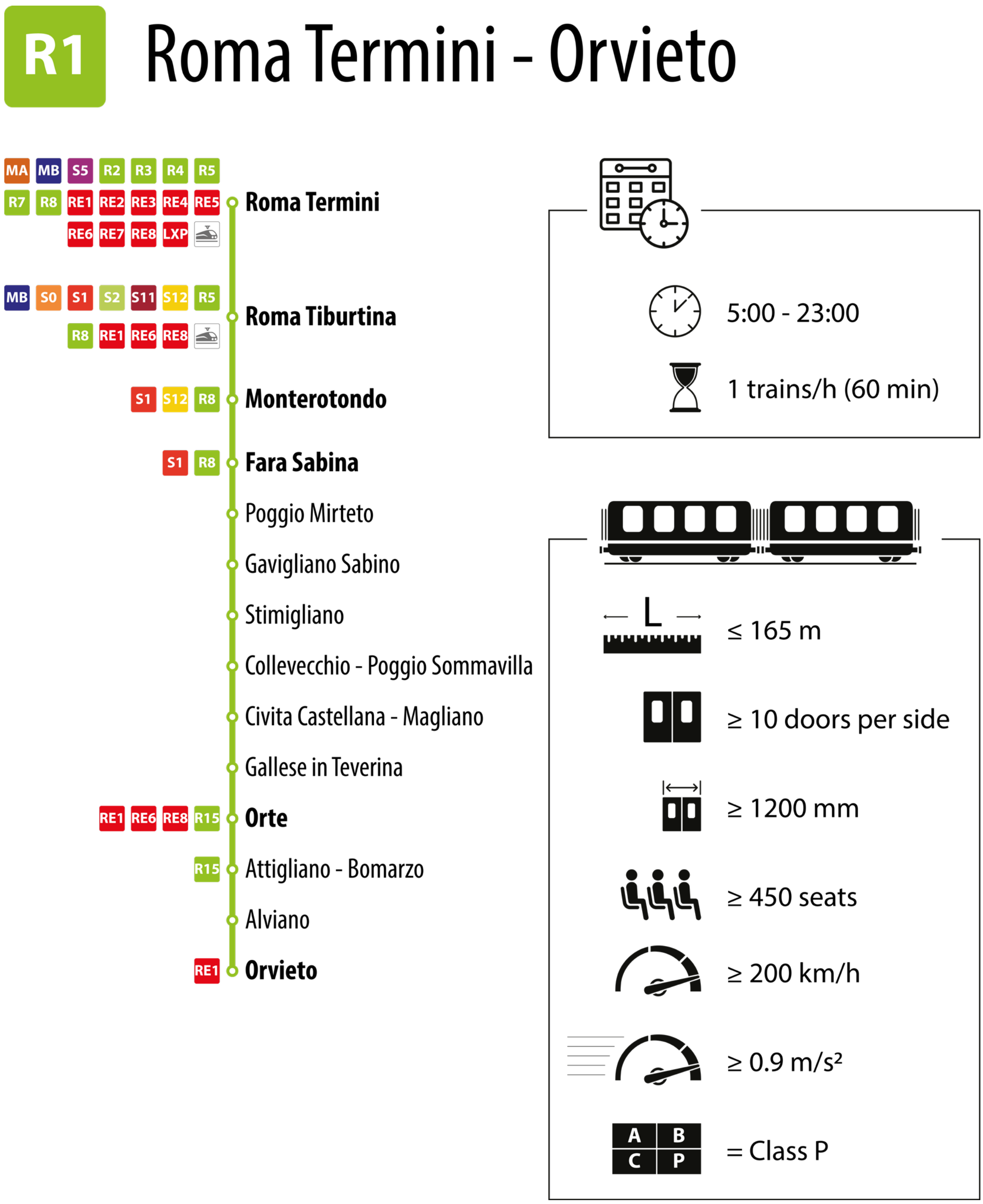


Figure 86 - R1 Line's Features. Author's drawing

Figure 87 – R1 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

R1 is a new line that, along with S1, will replace the northern part of existing FL1, but it will also continue up to the regional border and for a few kilometres outside the region borders to reach Orvieto. It will start from Roma Termini, providing the towns served with a direct connection to Rome main station, and it will end in Orvieto to provide the city with a direct connection to Rome and with an hour connection to Orte interchange node, where it will be possible to have connections for both Terni and Viterbo, the two biggest cities of this area. The line will run every hour from 5:00 to 23:00, providing a 30 minutes service along with R8 between Roma Termini and Fara Sabina where the majority of demand is condensed, using a rolling stock travelling under class P to take advantage of the infrastructure that presents a high number of bends, where tilting trains (that travels under class P) results very effective in reducing travel time. The infrastructure today do not allow the speed class P, thus trains are travelling under class B or C (RFI, 2020b), but in the future, the infrastructure manager could implement the P class and so allow tilting trains on the line. The length of the train is derived by the infrastructural limits of platform stations of the line.

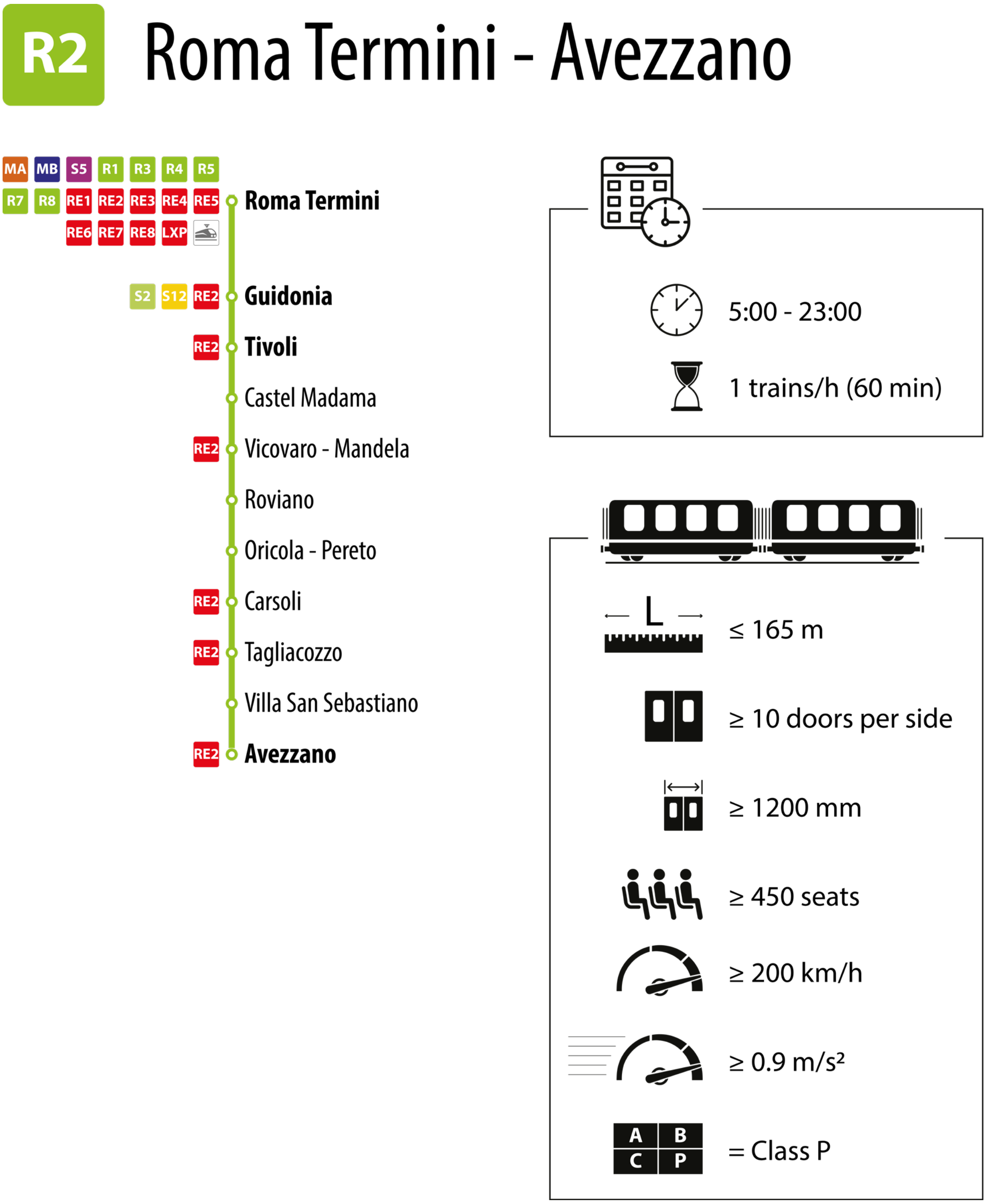


Figure 88 – R2 Line’s Features. Author's drawing

Figure 89 – R2 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The line R2, along with S2 and S12, will replace the existing FL2 and it will continue outside the region to reach Avezzano. It will start from Roma Termini, providing the towns served with a direct connection to Rome main station, and it will end in Avezzano to provide the city with a direct connection to the Capital. The line will run every hour from 5:00 to 23:00, using tilting trains to take advantage of the infrastructure that presents a high number of curves, where trains that travel under class P results very effective in reducing travel time. The infrastructure today do not allow the speed class P, thus trains are travelling under class B or C (ibid), but in the future, the infrastructure manager could implement the P class and so allow tilting trains on the line. The length of the train is derived by the infrastructural limits of platform stations of the line.

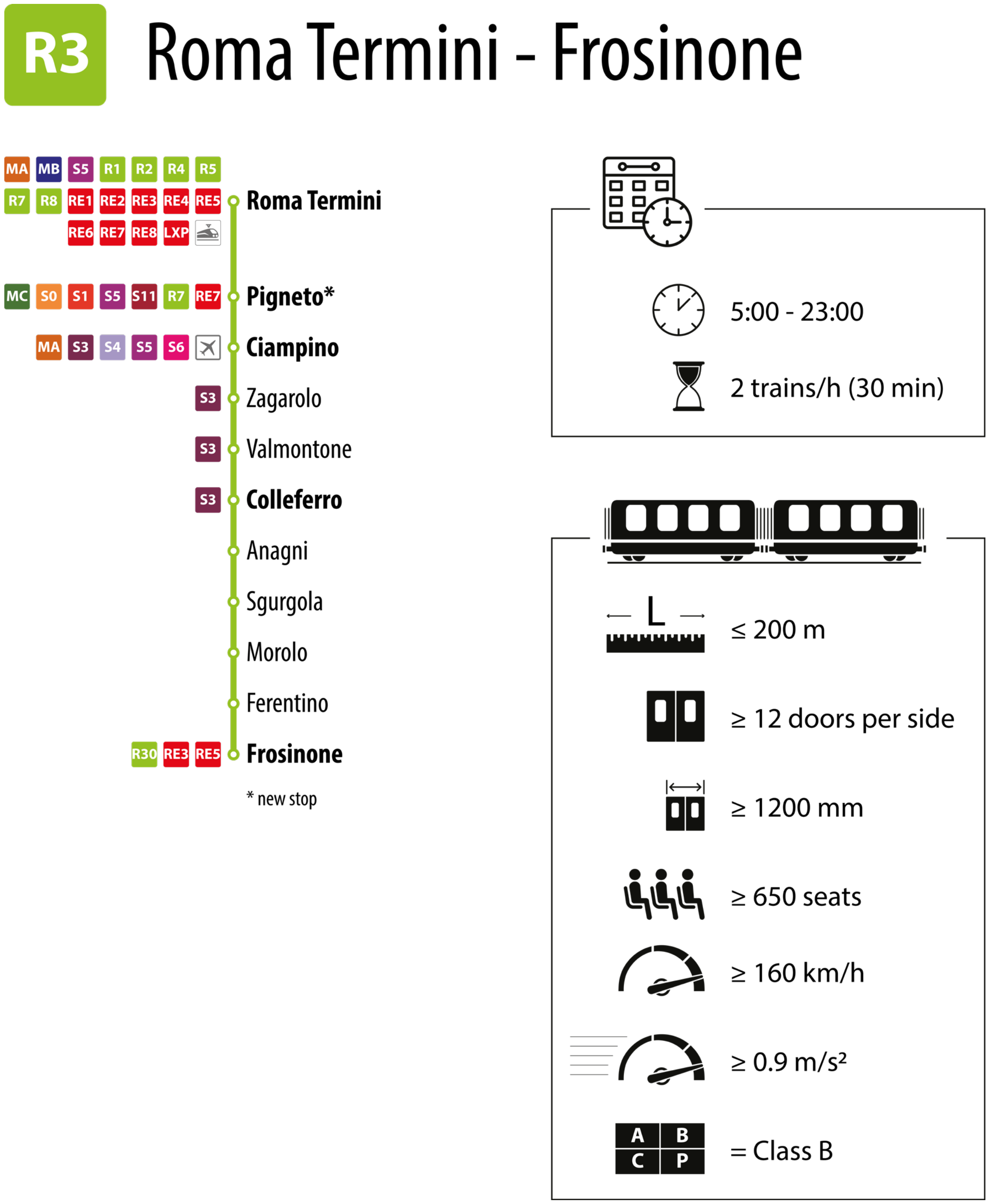


Figure 90 – R3 Line's Features. Author's drawing

Figure 91 – R3 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

This line, along with the S3 line, will take the place of the existing FL6. It will connect Frosinone and the northern part of its province to Rome and Ciampino airport. The line will run every 30 minutes from 5:00 to 23:00 using rolling stock travelling under speed class B. In fact, even though tilting trains would be very effective on this line, that present a high number of curves, the timetable does not require better travel times, because speed class B is sufficient to arrive at the right time in Colleferro's interchange station (terminus of line S3). Consequently, the infrastructure is ready for running the line. The length of the train is derived by the infrastructural limits of platform stations of the line.

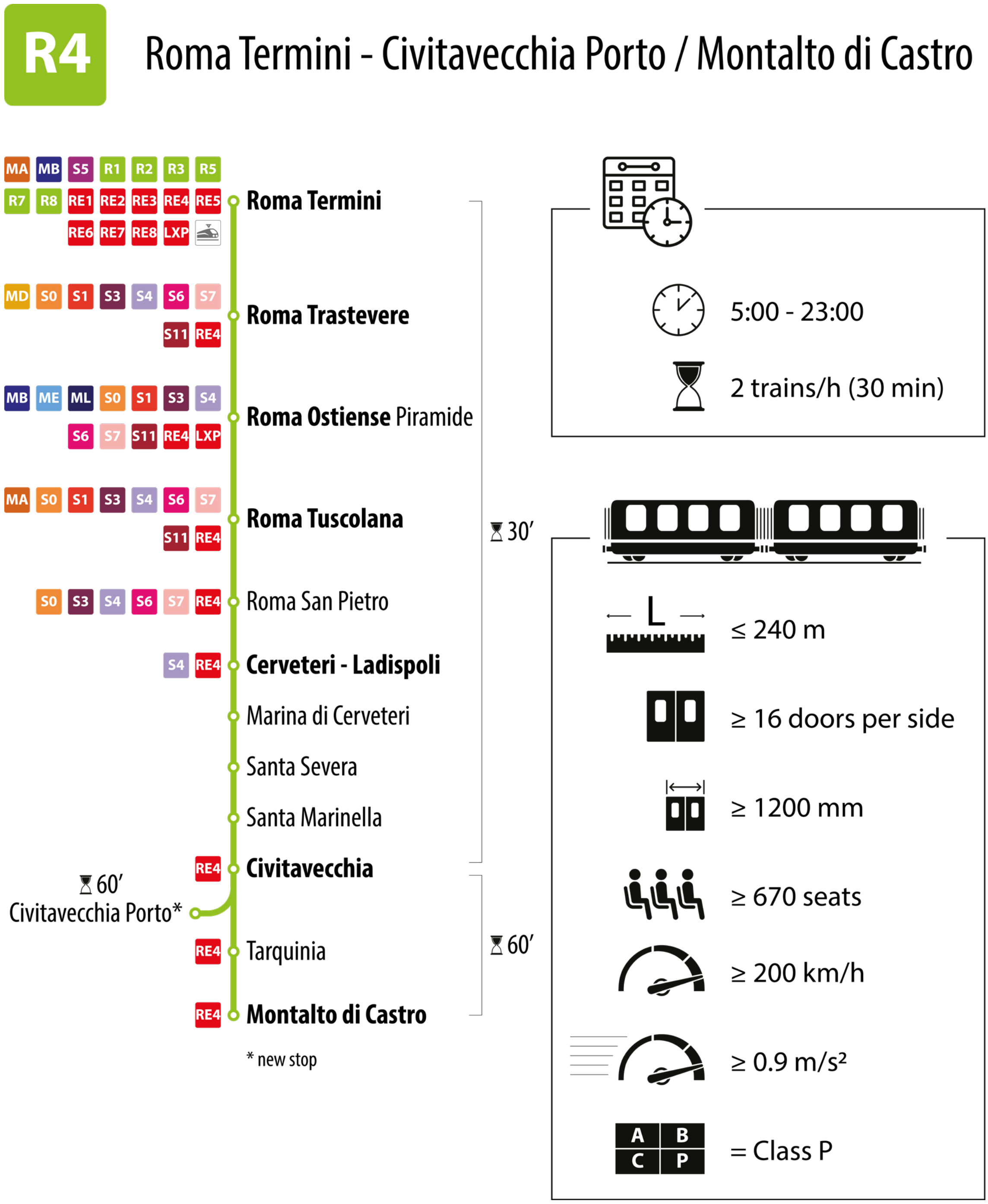


Figure 92 – R4 Line's Features. Author's drawing

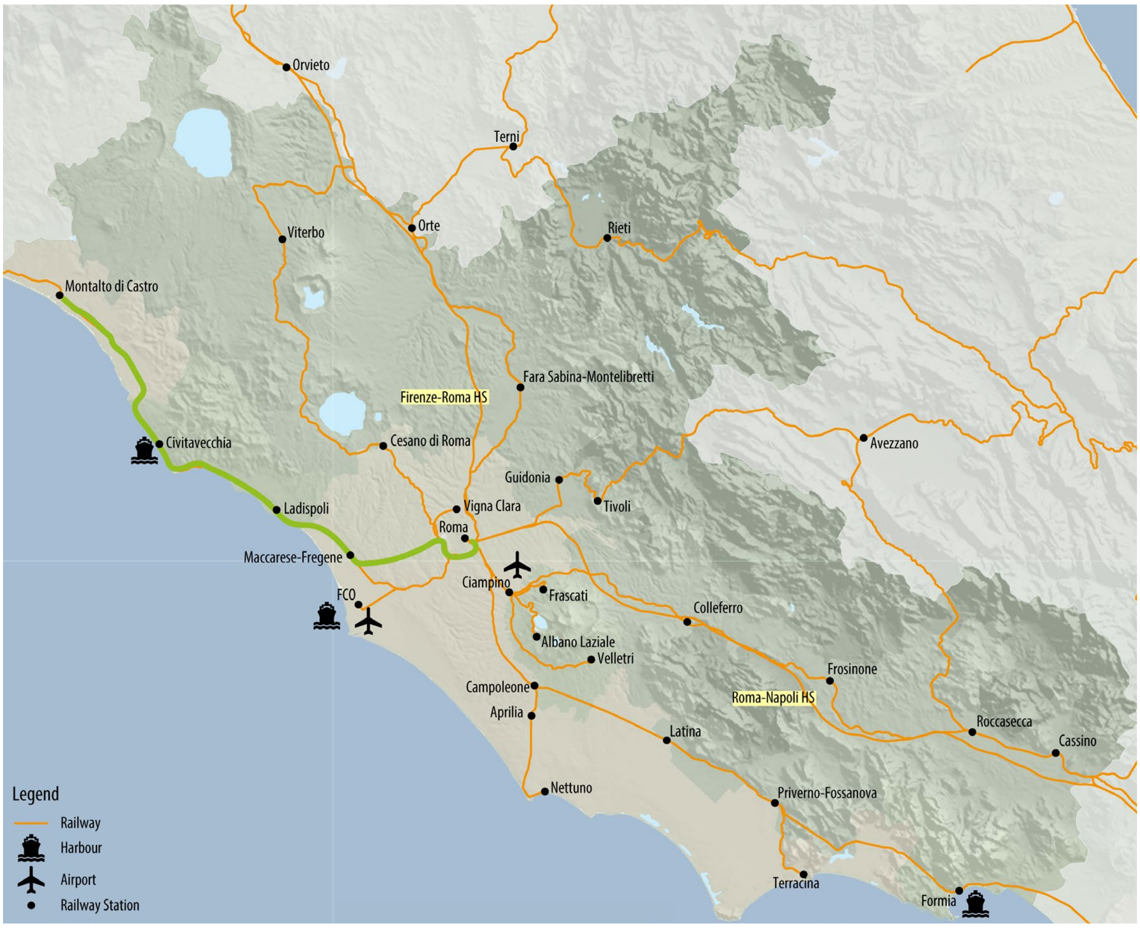


Figure 93 – R4 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

R4, along with line S4, will replace the existing FL5. It will connect Rome with the north-western part of the region, along the coast, providing the served localities with a train every 30 minutes, and so completing the timetable today used for FL5 which presents 30 minutes headways only during peak-hours (Trenitalia, 2020). However, compared to FL5, this new line will improve the service not only in the frequency: the FL5 ends in Civitavecchia, and today other Regional trains coming from Tuscany are used to link the two beyond Civitavecchia (1 train per hour per direction). The R4 will provide 2 trains per hour to Civitavecchia, then, one out of two will continue to the new Civitavecchia Harbour station, that needs to be built, and the other will proceed up to Montalto di Castro, the last train station of Lazio on this railway, providing it with a train per hour per direction, that along with RE4 will be two trains per hour per direction. R4 will run from 5:00 to 23:00, using a rolling stock travelling under class P to take advantage of the infrastructure. The infrastructure already allows class P trains so that it could be possible even today to activate the new line (RFI, 2020b.

R5 Roma Termini - Viterbo P. F.

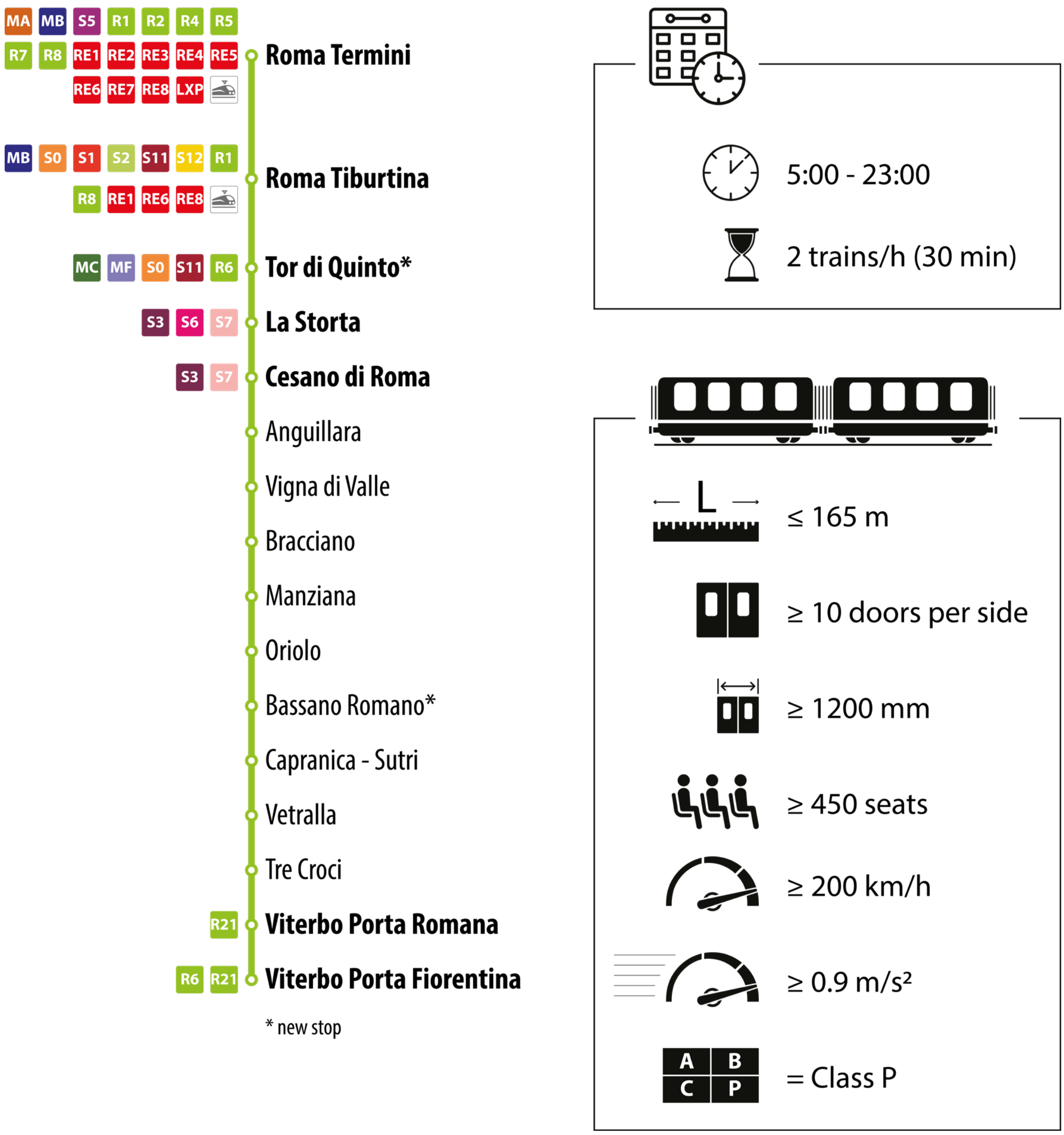


Figure 94 – R5 Line's Features. Author's drawing

Figure 95 – R5 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The regional line number 5 will take the place of the existing FL3 on the section among La Storta and Viterbo. The line will use, along with S11, the new infrastructure to allow high frequencies on the old railway, that will be used only for suburban lines (as explained into the previous section), and from La Giustiniana it will go back on its original itinerary up to Viterbo. In order to guarantee a good connection from Rome to Viterbo, that will not have a region-express line, the trains will run every 30 minutes in each direction from 5:00 to 23:00, using a rolling stock travelling under class P to take advantage of the infrastructure. The infrastructure today do not allow the speed class P, thus trains are travelling under class B or C (RFI, 2020b), but in the future, the infrastructure manager could implement the P class and so allow tilting trains on the line. The length of the train is derived by the infrastructural limits of platform stations of the line.

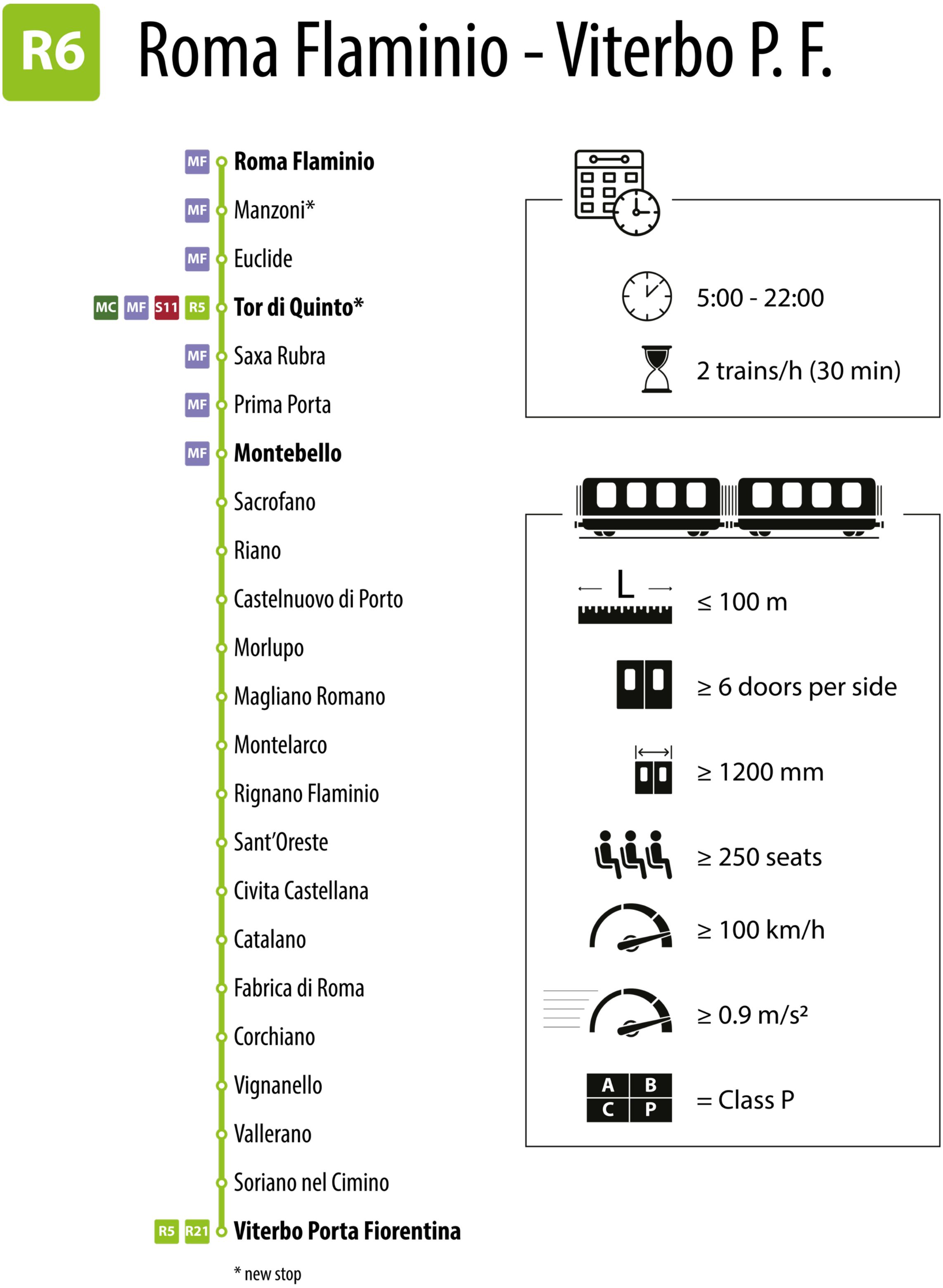


Figure 96 – R6 Line's Features. Author's drawing

Figure 97 – R6 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

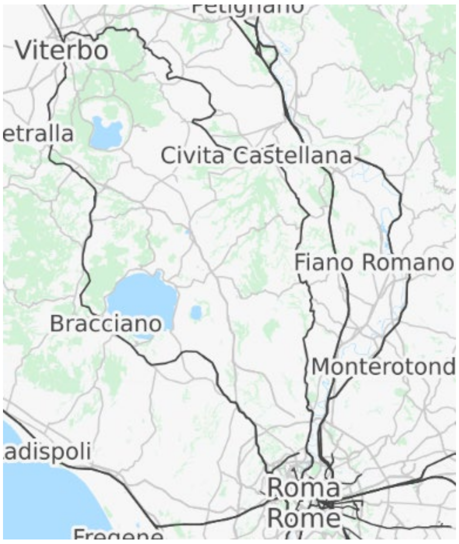


Figure 98 - Roma Viterbo Regional Railway. Image from openstreetmap.org

R6 is the only regional line that will not have Roma Termini as a terminus, but that will start from another station, Roma Flaminio. This line, indeed, will run on a railway physically separated by the rest of the network and that it is used as Metro its urban itinerary, but it is competence of the region, as well as the rest of the railway network. The idea of service is taken from the L6 in Barcelona, where on a similar infrastructure there are two metro lines and 3 regional services (MetroXRoma comitato, 2017). Hence, on this infrastructure the R6 will connect Rome to Viterbo every 30 minutes, from 5:00 to 22:00, using a rolling stock travelling under class P to take advantage of the infrastructure, that presents many bends. However, the size of the station will require the use of very short trains. Today, the infrastructure does not allow speed class P but it is possible to implement it.

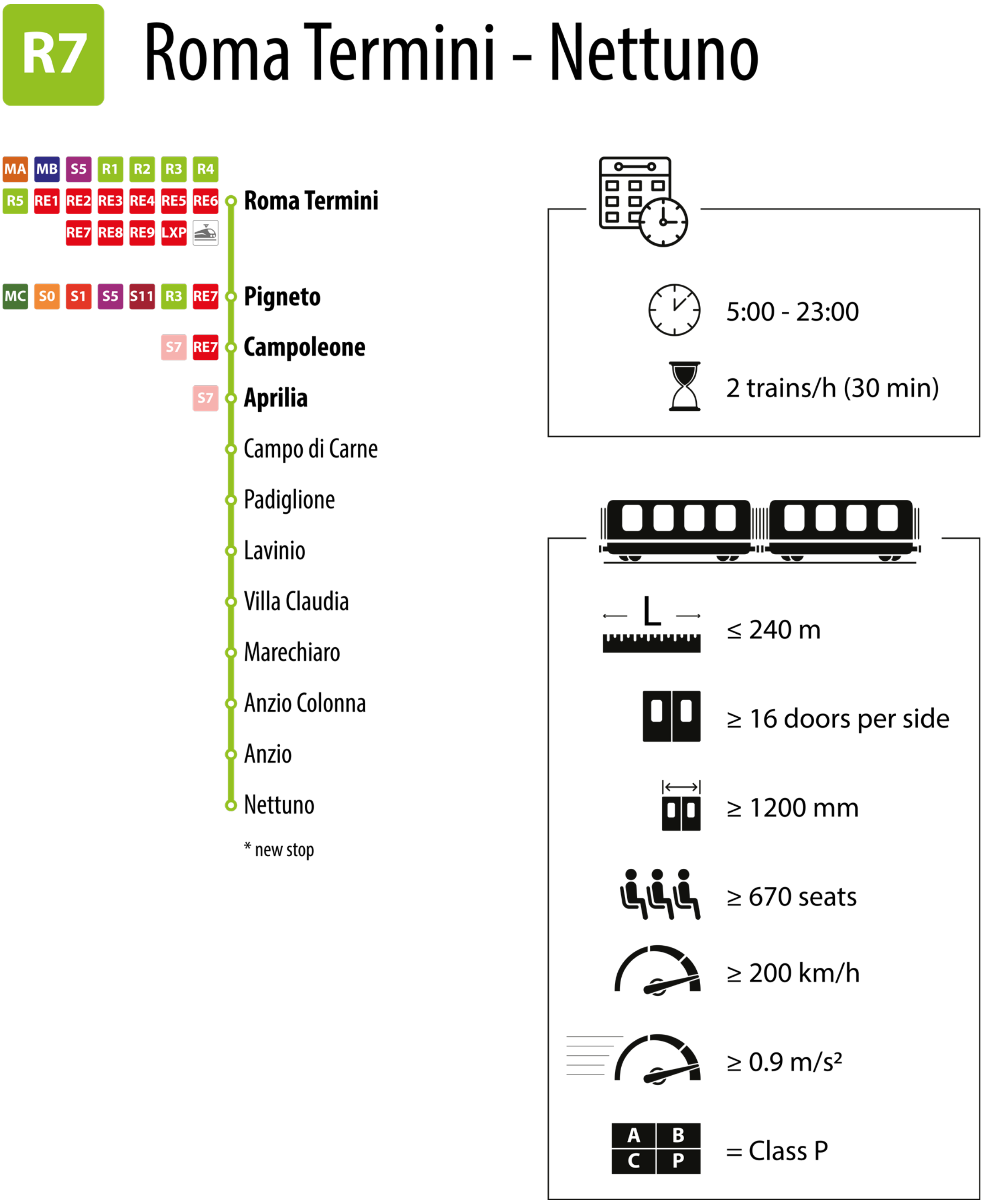


Figure 99 – R7 Line's Features. Author's drawing

Figure 100 – R7 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Along with line S7, the R7 will replace line FL8 connecting directly Rome to Aprilia (about 74,000 inhabitants), that will be the southern terminus of S7, Anzio (about 54,000 inhabitants) and Nettuno (about 49,000 inhabitants) providing them with a train every 30 minutes from 5:00 to 23:00 using a rolling stock travelling under class P. The need for class P rolling stock is not due to the infrastructural features of the line, that presents a limited number of curves, but because of commercial speed reasons. The R7, indeed, will overlap from Roma Termini to Campoleone the lines S7 and RE7. The ladder will have trains using speed class P and so it will be advantageous to use the same rolling stock, to guarantee the same commercial speed to avoid capacity waste. The design of this line respect the forecasted planning: it is already planned by the metropolitan mobility plan (Reoma Mobilità, 2019) that four trains should connect Rome to Aprilia every hour and that two should link Rome and Nettuno. The system S7 plus R7 will provide this amount of supply. The infrastructure is ready to host speed class P train from Rome to Campoleone where it is needed (RFI, 2020b), while into the urban section, the new planned station Pigneto will guarantee the interchange among R7, S0, S1, S5 and S11 and the connection to line C of the metro network.

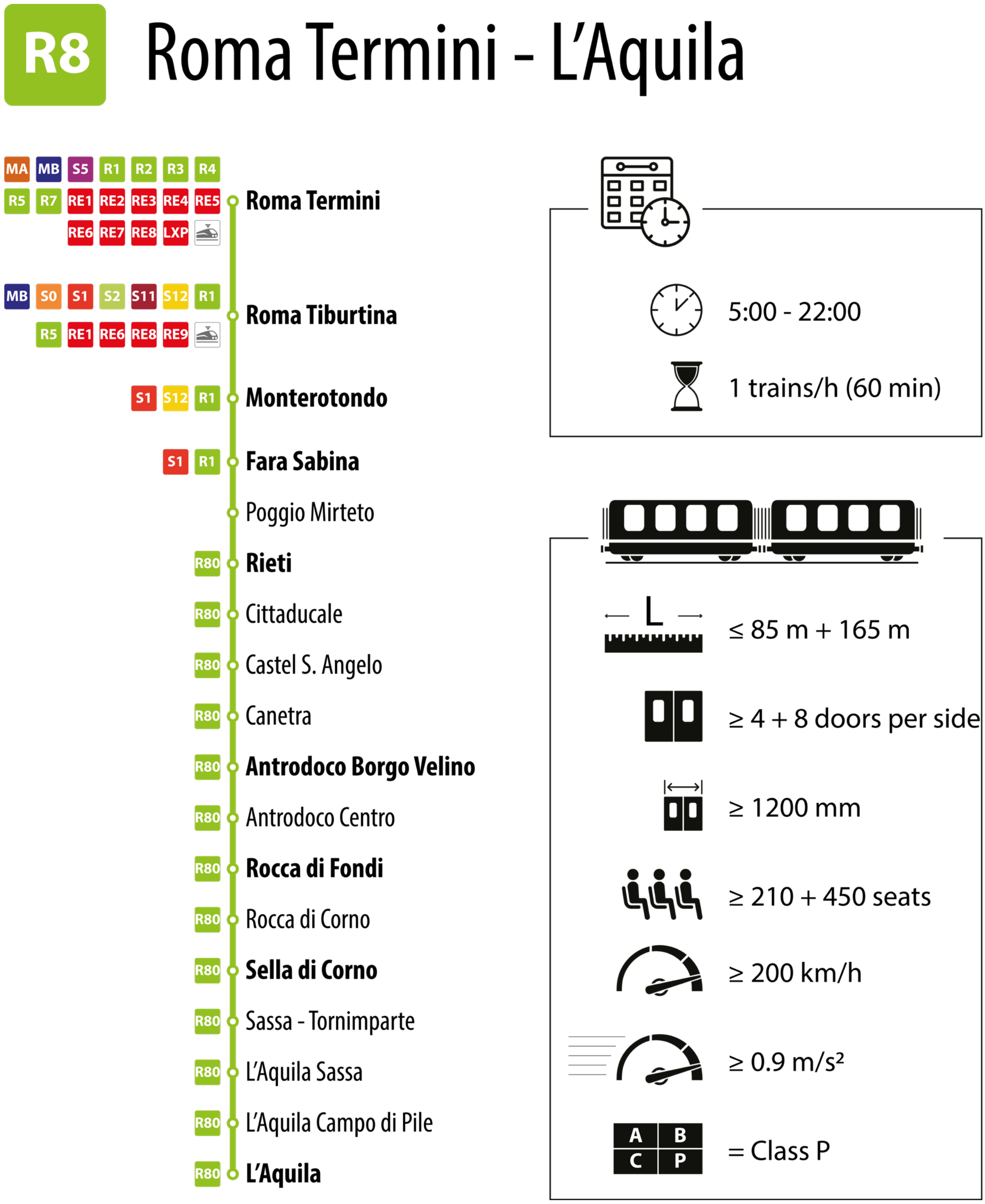


Figure 101 – R8 Line's Features. Author's drawing

Figure 102 – R8 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

R8 line is a new line that will use part of the existing infrastructure, from Rome to Fara Sabina station and from Rieti to L'Aquila, and a new railway, between Fara Sabina and Rieti. This new railway line is forecasted by the mobility plan of Rieti province (Musso, 2009) and it will guarantee a faster connection between Rieti and Rome. The R8 will run every hour on each direction from 5:00 to 22:00 and, along with R1, it will provide a 30 minutes headway between Rome and Fara Sabina. The rolling stock used will be a tilting composition made of two different trains, one long and another short, that will take advantage of the many bends presented on the line. The reasons behind the need for two coupled trains are the demand and the infrastructure features: from Rome to Rieti the demand will be consistent, whilst from Rieti to L'Aquila it will be much lower. Moreover, from Rieti to L'Aquila the infrastructure does not allow long trains, not only because of platforms but also because the single-track line presents short crossing points. Hence, from Rome to Rieti the trains will be coupled whilst in Rieti only the short train will go towards L'Aquila. As regards the infrastructure, the first section, from Rome to Fara Sabina needs to have the speed class P implemented, the second section from Fara Sabina to Rieti needs to be built and the last section, from Rieti to L'Aquila, needs to be electrified (RFI, 2020b).

R15 Orte - Viterbo P. R.

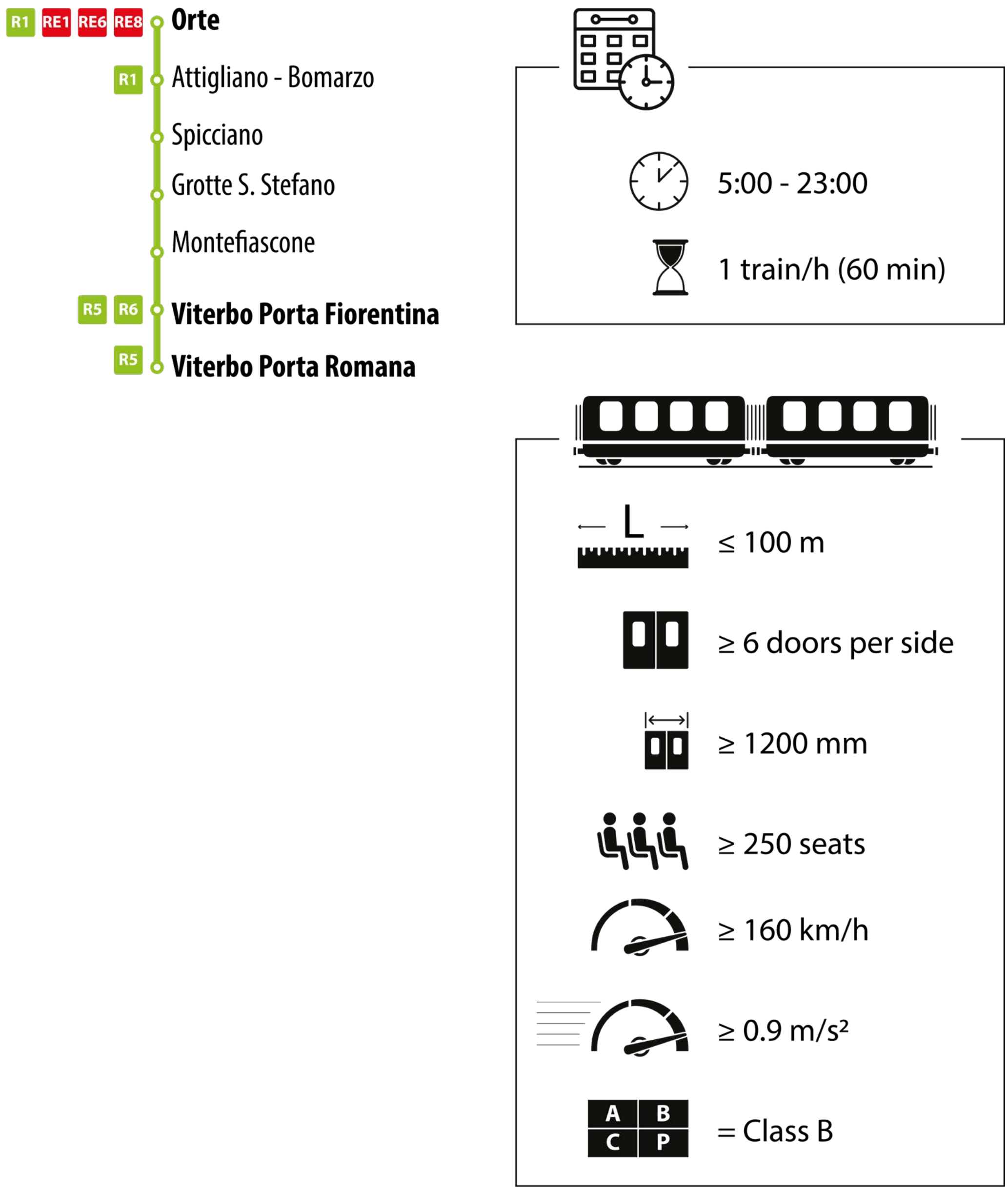


Figure 103 – R15 Line’s Features. Author's drawing

Figure 104 – R15 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

R15 is a regional line that will connect lines RE1 and R5, from Orte to Viterbo. It will substitute the existing services that today link those two cities, and it will provide, thanks to the interchange node of Orte, easy connections among Terni, Orvieto and Viterbo, the three main cities of the area. It will run every hour in each direction, from 5:00 to 23:00 using speed class B rolling stock. The journey time between the two termini, indeed, is fifty minutes (Trenitalia, 2020), perfect for linking the interchange node .00 of Viterbo to the interchange station .00 of Orte. However, if from the timetable design results that the nodes are different and minor travel time would be better on this line, tilting rolling stock would be back as an option. Nowadays, the infrastructure is not able to host class P trains so that it would need to be upgraded (RFI, 2020b).

R30 Frosinone - Cassino

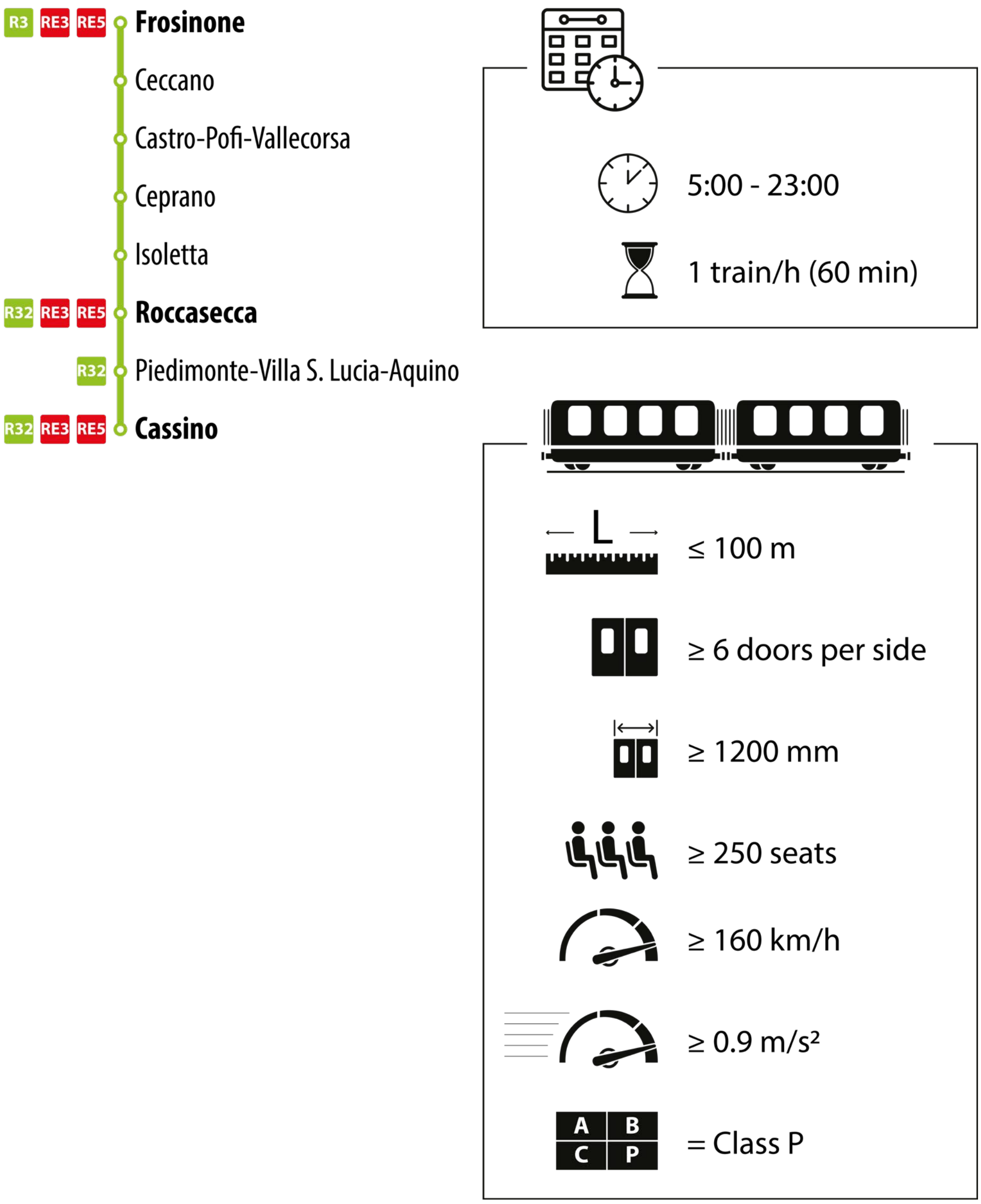


Figure105 – R30 Line’s Features. Author's drawing

Figure 106 – R30 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Line R30 is the ideal prosecution of line R3. It will indeed go from Frosinone to Cassino, passing throughout the interchange node of Roccasecca. It will run from 5:00 to 23:00 every hour, using tilting rolling stock in order to take advantage of the many bends presented on the line. The reasons why it will not be unified with R3 are two: firstly, the difference in demand is significative, and so running a big empty train between Frosinone and Cassino would be a waste of money (RFI, 2020b), secondly, it would not be possible to use coupled trains because in Frosinone, as it will be shown in next subsection, the R3 arrives 5 minutes before the RE3 or RE5 and line R30 leaves 5 minutes after RE3 or RE5 so that it would be useless to have a direct line forced to wait for 11 minutes in a station. Furthermore, people that need to go from Rome to one of the towns served by this line or vice-versa, would probably take the RE3 or RE5 and the R30, to minimize their travel time. Today, the infrastructure is not able to host class P trains so that it would need to be upgraded (ibid).

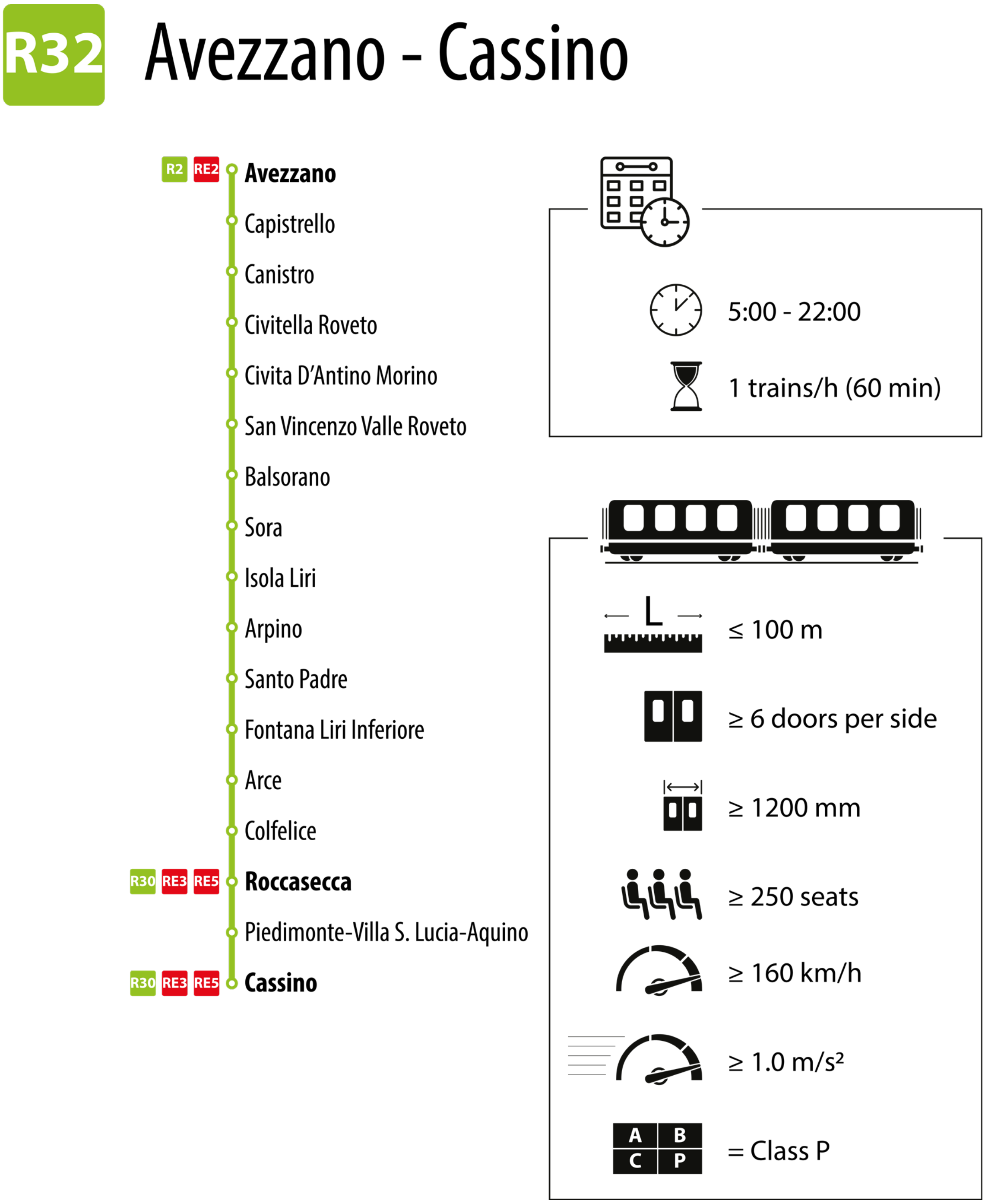


Figure 107 – R32 Line's Features. Author's drawing

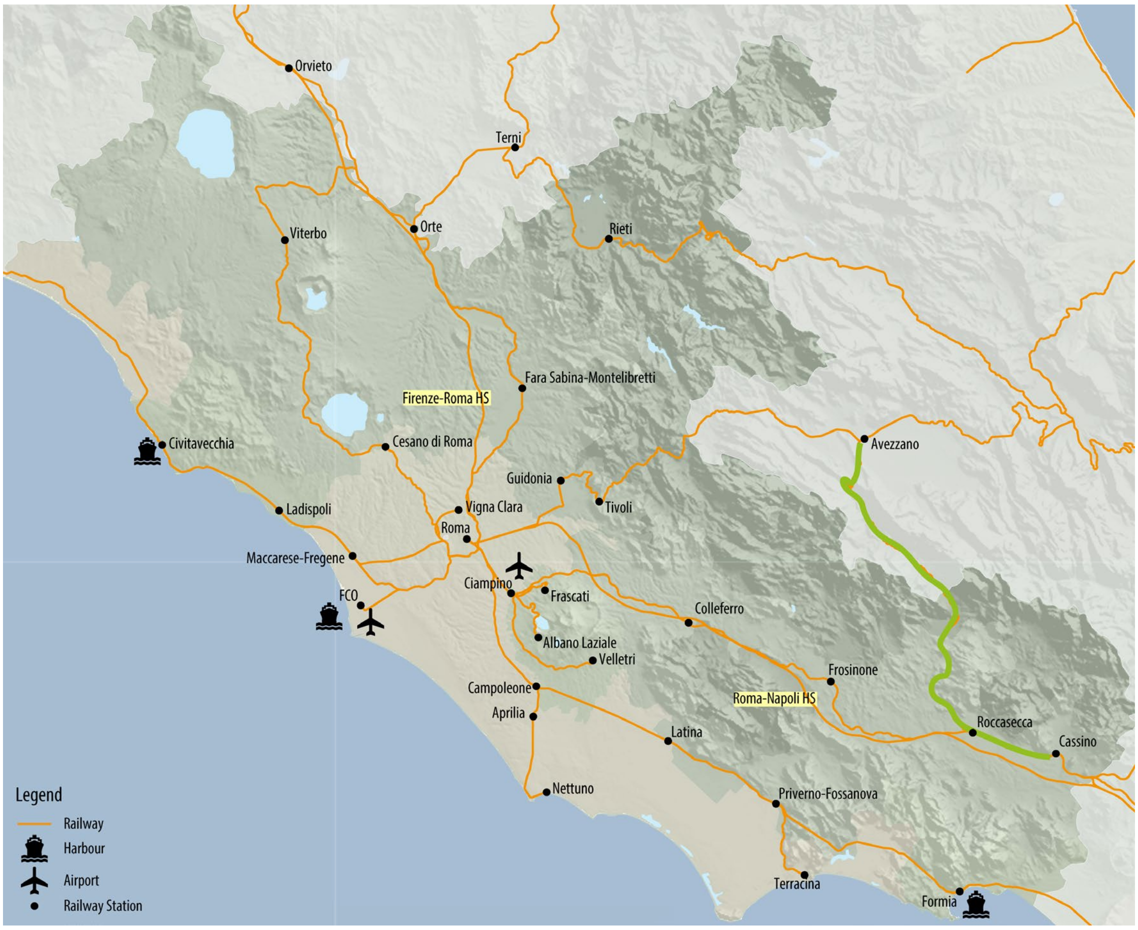


Figure 108 – R32 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

R32 is one of the few lines that will not start or end in Rome. It will indeed connect Cassino with Avezzano, linking the RE3 and RE5 with the RE2 in Roccasecca interchange node. There will be a train per hour per direction from 5:00 to 23:00, using short tilting trains, due to infrastructural feature, that does not present big crossing points but it does have many curves. The infrastructure is today not ready for speed class P trains neither for electric trains (ibid). Hence, upgrades are necessary, at least as regrads the speed class, whilst it could be not necessary to electrify the line.

R70 Priverno Fossanova - Terracina

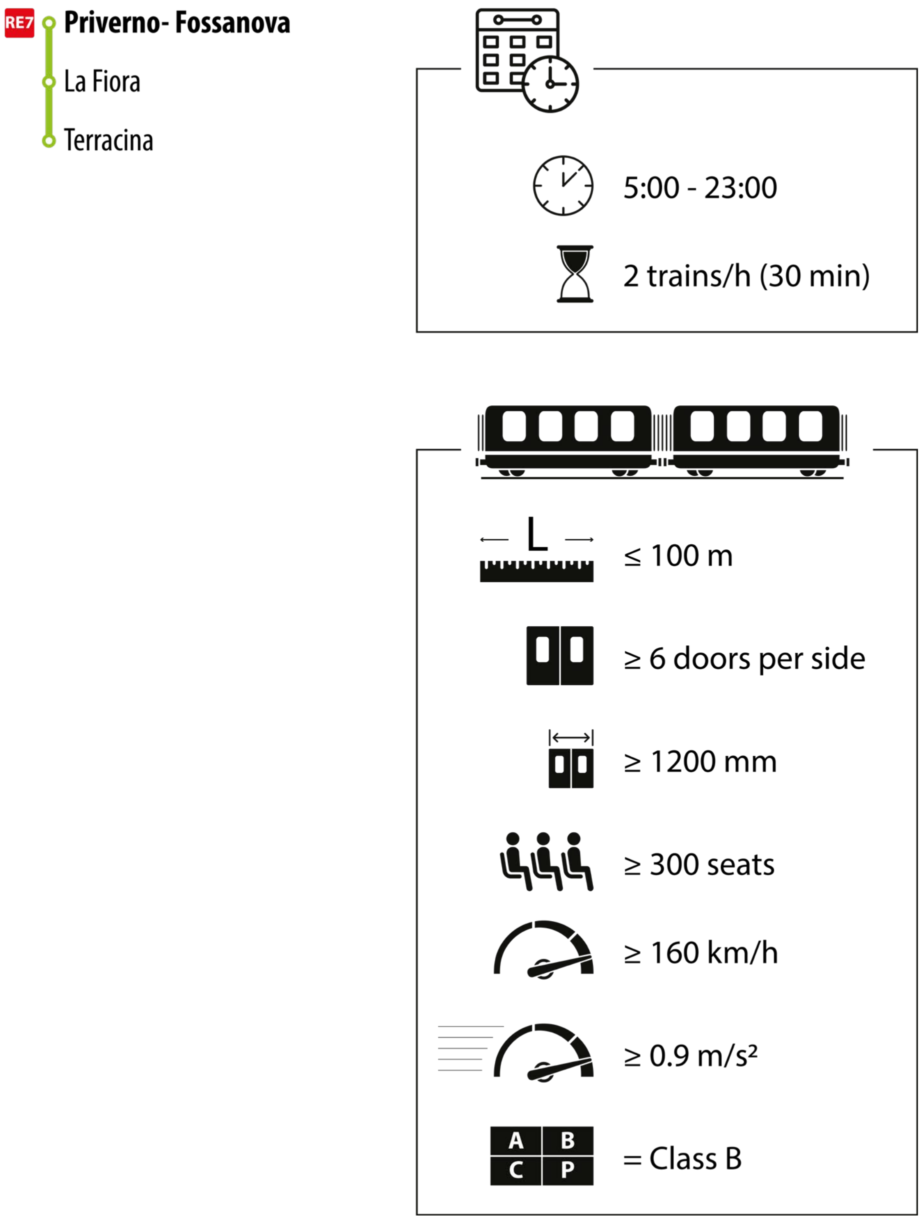


Figure 109 – R70 Line's Features. Author's drawing

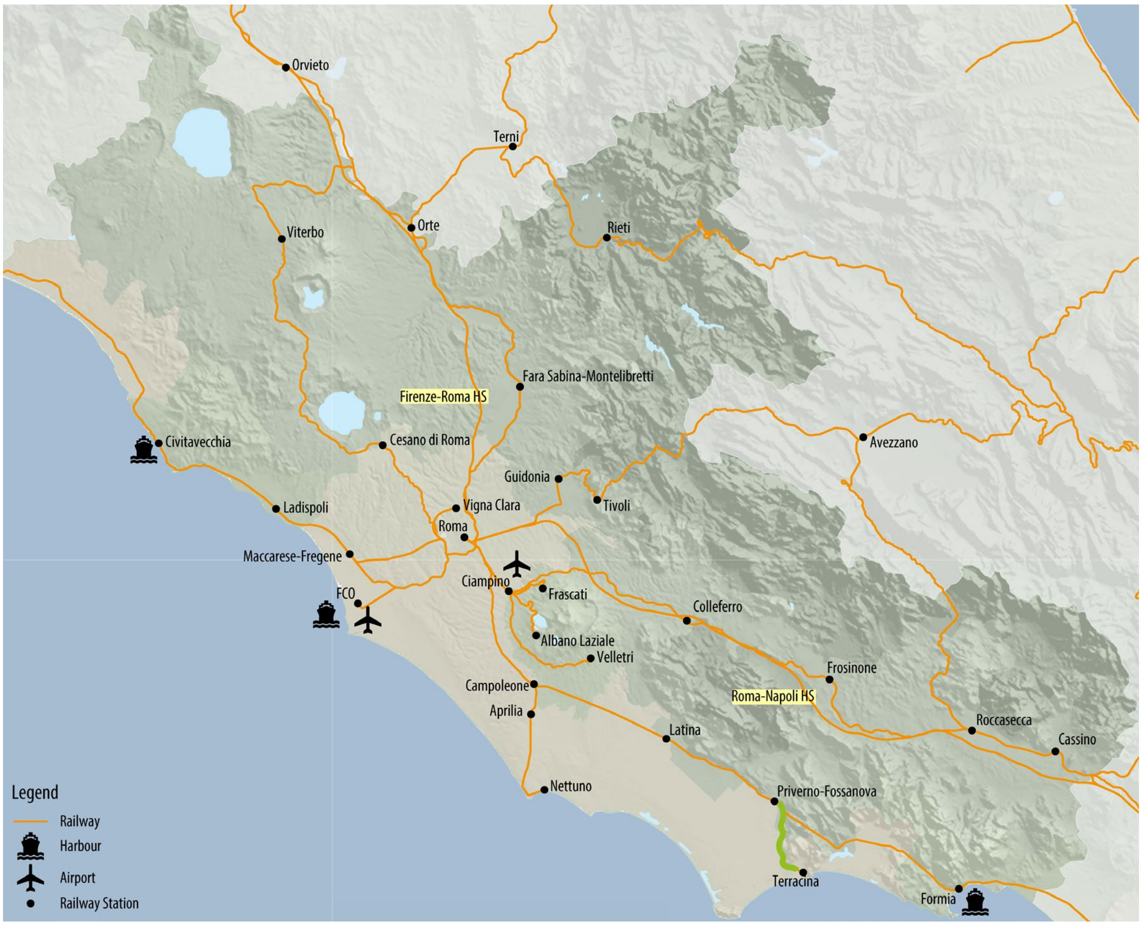


Figure 110 – R70 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

This short line will connect Terracina (about 46,000 inhabitants) with the line RE7 at Priverno interchange station and so with Rome and Napoli. R70 will run on an existing but interrupted-by-a-landslide line, that is planned to be reactivated in the next years (RF, 2020a). The line will run every 30 minutes, from the interchange node of Priverno to Terracina, from 5:00 to 23:00, using speed class B train.

R80 Terni - L'Aquila

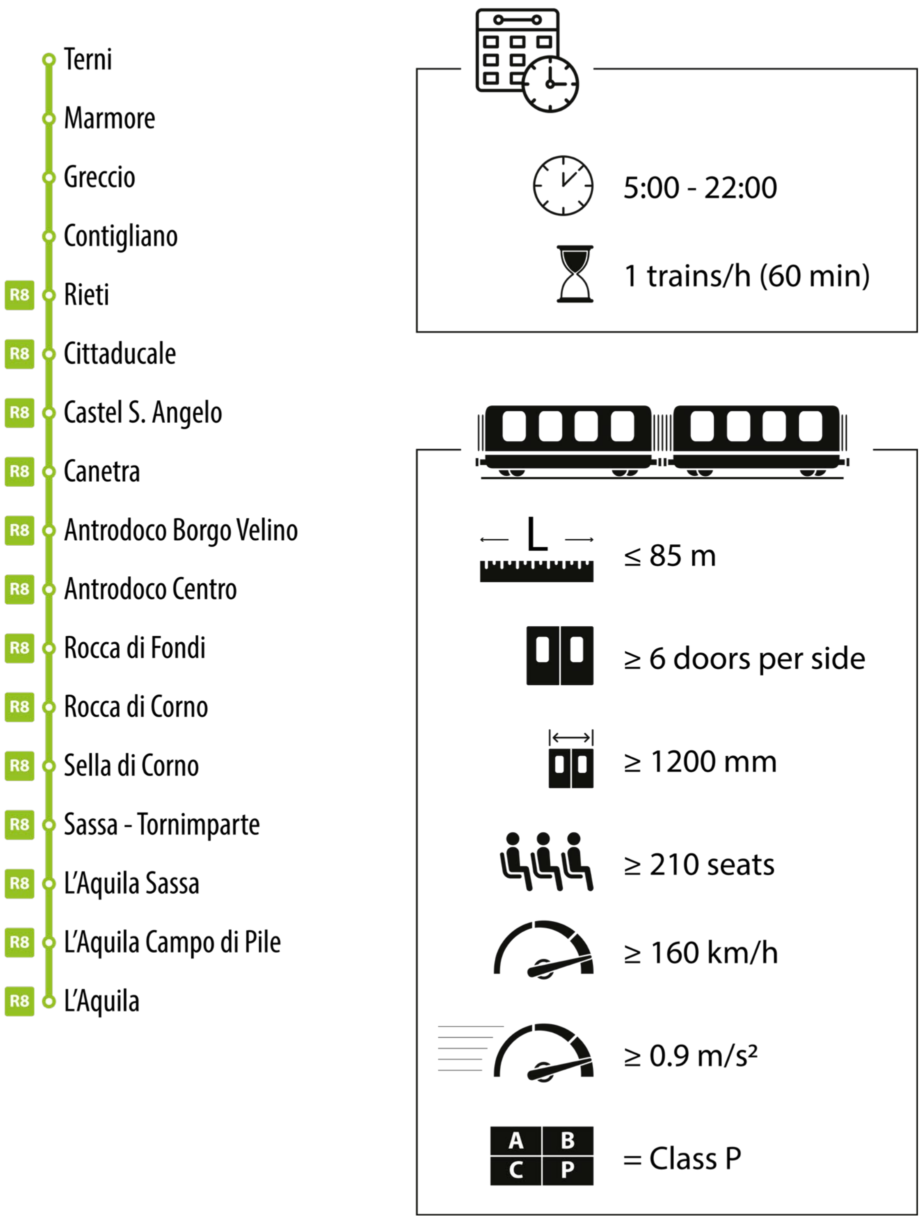


Figure 111 – R80 Line's Features. Author's drawing

Figure 112 – R1 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The R80 is a line that will travel on Lazio's territory just for half of its journey; however, due to the single-track infrastructure, it is strictly related to R8 that will be overlapped from Rieti to L'Aquila. From Terni to Rieti, on the contrary, R80 will be the only line connecting the two cities hourly, even though, on this stretch of line it would be possible to insert reinforcement trains during peak-time. R80 will run from 5:00 to 22:00 using tilting rolling stock to take advantage of railway's features. However, today the line is not ready for speed class P trains nor electric trains; hence, infrastructural upgrades are needed (RFI, 2020b).

3.1.3.3. Regio-Express Lines

Regio-express lines, as stated before (2.2.1), provide fast connection among the main cities and towns of the region and the adjacent regions. All the RE lines will have one of the termini in Roma Termini station, where they will offer connections to high-speed trains, other regional and region-express trains and the two lines for Rome's airports, S5 and LXP. Considering the Adjacent region, the lines will connect Rome with the capital cities of Tuscany (Firenze), Umbria (Perugia), Marche (Ancona), Abbruzzo (Pescara), Molise (Campobasso) and Campania (Napoli) included other important cities of those regions. The main principles used to design the lines are the analysis of the existent services along with the infrastructure features.

Each line will be described using the same pattern:

1. Line scheme and features.
2. Geographic context.
3. Line description.

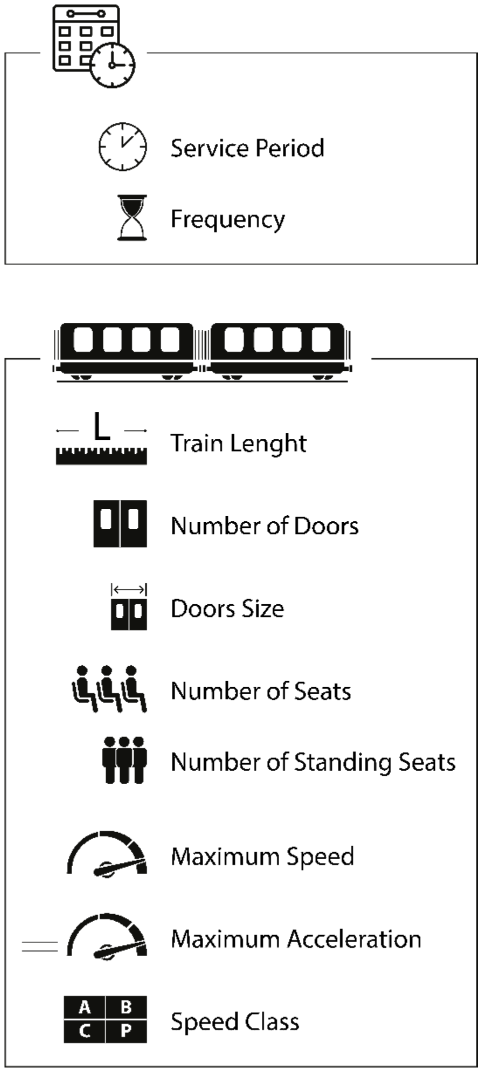


Figure 113 – Icons' Legend. Author's drawing

Figure 114 - SBB RABe 503, Wassen. Image dowloaded from https://www.railpictures.net/viewphoto.php?id=556227&nseq=69

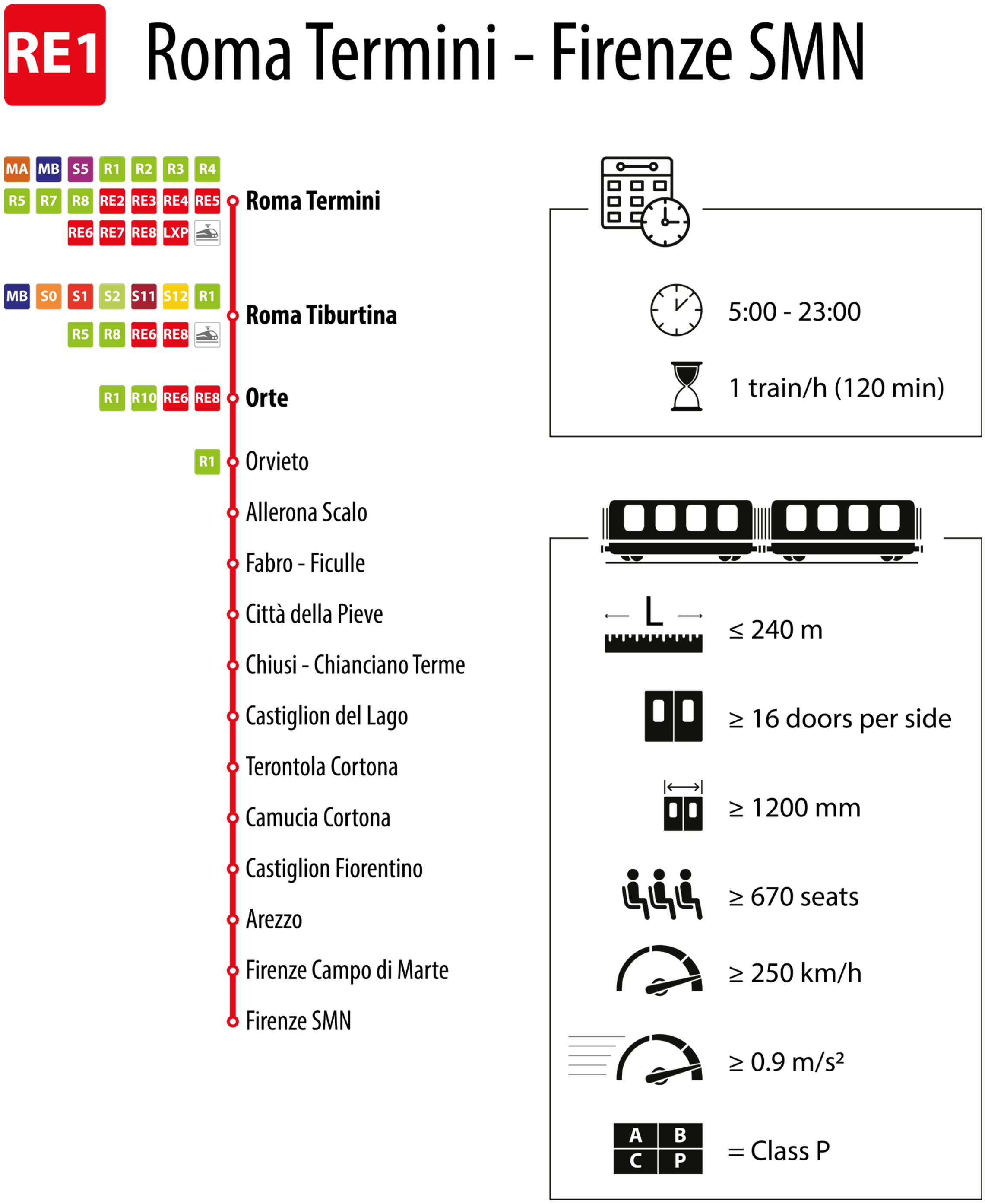


Figure 115 – RE1 Line’s Features. Author's drawing

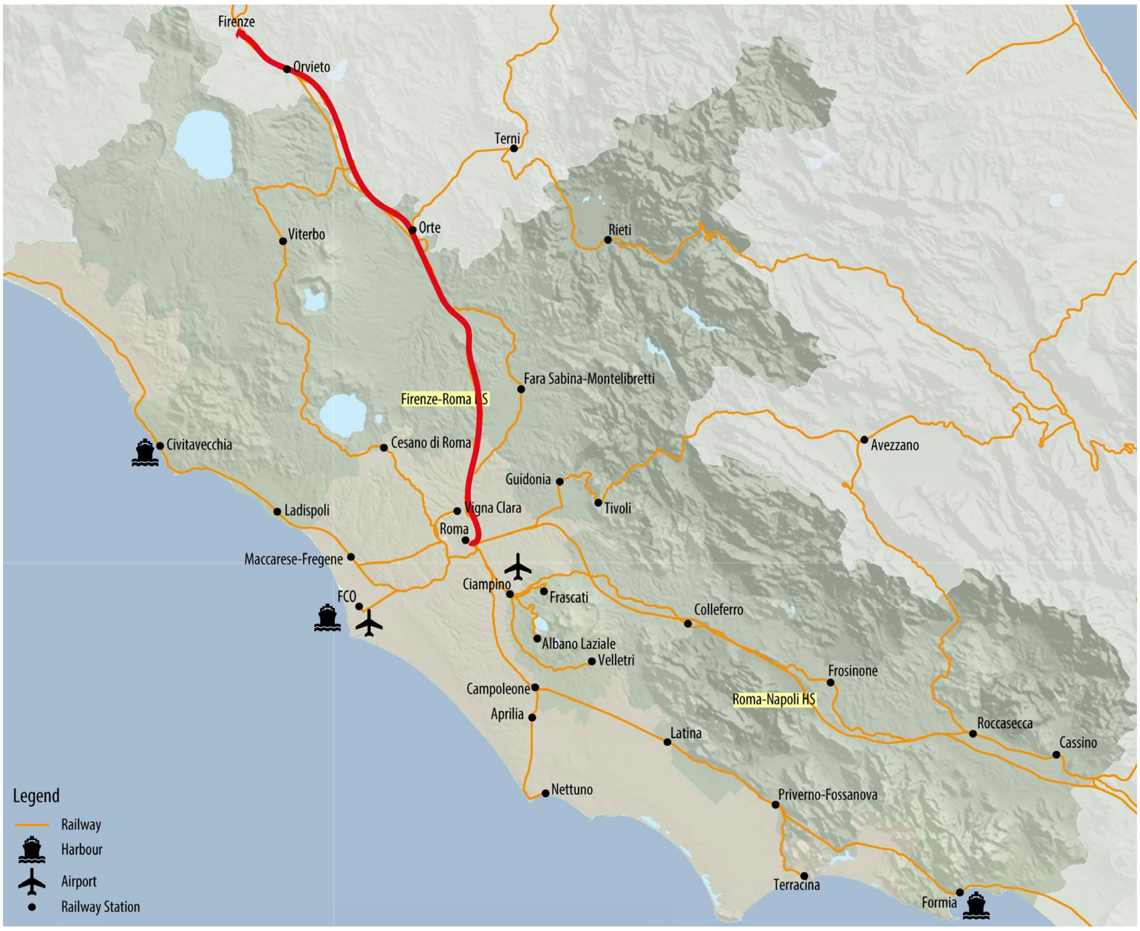


Figure 116 – RE1 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Regio-express line 1 will connect Rome with Firenze. It will upgrade the existing regional trains that connect these two cities saving stops between Orte and Orvieto, that will be served by R1, and using a better rolling stock, that will go up to 250 km/h because from Rome to Orte the trains will run on a section of the Rome-Firenze high-speed railway (RFI, 2020b). Today the itinerary is the same but the rolling stock only travels under speed class B (maximum 160 km/h). Besides, the trains of the future RE1 will have the tilting system so that they will be faster than today also on the rest of the itinerary, on the traditional railway that presents many bends but needs to be upgraded to allow speed class P (ibid). The line will run every two hours in each direction, from 5:00 to 23:00.

RE2 Roma Termini - Pescara

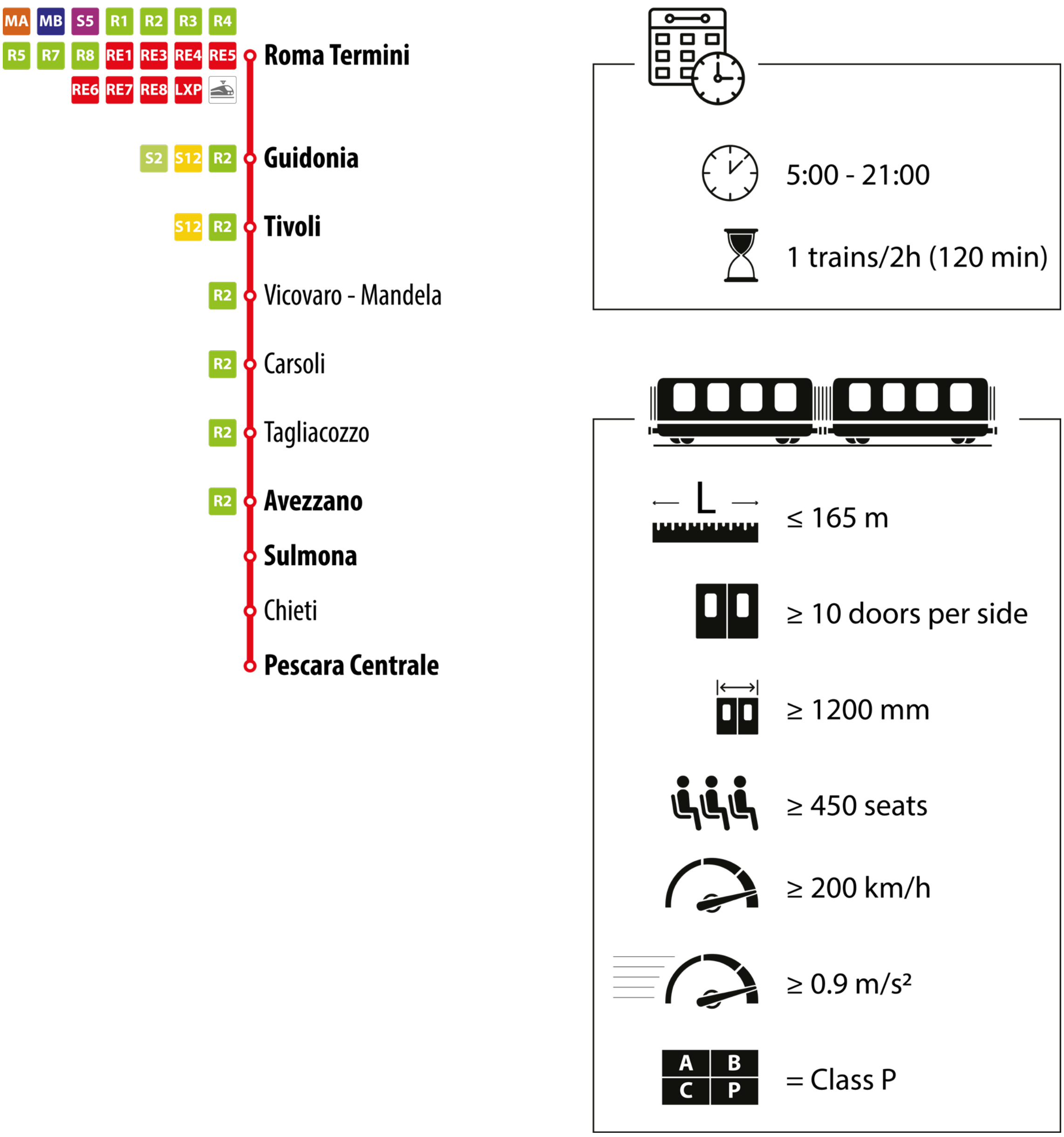


Figure 117 – RE2 Line's Features. Author's drawing

Figure 118 – RE2 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

RE2 will connect Rome to Pescara, crossing the Appennine Mountains and connecting the Tyrrhenian Sea with the Adriatic Sea. The line will run from 5:00 to 23:00 every two hours, using tilting rolling stock to take advantage of the many curves of the railway. The infrastructure will need upgrades to allow speed class P trains and the forecasted frequency (RFI, 2020b).

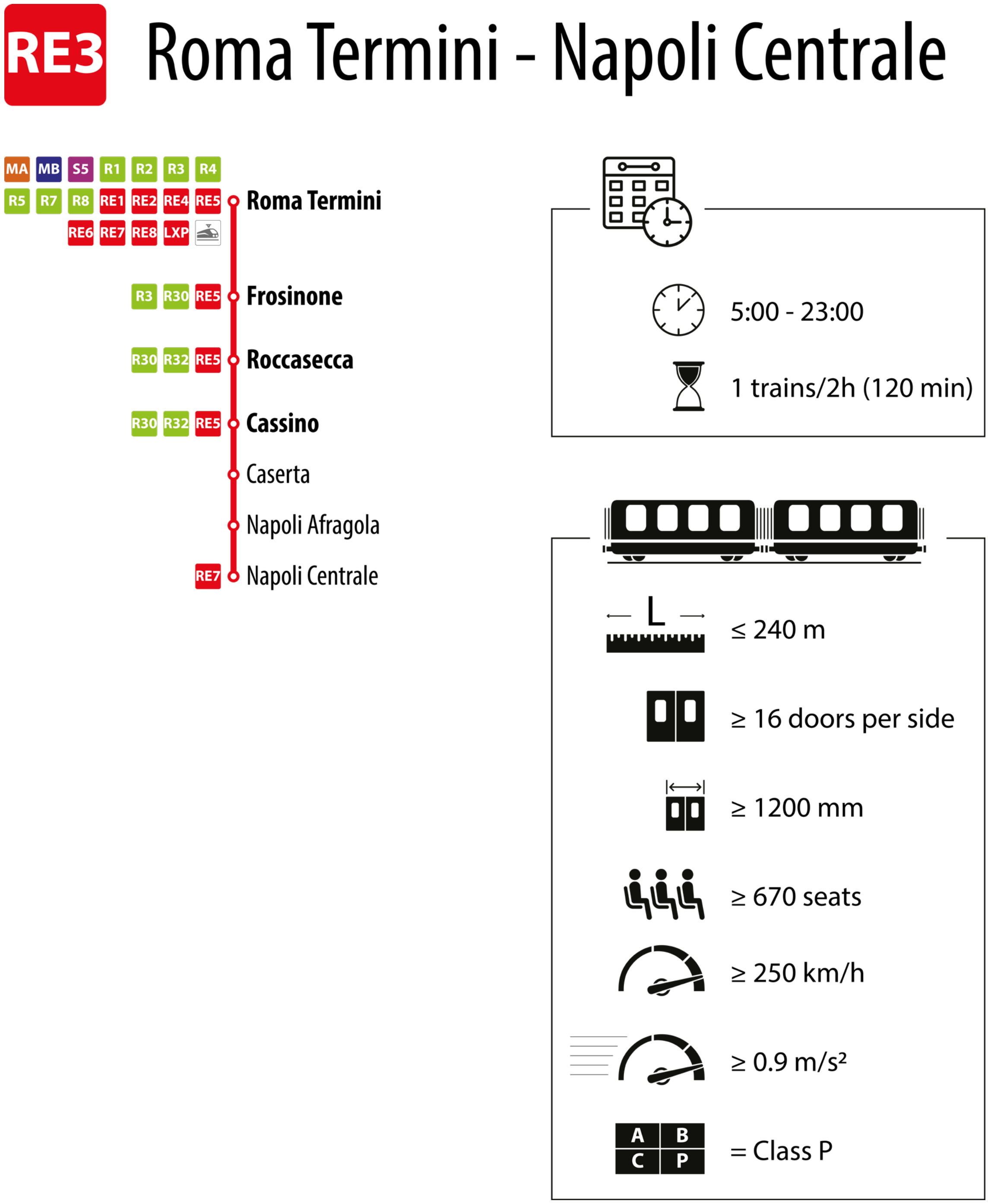


Figure 119 – RE3 Line’s Features. Author's drawing

Figure 120 – RE3 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The RE3 is a new line that links Rome with Napoli passing throughout Frosinone every two hours. The same rolling stock used in RE1 will be used, because also here there will be a mix of high-speed railways and traditional railways with many curves. The connection from Rome to Frosinone via high-speed it is completely new and it will reduce the travel time of at least 28 minutes while, as regards the Rome – Cassino connection, at least 31 minutes will be saved (Associazione Roma-Cassino Express, 2015). Moreover, Roccasecca interchange node will provide the localities served by line R32 with a quick connection to Rome. Similarly, the line will also guarantee a direct and quick connection to Napoli and Caserta, two important cities of Campania.

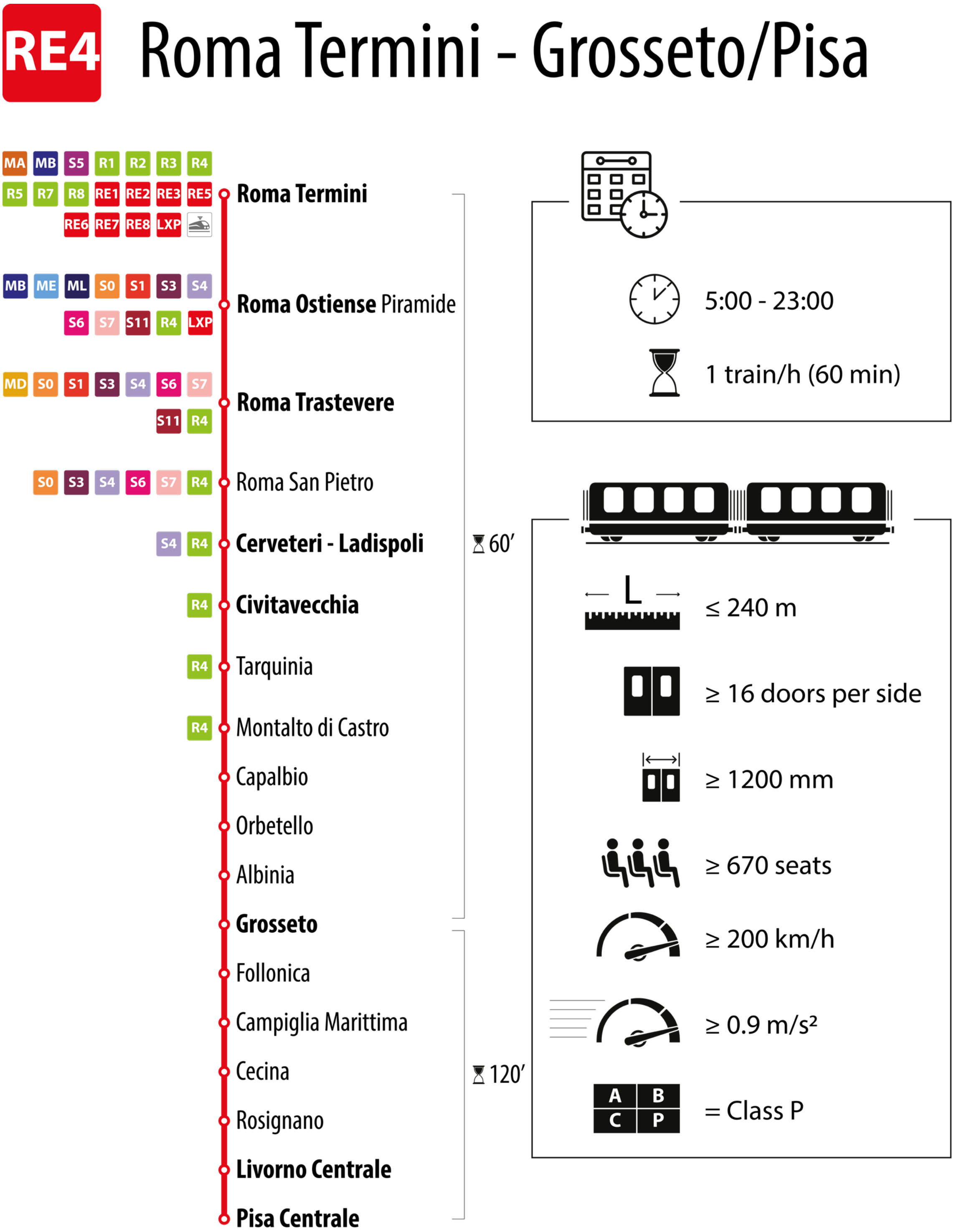


Figure 121 – RE4 Line's Features. Author's drawing

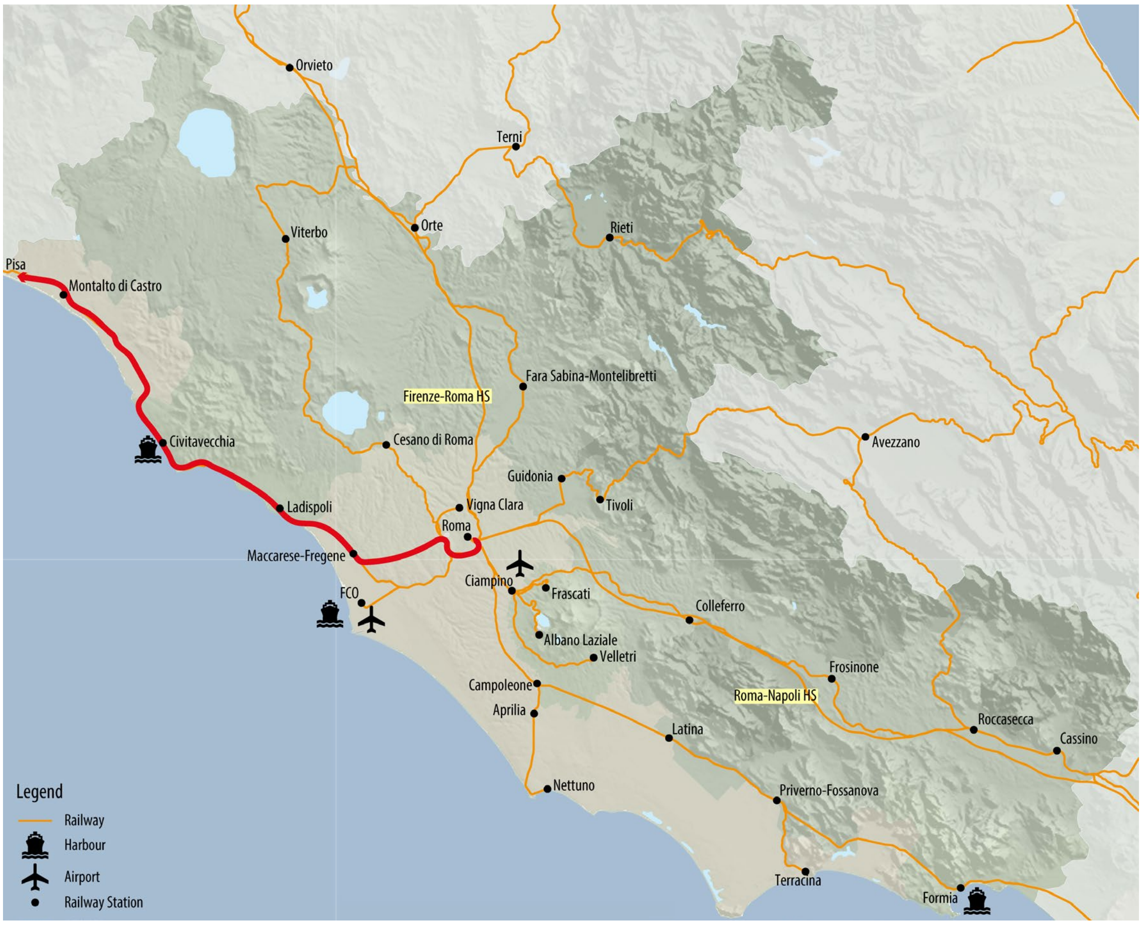


Figure 122 – RE4 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The RE4 line will replace the existent regional trains connecting Rome and Pisa through the coast. It will offer a connection every hour from Rome to Grosseto, in the south of Tuscany, and one out of two trains (one every two hours) will continue up to Pisa. The service period will be from 5:00 to 23:00, using tilting trains that could take advantage of the line, already set up for speed class P (RFI, 2020b). The travel time will be shorter than today, because the rolling stock will travel faster and because between Civitavecchia and Ladispoli, differently from today, there will be no stops. Ladispoli and Civitavecchia interchange nodes will guarantee quick connections with the localities not served by this line.

RE5 Roma Termini - Campobasso

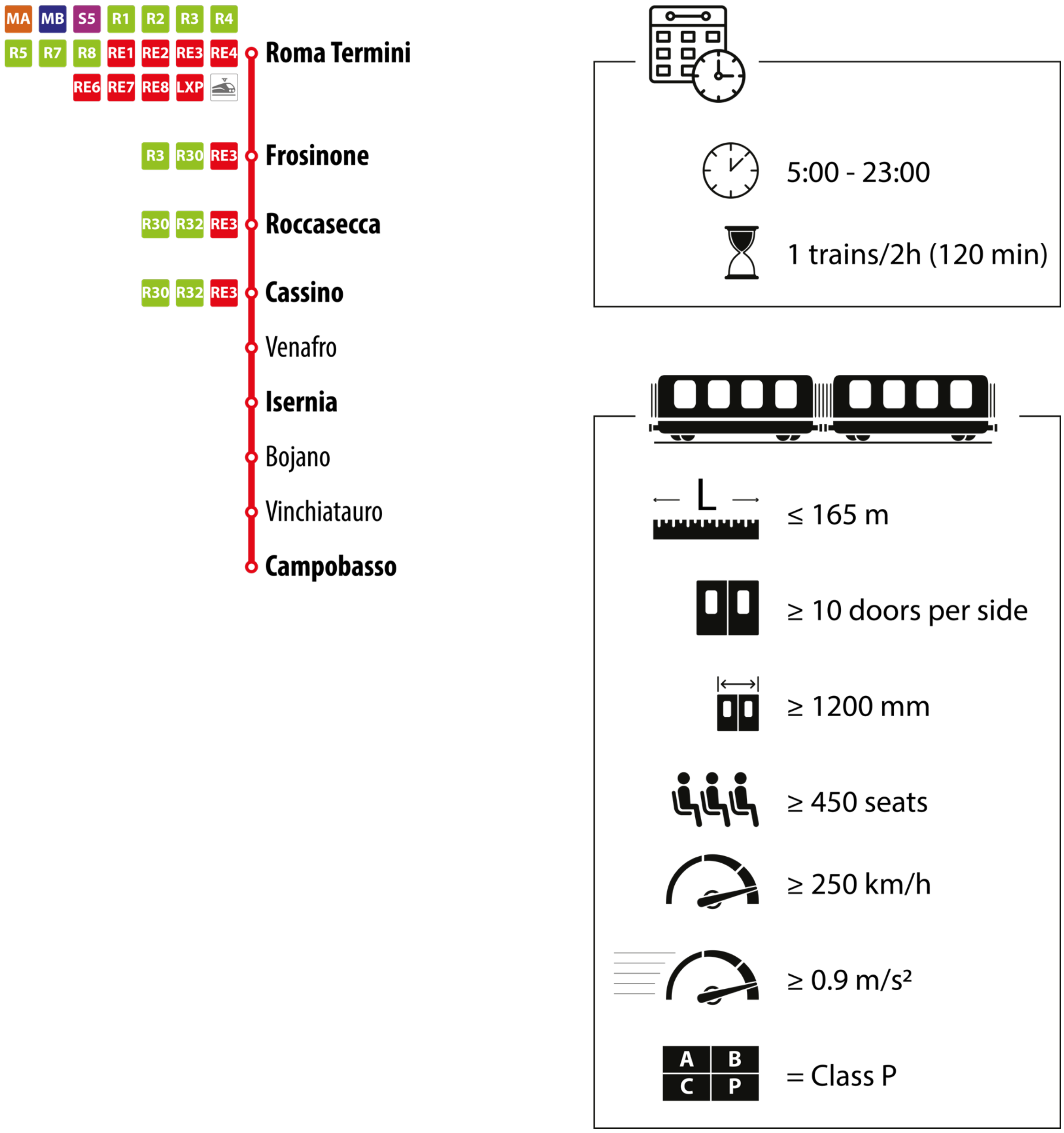


Figure 123 – RE5 Line's Features. Author's drawing

Figure 124 – RE5 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

RE5 is the line connection Rome with Isernia and Campobasso, the two main cities of Molise. It will have the same itinerary of RE3 into the regional bourders, connecting Rome and Cassino every two hours, and so guaranteeing a total frequency of one train per among Rome, Frosinone, Roccasecca and Cassino. It will replace the Rome – Campobasso regional trains that today use only the conventional railway, thus it will guarantee a journey at least 30 minutes shorter (Associazione Roma-Cassino Express, 2015) than today. The rolling stock will be shorter than the one used on RE3 because of the infrastructural features of the railway in Molise. As regards the infrastructure, for the first section it is valid what has been said for RE3, whilst, for the section outside the region upgrades will be necessary because the line today is not electrified and does not allow speed class P (RFI, 2020b).

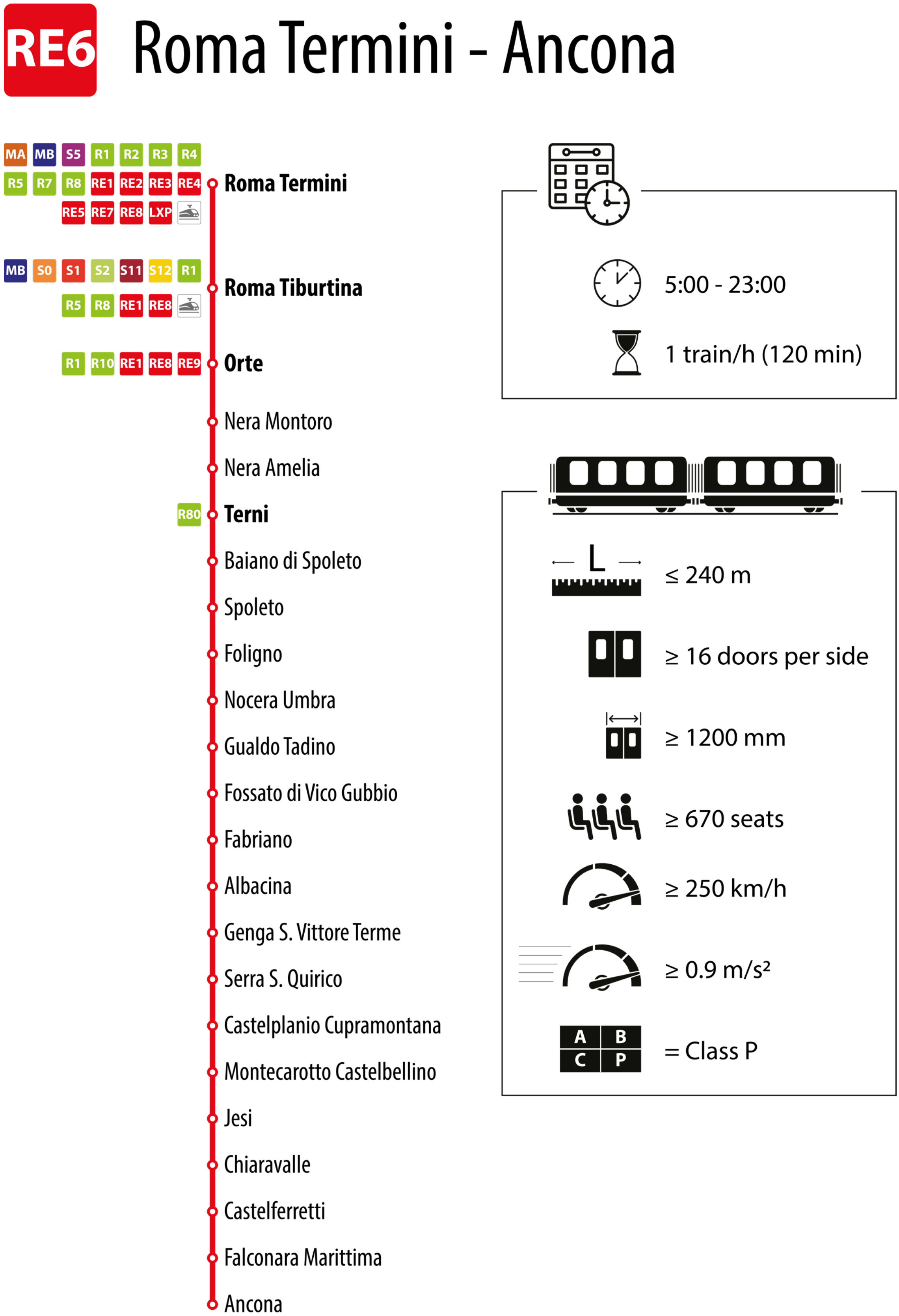


Figure 125 – RE6 Line’s Features. Author's drawing

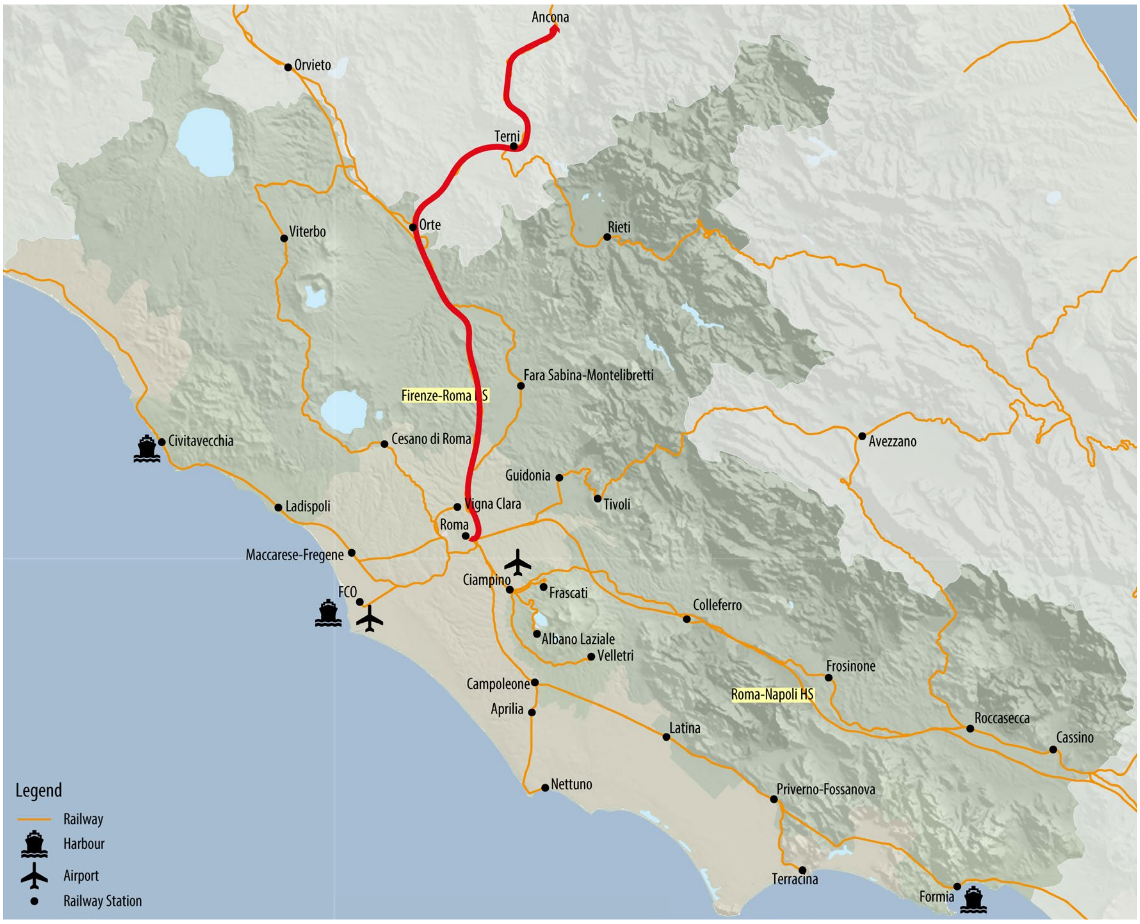


Figure 126 – RE6 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Regio-express line 6 will connect Rome with Ancona, crossing the Apennine Mountains and connecting the Tyrrhenian Sea with the Adriatic Sea. It will take the place of the existing regional trains improving the service quality saving time thanks to the major speed and the tilting system, which will allow saving time both in the high-speed section between Orte and Rome and in the other part of the line that presents many curves. Speed class P trains can already travel on this line (ibid), and RE6 will run every two hours from 5:00 to 23:00 in each direction, but overlapped with RE8 it will guarantee an hour connection from Rome to Foligno, in the middle of Umbria.

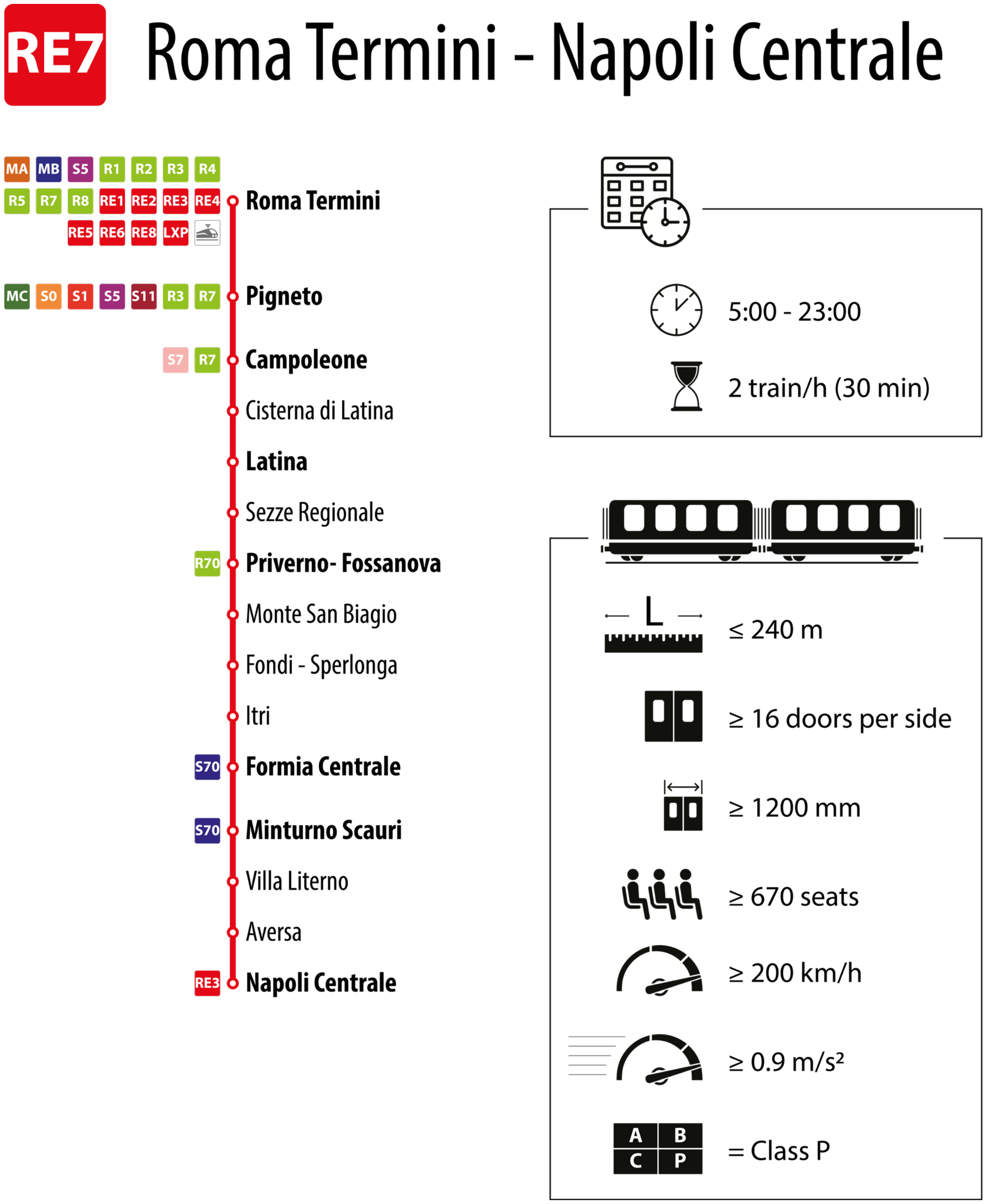


Figure 127 – RE7 Line's Features. Author's drawing

Figure 128 – RE7 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

RE7 will be the only region-express line running every 30 minutes in each direction. It will be the line that will replace the FL7 and the regional trains to Napoli, but considering the presence of high demand all over the line short headways are needed. This line will use speed class P trains to take advantage of the line infrastructure, that could host tilting trains also today. Compared to today's trains, the RE7 will offer shorter travel time, because class P will reduce the journey time and so several interchange nodes will be created (see the following subsection). The service period of the line will be from 5:00 to 23:00.

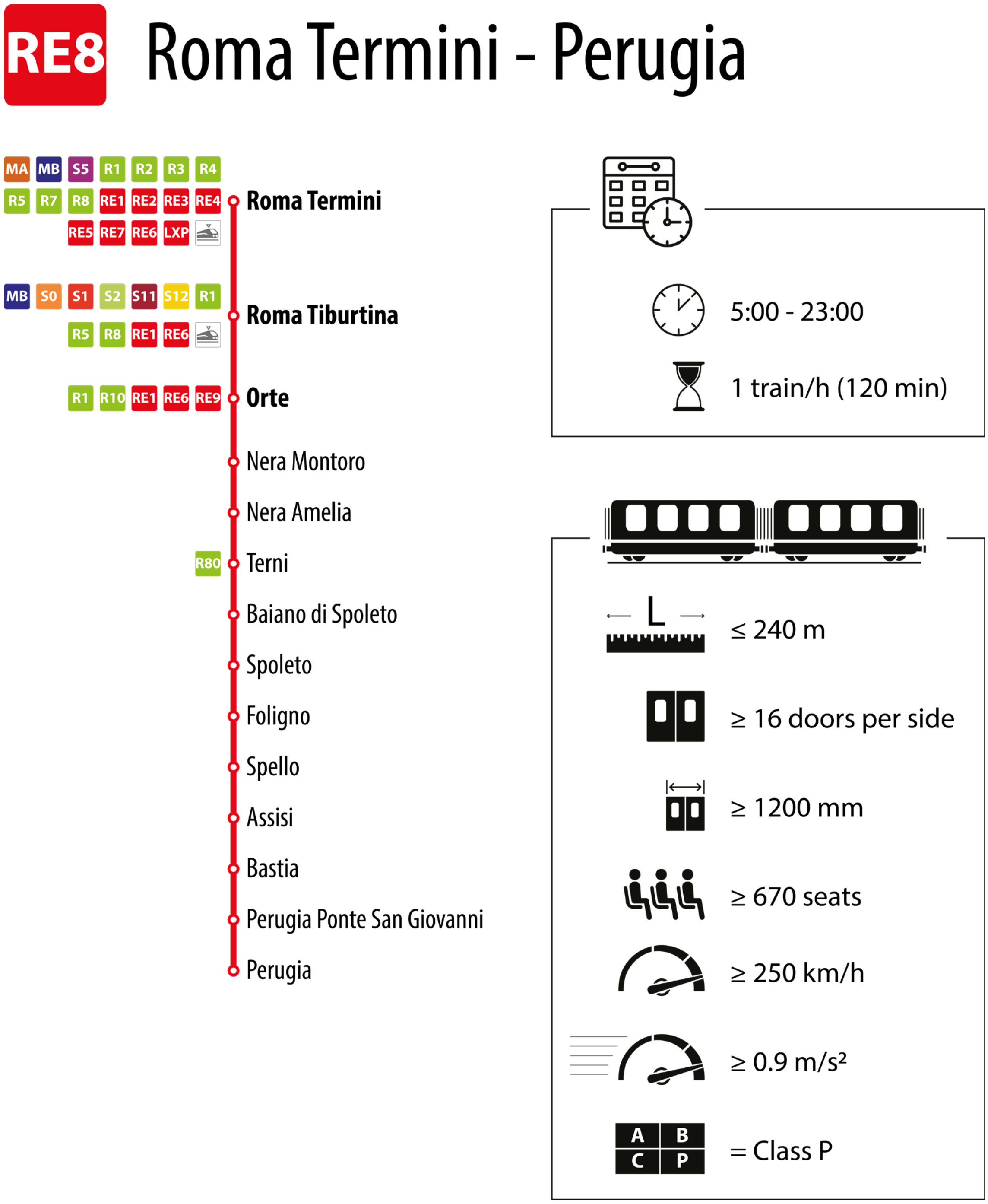


Figure 129 – RE8 Line’s Features. Author's drawing

Figure 130 – RE8 Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

Regio-express line 8 will connect Rome with Perugia, in the north-central part of Umbria. It will take the place of the existing regional trains improving the service quality saving time thanks to the major speed and the tilting system, which will allow saving time both in the high-speed section between Orte and Rome and in the other part of the line that presents many curves. Speed class P trains can already travel on this line up to Foligno (ibid), whilst infrastructural upgrades will be necessary for the remaining section. As regards the service period, RE8 will run every two hours from 5:00 to 23:00 in each direction, but overlapped with RE6 it will guarantee an hour connection from Rome to Foligno.

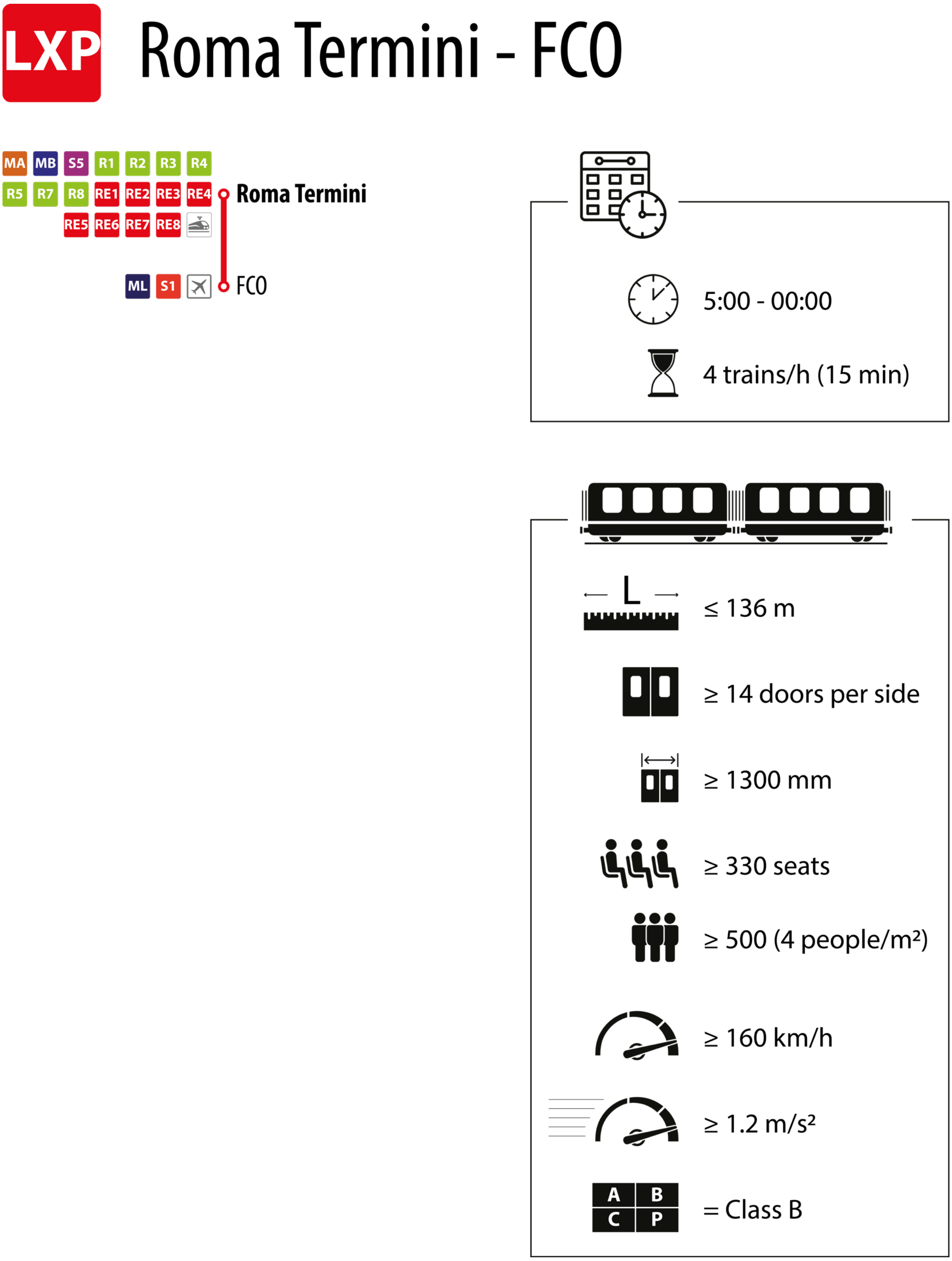


Figure 131 – LXP Line's Features. Author's drawing

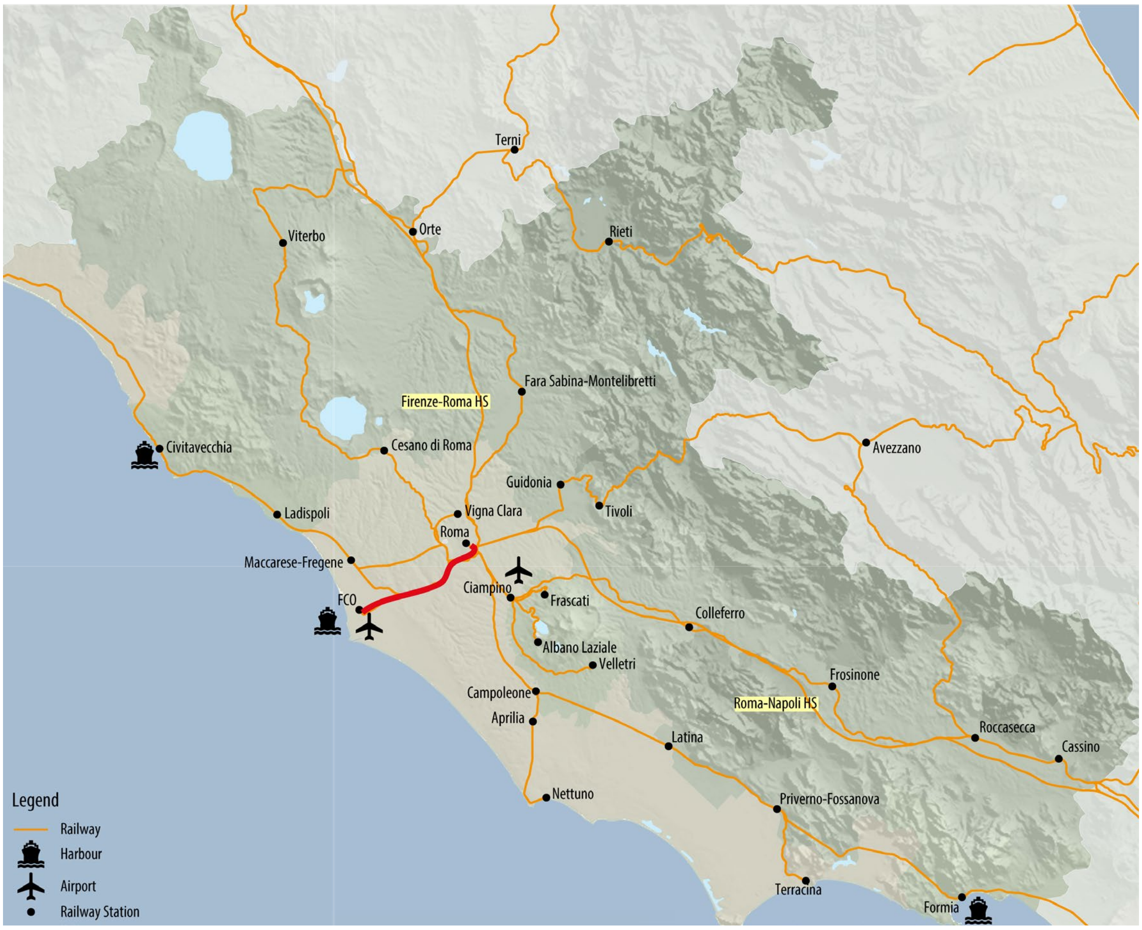


Figure 132 – LXP Line's Itinerary. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The LXP is the line connecting the major station of Rome, Roma Termini, to its main airport, Fiumicino. It runs already every day from 5:00 to 22:00, that will become from 5:00 to 23:00 in the proposed scenario. Even though the travel time is almost the same of S1, the line is needed in order to satisfy the demand generated by the airport and to connect Termini and so all the trains that start and/or end there with the airport. The rolling stock used is more similar to the trains used for S lines than to the regional trains, with the difference that the interior design needs to be though purposely for airport services.

3.1.3.4. The New Service Network

In this subsection, the network of the new lines presented until now is described and analyzed. In order to provide the reader with an overview of the new regional train system, a map has been designed (for a full understanding of this subsection is recommended to analyze the attachment 1 while reading). It is important to understand that this scheme (Attachment 1) is not something intended for travellers but it is just a technical draw picturing the overall network. Another pivotal element is that, being a long-term scenario, this scheme is representing an indefinite time in the far future, between 30 and 50 years from now.

The service scheme presented in attachment 1 is made of the following elements:

1. The new train lines that have been separately described in the previous section and now are all together.
2. The future metro network planned by the municipality (Roma Mobilità, 2019).
3. The existent regional fare zones.
4. The total headways where two or more S lines are overlapped.

In the following paragraphs, the network is analyzed pointing out the main findings that it shows.

Observing the map, the results of the Swiss model application are clear. The presence of different service levels that meet in defined interchange nodes is evident. The region-express lines, represented by the red colour, do not stop where regional lines and suburban lines stop, whilst regional trains, represented by the green colour, avoid suburban stops, except for the important localities.

Secondly, Roma Termini is the most important station for both regional and region-express trains. It is shown by the scheme as almost all the red and green lines, except for line R6, origin in this station, whilst only one suburban line starts here. S5, indeed, is the only suburban line ending in Roma Termini, while all the other 9 Roman S lines pass on a section of the railway city ring but start and end outside the urban area, represented by the fare zone A.

Besides, 7 out of the 10 Roman S lines run on the southern part of the ring, between Roma Tuscolana and Roma Trastevere stations, making of that railway stretch the core of the Roman suburban lines. There, indeed, the total headway is about 3 minutes, as much as a high-frequency metro line. Similarly, looking at the other urban sections of S lines (those inside the A fare zone), there is no stretch presenting headways bigger than 15 minutes, and many of those are even inferior.

On the other hand, another necessary consideration is that infrastructural upgrades needed by the network, and described in the previous section, did not take into account the presence of other lines on the same infrastructure. Thus, the amount of the necessary upgrades can be defined only looking at the overall network. For instance, among Roma Tuscolana and Ciampino other two tracks would be necessary to run all the planned lines. However, this update is already planned (RFI, 2020a), thus this scenario is compliant with the existent planning, as much as the 12 trains per hour on the railway connecting Fiumicino airport and Rome, where is already planned the signalling upgrade to have more capacity (ibid).

3.1.3.5. Summary

To sum up, this section has presented the new network initially line by line, to understand the features of each line and its requirements, and finally, it has described the overall network and what it is needed to make it work, from the technical point of view. Following the theory stated in the previous sections and chapters, it has been possible to design a new railway service network suitable for the 21st century. It has different and clear service levels that can answer different mobility needs and create new demand. The new network indeed, not only tries to absorb the existent demand inside the historic city of Rome and among Rome and the other regional cities but also increase the efficiency of the connection between the metropolitan area and the historic city, providing the users with an effective and efficient way to move between these two areas.

Next section will deeply describe the node network that can be finally designed into detail and some interchange nodes that represent the main node types, in order to explain practically the potentialities of the Integrated Regular Interval Timetables.

3.1.4. Interchange Nodes Focus

Designed the network lines, it is now possible to accurately design its interchange nodes. As stated before, an interchange node is a point on the network where trains of different lines meet in a short time allowing quick connections; generally, they correspond to symmetry points in the timetables. Taking all the principles explained before into account, the results in Lazio's network is shown by the following map.

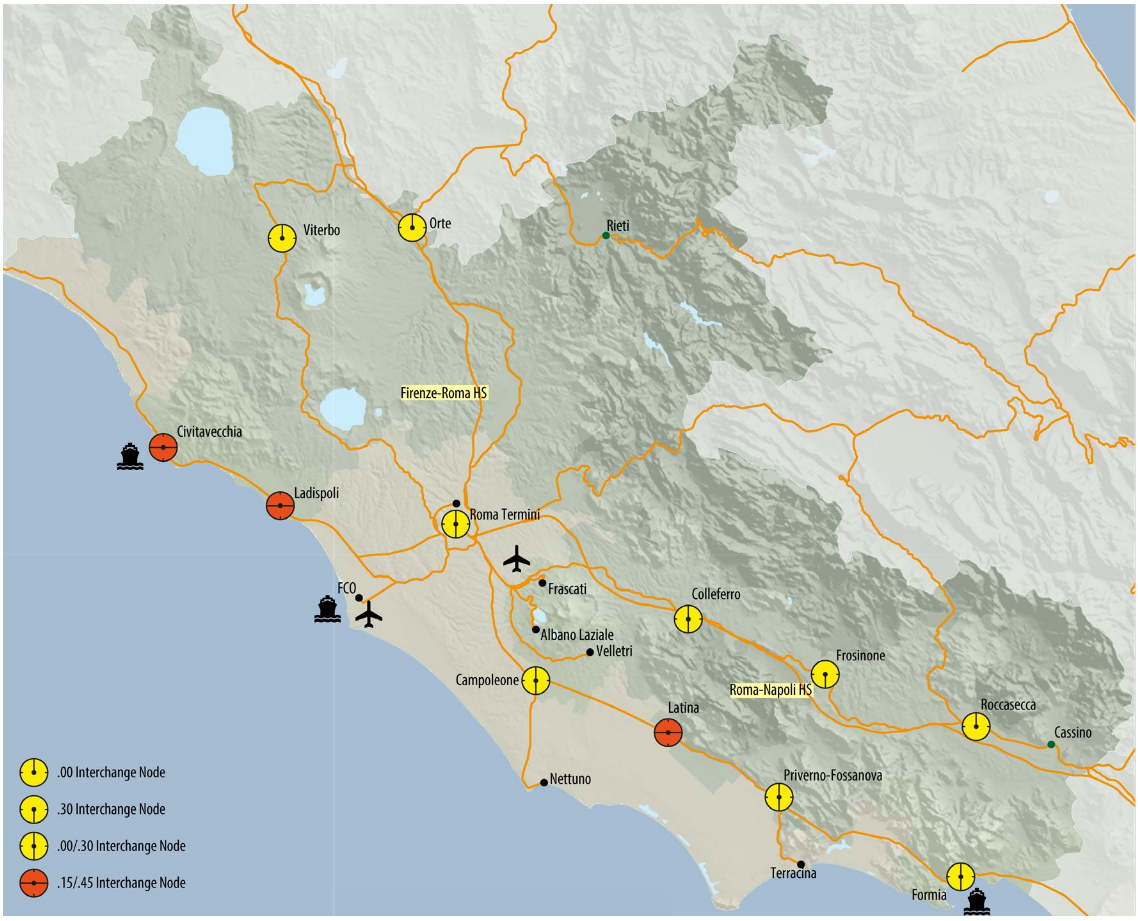


Figure 133 – Interchange Nodes in Lazio's New Railway Service Network. Image modified from http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Nelle-regioni/Lazio

The first thing to define is the concept of .00, .00/.30 and .15/.45 node. Adding the minute to the concept of node means defining the minute around which the connection is possible. In a .00 node, all the trains will arrive before minute .00 and will leave after that minute, in a .00/.30 node, the train will arrive before minute .00 and will leave after that minute, and 30 minutes later will happen the same things. A .15/.45 node is equal to the .00/.30 but the minutes change.

Looking at the map, it is possible to affirm that the majority of nodes work every 30 minutes, while only a few of those work once per hour. However, as regards the former type of nodes, it is important to understand that it will work two times per hour only for lines presenting 30 minutes headway because, as explained into the theory (chapter 2.2), the lines running one train per hour will have the trains running in opposite direction meeting at minutes .00 or .30. Hence, at the same station, there will be a main node, at minute .00 for instance, where the connection will be possible among all the lines stopping there, whilst there will be a secondary node, 30 minutes later, where the interchange will be possible only among lines having 30 minutes headway, excluding the lines having 60 minutes headway. This concept is valid for booth .00/.30 nodes and .15/.45 nodes.

Figure 134 - Railways in Netherlands. Image downloaded from https://www.pinterest.it/pin/318418636156861032/

Ladispoli is a clear example of a double node (.15/.45) with differences between the first and the second node.

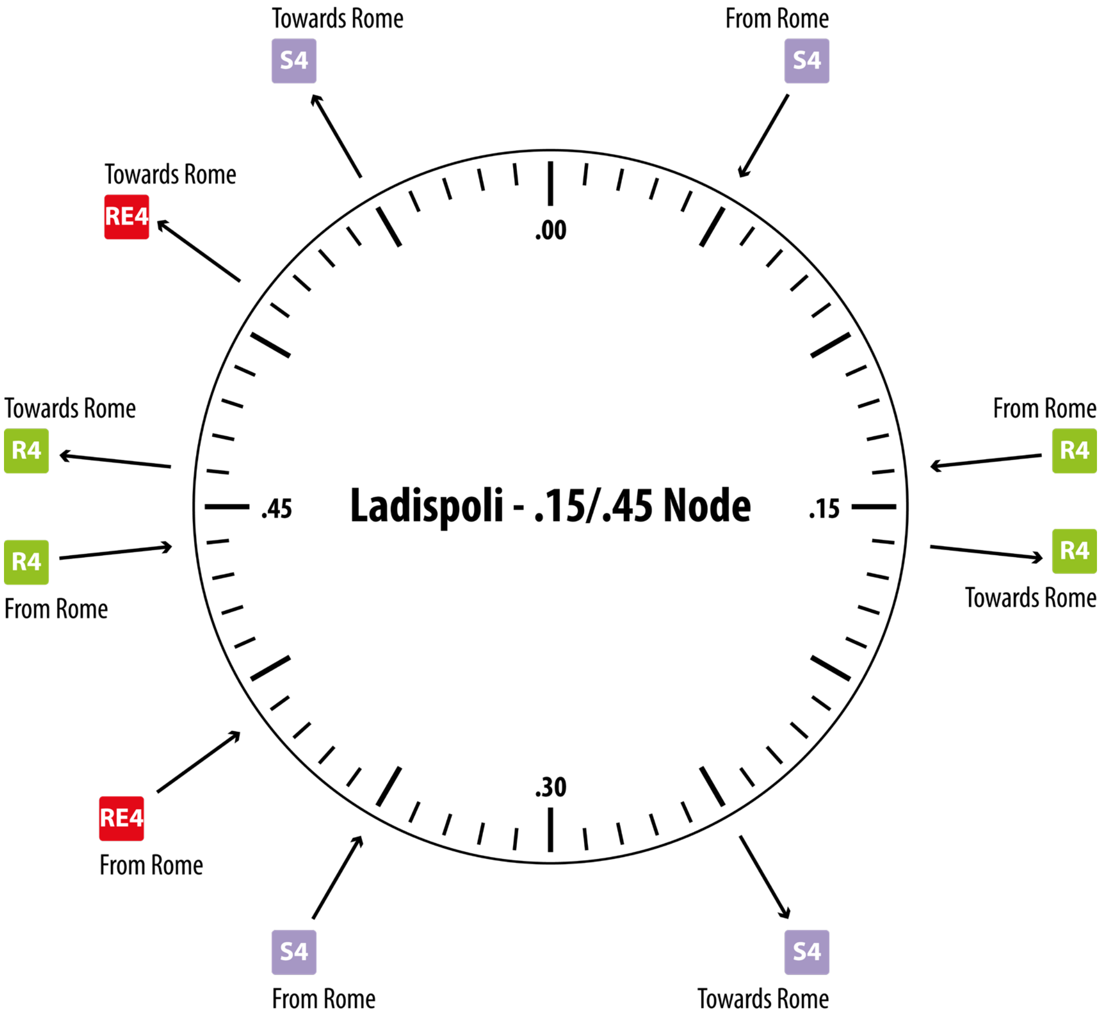
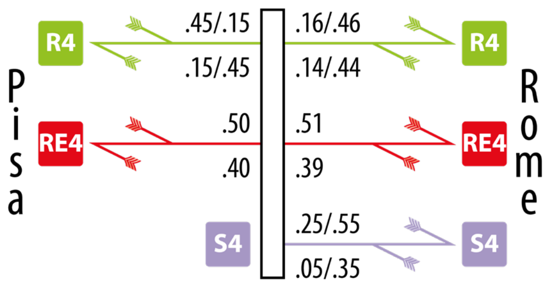


Figure 135 ↑ - Ladispoli's Node. Author's drawing
Figure 136 ↓ - Ladispoli's Node Netgraph. Author's drawing



As shown by the picture, the interchange among the three different service level it is possible only around minute .45, whilst, on the minute .15 node it is possible to have the connection only between the suburban and the regional line, both with 30 minutes headway. The second scheme (the netgraph) represents the arrival minutes of the trains in both directions (N.B. in Italian railways trains drive on the left thus the minutes follow this principle into the picture).

On the contrary, the Campoleone node is a .00/.30 node with no differences between the two periods.

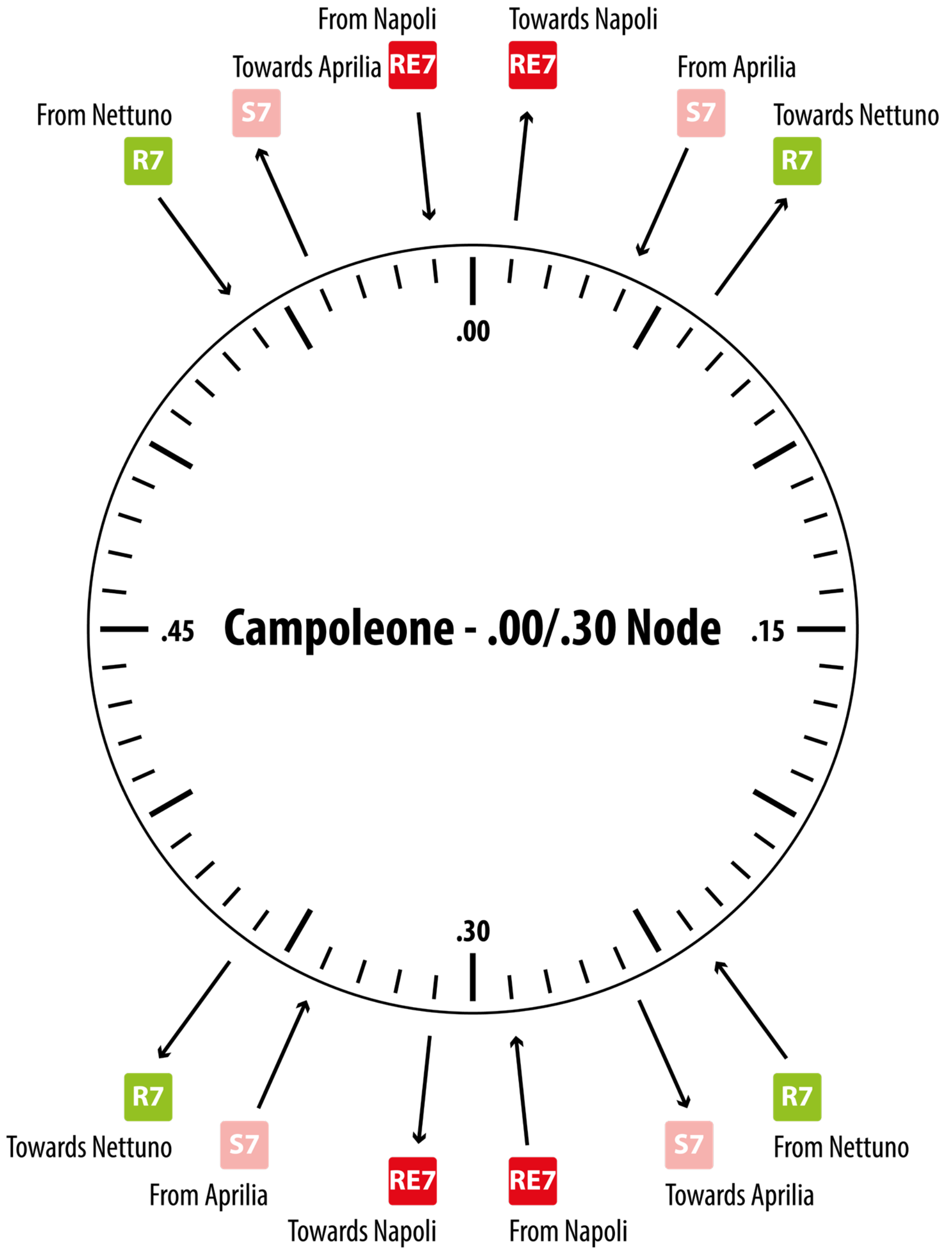


Figure 137 - Campoleone's Node. Author's drawing

However, analyzing this node another difference is notable here. Into Ladispoli node, all the trains coming from Rome arrive before minutes .45, and the trains going towards Rome, are passing throughout Ladispoli after minute .45. Here, differently, trains do not follow this rule. The netgraph of the line can help to understand better the reasons behind this different design (a netgraph of a line represents the main stations, thus the nodes, of the line, with the minute of arrival and departures of trains).

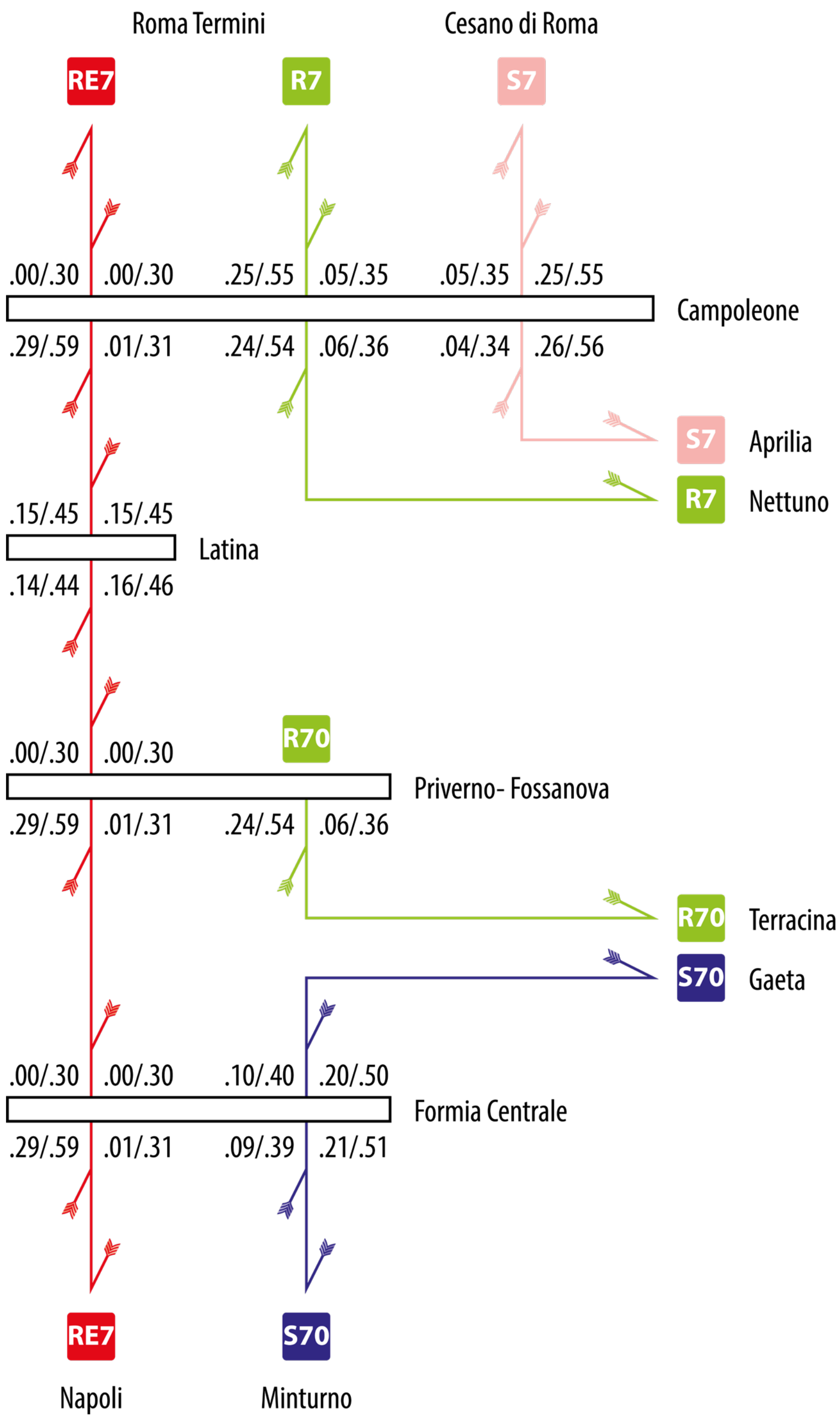


Figure 138 - Main Nodes' Netgraph on Roma-Napoli Railway. Author's drawing

Going from Rome towards south, around minute .00, the first train coming is the suburban train, at minute 0.55, then is time for the region-express, at minute .00, and finally, the regional train arrives at minute .05. The reason why it arrives after and not before, is that this node aims to grant easy connections between the S line coming from Rome to the region-express train going towards Napoli, and between the regional train coming from Nettuno with the region-express train going towards Napoli. Travellers coming from Nettuno and directed to Rome do not need a connection, they can just stay on the R7, whilst people that want to go to Napoli need to change, and so the node is designed to advantage this kind of connection. Being a symmetrical timetable, as it can be seen from Campoleone's clock picture, it works in both directions: from Nettuno to Napoli and from Napoli to Nettuno.

Figure 139 - Genova Quarto dei Mille Station. Image downloaded from https://it.wikipedia.org/wiki/Stazione_di_Genova_Quarto_ dei_Mille#/media/File:Stazione_ferroviaria_di_Genova_Quarto_dei_Mille_03.jpg

The opposite happens in Roccasecca, where the node is designed to advantage the connection between R32 and the RE3 or 5 going towards Rome.

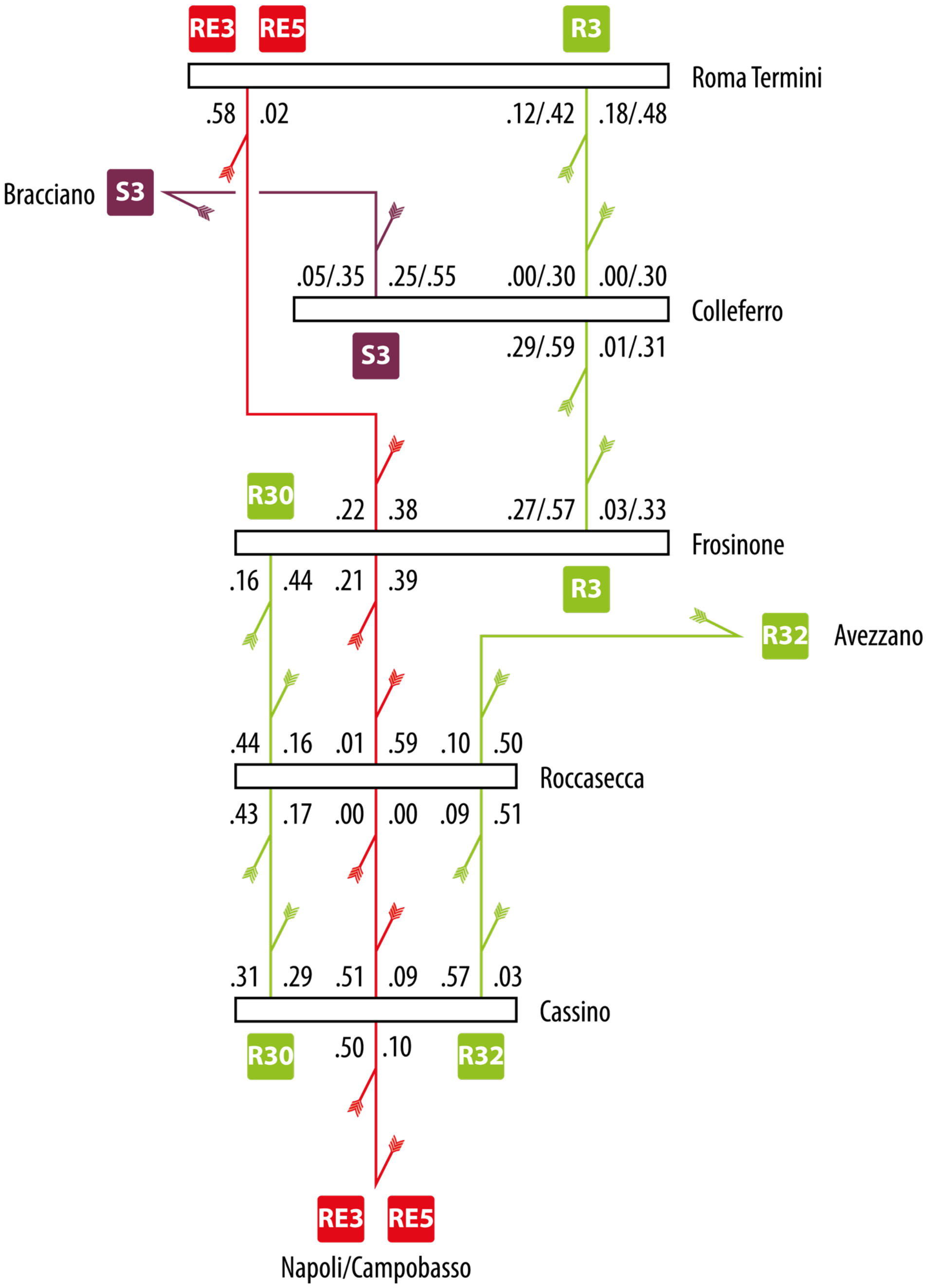


Figure 140 - Main Nodes' Netgraph on Roma-Cassino Railway. Author's drawing

The netgraph, and generally the nodes, can become an instrument for the local planner when they design the bus timetables. The principle of symmetry, indeed, are valid for trains as much for buses and all the other transport modes based on timetables. For instance, knowing that every hour all trains arrive at Colleferro station between minutes .55 and .05, and between minutes .25 and .35, the buses timetable could be designed to arrive at minute .50 and to leave at minute .10, so that all the bus users can take all the trains to each direction. Consequently, even though the bus had a 30 minutes headway, the travellers getting off the trains would always find the bus leaving in a few minutes, and vice-versa, the travellers getting off the bus would always find all trains leaving in a few minutes.

To sum up, in this section the design of interchange nodes has been applied to Lazio's network and some example has been detailed to make understand the concept of node. Moreover, it has been shown as nodes can be designed differently, and diverse designs mean different outcomes and so effect on travel.

3.1.5. Conclusion

In this chapter, it has been analyzed how to design the long-term scenario, the first instrument needed for implementing a new model. The first step is the infrastructural analysis. It had been already made in part 1, but this time it has been more detailed, in order to understand the theoretical capacity of each line. In Italy, the best technology allows to host up to 16 trains per hour per direction at slow speed on a double-track railway, 12 if trains run fast. However, it has been also explained that the maximum theoretical capacity is affected by the timetable. The design of a timetable, indeed, could decrease the capacity of a double-track railway down to 4 trains per hour per direction even though it is updated with the best technology available. This section outlines the importance of timetable design in relation to the infrastructure because a bad-designed timetable could stronmgly limit the efficiency even of the best railway in the world. After this, the focus has been moved to the lines' design principles, that are added to the theory explained in chapter 2.2. To design an effective service network coherent to the context, indeed, it is necessary to take into account four principles: the geometry of lines, the existent services, the existent planning strategies and the demand magnitude along with infrastructural features. Successively, in section 3.1.3, those principles and the previous theory have been applied to Lazio in order to design each line shaping the long term scenario. As stated in the theory, three different groups of lines representing three different service levels have been designed:

- Suburban lines, that thanks to the high frequency can compete with the private vehicle on both the displacements internal to the historic city and the connections between the metropolitan area and the historic city.
- Regional lines, that connect Rome to the regional localities and the main cities of the metropolitan area.
- Regio-express lines, that offer fast connection among Rome and the other important regional cities.

Finally, being all the lines designed, the interchange node design process, started with the infrastructural analysis, can be completed, designing the nodes in detail. The design of every node of the network will be made only if the scenario becomes reality, but here, it has been considered very important to design in detail the most common nodes as an example for the others' design.

Into the next chapter, it will be explained what are the tools necessary to transform a planned scenario into reality in the Italian context.

Figure 141 - Koln Railway Bridge, Koln. Image downloaded from https://www.railpictures.net/viewphoto.php?id=494953&nseq=981

3.2. Realizing the Designed Service

A railway service system, even though planned in every detail, is just the beginning. Indeed, an administrative process is necessary to start improving it. This chapter describes to the reader what is the administrative process, into the Italian context, to realize a plan, hence, how to start to implement the planned service network. In Italy, the regional train service is managed by the regions, that plan the service and pay for it. To manage it, three main documents are signed by the regions and the infrastructure manager: the '*Accordo Quadro*' (AQ) that mainly regards the service, the '*Piano Commerciale*' (RFI, 2020a), that talks about the infrastructure, and the Service Contract, that regulates the relationship between the region and the train operating company (TOC). In the first section, the AQ, the PC and the Service Contract are described in detail, concerning what they do and why it is important to look at them; nextly, the design of the short-term scenario, derived by the PC analysis is presented and explained, and finally, it is explained how to transform this scenario into reality, designing a new AQ.

3.2.1. 'Accordo Quadro', 'Piano Commerciale' and Service Contract.

The Accordo Quadro (AQ or Framework Agreement, in English) is a document signed by the region and the infrastructural manager (RFI in the Italian context) where the region reserves the capacity on the railway infrastructure over a period that can go from three to ten years (Consalvi, 2020b). Thus, from the infrastructure manager point of view, the AQ is an instrument used to assign capacity over a line to different train companies, whilst for the region, the AQ is the operative instrument that realizes the planned services (ibid). It is important to understand that, being the regional transport subsidized by the region at least for its 65% (D.lgs 422/1997), it is not the train operating company that will run the train, as it is for the high-speed trains, for instance, but the region that decides which and when trains will run, thus it is the region that signs the AQ. The AQ is made of many attachments but among those the most interesting are attachment A and D. The former includes the capacity requested for the first year of AQ validity whilst the ladder represents the service developments along with the AQ duration. To sum up, attachment A defines the service in year 1, whilst attachment D describes the service in the last year of AQ validity, taking into account the infrastructural upgrading that will occur during that period (Consalvi, 2020b). Those planned upgrades can be found mainly into the PC, that is the planning document of RFI, the infrastructure manager, where all the upgrades and the work planned are listed, divided by region. This document is designed by the infrastructural manager but each region and the central government contributes to defining the time and the type of work needed. It is updated every year, and the last version of February 2020 includes the details of all the planned upgrades until 2023 and the overview of the work after 2023 (RFI, 2020a). The third and last document that influences the short-term scenario design is the Contract Service, the contract signed by the public authority and the TOC where it is written everything related to the train operations: from the subside magnitude to the rolling stock that must be used on a defined line. It is signed maximum every 10 years, that can be 15 if the TOC invests money in the service, for instance in new rolling stock, as happened in Lazio.

Into the next section, the process of design of the short-term scenario is described explaining its relation with the current AQ, PC and Service Contract.

3.2.2. The Short-Term Scenario

Here, the creation of the short-term scenario is described in detail. The short-term scenario is the first planning scenario that can be transposed into reality. In this section, it is explained how, starting from the long-term scenario, the AQ and the PC it is possible to design a short-term scenario that is technically feasible. The first action is to define the temporal coordinates of the scenario, secondly, it is necessary to analyze the infrastructural upgrades that should be ready within this temporal frame and finally, it is possible to design in detail the short-term scenario, that is the first step to realize the long-term vision.

3.2.2.1. Defining the Timeframe

The timeframe of the short-term scenario is defined by the AQ and the PC. The former defines the time to make a new capacity request, thus when to modify the existent services, the latter, on the contrary, provides with the upgrades schedule, fundamental to decide which services can be activated. The present AQ signed by Lazio and RFI in 2nd February 2018 will be effective until 2023 with an extension option for the next 5 years, until 2028. Consequently, the first window available to propose any considerable change is 2023. Besides, the PC defines the upgrades timeframe until 2023, thus this year could be considered as time 1 to start implementing the new model. However, many different infrastructural updates will probably be needed, and it is unlikely that they will be ready all together. Thus, the approach to the new AQ that will be signed in 2023 should forecast the implementation of the model when the infrastructural upgrades needed are completed. On a different scale, it is the approach that has been used in Milan when the ‘Passante’ has been opened: linking the opening of a new infrastructure with the activation of new services.

Analysing the PC, there are some upgrades concerning the capacity that should be ready by 2023. From Cesano di Roma to Tiburtina and Ciampino, it will be possible to run 16 train per hour per direction instead of the actual 10, as regards the Cesano – Roma Tiburtina railway, and 12 as regards the Roma Termini – Ciampino railway. Similarly, by 2023 the double-track between Lunghezza and Guidonia will be ready, granting capacity for 10 trains per hour per direction, instead of the actual 2. Moreover, the new station of Pigneto and the new station of Villa Senni should be built by 2023, the former granting the interchange among trains going from Roma Tiburtina to Cesano or Fiumicino and Metro line C, while the latter allowing the double of frequency (2 trains per hour per direction instead of 1) from Ciampino to Frascati.

3.2.2.2. Designing The Lines

Stated this, it is now possible to design the short-term scenario, having a clear picture of the infrastructure that will be ready within the chosen timeframe. Attachment 2 shows the service network that could be viable in 2023 (for a full understanding of this subsection it is recommended to analyze the attachment 2 while reading). By observing the map and comparing it to the actual service, it is possible to understand the principles behind the design of this scenario. Before starting, the map has been designed to outline the new services, thus, the services that in this scenario have remained as they are today, are opacified. Firstly, it is clear that the new services regard mainly the infrastructures that have been upgraded:

- S2, ex FL2, will run on the new doubled track from Roma Tiburtina to Guidonia every 15 minutes, and 1 out of 2 trains will continue to Tivoli.
- S3, S6 and S7, will run from Cesano to Ciampino, where the new signalling system will be implemented, allowing high frequencies.
- S0, similarly to the previous lines, will start running from Roma Tiburtina to Vigna Clara.

The remaining new S lines, S1 and S5, will have the same itinerary of the existent correspondent lines, but the frequency will be increased: S1 will have 15 minutes headway from FCO to Fara Sabina all over the service period, while S5 will double its frequency from Roma Termini to Ciampino, passing from 1 to 2 trains per hour per direction. However, from Ciampino to Albano, because of infrastructural limits, the headway will remain of 60 minutes. Besides, on the Roma Flaminio – Viterbo railway, the new line MF will be activated, and the urban services finally separated by those urban.

Similarly, excluding line S1, on the railways where an S line will be activated, all the other services will be reorganized to create different service levels: along with line S2, S3, S6 and S7 the new lines R2, R3, R5, R7, RE2, RE3. RE5 and RE7 will be activated with their regular interval timetable. Moreover, some of the regional lines linked to the new lines will be upgraded, reordered and renamed: R30, R32 and R70. The renaming operation will regard only the lines that will be coherent with the long-term scenario principles (explained in chapter 3.2), as, for instance, the RIT and the service levels division.

However, even though regular interval timetables are introduced for the new lines, the integration among timetables with the interchange nodes will be very limited. The existent contract service between Lazio and Trenitalia, valid until 2032, designate the train operating company to provide with the rolling stock, that has different features from those indicated into the long term scenario. Hence, even though the implementation of the system will be possible, it will not be very effective, in the beginning, due to the rolling stock. Moreover, the service contract includes some service improvements, as the S1 and S2 (into the AQ and the service contract is forecasted that they will have 15 minutes headway all over the service period), but those regarding the other lines will need to be negotiated because 2023 is 3 years from now, not enough for buying new rolling stock to use for tendering the new services. Fortunately, 8 years, the time from now to the end of the next AQ, will be sufficient to buy new trains and to tender, at least partially, the train service (as it will be explained in detail in next chapter 3.3).

To sum up, designing the short-term scenario is fundamental to set up a timeframe, that will be defined by the AQ and the other contracts or documents regarding regional railways. The AQ is the contract used to reserve the capacity over a railway infrastructure, thus it is the document where the planning can become reality, and so the first document indicating the possible timeframe. Depending on the distance from time 0, when the new service is designed, and time 1, when the model is starting to be implemented, the time 1 service network is more or less influenced by the existing contracts. In this case, indeed, the creation of regular interval timetable on the new lines it will be possible, but the interchange nodes, due to the rolling stock, that depends also on the service contract, will not be as effective as they will be using proper rolling stock. Next chapter (3.3) will describe in detail the relation among the rolling stock and the service tendering, in addition to explaining the best theoretical way to tender a transport system.

3.2.3. Designing the New AQ

In this section, the principles that should be used to design an AQ, the document necessary to request capacity to the infrastructure manager, are described. This section is based on the experience of the author, during his internship in Regione Lombardia where he helped to design the Lombardia AQ for the period 2021-2026. The AQ, as it has been explained, is the only document that realizes the planned service, because is the document that defines in detail which trains are running on the network, where are they going, when are they going, in which station are they stopping and so on.

Once the short-term scenario is done, and it is time to design a new AQ, what has been decided for the scenario needs to be transported into the AQ. It is an official document with an official procedure, that requires to write things in a specific format, but everything that has been said until now, both regarding the long-term scenario and the short-term scenario, could be re-written to be compliant with the AQ format. As explained before, the AQ is made of many attachments but the most interesting for planning are attachment A and attachment D.

On the one hand, attachment A design is based on two different issues:

1. Which services can be implemented on this infrastructure?
2. Which services can be implemented with the available rolling stock?

As regards the first issue, the infrastructural upgrades planned and used to design the short-term scenario could be ready or not. Sometimes the work requires more time than expected, thus an infrastructure that was considered done by 2023 could be under construction by that time. Thus, when it is time to design the attachment A, it is needed to take into consideration the existing infrastructure and the upgrades that will be ready soon. All the AQ, indeed, are signed around February, and the attachment A is effective from the following 15th of December, thus attachment A can consider the existent infrastructure at the time the AQ is signed and those works that are going to finish in a few months. Nextly, once the infrastructure is checked, it is time to take a look at the rolling stock, in order to define which services can be really activated. The rolling stock, indeed, is fundamental: no trains means no services, independently from the ownership of the trains, that could be property of the region or the train operating company. In this case, it is already known that in 2023 there will not be trains bought by the region so that there will be necessary to agree with the TOC about the new lines to open, considering the trains needed and those available. Finally, into the attachment A something else is required: the table indicating the nodes and the headway of the different lines. It is indeed into the AQ that the symmetry and the interval of the timetables are established.

On the other hand, attachment D needs to be designed following one fundamental principle: the implementation of the new services on a railway needs to be linked to the infrastructural upgrades of the line. It is probable, as stated in the previous paragraph, that what is planned to be finished by 2023 will be finished later, and so that the short-term scenario will not be activated in one time. However, this is not an insurmountable problem. As it has been done by Lombardia in its AQ of

2017 and 2020, the attachment D can be designed taking into account this possibility. The attachment D is made of several schemes describing the services in the last year of AQ validity, but, into the standard format, there is no indication about what is going to happen in the years in between. The solution is to link the new services with the infrastructural upgrades. If, for instance, in 2023, the updates regarding the double-track from Lunghezza to Guidonia are not ready, and so line S2 cannot be activated (and with it lines R2 and RE2), into the attachment D there will be the scheme of the three lines, and the note that those will be activated once the infrastructure will be ready, no matter if in year 2 or 4 of the AQ. Besides, another issue to take into account is that from 2020 to 2023, hopefully, other infrastructural upgrades will be planned, so that the scenario to present into attachment D should consider also the new updates that will be done during the AQ duration that today are not planned.

However, into the 2020 AQ of Lombardia region, along with what is requested in attachment D, the region attached several schemes regarding the future network beyond the AQ timeframe. The reason behind this is to write into an official document the service that is wanted in the long-term. Thus, in this case, the map representing the long-term scenario could be attached to the AQ, to start telling the infrastructural manager which will be the future service wanted that will influence the next infrastructural upgrades.

3.2.4. Conclusion

This chapter has discussed the process of designing and implementation of the short-term scenario. The first section has described the main tools that will be used to implement it: the AQ, the PC and the Service Contract. The first is necessary to reserve the capacity on the network, the second to analyze the planned infrastructural upgrades and the third to regulate the relationship between the region and the train operating company. Once explained the tools, the short-term scenario con be designed. Firstly it is necessary to analyze the existent AQ, PC and service contract to set up the timeframe, that will be strictly related to the infrastructural updates panned into the PC. Designed the short-term scenario, it is needed to realize it. This can occur thanks to the AQ. When the present finishes its validity the short-term scenario will be used to write the new one, using one main principle: the new service will be linked to the infrastructural upgrades. When new infrastructural updates will be ready, new services will be opened on that infrastructure.

The next chapter will look at other governance tools necessary to following the implementation of the new service network, in relation to the choice of the rolling stock and the train operating company that will run the service.

Figure 142 - Railway Tracks. Image downloaded from https://libreshot.com/railway-tracks-and-train/

3.3. Tendering the Service

Contemporary to the AQ design, it is necessary to start thinking about who will run the planned service. There are two main approaches to decide which TOC will run the service (or part of it): a direct award or a public tendering. In this chapter, it is explained why between the two options a public tendering is more advantageous for the public authority, and how should a tender be designed in order to maximize the service efficiency and effectiveness. Hence, the first section of the chapter will be focused on the advantages of the tendering compared to the direct award; secondly, there will be defined gross and net cost contracts (NCC) and explained why the gross cost contract (GCC) is the best option; the third section will be about the unbundling concept and its benefits, whilst, finally, the relation between public tendering and rolling stock owned by the region will be enounced.

3.3.1. Tendering VS Direct Award

In this section, it will be explained why tendering the train service is more efficient than directly award it. In the beginning, the concepts of tendering and direct award are explained, and after that, the reason why tendering is more efficient than directly award the service. As regards the concepts of tendering and direct award, the former is a "*compromise between competition and regulation, where the public authority manages the competition among the companies that want to operate in a defined area organizing an auction with defined rules*" (Consalvi, 2020a, p. 3) whilst the latter is when a contract is awarded to a company, generally owned by the public authority itself, without competition (Law Insider, 2020)

Between these two, it is stated by the theory that tendering is more efficient because the subsidy cost for the public authority decreases when the service is tendered. In Germany, for instance, since 1996 the public transport networks are managed by the Lands that outsourced It to tendering authorities which opened part of their transport networks to competitive tender (Consalvi, 2020a; Beck & Kuhl, 2007). The data demonstrated that tendering operation had a very good impact on the cost-effective ratio of the service, reducing the subsidy level. In the Schleswig-Holstein Land, the tendering process has reduced the cost per train-kilometre from 7.48€ to 4.37€, whilst, in the Hesse Land the cost did not decrease but the service quality raised significantly (ibid). Furthermore, it has been demonstrated that even though the winner of the competition is the previous monopolist, the tender process increases the efficiency of the service. On the Passau – Munchen line in Bayern, for instance, the tender has been won by DB, the Germany state company that was running the service before the tendering. However, the subsidy cost per kilometre has passed from 8.5€ to 0.75€ and new rolling stock has been purchased by the company (ibid). Similarly, in London, the subsidy cost for bus operations decreased by 20% after the introduction of competition in 1985 (Consalvi 2020a; Kennedy, 1995). Hence, it is possible to argue that tendering the transport service makes it more efficient reducing the subsidy cost per kilometre or increasing the service quality or sometimes both.

Stated this, in the next sections, it will be explained how to increase the efficiency of the tendering system, because the results generated by a tender depends on the tender design itself.

3.3.2. Gross Cost VS Net Cost Contracts

Into the transport world, when a public authority signs a contract with a transport company, it could be a gross cost contract (GCC) or a net cost contract (NCC). In this section, the concepts of gross cost and net cost are briefly explained and then it is argued that the GCCs are the best option for the authority because they are cheaper than NCC. Both contract types provide the transport companies for a subsidy, but they differently treat the revenue risk: in the gross cost contract, it lays on the public authority, whilst in the net cost contracts it lays on the transport operator (Consalvi, 2020a). Thus, in GCCs the public authority collects the revenues and covers all operators costs with subsidy (Laljibhai Chaudhary, 2005) whilst in NCCs, public authority covers around 65% of the costs and the companies collect the fares to earn the remaining 35% (D.lgs 422/1997). Consequently, on the one hand, the gross cost contracts ensure that the system runs efficiently despite the number of revenues, while, on the other hand, the net cost contracts should ensure the maximum efficiency of the companies, pushing it to collect the fares and to increase the number of users, that would raise company's revenues (Consalvi, 2020a).

In 1995, P. White and S. Tough have written a paper comparing different data about competitive tenders made in England in 1991 by the authorities of Essex, Oxfordshire, Wiltshire and East Sussex, demonstrating that GCCs are cheaper for the authority than net cost contracts. They have stated indeed that "*GC contracts in Essex represent a 13% saving on the cost per mile compared with [net cost (NC)] contracts in Oxfordshire. Similarly, within the dual-tendering authorities of Wiltshire and East Sussex, GC contracts represented savings on [NC] on a cost per mile basis of 27% and 7% respectively. In considering the effect of these GC advantages on a typical local authority budget of around 3 million, a GC contractor such as Essex County Council could operate 600,000 more contracted miles on the same budget as an authority using [NC] methods*" (White & Tough, 1995). The main reason behind this difference is that in the case of gross cost contracts, laying the risk on the public authority, also small operators take part in the competition, whilst for net cost contracts the number of bidders is smaller. Comparing the Essex (GCC) and the Oxfordshire (NCC) tenders, for instance, it is observable that the number of medium-sized operators is the same, but in Essex, 25 more small operators made the difference (White & Tough, 1995; Consalvi, 2020a). It has been demonstrated, indeed, that the more are the bidders, the small is the subsidy (Amaral et al. 2013), or in other words, that a bigger competition means better results for the authority (Consalvi, 2020a). Besides, in complex contexts, as it could be Lazio, the GCC are better also for the fare integration management, because it is much easier and so cheaper, for the authority, to manage it (ibid).

To sum up, data on different tenders based on both GCC and NCC demonstrated that gross cost contracts are cheaper for the authority because, laying the revenue risk on the public authority, more small operators participate in the competition, and so the average cost per kilometre decreases. The same principle is behind the network unbundling that will be explained in the next section.

3.3.3. Unbundling the Network

Unbundling the network is another instrument that the public authority can use when designing the tender in order to reduce the subsidy magnitude. In this section, the unbundling will be defined and the reason why it makes the system more efficient explained. Unbundling is defined by Cambridge dictionary (2020) as "*dividing a business into separate parts"*. In relation to the transport context, unbundling a network means dividing the service management among different companies, that will run different lines of a network (Consalvi, 2020).

Data about London between 1999 and 2008, when more than half of the network had been tendered at least once, show that the bigger was the contract size, the smaller was the number of bids (Amaral et al, 2013). In London indeed, the network is tendered by bus line or by groups of bus lines. The dimension of the contract influences the number of companies participating in the bid because there is a direct proportion between contract magnitude and company dimension. As stated before, the offer is related to the bidders' number. Indeed, *"the average cost per mile corresponding to the winning bid decreases from about £7.80 in one-bidder auctions to £2.66 per mile in nine-bidders auctions"* (ibid p. 24).

To sum up, similarly as what happens with gross cost contracts, the size of the contract influence the number of bidders. The bigger it is, the smaller will be the offers' number and so the bigger will be the service average cost per kilometre. Hence, to decrease it and so increase the system efficiency, it is appropriate to divide the network into different parts and separately tender those.

3.3.4. The Importance of Owning the Rolling Stock

This section will explain why it is advantageous that the rolling stock is owned by the public authority that is tendering the service. As stated until now, a tender process is efficient when many companies participate in the competition, because it leads to small subsidies. Inside the competition, the rolling stock can play a pivotal role in influencing the bids. Into the railway world, indeed, rolling stock is very expensive. Lombardia, for instance, has bought, in 2017, 176 new trains and paid for those 1.6 billion euros, which is on average 9 million per train (Il Cittadino MB, 2020). If the rolling stock is not owned by the public authority that is tendering the service, the region in this thesis context, the train operating companies will have to provide with it. However, being the trains expensive, only big companies or the company that is already running the service will be able to take part in the tender, and this, as said in the previous sections, does not help the public authority to reach its aim: make the service as efficient as possible. On the contrary, if the authority provides with the rolling stock, also small companies can participate to the tender process, and, if a company does not respect the contract, it is easier to substitute it because it will be easier to find another one. Hence, If the rolling stock is owned by the public authority that designs the tender, the competition will be more fair and open to many companies, and so the subsidy cost will be smaller.

3.3.5. Conclusion

To decide which TOC will run a transport network and to make it cost-effective for the public authorities, a public tendering is more efficient than a direct award because it reduces the subsidy cost. However, to make the tender as efficient as possible, the contract offered needs to have some other features. Firstly, the contract must use the gross cost principle, secondly, the network must be unbundled, so many tenders need to be designed, each one for a portion of the network, and finally, the public authority must own the rolling stock. Those features have the same impact on the tender: they allow a bigger number of bidders because they permit also to small companies to participate. The major is the number of participants, the more convenient will be the final offer for the public authority. Besides, owning the rolling stock would make easier to substitute a company that does not respect the contract.

If these concepts are applied to Lazio train service, it is clear that the absence of the rolling stock and the presence of an existent contract valid until 2032 makes it difficult to tender the service in the next few years. However, those years until 2032 are a sufficient period to buy new trains and to define how to unbundle the network.

3.4. Service Branding

This chapter aims to provide the reader with the basic elements necessary to effectively brand the service, that is one of the most important things that should be done before the new service implementation. As explained in section 2.2.7, in order to make it effective, a transport system needs to be branded and along with that, it is necessary to design the relative wayfinding system. Thus, the following objects need to be designed before 2023 (that is the year when the service implementation will theoretically start):

1. The System Logo.
2. The Service Map.
3. The Lines Scheme.
4. The Wayfinding System.

The system logo should be designed and installed in all the station where the new lines will stop, to make the new service recognizable. The principle is to create the Lazio's logo for railway service alike the underground logo used in London or Madrid or the S and R logos used in Lombardia, but, most importantly, it must be coherent with the other three points of the previous list.

The service map is pivotal to provide the traveller with an overview of the system and make him easily orientate into the network. The map should be similar to an underground system map, but as happens in Lombardia, there could be many versions having different scale. It could be a scheme of the network, similar to attachment 1 and 2 (but it should be remembered that those are not map thought for travellers), or a map geographically accurate. The message must be clear, and so the map must be very user-friendly and easy to read.

Figure 143 - S Lines Schemes, Milano. Photographed by Elena Foresti

Other fundamental objects that must be designed are the line schemes. They must be located on every platform and they must provide the travellers with detailed information about the line they can use on that platform, similar to the panels introduced in Lombardia for Expo 2015. The fundamental information that should be provided are stops, connections and frequency.

Finally, the wayfinding system must be designed, with its graphic, from text font to logos. It must include the other elements described until now, providing them with a comprehensive graphic style that will make them communicate among themselves and with the other elements of the wayfinding system, from the toilette sign into the stations to the arrows indicating the platform location.

To sum up, contemporary to the service design, it is necessary to create a logo for the system, at least one map to help the navigation through the network, line schemes to put on platforms and a comprehensive wayfinding system including everything, from the logo and the maps to the signs inside the train stations. This policy aims to increase the effectiveness of the system providing it with a clear identity, recognizable by the travellers and that can help them to navigate into the system.

3.5. Future Steps

This chapter is about what the public administration should do once the implementation process has started. It is based on the assumption that the new AQ is signed and so that the implementation of the new service model is going on. In the first paragraph, the processes that need particular attention are outlined, whilst in the second and the third there is a description of what the administration should start thinking to implement and upgrade the model.

Once the model implementation has started, thus the new AQ is signed, the work has just begun. Even though the near steps are planned and designed, some processes are still ongoing and it is necessary to take care of them. The rolling stock, for instance, in this situation need to be purchased and, considered that by 2023 would not be possible to have it, the new lines that require new trains will be the object of the new AQ, probably in 2028. Purchasing trains is a long operation, that requires years, as it has been already said for Lombardia region, that has started the buying process in 2017 and the first train has arrived at the end of 2019.

Contemporary, it is fundamental that the public authority starts to work on infrastructural planning. If the implementation of the long-term scenario has passed through the analysis of the actual infrastructure and its forecasted planning in order to design the short-term services, it is pivotal to reverse the process and so changing the PC coherently to what is included in the long-term scenario. The first infrastructural upgrade not planned but needed by the scenario is the implementation of speed class P on the network, to be ready by 2038 with both the new rolling stock and the infrastructure to activate some of the new lines. Contemporary, it would be necessary to start working on the big projects that will require many years to be completed, as the new railway from Fara Sabina to Rieti.

Furthermore, as regards the service, the public authority should start planning those extraordinary services that will be activated in case of special events. If special events take place all around the region, there should be a temporary service strengthening on the lines that supply that location. For instance, if there is a Pope special event in Rome, the lines passing through Roma San Pietro station should have a frequency increase, or, if there is a football match in the evening, the train service should be prolonged to allow the supporters to go back home after the match. Besides, it could be implemented together with the municipality, a night urban network to serve those areas where the train is the only effective mode except for the private car. Another policy that could be implemented on the regional scale, thanks to the new long-term scenario, is a strong transit-oriented development strategy, that takes into account the forecasted planning to shape the urban development over the region, as happens in Copenaghen since 1948 (Ministry of the Environment, 2015), where the regional development has followed the railway infrastructure.

To conclude, it is clear that starting to implement the model is just the beginning, but to make it efficient and effective, many other actions are necessary. The rolling stock purchasing process, for instance, needs to be followed, and along with it the paradigm of infrastructural planning need to be changed, in order to have in the future an infrastructure able to host the lines planned in the long-term scenario. Moreover, many other mobility strategies regarding the railway service can be improved, as special trains for special events or a night urban network.

3.6. Conclusion

In part 3, the theory explained in part 2 has been applied to Lazio's context to address its mobility problem outlined in part 1. The first step to applying the theory explained has been to build a service network long-term scenario, that works as a target to reach. The design of the long-term scenario requires different steps: some of them has been presented in chapter 2.2 whilst others more practical has been described in the first section of this chapter, as the infrastructural context analysis and the lines design principles. Described the principles needed to design it, the long-term scenario has been presented line by line, describing in detail all their features, and the structure behind the new network has been explained. After that, in chapter 3.2, it has been shown how to realize the plan. The first step is to design a short-term scenario, that can be designed only analyzing some administrative documents, that have been presented and explained at the beginning of the section. Those will be necessary to design the short-term scenario and to implement it. Successively, in chapter 3.3 the need for tendering the system has been explained, explicating also how it is possible to increase its efficiency. Similarly, chapter 3.4 has described the basic elements necessary to effectively brand the new network, whilst the reasons behind those have already been described in chapter 3.2. Finally, chapter 3.5 talks about the next step that the public authority should undertake to improve the renewed mobility system once the actions described in previous chapters have been carried on.

Figure 144 - Railway Bridge. Image downloaded from https://bashooka.com/inspiration/monochrome-photographs/

4. Conclusion and Future Perspective

This last part of the thesis summarizes concept expressed in this dissertation, the main findings and the future perspective opened by it.

4.1. Summary

The increasing environmental crisis is pushing the world to find solutions to its problem. Among these problems there is transport which contributes to it generating a significant amount of CO_2. Among the different transport modes there are some more polluting than others, mainly because of technical reason, first from all, cars. Along with the pollution problem, the role itself of cars into many cities has been discussed, in order to go back to design cities for people and not vehicles. This environmental and city-dimensional pressure is perceived also in Rome and its region. It is indeed argued in this thesis, in part 1, the existence of a mobility problem in both Rome and Lazio, throughout the critical analysis of the mobility data available for this area. The main results are that on the one hand, the public transit modal share is lower than in other European capitals, and on the other, that the road network is not efficient to meet the mobility demand, that generates a loss of over than 250 hours per person per year. If the two elements are considered together, it is arguable that the public transit system is not efficient nor effective, preferring people to lose time in congestion instead of using it.

Consequently, to improve the mobility of both city and region, that has been analysed how strictly related are, it is debated the necessity to work on a mobility system that could address this multiscalar problem. Because of its characteristics, the railway network has been chosen as the best system to solve this mobility issue, so that Lazio's railway network has been analysed from three different perspectives: infrastructure, service and rolling stock. The analysis shows that the system is not poor but that improvements can be made and must be made if it is wanted to have it address the regional mobility problem.

Moving from the need for improving the regional railway system, part 2 of the thesis argues that the most efficient railway service model in terms of passenger volume is the so-called Swiss model. Indeed, due to its characteristics, for instance, the integrated regular interval timetables, it makes the train a valid transport solution. The model design, indeed, not only takes into account the transport theory but also the mobility theory, considering the overall aspects of this phenomenon. After the theoretical discussion, data about Switzerland and Lombardia, two different contexts where the model has been applied, are presented, demonstrating that after its implementation the number of passengers on the network has significantly increased.

Nextly, part 3 designs the new railway service in Lazio and Rome, the context analysed in part 1, following the principles of the Swiss model discussed in part 2. However, it is argued here that addition empirical knowledge is needed for the model design, thus other design principles are debated before the actual design process. Along with the design process, in this part, there is also reviewed the administrative process necessary to realize the designed service model, looking through the administrative tools needed for it. Finally, last chapters talk about other policies that the public authority should develop in order to increase the effectiveness of the model.

4.2. Main Findings

This chapter is dedicated to outlining the main findings of this thesis. First of all, it is confirmed by Rome and Lazio's recent history the strong relation between mobility and its spatial context. The city and the region, indeed, shape the mobility, that influences back the surroundings. This circle, if not properly managed, could bring to critical situations, like the extreme periphery of Rome, where the neighbourhoods built to take advantage of the high accessibility granted by the highway finished congesting the highway itself, ending in a complicated situation with complicated solutions.

Secondly, in part 2 the model analysis underlines the importance to treat the classical transport intervention, as the railway service planning can be, as mobility intervention. Analysing the new service implementation as a mobility work means to increase significantly its effectiveness. The mobility perspective indeed enlarges the perspective and allows solutions that are more effective, due to a better analysis that takes into account the complex and multifaceted nature of the mobility phenomenon.

Another principle argued by this dissertation is the methodological approach to railway planning, that must consider together service, infrastructure and rolling stock, or in other words, software and hardware. A railway system is indeed made of both hardware (infrastructure and trains) and software (timetables). As argued in part 2, the effectiveness and efficiency of a railway network mainly depend on the service rather than on the tracks. Thus, it is possible to state that from the methodological point of view the timetable design is more important and must be used to define the infrastructure development along with the rolling stock, as applied in part 3. The infrastructure and the rolling stock need to realize the service and to make it following its principles: into the Swiss model, for instance, the travel time between two stations is fundamental for the model functioning so that the infrastructure and the rolling stock need to guarantee the respect of that parameter.

Furthermore, as stated into the methodology, this thesis is made of 3 fundamental parts:

1. Context analysis.
2. Theory of the model.
3. Model implementation in the analysed context

These three main parts are a methodological structure that could be applied to almost any model and context. Analysed a spatial context and a mobility model, it can be designed a mobility intervention based on the theory of the model applied in the context, and obviously, the results will change depending on both context and model chosen, but methodologically the process would be identical to that used in this thesis.

Finally, as regards, on the contrary, the realization of the designed model, this thesis can be a guideline to the realization of the designed railway service model (any model) in the Italian context. The administrative process described in the second half of part 3, indeed, is made throughout rules and documents that are constant in all the Italian regions. Similarly, the methodological process behind the service design, that requires as first step the designing of the long-term vision or scenario, can be applied to all the mobility planning interventions, in this case not only in the Italian context but everywhere.

4.3. Future Perspectives

This dissertation could be considered as an example of a holistic approach in railway service planning. It is indeed interesting to observe that the literature generally does not comprehend the analysis of all those topics treated here, but it is generally focused on singular or just a few aspects of the same branch of study: for example transport, or branding or planning. However, considered the number of themes analysed and the relatively short amount of time at disposal, it has been chosen to spend more words and analyse into detail those less treated into the literature. That is why, for instance, the interchange node design is very detailed whilst the branding and wayfinding systems are just briefly debated, focusing on the reasons why they are needed more than on the effective design. If the author had more time, indeed, he would have probably enhanced the branding and wayfinding analysis, probably designing at least a map for the users (it is important to remember that the attachment 1 and 2 are maps that show the network design but are not thought for public exposition). Similarly, the timetable design could have been more detailed and not only related to the long-term scenario but also to the short-term one, better underlying the difference that the suitable rolling stock could make on the system.

Future research, in addition to increasing the details of every topic discussed in this thesis, could also apply the same theoretical and methodological model to different contexts, Italian or international, to observe the different outcomes but also the similarities that there could be. Similarly, the same method could be applied to Rome context changing the model to apply and then comparing the results. Finally, this dissertation does not intentionally take into account the economical aspects of this intervention so that it would be interesting to research the cost-benefit ratio that could have this project, but it requires competencies that are not part of the author's background.

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