SAPIENZA
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Rail freight transport: multicriteria analysis of traffic control room workloads

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[… Ho passato da bambino interi pomeriggi con mio nonno, veterinario in pensione, sul cavalcavia di Firenze Campo Marte e la ritengo un'esperienza di formazione non meno importante della lettura dell'Eneide …]

ENRICO MENDUNI – *Andare per treni e stazioni*

Contents

1. Introduction

Transport is fundamental to our economy and society. Mobility is vital for growth and job creation. The transport industry directly employs around 10 million people and accounts for about 5% of gross domestic product (GDP). Effective transport systems are key to European companies' ability to compete in the world economy. Logistics, such as transport and storage, account for 10%–15% of the cost of a finished product for European companies. The quality of transport services has a major impact on people's quality of life. On average 13.2% of every household's budget is spent on transport goods and services.
These data are reported in [1] and they are relative to Europe during the writing of White Paper in 2011.
Between the end of XX and the beginning of XXI century, Europeans started to understand that an important improvement was necessary in transport field. Between 2000 and 2030 the demand of passengers was expected to increase of 42% instead, about freight, tonne-kilometre was predicted to increase of 63% [2]. Therefore since 1992, Europe has promulgated strategies in order to create a transport system that is competitive, efficient and more respectful for both present and future generations. The last program is the *White Paper* published in 2011 [3] with the implementation of 2016. Forty concretes ventures, to realize by 2050, are defined. There are many objectives where one of them is the reduction of greenhouse gas (GHG) emission. In fact the target value is 80-95% with reference to values of 1990. Others are about freight traffic by railway because this mode is indispensable to obtain a sustainable mobility based on low values of externality and road congestion. For example one strength of the railway is

the possibility of carrying high volumes on long distance (more than 300 km) between the first and last mile. The objective is the creation of trains with a length of 1,000 metres in order to reduce the flow of freight on roads. The target value is 30% of European freight moved by rail by 2030 and 50% by 2050. This will possible also through the realization of corridors called TENT-T (Trans-European Transport). They will be characterized by high degree of connection to world market, barriers reduced to minimum values and priority given to freight traffic. The latter condition is inspired to North America where there are railway lines dedicated to goods. In this way it is possible to reduce costs: in North America the cost is 1 cent per ton/km that is eight times lower than European value.

Therefore railway traffic of goods has become more and more important but how is it organized? How is a company able to organize all its resources in order to satisfy the demand? But in particular, how does the organization of drivers and locomotives work? There are many studies about train crew management. The most important were published between the end of 1990 and the beginning of 2000 [43] where few models were defined. These models are able to determine the crew distribution and the total number of crew (planning phase) or to allocate service to a known number of drivers (operating phase). Instead scientific research is poor considering the workload inside a traffic control room. How is workload distributed during the week? Is it homogeneous or are there days in which an operator is busier and other in which he is less busy? Hence the thesis has the object to answer to these questions. But before to go inside a traffic control room, fundamentals of freight railway traffic are explained with a special care to the kind of services that are supplied (chapter 3) and to the liberalization process in Europe and in Italy (chapter 4). Then there is a brief presentation

of FSI group with focus on Polo Mercitalia (chapter 5). Chapters 6, 7 and 8 deal with the presentation of the structure (Impianto Operativo Verona) of the traffic control room in which I developed my analysis. The analysis studies workloads of four operators that are inside the traffic control room of Verona. Instead for two operators is proposed a new scenario.

2. Supply chain management

The definition of *transport* given by the Cambridge dictionary [4] is "the movement of people or goods from one place to another". For this to be a transport it is necessary a mutual interaction between demand and supply (how someone, that needs to move from one origin to one destination or that needs to consume a good produced in some industries, may be satisfied using infrastructure and service networks). But transportation is only a small part inside the supply chain that is defined [5] as *a global network used to deliver products and services from raw materials to end customers through an engineered flow of information, physical distribution and cash*.

The simplest supply chain is made up by three entities (see *Figure 1*):

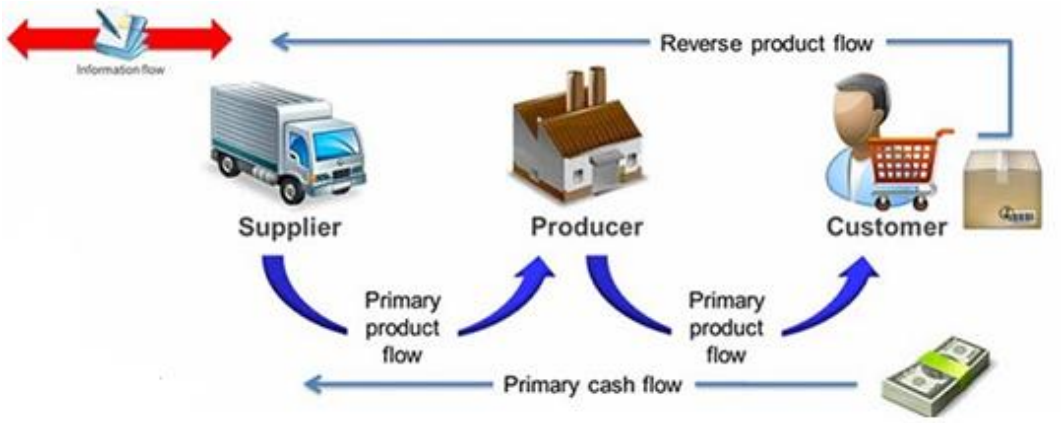

Figure 1 Supply chain entities and flows

- One supplier: a provider of goods and services with whom the buyer does business. It provides raw materials, energy, services, components for a product or services such as plastic, fabric or trains.

- One producer: it receives components from supplier to produce finished goods or service such as crockery from plastic, shirt from fabric and provide service from trains. In the last case supply chain management may be more abstract than the other one.
- One customer: it receives the final product therefore it wears the shirt, it uses the crockery and it travel on trains.

There are four basic flows that connect supply chain entities together:

- Flow of physical materials and services from supplier to the end customer (materials, components, supplies, services, finished products, etc).
- Flow of cash from customer to supplier of raw material (payments of products, supplies, etc).
- Flow of information back and forth along the chain.
- Reverse flow of products returned.

2.1. Logistic management

One of the activities that is fulfilled inside the supply chain management is the Logistics Management. It is defined as [6] *the art and science of obtaining, producing and distributing material and of producing in proper place and in proper quantities*. In other words, it is the part of supply chain management that plans, implements and controls the efficient forward and reverse flow, the storage of good, services and related information between the points of origin and the points of consumption. It is done in order to meet customer requirements. Logistics management is described by seven R's: Right product, in the Right quantity, in the Right condition at the Right place, at the Right time, to the Right customer at the Right place. There are specific areas that contribute to an integrated approach to logistics within supply chain management:

- Transportation: many modes of transportation play a role in the movement of goods through supply chain (air, rail, road, water, pipeline); selecting the most efficient combination of these modes it can be possible to improve the value created for customers by cutting delivery costs, improving the speed of delivery and reducing damage to products.
- Warehousing: it is related to activities like receiving, storing, shipping material to and from production or distribution locations; when freight is not on move between locations, it has to spend some time in warehouse.
- Reverse logistics: it is a way to handle the return, re-use, recycling or disposal of products that make the reverse journey from the customer to the supplier.
- Third party logistics (3PL) [7]: it is one company that works with shippers in order to manage another company's logistics operations department. It is the action of outsourcing activities that are related to logistics and distribution. It is usually specialized in integrating operations, warehousing, transportation services, cross-docking[1], inventory management, packaging and freight forwarding.
- Fourth party logistics (4PL) [7]: it is an integrator that accumulates resources, capabilities and technologies to run complete chain solutions; services provided are procurement, storage, distribution and processes; a 4PL company takes over the logistics section of a business.

[1] Cross-docking: it is practice in logistics of unloading material form an incoming semitrailer truck or railroad car and loading these materials directly into outbound trucks, trailers or railcars with little or no storage in between.

The main difference between 3PL and 4PL is that 3PL targets a single function whereas 4PL manages the entire process.

The fundamental goal of logistics is the achievement of customer satisfaction at the lowest cost. Therefore two fundamental aspects are cost minimization and service namely to outperform competitors in a cost-effective manner in a way that service levels are the same in each area without reducing costs only in one place or in another. In order to reach these objectives, following tactics are defined:

- Coordinating functions: full awareness of the effects on other parts of the system. Decisions made in any functional area are very likely to affect performance in other areas and an improvement in one may have negative consequences in another. Coordinating functions means that a cross-functional approach is necessary in logistics.
- Integrating the supply chain: it is possible through a series of steps that need to be defined during the design of logistics network.
    - to locate in the right countries: to analyse forward and reverse supply chains in order to select most suitable geographic locations that could make the logistics function more efficient and effective (not all countries are equal in terms of relevant concerns such as infrastructure, labour, regulations and taxes).
    - to develop an effective import-export strategy: to determine the volume of freight and to decide where to allocate inventory for strategic advantage.

- to select warehouse location: to determine the optimal number of warehouse, to calculate the optimal distance from markets and to establish the most effective placement of warehouses around the world.
- to select transportation modes and carries: to determine the mix of transportation modes that will most efficiently connect suppliers, producers, warehouses, distributors and customers and to select specific carriers
- to select the right number of partners: to select the minimum number of firms, freight forwarders and 3PL or a 4PL to manage forward and reverse logistics.
- to develop state of the art information systems: it is necessary in order to reduce inventory costs by more accurately and rapidly tracking demand information and location of goods.

- Substituting information for inventory: physical inventory can be replaced by better information in the following ways:
  - To improve communications: to talk with suppliers regularly and to discuss plans with them.
  - To collaborate with suppliers: to use HT to coordinate deliveries from suppliers, to remove obsolete inventory and to use continuous improvement tools and to share observation about trends.
  - To track inventory precisely: to track the exact location of inventory using bar codes and/or RFID (radio frequency identification) with GPS.

- Reducing number of partners: it is important because more partners there are in the chain and more difficult and expensive is to manage the chain. Reducing the number of partners can reduce operating costs, cycle time and inventory holding costs. There is, however, some lower limit below which create more problems rather than solving them.
- Pooling risks: it is a method of reducing stockouts by consolidating stock in centralized warehouses. The risk of stockouts increases as supply chains reduce the safety stock held at each node, move toward Just-In-Time ordering procedures and exceed expectation are bought. Statistically, when inventory is placed in a central warehouse, the total inventory necessary to maintain a level of service drops without increasing the risk of stockouts. An unexpectedly large order from any one customer will still be small in relation to the total supply available.

3. Transportation of goods

In this thesis the attention is focalized only on one part of the entire supply chain. In particular on freight transportation and on activities related to it. As explained before, the objective of a person/company that needs a transport is the utilization of one (or a combination) mode that is the best compromise between efficiency, safety and cost and that is able to realize a door to door service interacting with the minimum number of actors. The mode that, because of its flexibility, is the most suitable for the door to door service is the road. But in many cases the combination between modes is more useful in order to reduce disadvantages and to increase potentiality of each one. The transport on road has, among its strengths, the accessibility to the network and the flexibility of each route. These benefits are lost if the trip has a length of more than 350-600 km. It is possible to reduce the distance if the maximum length of trains is increased and if externalities are considered like air pollution. At this point the most suitable mode is the train that supplies more safety and capacity. For example a train with a length of 750 m can carry 80 TEU instead in United States a double-stacked[2] train with a length of 3,000 metres can carry 600 TEU (200-300 containers).

3.1. Intermodal transportation

A railway service rarely is able to realize a door to door service therefore it is indispensable the combination between a train and trucks for supplying the first and last mile. The only exception there is when both sender and addressee own a siding that connects the plant to the main railway network.

[2] Double-stacked rail transport: it is a form of intermodal freight transport where railroad cars carry two layers of intermodal containers.

But in last decades many sidings have been closed because of high cost of management. Therefore it is possible to say that in almost all cases an intermodal[3] service is necessary. In the beginning it was impossible to think about intermodality because each mode saw others as rival. In this rivalry governments played an important role because they supported one of them and they financed only it (for example the high rail modal share in Eastern European countries is given by high investments of communist regimes in railway field). Further complicating matters is the difficulty on transferring freight from one mode to another because of the absence of standard for boxes. If today container can be considered as [8] the pivot on which automatized systems of freight transport turn at global level, many years ago it was not evaluated in the same way. Because of quantity that is transported, the mode that needed containers most is maritime transport that however has always been conservative. Therefore it opposed strongly to the introduction of standardized boxes. Anyway since last years of XIX century, the importance of containers has been noticed. They avoided transporting unpacked freight and to manage singularly each good in each transfer. The first example [9] of containerization was made by Britain and France railways that tried to use wooden boxes for the transportation of furniture. By means cranes they moved boxes from wagons to horse-drawn carriages. Instead in 1920 the New York Central utilized aluminium containers characterized by low background and liftgate. Six aluminium containers filled one railway wagon. Another important intuition was that of Pennsylvania Railroad which decided to used container with a length of 2.5 metres (one-sixth of the dimension of a wagon). They thought about a smaller unit because each customer, remanding to fill a single wagon, could

[3] Intermodal service: it is a service that involves two or more different modes of transport

block a railroad car until 10 days. The wagon with containers was coupled to a train in order to reach an intermediate stop. Here, instead of loading and unloading unpacked freight, forklifts sorted containers from one train to another. In this way loading/unloading operations were reduced from 85 to 4 cents per tonnes. Slowly associations were born with the goal of promoting intermodal transport at global scale. For example in 1933 London Midland, Scottish Railway and France railways founded International Container Bureau. A container had a mass (tare + payload) of about five tonnes and standardized dimensions were 3.25x2.15x1.10 metres. But important improvements there were after an analysis of American government about the trip of a cargo ship, the Warrior. It travelled for 10 days to reach Bremerhaven (Germany) from Brooklyn, the same time to load/unload unpacked freight (six days for loading phase and four days for unloading phase). At this point it was clear that it was necessary an equipment able to package, move and load/unload freight. The first attempt consisted in getting on the ship the entire trailer. But immediately became evident that trailer without chassis and wheels was better in term of weight and space. Therefore in 1956 the oil tanker Ideal-X set sail from the port of Newark. For the first time spreader was used. It was an important innovation because it took automatically containers without a team of longshoremen that went on the top of transport unit in order to fix it to the handled equipment. The ship carried 58 containers and it was loaded in less than eight hours. Each container had a length of 33 feet (10.5 metres) and it was handled in seven minutes. In this way loading/unloading costs were reduced abruptly: they went from 5.83 to 0.16 dollars per tonnes. But for the definitive success of containers and intermodalism it is necessary to wait ISO. It was the International Standards Organization that was designated

to define standard dimensions that were valid at global level. After nine years of negotiation, it decided for fixed dimensions about height and width (8 feet) whereas length could assume values of 10, 20, 30 and 40 feet. The reference value was 20 feet and it was called "Twenty-foot Equivalent Unit" (TEU). Since the great majority of containers are now 40-foot-long, the term "Forty-foot Equivalent Unit" (FEU) is also used, but less commonly. Its capacity is 2,400 cubic feet or 68 cubic metres.
Before the definitive introduction of container there were also other attempts in order to facilitate the intermodalism. For example pallets were the most diffused unit, but their small size and lack of protective frame made their intermodal handling labour-intensive and prone to damage or theft. Other techniques were implemented like the piggyback (TOFC[4]) and LASH[5]. The first form of intermodal application to rail appeared in the late nineteenth century with practices dubbed "circus train" because lorries were rolled in on flatcars using a ramp, a practice that was pioneered by circuses (Barnum in 1872). This simple ramp-based technique enabled many rail terminals to become "intermodal" by offering piggyback services.
To sum up [10], the container is a large standard-size metal box into which cargo is packed for shipment aboard specially configured transport modes. It is designed to be moved with common handling equipment, enabling high-speed intermodal transfers in economically large units between ships, rail cars, truck chassis and barges using minimal labour. The use of containers shows the complementarity between freight transportation modes by offering a higher fluidity to movements and a standardization of loads. The container has substantially contributed to the adoption and

[4] TOFC (Trailers on flat cars): truck trailers are placed directly on rail cards.
[5] LASH (lighter aboard ship: river barges are placed directly onboard on seagoing ships.

diffusion of intermodal transportation, which has led to profound mutations in the transport sector. Through reduction of handling time, labour costs and packing costs, container transportation allows considerable improvement in the efficiency of transportation. It is estimated that containerization has reduced travel time for freight by a factor of 80 per cent. Thus, the relevance of containers is not what they are - simple boxes - but what they enable: intermodalism. Globalization could not have taken its current form without containerization.
While handling technology has influenced the development of intermodalism, another important factor has been changes in public policy. Deregulation in the United States in the early 1980s liberated firms from government control. Instead in Europe it appeared in 1986 when was signed the Single European Act (SEA) by the 12 CEE state members. The main objective was to complete the internal market by 1st January 1993. The internal market [11] is an area with no internal borders and in which there is a free movement of goods, people, services and capitals. Instead the directive number 440 of 1991 issued by CEE was the first one specific for the rail world. It allowed free European railway market. Now company were no longer prohibited from owning across modes, which developed a strong impetus towards intermodal cooperation.

In an intermodal transport chain there are four main functions (see *Figure 2*):

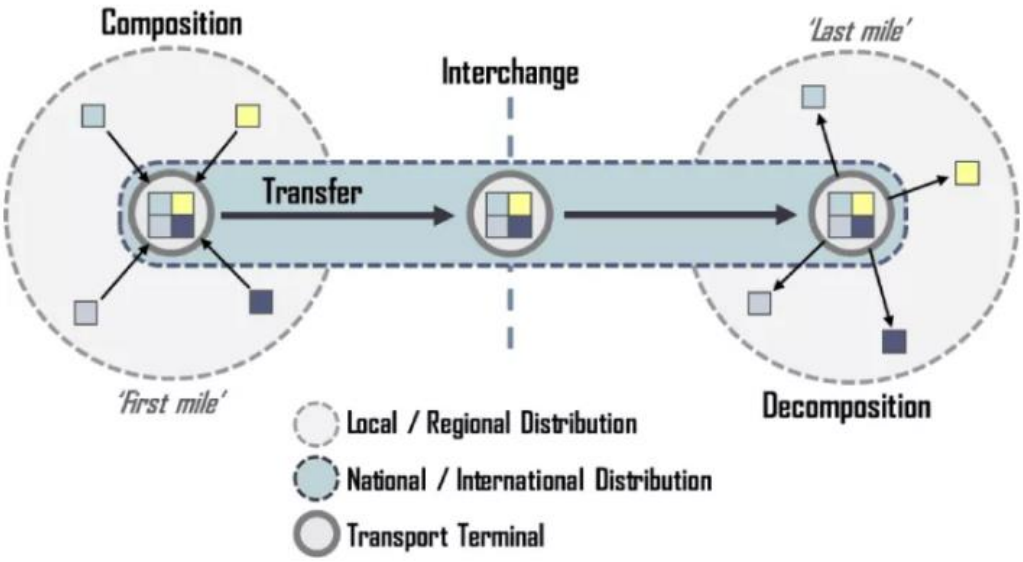

Figure 2 Intermodal transport chain

- **Composition (first mile):** the process of assembling and consolidating freight at a terminal that offers an intermodal interface between a local/regional distribution system and a national/international distribution system. Loads of freight coming from different suppliers are assembled at distribution centres so they can be forwarded to high-capacity modes such as rail and maritime shipping (transportation seeks massification but it is constrained by atomization). The dominant mode for such a process is trucking, as it offers flexibility and door-to-door services.
- **Connection (transfer):** involves a consolidated modal flow, such as a freight train or a containership, between at least two terminals, which takes place over national or international freight distribution systems.
- **Interchange:** the major intermodal function takes place at terminals whose purpose is to provide an efficient continuity within a

transport chain. Those terminals are dominantly within the realm of national or international freight distribution.

- **Decomposition (last mile):** once a load of freight has reached a terminal close to its destination, it has to be fragmented and transferred to the local/regional freight distribution system.

3.2. SWL and FLT

3.2.1. SWL and FLT definition

Who needs to send freight can follow two fundamentals ways (see *Figure 3*):

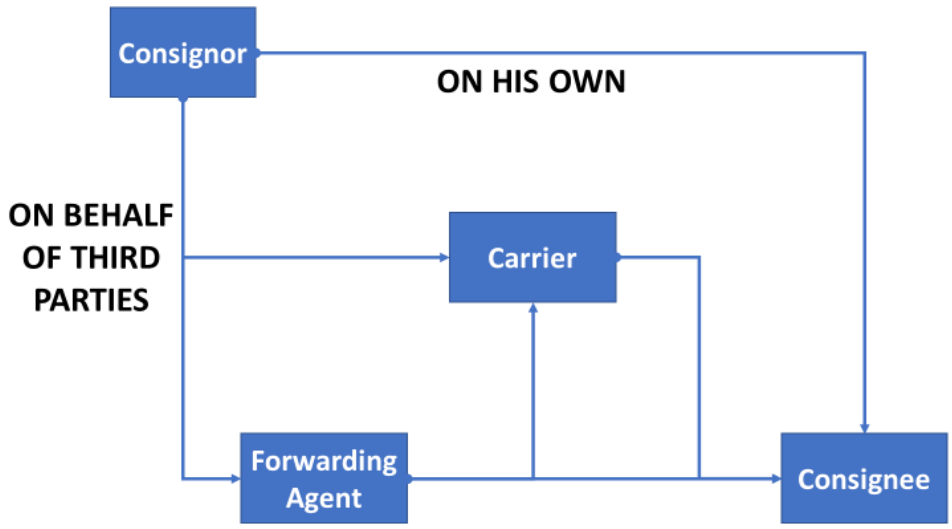

Figure 3 Fundamental actors of transport

- **On his own:** the consignor and the consignee utilizes own means of transport.
- **On behalf of third parties:** the consignor and the consignee entrust the shipment to a *carrier* (or, if necessary, more than one) or to a *forwarding agent* that arranges the delivery. The forwarding agent

may be also a carrier otherwise it assigns transport operations to another company.

Regarding deliveries that utilize a train, there are not consignor and consignee that are also railway undertakings. Therefore the way "on his own" is not followed. The unique path that is covered is "on behalf of third parties". But before to define when forwarding agents are involved, it is important to describe two kinds of services:

- *Single wagon load (SWL), Less than Full Train Load (LTFT) or diffused traffic:* the train is composed by groups of wagons with different origins and destinations. They cross rail terminals where groups of wagons are handled horizontally to constitute new trains.
- *Full train load (FTL) or direct trains:* train with an unique origin and destination and it doesn't allow any vertical handling of ITU and any horizontal movement of wagons during the journey.

The first kind of service is organized when it is not possible to create a train with the maximum capacity (full train) from the origin to the destination. In order to increase the number of carrying wagons, stops are needed at terminals during the journey on favour of leading other wagons or to allow wagons to reach different destinations. By definition the diffused traffic is used by single companies that need a transport, they contact directly a carrier but they ship only one, a part or a group of wagons**.** Anyway freight forwarder is presented also with SWL but it is less common. In order to reduce the cost of each shipping a railway undertaken (RU) is forced to put together different deliveries with different origin and destination. The opposite situation is when there is a forwarding agent that organizes and that is responsible for the whole trip from the origin to the destination. It is common to resort to it especially when the freight is clustered in ITU. The

adoption of ITU favours the use of more than one mode and many actors are involved in the transport chain. In order to simplify all the process, the figure of a forwarding agent becomes very important. Therefore in 1980 the United Nations Conference defined the Multimodal Transport Operator (MTO) as [12] "any person who on his own behalf or through another person acting on his behalf concludes a multimodal transport contract and who acts as a principal, not as an agent or on behalf of the consignor or of the carriers participating in the multimodal transport operations, and who assumes responsibility for the performance of the contract". The meeting explained also the meaning of multimodal transport: "the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a place designated for delivery situated in a different country". They signify that a [13] multimodal transport is the carriage of goods by two or more modes of transport, under one contract (see *Figure 4*), one document and one responsibility party (MTO) for the entire carriage.

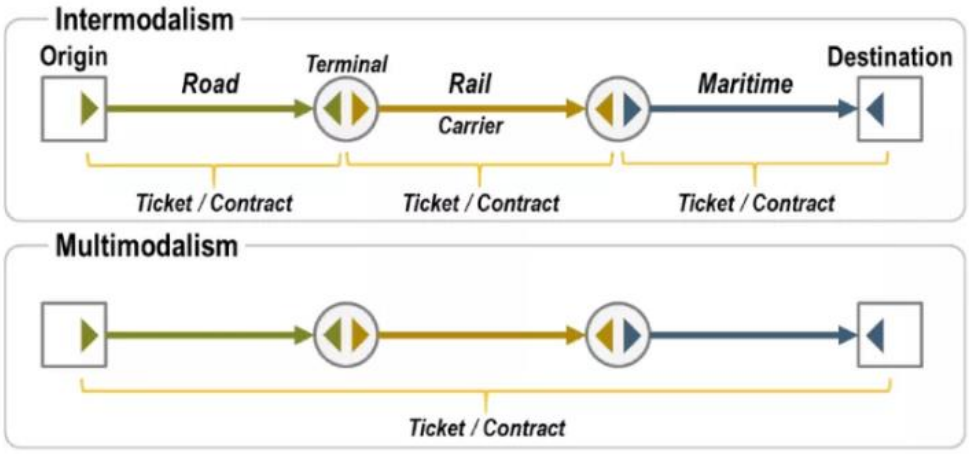

Figure 4 Multimodal transport under one contract. Source: https://transportgeography.org/?page_id=2545

In other words, the customer avoids signing contracts with each carrier involved in the trip and in the other hand it relates to only one operator (MTO) that organizes, coordinates and that is responsible for the entire trip.

In order to explain better the role of a MTO it is possible to make the example given by [14]. Assume that a factory needs to transport freight from its plant in Como (North of Italy) to Riyad (Arabia). It contacts a multimodal transport operator to realize the door to door service from the origin to the destination. The MTO stipulates an unique contract with the customer in which it is responsible of what can happen from Como to Riyad. At this point it signs subcontracts with all handling companies that move freight from one mode to another and with each carrier that performs the trip. For instance, a truck company that puts the freight inside containers and that moves them from Como to the intermodal terminal in Milano, a railway company that carries containers from Milano to the port of Ravenna, a maritime company that brings containers from Ravenna to the port of Geddah and a truck company that delivers the freight from the port to the final destination. An important role of the MTO is to coordinate all operations so that it can supply a service that is reliable, safe, as fast as possible.

The most important Multimodal Transport Operators [15] operating in Italian national traffic are Hupac founded in 1967 and Mercitalia Intermodal (ex Cemat that was founded in 1976). Hupac has the headquarter in Chiasso and in 2016 it registered a traffic of 1,100,000 TEUs. Mercitalia Intermodal is given by the merger of Cemat and Italcontainer and this internal division still exists. In fact Cemat is the continental section because it dealt with combined transport among freight villages instead Italcontainer is the maritime section because it managed the transport of ITUs coming, or

directed to, rail terminals located inside ports. In 2016 they registered a traffic of 585,000 TEUs and they have the headquarters in Milan. The major MTO for international traffic is Kombiverkehr, that is in operation since 1969, especially for Italy-Germany trains. In 2016 it registered a traffic of 1.960,000 TEUs and it has the headquarters in Frankfurt am Main. It is a normal practice that these three MTOs use code sharing train, a train that carries ITUs on behalf of all MTOs which share the train.
Other two historic MTOs are Novatrans and IFB (Interferryboats). Novatrans is a French company with headquarter in Paris and it registered a traffic of 450,000 TEUs in 2016 but it has few connections in Italy. Instead IFB is a Belgian company that offers mainly services from Italian freight villages or intermodal centres to the port of Antwerp and Zeebrugge and vice versa. It has the headquarters in Antwerp and in 2016 it registered a traffic of 450,000 TEUs

After the liberalization of railway transport in Europe in the beginning of 1990 many MTOs, that until then operated mainly in road and maritime transport or that were founded in this period, increased their traffic in combined rail transport market. Examples are Alpe Adria (headquarters in Trieste and in 2016 it registered a traffic of 245,000 TEUs), Contship and Samskip that are maritime MTOs instead GTS Trasporti, Ambrogio Trasporti (headquarters in Gallarate and in 2016 it registered a traffic of 85,000 TEUs) and Move Intermodal are specialized in continental ITUs.

FTL are also organized without using a forwarding agent**.** This is the case of factories that produce non-containerized freight and that are able to create a direct train with all wagons from one destination to one origin. Italian examples are in break bulk cargo sector with FIAT and Marcegaglia.

Coming back to the SWL it is important to say that, in average, in the last years it has lost its importance. A few years ago the volume of SWL traffic in Europe was estimated to be about 100 billion tonnes-km [16]. But as *Figure 5* shows, diffuse traffic has a downward trend. In fact, in 2012 the total SWL volume was 75 billion tonnes-km representing 27% of the total rail traffic.

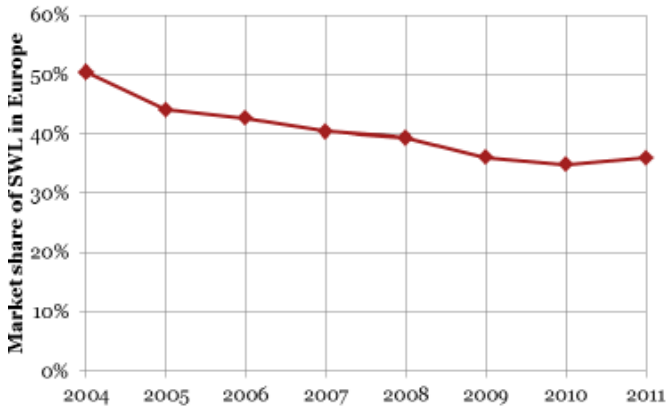

Figure 5 Market share of SWL in Europe. Source [16]

The reduction is given by four main reasons:

- Reduction of the demand of commodities that are captive for SWL services (basic metals, fabricated metal products, chemical products, coal, lignite, oil, LNG, heavy industry and products of agriculture)
- Low or completely lacking profitability for the RUs; costs are twice the costs for FTL but, if tonnes-km are considered, costs are from 3 to 8 times more. This is due to high costs for collection/delivery traction services and to those for marshalling and shunting.
- Because of complexity and lower profitability, after the liberalization new entrants focused on the intermodal and full train markets.

- The number of marshalling yards in operation has decreased significantly in several countries in the past 10 years (a 30-40% decrease on average), and/or plans for further downsize exist. Also private sidings has seen an important reduction. Their rehabilitation or construction is a significant expenditure and administrative burden for the company owning the plants connecting by the siding, and only some countries support with dedicated actions their existence and possibly development. On the other hand, road connections to factories are built and maintained at no cost for the companies.

An important factor is that a large proportion of SWL traffic is international and this means that the decision to eliminate such service by the dominant RU of a given country is very likely to affect diffused traffic in all other countries exchanging goods with that country. Nevertheless there are nations that still invest in this kind of service. In fact six main RUs of Central and North Europe (CFL Cargo, DB Cargo AG, Green Cargo, Lineas, Rail Cargo Group, SBB Cargo) are involved in the X-Rail alliance [17]. Their aim is to create an European Single Wagonload integrated network and a more competitive and more sustainable alternative to road transport based on reliability, punctuality and customer orientation.

The alliance is trying to change the philosophy of SWL traffic. The conventional production system is characterized by no-capacity check and no-booking on specific trains. The arrival time span and the maximum time are usually communicated to the customers. Priority is given to the first picked up (FIFO rule[6]) and normally there is no booking limit for the

[6] FIFO rule: First In First Out rule means that the first that arrives is the first to go away

customer. This system is called conveyor belt logic[7]. Instead with the new strategy there is a capacity booking system where an order is confirmed only after a capacity check and booking on real trains. The customers are informed on the of Estimated Time of Arrival (ETA) based on the routes with free capacity. Priority is given to the first booked, the volume is limited by the available train capacity and yield management (e.g. price differentiation) is allowed.
Countries (Austria, Belgium, Czech Republic, Germany, Sweden and Switzerland) involved in X-Rail network present an average share of total land traffic moved by rail of 28% against 16% of other countries. The maximum value is in Switzerland with 45.9%. Instead if only the rail market is considered, Czech Republic and Germany have SWL for about 40% while it is 14% in Italy.

3.2.2. SWL and FTL layout

FTL is a train at the maximum capacity that doesn't need intermediate stops. In this way the typical layout is the P2P (point to point) or direct link where both terminals are the origin and destination of goods in the rail phase (see *Figure 6*). This is a centrifugal network structure where any specific location achieves advantages. But the recent decades have seen the emergence of a new version of P2P because there are less terminals available in order to increase the economy of scale.

[7] Conveyor belt logic: it is when wagons are directed towards the next train leaving for the planned destination

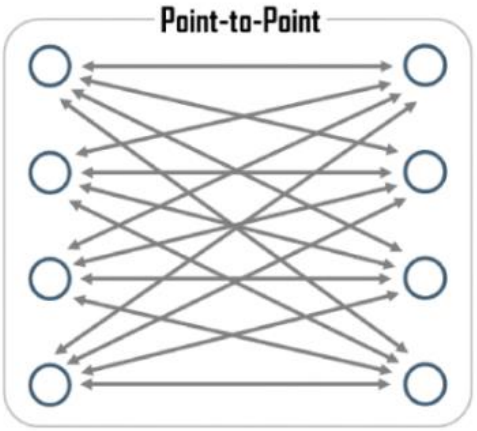

Figure 6 Point to Point layout

Since the number of points is reduced, network is made up by a limited amount of routes. Therefore the structure has become centripetal where a small number of locations are favoured. Existing terminals are bigger because they are able to manage a larger amount of freight at lower cost. Nowadays global flows are handled by *gateways* and *hubs* (see *Figure 6*) that are specific nodes of the transport system.

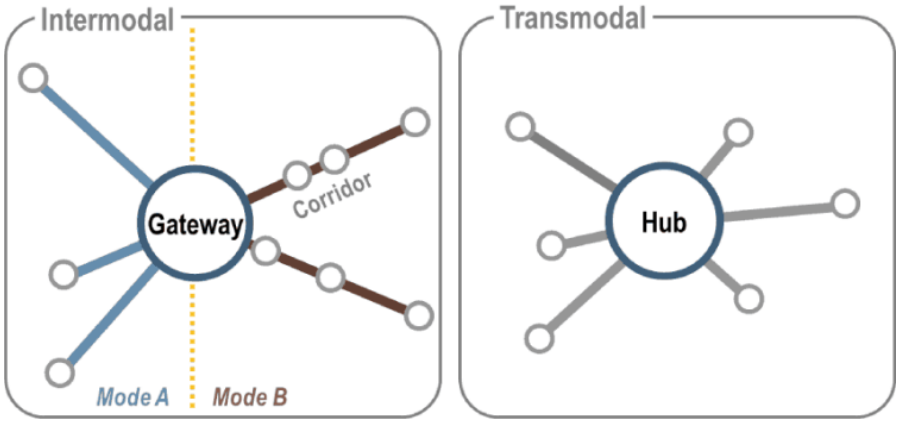

Figure 7 Gateway and Hub

A gateway is a location offering accessibility to a large system of circulation of freight and passengers. Gateways reap the advantage of a favourable physical location such as highway junctions, the confluence of rivers, a good port site and have been the object of a significant accumulation of transport

infrastructures such as terminals and their links. A gateway is commonly an origin, a destination and a point of transit. It generally commands the entrance to and the exit from its catchment area. In other words, it is a pivotal point for the entrance and the exit in a region, a country or a continent, and often requires intermodal transfers.
Instead a hub is a central point for the collection, sorting, transhipment and distribution of goods for a particular area. It is a central location in a transport system with many inbound and outbound connections of the same mode.
In order to sum up it is possible to say that a gateway is performing an intermodal function whereas a hub is mostly transmodal. Anyway, the term hub is more used even if it is not the most appropriate.

Connections have a high frequency because there is concentration of goods only in few points. In such way the correct layout of the network is a direct link between hubs (see *Figure 8*).

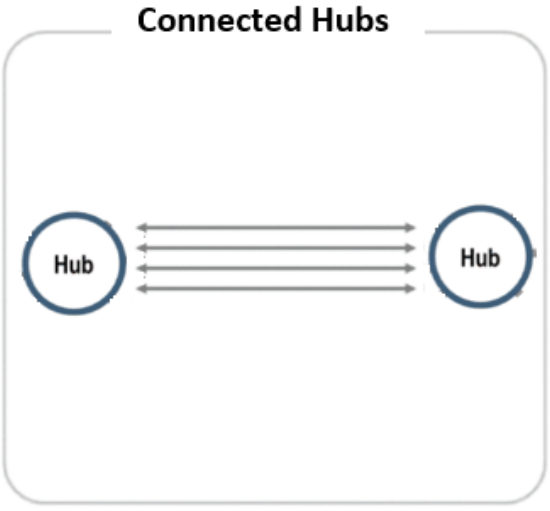

Figure 8 Connected Hubs Layout

For example with the previous configuration (P2P) there is one service per day between any two pairs instead in the new one (Connected Hubs or Hub

to Hub) there are four services per day. However potential disadvantages may also occur because, for example, additional transhipment as fewer P2P services are offered, which connection may involve delays and potential congestion as the hub becomes the major point of transhipment. This is the layout that described MTOs, which have a network mainly developed between hubs. In other words, they organize FLT between terminals that are connected by liner trains (shuttle trains) where one of the aims is the punctuality in order to increase reliability. It is possible to add that "MTOs buy in wholesale to sell retail" that is to say MTOs buy a FLT from one hub to another and then they sell each part of the train to different shippers. It is possible that in some case the forwarding agent uses more than one link for a single delivery. In this case the layout is called Hub & Spoke. An example is the connection between South of Italy and Europe because terminals in the Padan Plain are intercepting hubs and terminals in Southern Italy play the role of spoke. Another is for UTIs from Verona to Wels (Austria). There is not a direct connection therefore it is necessary the vertical handling of UTI in Ludwigshafen (Germany) from the first train (Verona- Ludwigshafen) to the second (Ludwigshafen-Wels).

SWL is a train that during its trip need stops at terminal in order to collect wagons. The oldest layout is the grid (see *Figure 9*) that is characterized by many points in the network and many connections between them. This configuration tends to be centrifugal since the high distribution of freight yards.

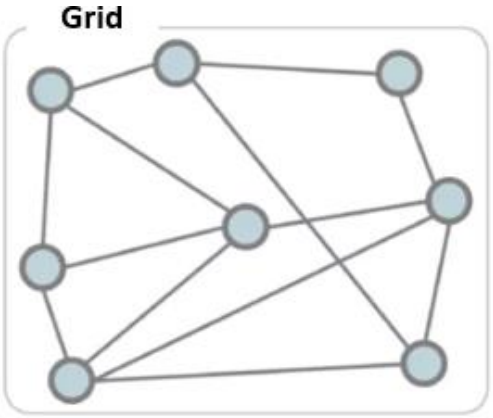

Figure 9 Grid layout

A new version of SWL layout is the corridor where the flow is along an artery and short capillary services are organized from and to nodes off the corridor. Another configuration is the Hub and Spoke (see *Figure 10*)

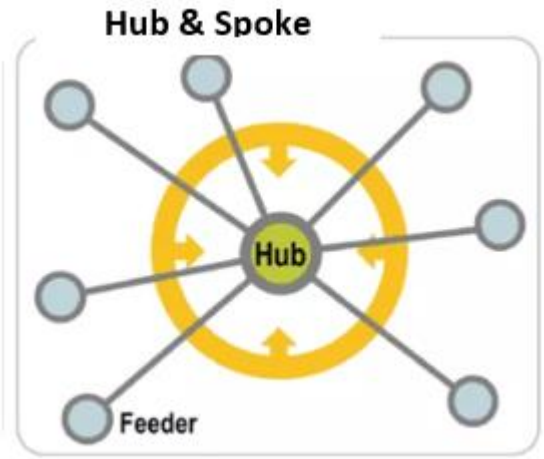

Figure 10 Hub and Spoke Layout

where there is one node in the middle and where all freight is forced to pass. Feeder trains during its trip carry group of wagons that have different destinations. In the marshalling yard, wagons are moved horizontally in order to create trains with the same destination

4. The liberalization of railway transport

Who needs to organize a delivery using the rail mode has a wide range of choice. This is because after the liberalization of European market, many companies decided to make their business in competition to the national railway society. Therefore it is necessary to make a brief explanation [18] of evolution of European and Italian free market that is stronger than passengers in freight sector.

4.1. EU principles

In first decades of XX century rail mode had a share of land traffic that was not far from 100% both for passengers and freight. But during years it has reduced its supremacy. The first reason [19] is that in the beginning the road infrastructure was almost null but then governments decided to invest only in road infrastructures.

In the second instance, railway supply has been unable to adapt to transformation processes given by globalization. In fact historical leading sectors are transportation for chemical, automotive and steel industry. But in last years this kind of factories have seen a delocalization from developed to emerging countries and only functions like assembly and commercialization are carried out in old industrialized nations. In the other hand European rail systems were not able to organize efficient services dedicated to final consumption of imported products. In other words, globalization had changed the demand but railway has not been able to perform an adequate service.

Thirdly railway system has always been considered a public service therefore network and services were both managed by an unique public entity. This inseparability was not able to manage some criticalities like high

operative costs, wrong investments, deterioration of infrastructure, services that were not appropriate with market requirements, continuous use of general taxation and heterogeneity (safety rules, 15 signalling systems – *Figure 11* -, 5 different voltages – *Figure 12* -, track gauge and more than 7 loading gauge – see *Figure 13* - all around Europe).

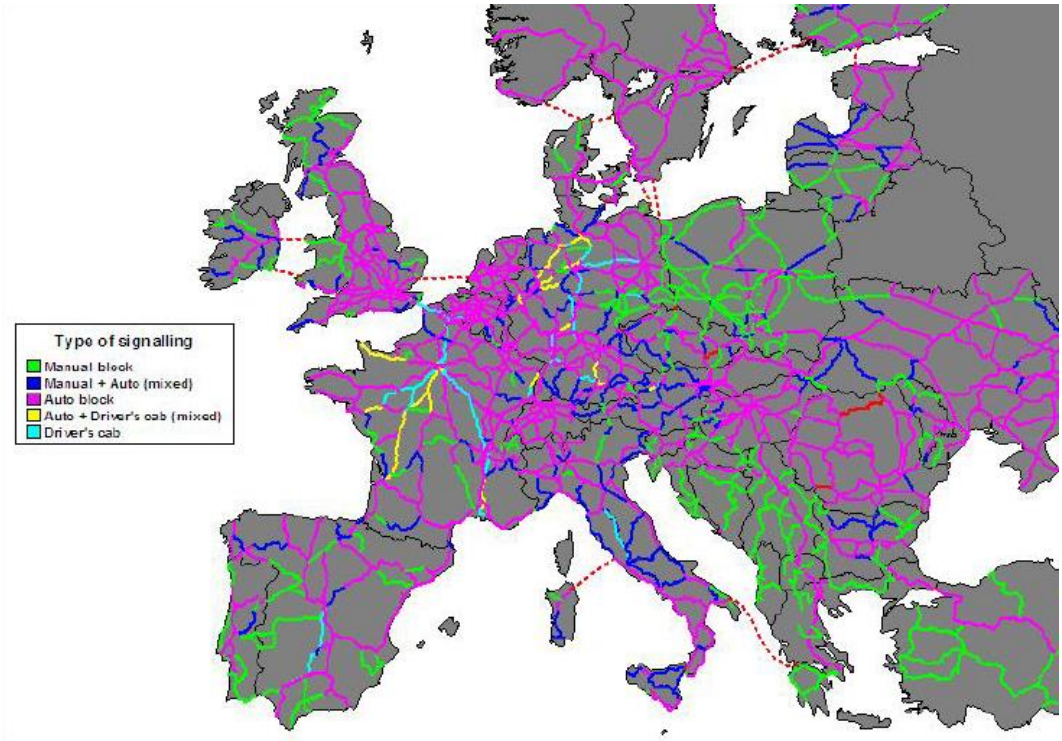

Figure 11 Different signalling systems

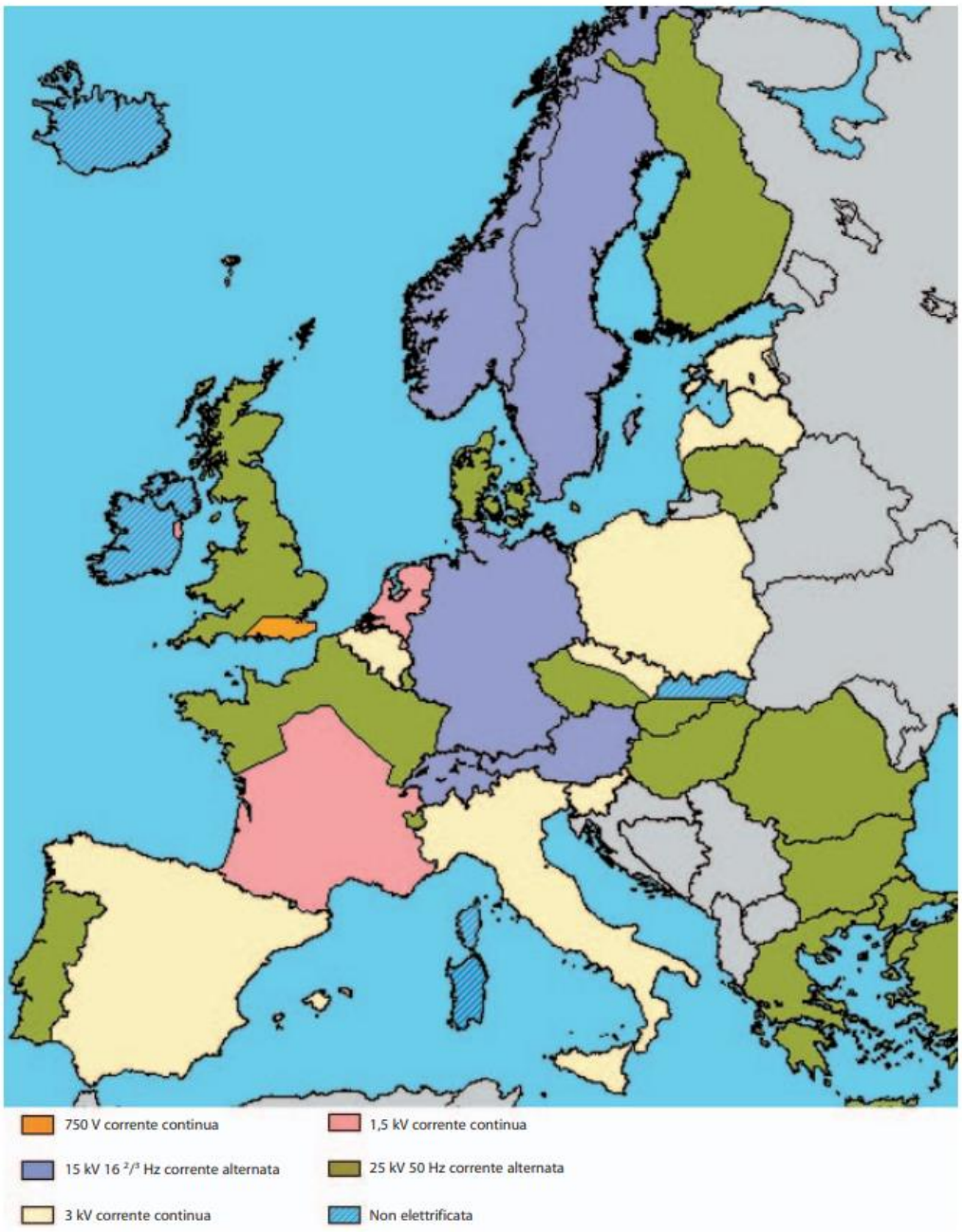

Figure 12 Different Voltages

In order to change the direction, Europe decided to start a path torward the liberalization of rail market.
The first step was the Directive 440 of 1991 [20]. European Economic Community thought that renovation of national railway could start from

the split between infrastructure manager[8] and railway undertaking[9]. In particular the division was mandatory only from an accounting point of view whereas it was facultative from an organic and institutional prospective. Then, in order to encourage international rail market, national railway undertakers were free to form groupings with railway undertakers of other States. Such international groupings could have free access to the infrastructure but only after the payment of a fee to the infrastructure manger. The toll was calculated in such a way as to avoid any discrimination between railway undertakings. It was function of the mileage, of the composition of train and of other factors like speed, axle load and the period of utilization. The same opportunity could be given to any railway undertaken engaged in the international combined transport of goods.

To sum up, it is possible to say that liberalization was allowed only for international traffic and for combined transport after the payment of a toll. Another objective of this directive is the financial recovery of each national railway undertaking that could be possible by means of subsidy of European nations.

Implementations of the directive 440/1191/EEC were the directive 95/18/EC and the directive 95/19/EC. The first concerns criteria applicable to the issue, renewal or amendment of licences for railway undertakings instead the latter defines principles and procedures to be applied with regard to the

[8] Infrastructure manger: any body or undertaking responsible in particular for establishing and maintaining railway infrastructure

[9] Railway undertaking: any public or private undertaking licensed according to applicable Community, the principal business is the of which is to provide services for the transport of goods and/or passengers by rail with a requirement that the undertaking must ensure traction

allocation of railway infrastructure capacity and the charging of infrastructure fees.

These regulations represent an important innovation in European rail sector but anyway they had many problems to realize what was written on the paper. In fact each European nation acquired them in a different way or only a small part was assimilate in own laws. Another element is the prudence in relation to some aspects. For example the liberalization was allowed only for international trade and combined transport of goods. Therefore on 26TH February 2001 European Commission released three different directives (First Railway Package) that were an upgrade of the previous. In particular directives 2001/12/EC, 2001/13/EC and 2001/14/EC are respectively the upgrade of directive 91/440/EEC, 95/18/EC and 95/19/EC. Main objectives were to facilitate the access to the infrastructure to a wider range of railway undertakings and to maximize the utilization factor of the network in a non-discriminatory basis. In a bit more detail:

- Directive 12: it defins a network made up 50,000 km all around Europe called Trans European Rail Freight Network (TERFN). The access can be allowed to all international freight trade within two years and to the entire freight sector no later than seven years. Then it is requested the creation of an independent body (external to railway services) that determins equitable and non-discriminatory access to the infrastructure, an agency that is able to monitor the situation. Moreover, each company that supplies both passenger and freight services is forced to split results in order to have different financial reports.
- Directive 13: it is regarding the release of license to railway undertakers. Each company that supplies a service, at more than

regional level, is forced to have a license. The latter can be given by a body that is external to rail service.

- Directive 14: it is regarding the capacity and the right of use of the infrastructure. A more precise method for the calculation of the tool is defined.

In the Fist Railway Package the foundations are laid for the liberalization therefore now it is necessary to pay attention to supervision, quality and security issue.

To accelerate the liberalization on 29th April 2004 was released the Second Railway Package composed of three directives (2004/49/CE, 2004/50/CE and 2004/51/CE) of one Regulation (2004/881/CE)

- Directive 49: it establishes a Safety Authority in each nation. This body was trustee of all question about safety, included issues related circulation that until then were under the supervision of infrastructure manger. It was defined as an independent body concerning rail accident investigation and it must follow European guideline.
- Directive 50: it defines how to increase interoperability between rail lines of each country related to conventional and high-speed trains.
- Directive 51: it is an update of the question related to liberalization. Since 2007 it imposes cabotage[10] but only for freight traffic.
- Regulation 881: it creates the European Railway Agency in order to introduce common procedures for accident investigation and to increase interoperability. It is also the supervisor of each national

[10] Cabotage: it is the transport of goods and passengers between two places in the same country by a transport operator from another country

Safety Agency and it facilitates communication between them. The European Railway Agency is situated in Valenciennes (France).

In order to increase quality and safety on 23rd October 2007 the Third Railway Package was published. It is made up by two directives (2007/58/EC and 2007/59/EC) and three Regulations (1370/2007, 1371/2007 and 1372/2007):

- Directive 58: for the first time a directive deals with liberalization for passengers. Since 2010 a railway undertaking with the license and the security certificate may supply an international service.
- Directive 59: it regards the driving license. A train driver may fulfil his job all around Europe. It explains how to obtain a license (the drivers will have to meet basic requirements concerning their educational level, age, physical and mental health) and what kind of information the certificate has to show (kind of lines, locomotives and other skills of the driver).
- Regulations 1370-1371-1372: it defines rail passengers' rights in international trips. There are all kind of laws regarding before and after the journey, liability in case of accidents, delay, complaint, personal security of passengers in stations and assistance to people with reduced mobility. The last part has the objective of increasing the quality of rail freight trade. An example can be the introduction of clauses between customers and railway companies.

Between the Second and the Third Railway Package there is the European Directive No 34 of 21st November 2011 that is a recast of the First Railway Package. It wants to put together principles that are explained in the previous Directives and it want to align to White Papers published in 2011. The main objective is the obtaining of *Single European Railway Are*a where

each Railway Undertaking is free to move following conditions equal all over European network. It is necessary that in that space the competition is encouraged through transparency, non-discrimination and equity. It is necessary also an high degree of interoperability and safety.

To complete the picture above mentioned the Fourth Railway Package is the last step of Single European Railway Area. It is made up by three Directives and Three Regulations published between May and December 2016:

- Directive 2016/797: it simplifies procedures ensuring interoperability.
- Directive 2016/798: it simplifies procedures ensuring security.
- Directive 2016/2370: it deals with the opening of domestic passenger market and with the improvement of governance of railway system.
- Regulation 2016/796: it establishes an Agency for European railway.
- Regulation 2016/2237: it is about the normalization of accounts of railway undertakings
- Regulation 2016/2238: it introduces laws for the opening of domestic passenger market.

In particular the objective is the reduction of administrative and technical costs in order to increase attractivity. The expected reduction is 20% for both time and costs with a total saving of 500 billion € in 10 years. The entry of new railway undertakers can be useful for the creation of new services. It is necessary also the maximum level of equity and transparency therefore the infrastructure manager needs to be independent from all other companies especially from a financial and ad operative point of view. It is important also the quality of the personnel. It is necessary a staff that is qualified,

motivated and that is able to work a more innovative and competitive context.

4.2. Italian principles

Under the pressure of European directives, Italy started to question traditional management policy of public services, including transport sector. The objective was to create a competitive market where new companies could confront with others. If the European legislation follows an orderly process, in Italy the situation is more confused especially in early years without a planned long-term regulation. This is because Italian documentation is due to assimilation of community legislation or to resolve problems that occur.

In the beginning the Italian liberalization process is simply a rationalization and rearrangement of the monopolistic railway public operator (F.S. Ferrovie dello Stato) in order to adapt to community regulation. European liberalization started in 1991 but as early as 1985 FS became a public economic body (in Italian legislation it is "ente pubblico economico[11]") acquiring a management independence as a commercial firm. In 1992 [21] FS turned into a joint-stock company (Ferrovie dello Stato – Società di Trasporti e Servizi per Azioni). But it is just a formal privatization[12] and not a substantial privatization[13]. It was established in order to perform

[11] Ente pubblico economico: it is a public body with own legal personality, own asset and own employees

[12] Formal (or organizational) privatization: it is the transfer of property rights or the delegation of state tasks to private law entities, such as companies, of the public sector. These are established by the state in order to perform economic activities, which are essentially private. State acts through them no longer as public authority but rather it uses private law forms of organization and action instead. In the formal privatization the transition is within the public sector.

[13] Substantial privatization: it is the transfer of property rights or the delegation of state tasks to 'genuinely' private persons. It involves a transition from the public to the private sector.

economic activities, such as recovery plan, with higher freedom. The directive 440/1991 released by EEC was implemented through a Decree of the President of the Republic (D.P.R.) 277/1998. It imposed the accounting segregation between infrastructure manager and railway undertaking and the free access to the network but only for international associations and combined traffic. There is a difference of seven years between the European Directive and the Italian D.P.R. because Italian railway was based on a monopolistic public organization and the study of a liberalization process was not simple. Instead directives 95/18-19/EC were implemented through D.P.R. 146/1999. It introduced principles concerning the issue of licenses, the allocation of railway infrastructure capacity and the charging of infrastructure fees. On 10th May 1999 Ferrovie dello Stato was divided into four departments (Divisioni): Passengers (Passeggeri) dedicated to international, InterCity and Eurostar trains, Regional Transport (Trasporto Regionale) dedicated to regional trains, Freight (Cargo) dedicated to freight traffic and Infrastructure (Infrastruttura). It is famous the spot of that time "We bend over backwards" ("Ci siamo fatti in quattro"). But this subdivision lasted for only some months because on 1st July 2001 Italy decided to go beyond the accounting segregation between infrastructure manager and railway undertaker. Passengers, Regional Transport and Freight departments became Trenitalia s.p.a.[14] instead the Infrastructure department changed into RFI s.p.a. (Rete Ferroviaria Italiana). They were two different companies under the same holding (Ferrovie dello Stato s.p.a.). At this point the separation between infrastructure manager (RFI s.p.a.) and railway undertaking (Trenitalia s.p.a.) was completed.

[14] S.p.a. (società per azioni): it is equivalent to joint stock company

The First Railway Package was adopted through the Legislative Decree No 188 of 8th July 2003. But the Italian Decree is not the simply assimilation of community indications. It is prophetic because it reveals in advance what will written in following Railway Packages. In particular it defines principles for infrastructure utilization and management, for toll definition, for issue, renewal and amendment of licences and for the allocation of railway infrastructure capacity and the charging of infrastructure fees. It explaines also how a general railway undertaking may use the infrastructure. It is possible only if the RU:

- Has a licence released by Ministry of Transport. RU must demonstrate that has got requisites of honourableness (not to be declared bankrupt, not to be in administrative compulsory winding up, etcetera), financial capacity (ability of meet actual and potential obligations for at least 12 months) and professional competence (to be able to have an efficient management organization and to have necessary knowledges and experiences in order to perform the activity). Furthermore it must have insurance cover for civil liability in the event of accidents, rolling stock and staff in order to perform a service. The licence has unlimited duration excepting inactivity or loss of basic requirements.
- Has a security certificate released by infrastructure manager that verifies correspondence of staff, internal organization and rolling stock to standard required by each line in order to perform a safe service.
- Has a contract for the definition of the allocation of infrastructure capacity.

Then it is defined what kind of RU can use Italian infrastructure:

- International associations with at least one RU with headquarter in Italy. They can supply any kind of international service
- International association with no headquarter in Italy. They can supply any kind of international service but only with the right of transit.
- A general RU with headquarter in an European country for the supply of both international and national transport of freight (conventional and combined) and passengers (long and medium haul).

The Italian Legislation defines also the figure of "authorised applicant" (richiedente autorizzato) that is any body (regional or provincial entity or a railway company) that is interested to organize a public or commercial service and the "Framework Agreement" (Accordo Quadro) between infrastructure manager and authorised applicant. The Framework Agreement lasts 5 years and it doesn't identify specific paths but simply number of paths in one day and in which hour slots are requested.

The Second Railway Package was implemented in 2007 through Legislative Decrees No 162/163 of 10th August. It established National Agency for Railway Security (Agenzia Nazionale per la Sicurezza delle Ferrovie, ANSF). In the beginning ANSF monitored only IF on national Infrastructure but then it gained power also towards RFI. Therefore since 21th May 2008 it has started to release authorizations like security certificates and to make inspections as audit and monitoring activities for both IM and RUs. It is important to highlight Viareggio accident of 29th June 2009 where the capsizing of a tank wagon caused the death of 32 people. From that moment the attention on security experienced a drastic increase.

The Third Railway Package was implemented in 2010 through Legislative Decree No 247 of 30th December. It defined procedures for obtaining the driver licence valid all over European network. The licence must be accompanied by a complementary certificate where each driver specifies his educational level (lines, locomotives, kind of service).

Between Third and Fourth Package Italy implements European Directive 2012/34/UE through the Legislative Decree 112 of 15th July 2015.

One part one the Fourth Package was implemented in Italian legislation through the Government Act no 40. The dossier [22] about it was published 11th September 2018 and it is made up of 20 articles that modify Italian Legislative Decree No 112 of 2015. In particular main topics are:

- Independence and impartiality of infrastructure manager: the infrastructure manager must be a legally separate entity from any railway undertaking. Separation to maintain also in case of vertically integrated undertaking[15].
- Liberalization of passenger national transport: each railway undertaking can access to the infrastructure of each European country for supplying a passenger service. Therefore in each nation, not only for an international trip, a RU has the right to allow boarding and alighting of people.
- The right of access to high speed network: it is in order to increase the competition on high speed lines and to increase positive effects for passengers.

[15] Vertically integrated undertaking: it is the case of Italian Railway where Ferrovie dello Stato Italiane is the holding that owns shares of both Trenitalia s.p.a. and RFI s.p.a.

- Conditions for the allocation of paths: a path can be requested at least 18 months before the entrance into force of the working timetable.

Following European Directives, in the beginning competition was allowed only in freight sector. Therefore the first railway undertaking, external to the holding Ferrovie dello Stato Italiane, was Ferrovie Nord Milano Esercizio[16]. On 25th Septmeber 2001 the first service was fulfilled from Melzo Scalo to Zeebrugge. In a second step (2003) the competition was permitted also in passenger traffic for both international and national services. Italy was the first European country to allow competition on high speed line. On 11th December 2006 Italo – Nuovo Trasporto Viaggiatori was founded. The first train started on 28th April 2012 through the high-speed line between Naples and Turin. On 2006 another railway undertaking was founded. Arenaways carried out its first service on 2010 as a competitor to Trenitalia s.p.a. between Milan and Turin. At the beginning the company got rejected because the service was similar to a regional one. In fact Italian legislation allowed competition only on long haul trips. The first train could start when some stops were deleted. On December 2009 DB and OBB started to supply international services across Brennero.

In the last, update that was published by Italian Ministry on 12th May 2017, there are 39 railway undertakings that can supply a service along Italian network. But seven of them have the license that is inactive. Then there are three kinds of licenses:

- Freight license: it is related to railway undertakings that can organize only freight trains. They are 14 and the most important are D.B.

[16]Ferrovie Nord Milano Esercizio: in 2005 it became Gruppo FNM s.p.a.

Cargo Italia Srl, Mercitalia Rail S.r.l., Rail Cargo Carrier Italy S.r.l., Rail Traction Company S.p.a. and SBB Cargo Italy S.r.l.

- Passenger license: it is related to railway undertakings that can organize only passenger trains. They are 8 and the most important are Nuovo Trasporto Viaggiatori S.p.a., Trenord S.r.l. and Trentino Trasporti Esercizio S.p.a.
- Freight-Passenger license: it is related to railway undertakings that can organize both passenger and freight trains. They are 10 and the most important are Sistemi Territoriali Trasporti and Trenitalia S.p.a.

In order to sum up results given by first years of liberalization it is possible to see *Figure 8 and 9*

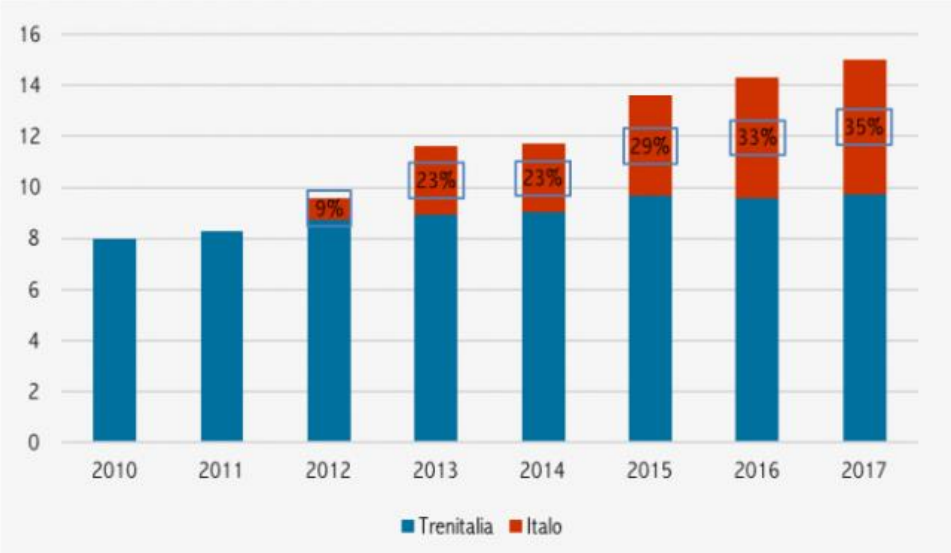

Figure 13 High-speed traffic. Risults in billion of passenger-km (Source: https://www.lavoce.info/archives/51290/ferrovie-frutti-liberalizzazione-caso/)

The liberalization regarding high-speed lines is allowing the increasing of passenger-kilometre. Since 2012 the trend is positive for both Trenitalia s.p.a. and Italo. Before the first trip of Italo passenger-kilometres were about 8 billion instead now the value is more than 14 billion. Therefore it is

possible to say that in six year of liberalization passenger-kilometres are increase of almost 60%.

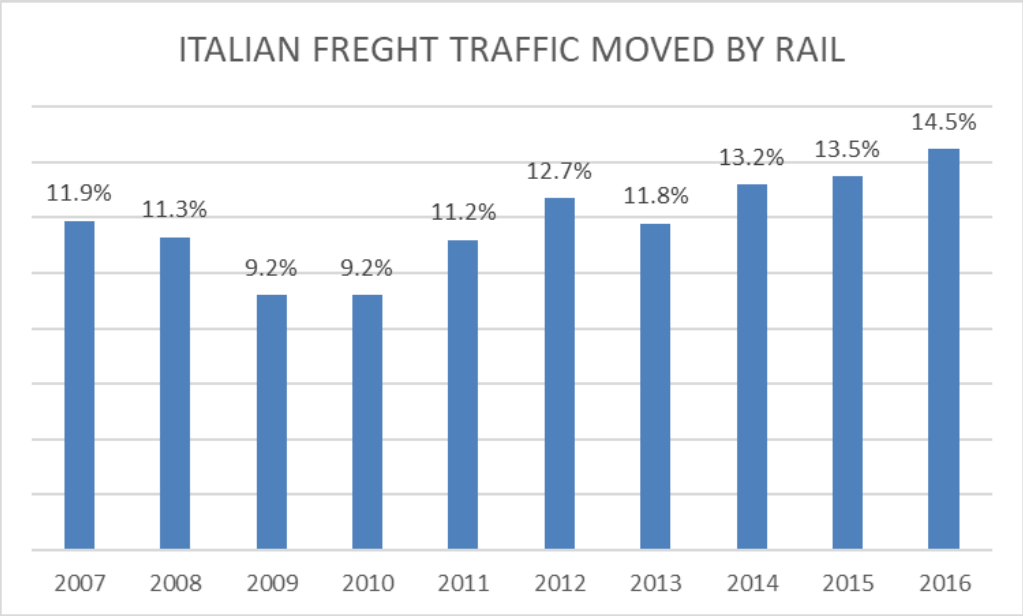

Figure 14 Italian freight traffic moved by rail. Source: ISTAT

Instead about freight traffic there is a positive trend but the increment is lower than high-speed market. In fact in four years, from 2013 to 2016, Italian freight moved by rail goes from 11.8% to 14.5% with an increasing of only 2.7%. These percentages are far from European goals. In fact requested values are 30% by 2030 and 50% by 2050.

5. Ferrovie dello Stato Italiane (FSI) group

Ferrovie dello Stato Italiane (FSI) group[17] [24] is one of biggest Italian industrial reality and it is the biggest Italian railway company. Since 1992 it is 100% owned by the Ministry of Economy and Finance. The holding Ferrovie dello Stato Italiane S.p.a. controls its operating companies in the four sector of supply chain (see *Figure 15*):

- *Transport*: it includes companies that performs passenger and/or cargo transport services by rail, road and sea;
- *Infrastructure:* it includes companies that are responsible for maintaining, using and developing rail infrastructures and sea link services to the major islands;
- *Real estate*: it includes the companies that manage the main stations and take care of managing and valorising the Group's property portfolio
- *Other services:* it includes companies that manage activities not directly related to the rail services (administration, building and facility management, leasing, factoring, transport system certification etc.).

Additionally, through Central Management Teams (the actual general director is Gianfranco Battisti), the parent company definies strategic guidelines and ensures the management and coordination of the operating companies industrial policies.

[17] FSI Group: the previous name was Ferrovie dello Stato but on 22nd July 2011 there was the addition of "Italiane" to increase the sense of Italian spirit inside a market that increased its internationality. Moreover the Italian spirit was accentuated by the new logo that adopted the Italian flag (green, white and red).

FSI Group is leader in both passenger rail transport sector and in freight

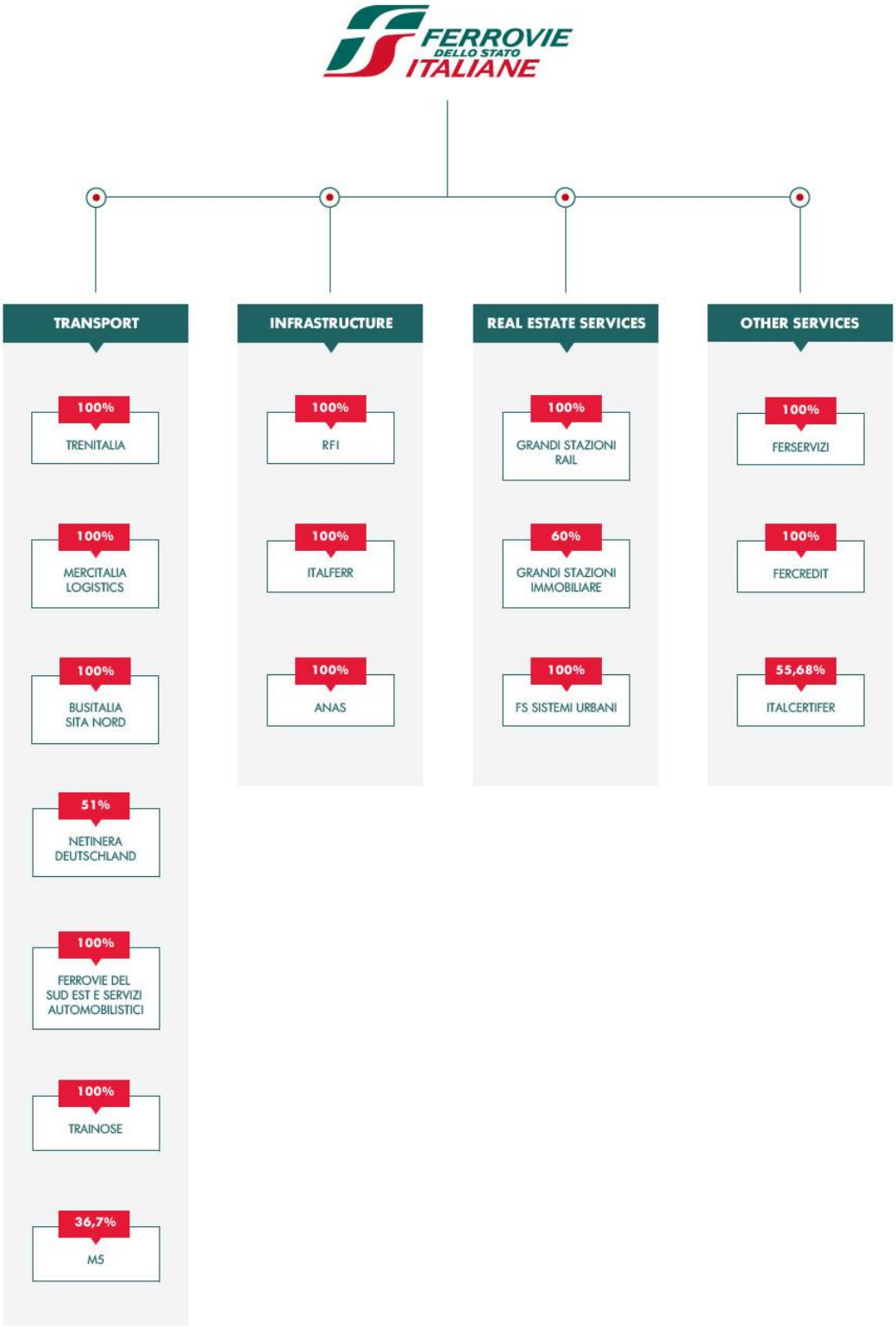

Figure 15 Ferrovie dello Stato Italiane group. Source: https://www.fsitaliane.it/content/fsitaliane/en/fs-group/group-companies.html

rail sector. In fact in Italy 88% of people that use a train are supplied by FSI instead 7% of freight are moved by companies of Polo Mercitalia. FS Italiane Group has more than 81 thousand employees, more than 10 thousand trains running every day (about 8 thousand in Italy and more than 2 thousand abroad), around 750 million rail passengers (600 in Italy and 150 abroad), 300 million passengers on the road per year along with 50 million tons of goods. The railway network managed by Rete Ferroviaria Italiana (RFI) is over 16,700 km long, of which more than 1,400 km is dedicated to high-speed services.

FSI goal is the creation of a service that is capable of creating lasting value for both customer and surrounding environment. Therefore each action is based on basic points:

- *Customer at the centre*: rail passengers and, above all, commuters are main focal elements. The aim is to continue to work intensively to achieve ever higher standards of safety, quality and efficiency in regional and local rail transport. FSI operates so that it reaches, also on local railways lines, security standards. The objective is to achieve full national rail interoperability, integrating local lines into the main network;
- *Integrated mobility*: the collaboration between all undertakings has the objective to make travel experiences more fluid and streamlined;
- *Digitalisation*: it is essential to meeting demand in an increasingly more widespread and efficient manner and to accompany passengers throughout their entire travel experiences, providing them more assistance and more effective and timely information. The aim is to realise optimised industrial processes with a reduction of time and costs. Digital devices that for example allow to predict

maintenance on trains can be useful to increase punctuality, regularity and safety;

- *Sustainability*: new, more comfortable and more technologically-advanced trains, modern stations that are increasingly integrated into metropolitan fabric, and rail/road integration. Sustainability together with ethic is at the heart of FSI strategic decisions because only a balance compromise between environmental, economic, social and elements can lead to solid and lasting development of the group and the country;
- *Intermodality*: it is important to create a network in which each mode can enhance its specific purpose. In particular a collaboration with road transport or investments in hubs or gateways is essential to increase profitability, reliability, sustainability and efficacy.

5.1. Industrial plan 2017-2026

On the eve of Industrial Plan (2016), FSI group managed a freight flow of about 50 million of tons [25] or rather 7% of freight transported in Italy. This value was one half of freight transported by trains (92,948,907 tonnes or 14.6%). The average European value is 17.4% but the peak value is in Latvia where rail is used to transport 79.8% of national freight. For each country the goal is given by community directives that is 30% by 2030 and 50% by 2050.

FSI Group, in order to be prepared to changes imposed by Europe and to assume a role of protagonist inside European network, has decided to invest € 94 billion during a period of ten years. It is a very important event because in Italy there's never been a plan of this duration in railway field. All the program has been illustrated in Industrial Plan 2017-2026 (Moving Forward 2017-2026) [26]. It is based on five strategic pillars:

- Integrated mobility;
- Integrated logistic;
- Integration between railway and road infrastructure;
- Internationalization;
- Digitalization;

Infrastructures need a special attention because they will receive an investment of € 62 billion. The objective is to upgrade existing lines (one example is the adjustment to structure gauge P/C 80 in order to allow ROLA[18] service) and to build new lines for completing Italian high speed/high capacity (AV/AC) network and Italian part of four TEN-T corridors.

5.1.1. Integrated Logistic

In integrated logistic is established the investment of € 1.5 billion that € 1.1 are dedicated to rolling stock, € 300 million are dedicated to terminal and logistic and € 100 million are dedicated to ICT (Information and communications technology).

Inside FSI holding there are many companies that are involved in freight sector. But the problem is that they don't have an unique mediator for customers. If the objective of an undertaking must be the customer satisfaction, freight must be considered as passengers that want a door to door service as simple as possible without the interaction of many actors. A service of this typology is easily feasible through road transport because almost always first and last mile are carry out by this mode. Therefore in order to create a more competitive company, FSI group decided to simplify

[18] ROLA: Rollende Landstrasse or Rolling highways. It is a form of accompanied combined transport of rail.

all the process. All undertakings, that were involved in freight field, were integrated under an unique sub-holding called *Mercitalia Logistics* that is in charge of *Polo Mercitalia (*see *Figure 17*). The only company that operated in freight sector and that was excluded was Terminali Italia in order to not the lose possibility of use directly rail yards own by RFI.

Companies that belong to Polo Mercitalia and that supply terminal, logistic and traction phase as a whole, are [27]:

Figure 16 Mercitalia Logistics layout

- Mercitalia Rail (MIR): it supplies services in Italy and abroad, promoting, attaining and managing every initiative and service regarding the freight transport by rail field, as well as any instrumental, complementary and connected activity;
- Mercitalia Transport & Services: it studies, organises (either directly or indirectly), produces, manages and sells transport and logistics services in Italy and abroad, to be carried out mainly for Gruppo Ferrovie dello Stato Italiane companies;
- Mercitalia Shunting & Terminal (MIST): it is the company that manages the Last Mile, that is specialized in shunting rail and maintenance of rolling stock activities, in designing, construction

and maintenance of railway infrastructure and in the management of intermodal terminals.

- Mercitalia Intermodal (before was Cemat): it is one of the largest European operators that manages, organizes and markets combined Rail-Road door to door transport services. Mercitalia Intermodal works both nationally and internationally, managing a network of trains that connects more than 150 intermodal terminals located throughout;
- TXLogistik: it was founded in 1999 at Bad Honnef (Germany). It is today one of the largest railway transport companies in Europe. It designs transport networks without "boundaries", and develops personalised freight transport solutions from A to Z. It is important for FSI group to tackle foreign market with an already established company. In fact it is the second freight railway undertaking in Germany.
- Teralp (Terminal AlpTransit Srl): it produces and manages freight railway terminals in Northern Italy with the purpose of developing – within areas in the heart of the existing railway stops of Milano Smistamento and Brescia, currently the property of Mercitalia Logistics – front running intermodal terminals dedicated to the unaccompanied combined transport of freight and equipped with rail-rail and rail-road transfer systems of the Intermodal Transport Units (ITU).

Polo Mercitalia has a turnover of € 1 billion per year, more than 4,000 employees, 26,000 wagons and 600 locomotives.

The main objective of Polo Mercitalia is to allow to FSI group to achieve attractiveness, credibility and competitiveness that has been lost. In other

words, the goal is to return dignity to people that work in freight field. The path to become one of the most profitable rail-based logic player all around Europe is based on four basic steps:

- To double the turnover;
- Investments of € 1.5 billion;
- Fulfilment of working and operation security;
- Professional development of employees.

5.2. Mercitalia Rail

The company in which this thesis is developed is Mercitalia Rail (the logo is shown in *Figure 18*) that is one of undertakings inside the sub-holding Mercitalia Logistics. It is the main cargo company in Italy and one of the most important in Europe

Figure 17 Mercitalia Rail logo

Mercitalia Rail offers a wide range of solutions for conventional and combined transport. Running 2,000 trains a week and 100,000 trains per year, it provides links to the main ports, interports, terminals and industrial sidings throughout Italy and European transport corridors, where it works directly or in partnership with other undertakings.
The company offers flexible and customized services to the largest Italian and European operators and, because it is integrated with other Mercitalia Group companies, completes the range of rail transport options with complementary logistics services.

Mercitalia Rail's sales force is organized in business sectors:

- Conventional which is given by the unification of Industry (iron and steel, chemical and automotive supply chains) and General Cargo that deals with a various range of sectors like consumer goods, raw materials, major infrastructure projects, military transport and exceptional loads;
- Intermodal which provides rail and logistics services to multimodal operators (MTO), to large domestic and international freight forwarding companies and to principal shipping lines.

Mercitalia Rail has a big fleet of locomotives (300 locomotives are electric and 100 locomotives are diesel) and wagons (19,600 wagons, which are specially designed for the freight to be transported). The company is certified as an Entity in Charge of Maintenance in accordance with European regulations and has its own workshops for maintaining and revamping all its rolling stock.

Innovation and development are strategic drivers for Mercitalia Rail, which is implementing more efficient and competitive transport solutions, which respond to customer demands for heavier and longer trains (2,500 gross tonnes and 750 metres).

Mercitalia Rail implements sustainable development policies with special attention to safety and environmental protection: in 2017 rail transport took 1.5 million trucks off the road, thus helping to reduce the emission of greenhouse gases and other harmful substances (around 40 million tonnes of goods were transported in 2017, saving 1.3 million tonnes of CO_2 compared with equivalent road transport).

6. Production Train Process

For the purpose of production train process Mercitalia Rail is divided into two main families: Business Direction (Direzione commerciale) and Operational Direction (Direzione Operativa). The objective of the entire system is to ensure the achievement of quality and efficiency in order to obtain customer satisfaction following guidelines given by FSI Group. Anyway two families are not completely separate because they change continuously information to achieve an integrated approach.

6.1. Business Direction

The Business Direction is the part of Mercitalia Rail that [28], respecting quality, punctuality and designed plans, manages sale, post-sale and assistance processes (see *Figure 19*).

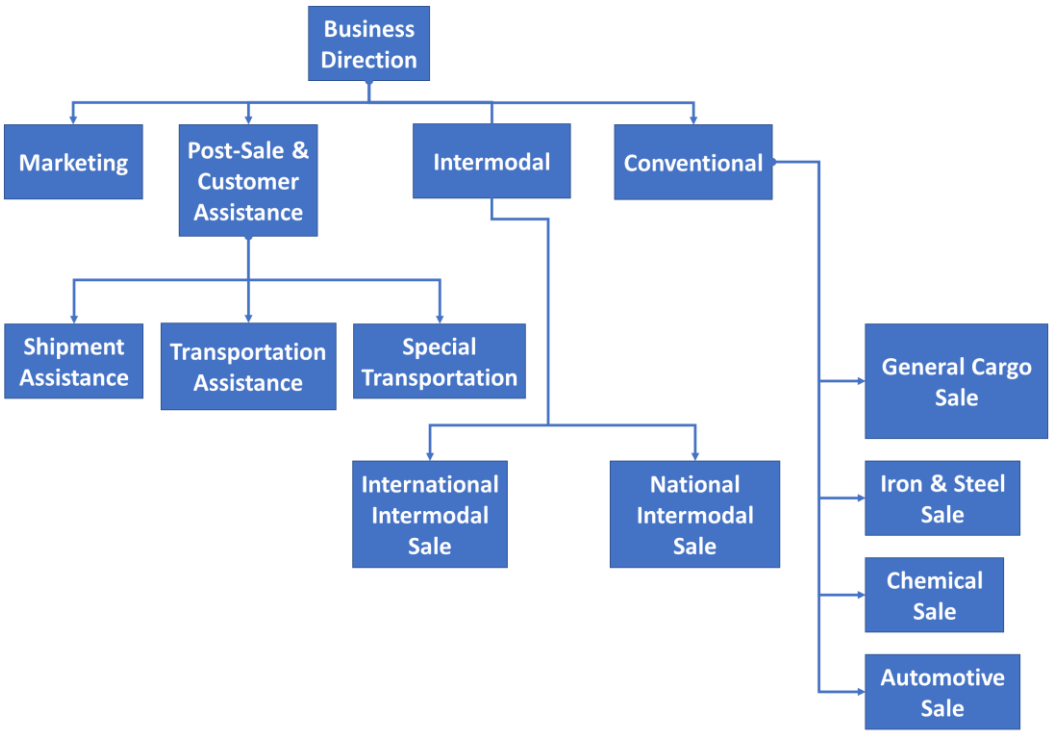

Figure 18 Business Direction layout

In particular it is divided into four macro structures:

- Marketing;
- Post-sale and customer assistance;
- Conventional;
- Intermodal.

Post-sale and Customer Assistance in turn is divided into three micro structures:

- Shipment Assistance (Assistenza Spedizioni): its roles are
    - To manage shipping execution/acceptance and preparation of the digital transport documentation;
    - To interact with customers when anomalies or damages occurs;
    - To manage interface with new customers in order to explain supplied services and to address them to the appropriate branch sale;
    - To optimize the use of documentation in order to speed-up operations like development of statistics and invoicing of company incomes.
- Transportation Assistance (Assistenza Trasporti): its roles are
    - To track and trace in real time, with notification of any issues or delays during the journey;
    - To manage weekly and daily requests (short term planning) verifying wagons, driver and terminal availability;
    - To manage fleet of wagons on the basis of company needs.
- Special Transportation (Trasporti Speciali): its roles are

- To give assistance to markets that require non-standard operations. Examples are exceeding loading gauge, military and dangerous good trains.

Conventional and Intermodal are two macro branches called macro Filiere. They represent two business units that cluster all kind of traffic. They are responsible for establishing relationships with each market sector, identifying customer needs and defining cost of each supplied service. Macro Filiere are split in micro Filiere and each one tries to organize a service as much as possible flexible, international, personalized and tailor-made. It is carried out for both large companies that own railway siding, as well as to small/medium companies with value-added logistical services provided by other companies from Mercitalia Group or through partnerships with Italian and European operators. Inside Conventional Business there are four specialized areas:

- General Cargo: it is specialized in different sectors:
  - Consumer Goods: drinks, foodstuffs, electrical appliances, paper, goods on pallets;
  - Raw Materials: wood, cereals, animal feed, cellulose, building materials and aggregates;
  - Infrastructure Works: prefabricated structures, excavated material, gravel, railway sleepers;
  - Military Transport: vehicles and personnel for Italian and foreign armed forces;
  - Exceptional Transport: oversized or overweight loads and rolling stock not able to circulate autonomously.
- Iron & Steel or Heavy Industry: it deals with ferrous scrap, steel coils, semi-finished goods, long goods, tubes, rail tracks and goods that are

characterized by oversize and exceptional loads. Companies that use this kind of service are ILVA and Marcegaglia.

- Chemical: it works with base chemical industry, petrochemicals, fuels, recycling and products. The main problem of this sector is the attention to safety, laws and environment. In most cases it deals with the transportation of dangerous goods. A company that uses this kind of service is ENI.
- Automotive: it deals with transportation of road vehicles (new cars, lorries and tractors) and components for car plants. An Italian company that uses this kind of service is FIAT.

The second micro Filiera deals with intermodal business. It provides rail and logistic services to Italian and international freight forwarder for the transportation of ITU. This service is carry out, as what happens with the first Filiera, in collaboration with other companies of Polo Mercitalia to realize an efficient door to door service. For example TX-Logistics and Mercitalia Intermodal. For instance Mercitalia Intermodal is an MTO that organizes a door to door trip and gives to Mercitalia Rail the traction part. Or it can be possible that a trip is organized in a way that the Italian traction phase is carried out by Mercitalia Rail and traction phase in foreign country is carried out by TX-Logistics.

6.1.1. Mercitalia rate [29] and consignment note [30]

Mercitalia Rail stipulates, with each customer, contracts in which specific services and rates are agreed. Anyway there are general fares. If a trip has a length of more than 100 km, cost for supplied service is 50.00 €/km for a full train or 3.80 €/km per wagon for a single wagon service. Moreover there are fares also for other services or penalties in the case that agreements are not respected. When a carrier carries out a trip in a time that is longer than

the stipulated time, the holder of a wagon can ask a compensation for the non-use of the wagon. The penalty is 15 €/day for a wagon type U[19] or Z[20] and 9€/day for all other types of wagons. Instead in the case that the consignee or the consignor is not able to receive a wagon for loading or unloading operations, the penalty is 52.00 €/day per each wagon.

A special attention must be given to the Consignment Note because it is the document that summarizes all railway agreements between consignee, consignor, carrier that signs the contract and other entities that are involved in the settlement as freight forwarders. Uniform rules concerning international carriage of goods by rail are synthetized in Consignment Note type CIM. It is made by five sheets that can be written in more than one language but, except different covenants, one must be English, French or German:

1. It is the original part that must be delivered to the consignee;
2. It is the authorization to the trip and it summarizes all phases that occur during the trip. It must be consigned to each carrier involved in the trip;
3. It is the arrival note for potential customs;
4. It is the duplicate of the Consignment Note that remains in the use of consignor;
5. It is the duplicate of the second sheet. This is for the carrier at the departure.

The Consignment Norte is a quickly and easy way to explain in some pages all arrangements between many companies. In fact each page is made up

[19] Wagon Class U: it is a special wagon like well wagons or it used to carry bulk goods like powders.
[20] Wagon Class Z: it represents the family of tank wagons.

by cells where a simple combination of alphanumeric strings is able to explain the entire business. For example a simple ✓ is able to say if the transportation is paid by the consignor, by the consignee or by both. In the last case it is also possible to explain which undertaking is responsible for the payment of a specific part.
Or in other cells it is possible to show the path of the trip and which carriers are involved (the contractual one and others that bring the train to destination).

In the case that a carrier supply a full train service, there is only one Consignment Note with, in attachment, a list of all wagons. For each wagon characteristics (length, weight, maximum speed, etc.) and carried freight are illustrated. Instead in the case that the service is single wagon load, there is one Consignment Note per each wagon.

6.2. Operational Direction [28], [31-37]

The Operational Direction is the part of Mercitalia Rail that, respecting quality, punctuality and designed plans, manages locomotives, wagons and all people related to them (see *Figure 20*).

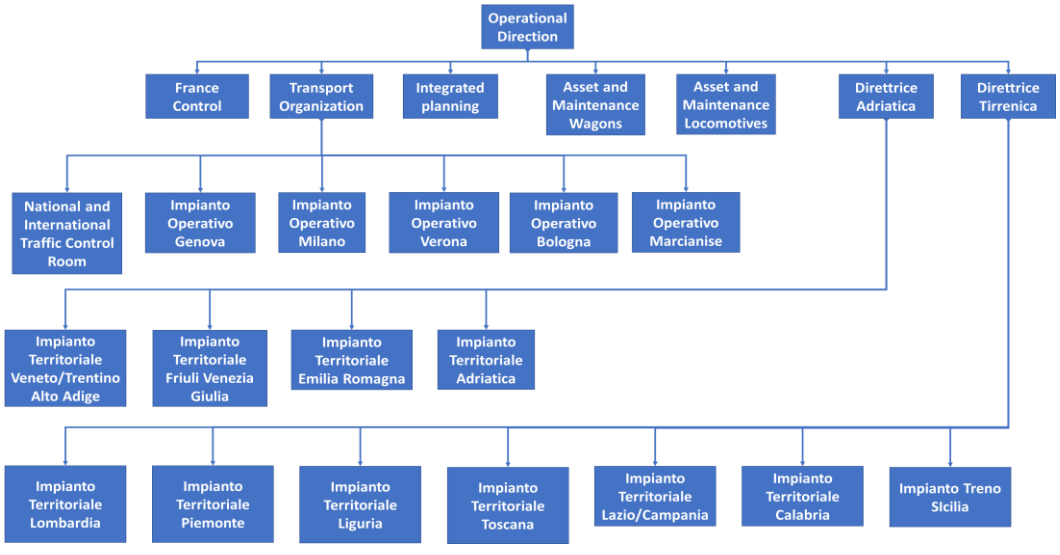

Figure 19 Operational Direction layout

In particular it is divided into seven macro structures:

- France Control: it manages trains that are involved in French territory. Considering the traction phase, Mercitalia Rail sends own locomotives 50 km across Italy-France border.
- Transport Organization: it manages the fulfilment of short (weekly and daily) and long-term transport plan, optimizing available resources (crews and locomotives) and it supervises contacts with IM to allow rescheduling during traffic disruptions. It is made up by five Impianti Operativi, each one has the responsibility on a specific area but anyway they represent a whole. In fact they collaborate in order to resolve problems that occur in one area or in another. Operations are coordinated by National and International Traffic Control Room that manages also contacts with other IM and RU (both Italian and European).
- Integrated Planning: it plans services, timetable and locomotives and drivers shift at long term (yearly and adjustment in progress). Therefore it contacts IM for long term issue.
- Asset and Maintenance Wagon: it is responsible for maintenance of wagons that Mercitalia Rail plays the role of maintenance responsible entity. In particular it provides legislation and it verifies the correct implementation. It analyses data in order to study each kind of malfunction and to identify corrective and improvement actions. It defines needs with a view to satisfy the demand considering rolling stock that is not available for maintenance.
- Asset and Maintenance Locomotives: it is the same of Asset and Maintenance Wagon but it is related to Locomotives.

- Direttrice Adriatica and Direttrice Tirrenica: they carry out same activities with the difference of controlled area. Direttrice Adriatica has the responsibility on the East part of Italy (regions with Adriatic coast line plus Trentino Alto Adige) instead Direttrice Tirrenica has the responsibility on West part of Italy included Sicily. They manage activities related to departure/arrival of trains in rail yards like management of shunting staff, supervision of rolling-stock technical characteristic, issue of accompanying documents and monitoring of dangerous goods. Each Direttrice is made up by Impianti Territoriali that have responsibility on rail yards of a specific area. A special attention must be given to Impianto Treno Sicilia that belongs to Direttrice Tirrenica. It is also called Impianto Unico because it clasts functions of Impianto Operativo and Impianto Territoriale, therefore it manages both rail yards and shunting staff and also drivers and locomotives.

  In order to sum up, Mercitalia Rail geographic split is shown in *Figure 21* where blue spots are Impianti Territoriali, orange spots are Impianti Operativi and red spots represent Maintenance centres. The black line, that split Italy into Eastern and Western parts, is the border between Direttrice Adriatica (East) and Direttrice Tirrenica (West).

Figure 20 Mercitalia geographic split

6.2.1. Transport Organization

Going more deeply, Transport Organization is the part of Operational Direction that:

- Manages implementation and monitoring of transport services through the fulfilment of transport plan, optimizing available resources (locomotives and drivers) and considering ratings held by each driver and performances of each locomotive.
- Manages relationships with IM (RFI) to ask new train paths or variations to existing one when traffic disruptions occur.
- Manages relationships with Transport Assistance (Business Direction) to study feasibility of short term (weekly and daily)

transport plan for requests concerning additional and exceptional trains or for cancellation of scheduled trains.

- Manages operations related to waste and dangerous goods.
- Manages assignment of delay reasons.
- Manages respect for the law in term of security, environment, operative.
- Manages labour relations.

Transport Organization is one macro structure that is divided into five Impianti Operativi. Each Impianto Operativo has the responsibility on a specific area. For example Impianto Operativo with venue in Verona organizes its activity in three regions (Veneto, Friuli Venezia Giulia and Trentino Alto Adige). Each Impianto Operativo manages these kinds of activities within its territory:

- It implements entrusted services using own resources (locomotives and drivers). If it is necessary an Impianto Operativo can use resources of another Impianto Operativo.
- It manages real time and planning situations in order to optimize crews[21] considering their ratings.
- It talks with *Integrated Planning* to improve efficiency of long term turn and to allow the definition of a new business offer.
- It manages flow in real time involving its area.
- It supervises production chain to reach punctuality during departure phase.
- It manages variation to long term transport plan (yearly) defining a short term plan (weekly, 48h and daily). It is done also engaging

[21] Crew: from a traction phase point of view, the crew is made up by two people

National and International Traffic Room and RFI to ask new train . paths, cancellations and variations to existing one.

- It manages locomotive allocations considering performances, maintenance cycles and driver ratings.
- It manages assignment of delay reasons.
- It manages labour relations.

6.2.1.1. Impianto Operativo

Activities carried out inside an Impianto Operativo are organized following a temporal organization. The reference time (time equal to 0) is the time departure of the train and time considered is calculated before the starting hour (*Figure 22)*. As much time is high as it is before the starting.

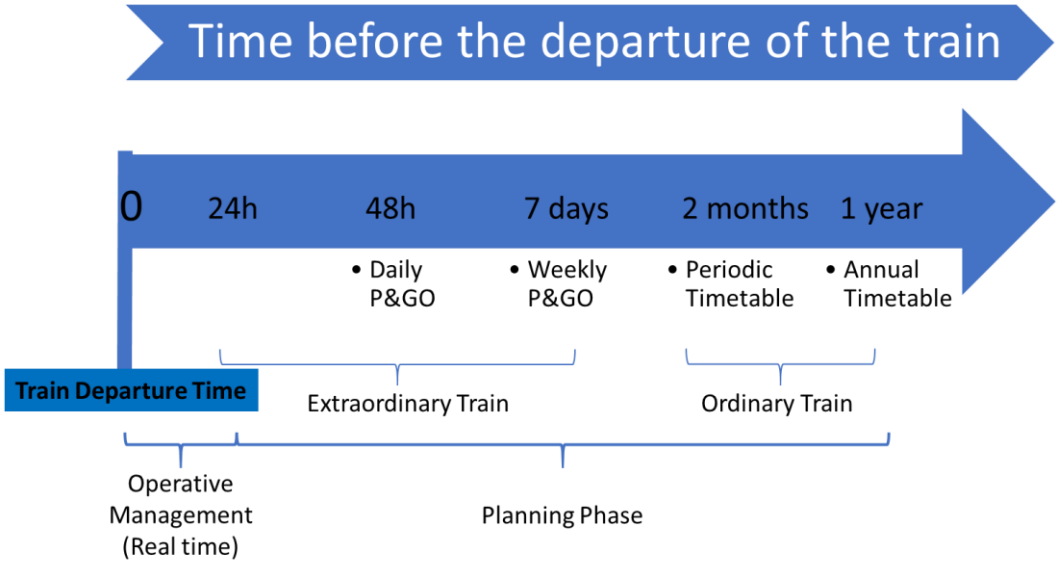

Figure 21 Impianto Operativo organization

Therefore there are different operators: who manages trains some days/months before the departure time or another one that for example, in real time, supervises a train with delay.

All activities are divided into two parts:

- Planning phase: it represents activities that are related to slot 1 year – 24 hours before the departure of the train.
- Operative Management (Real Time) phase: it represents activities that are related to slot 24 hours before the departure of the train - departure time of the train.

6.2.1.1.1. Planning Phase

In reality activities far (1 year - 2 months → long term) from the reference time are jobs that are not executed in an Impianto Operativo. In fact they are done in another structure (*Integrated Planning*) where trains, set up[22] by Business Direction, are organized into a shift for drivers. This is done optimizing available resources (drivers) and respecting legislation on working hours. Anyway Impianto Operativo is continuously in contact with Integrated Planning in order to suggest feasibility of new trains and how to improve future shifts. First kind of planning is done on annual timetable where there are trains that run for one year (every day or only in specific days of the week/month). Every year on December this timetable is published and it is valid until next December. Because of freight demand is not constant during one year, about every two months there is another timetable that updates the previous one. Every train, that is defined by these timetables, is called *ordinary* by the Infrastructure Manger. All trains that shape a shift are entrusted to a specific number of drivers that as soon as it is published they will know how they will work in next months. Drivers shift is explained in depth in Appendix 1.

[22] To set up a train: it means that Business Direction has already stipulated a train with a customer and Infrastructure Manager has already given the train path. Therefore the departure time and the arrival time are well defined.

Advancing on the time line the following step is composed by trains set up one week before their departure. All the process is shown on *Figure 24*.

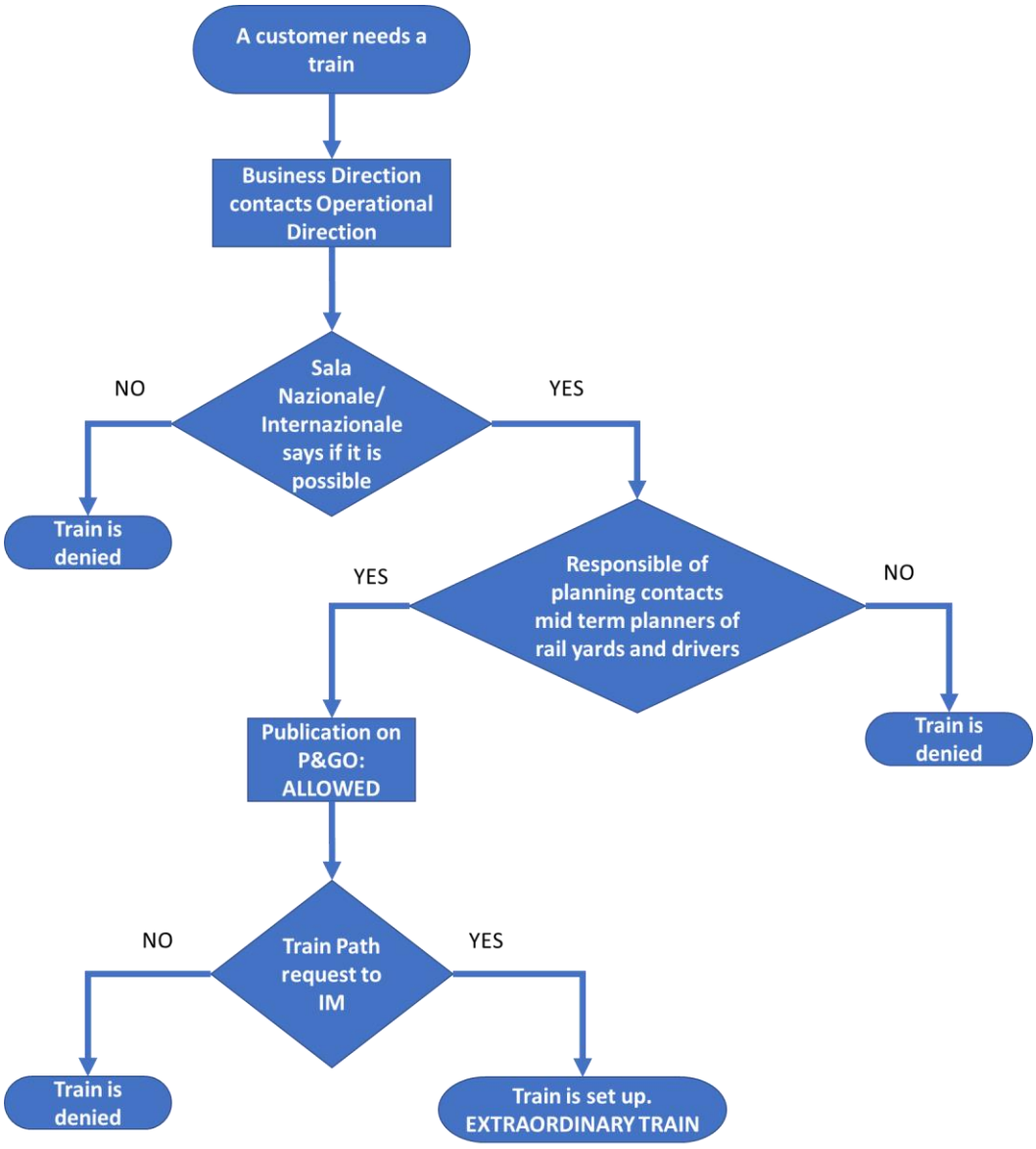

Figure 22 Flow chart of an extraordinary train

The first operation is done by a company that needs a service at medium term, therefore it contacts Business Direction of Mercitalia Rail. Then all requested are evaluated by Operational Direction. A first kind on analysis is done by Sala Nazionale/Internazionale that manages the entire traffic of Mercitalia Rail. At this point trains are divided between Impianti Operativi. Each Impianto Operativo studies feasibility of trains that start in rail yards

belonging to its area. Here there is the middle term planner (he is a responsible of Impianto Territoriale) that is familiar with the situation of all terminals of his jurisdiction and he knows if there is the availability of shunting teams to prepare requested trains. When he gives his consensus, he says also when (in which slot) the shunting team is available. Then there is also the middle term planner of drivers that per each day knows the availability of drivers. For example if in one day available drivers[23] are much less of not assigned services, it means that it is impossible to add other trains. Therefore if both middle term planners of rail yards and drivers give their consensus to the responsible of planning, it is possible to consider the train as *allowed* otherwise it is denied. At this point it is possible to publish allowed trains on the weekly plan (P&GO[24] settimanale). All the process that involves the responsible of planning is done during Tuesday and Wednesday. The weekly plan is published each Thursday during the afternoon and it contains all allowed trains from next Tuesday to following Monday. But it can happen that one train printed on P&GO is not still request to the infrastructure manager or it is in status of pending validation. The main problem is that any train path request has a cost hence a company waits the last instant to ask the train path. But there is a compromise because more the train path request is near the departure time and more is high the probability that infrastructure manager will not allow the train.

The next step on the time line is the short time plan. It means that a train is requested less than three days before its departure. Specifically it concerns requests that arrives in an Impianto Operativo two days before the departure. It means that a train that starts on Friday is requested to an

[23] Available drivers: they are drivers with any service for a specific day.
[24] P&GO: In Italian it is Programmazione e Gestione Orario

Impianto Operativo during Wednesday morning (by 10:00) and it is published on Wednesday afternoon (by 15:30) on daily plan (P&GO giornaliero). The process follows same steps of weekly requests but in this case is higher the probability that train will not allowed. If in the medium plan the middle term planner of drivers is not influent in the decision, in the short term he is important. This is because it is quite impossible to forecast available drivers one week before the departure of a train. There are many factors occurring at short term that define unavailability (sickness, special permits, refresher courses and etcetera). All trains that are published on P&GO giornaliero and settimanale are considered extraordinary by the Infrastructure Manager. They are organized in services by middle term planner of drivers that optimizes them through information on his possession: for example he knows which trains are delated. 24 hours before the starting of the train services are assigned to available drivers by another operator. This is the operator (short term planner of drivers) that allocates not assigned services to available drivers.

Inside an Impianto Operativo there are two kinds of drivers (see *Figure 24):*

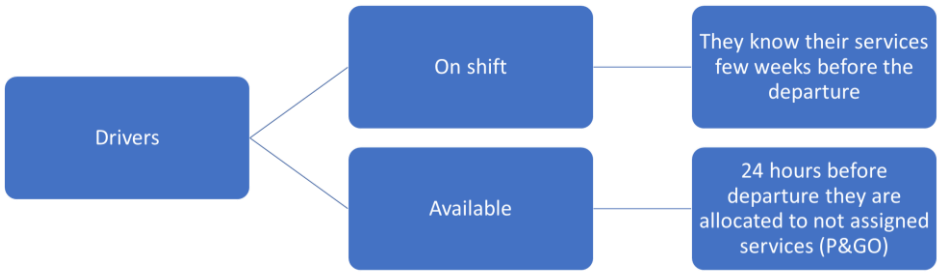

Figure 23 Types of drivers

- Drivers on shift: they know their services few weeks before the departure. Their services are created by *Integrated Planning* structure and assigned trains are defined in periodical and annual timetable.

- Available drivers: they know their services during the previous day of the departure. Their services are made up by trains published on P&GO settimanale e giornaliero.

Coming back to the short term planner of drivers, his principle activities are synthetized in *Figure 25*. The objective of this workstation is to optimize available resources (available drivers) in order to allocate them to all not assigned services. The first thing done by the operator is to understand the starting situation of the day that is defined by three parameters:

- Available drivers: they are drivers that are not on shift. They include also drivers on shift that don't have a service. It is because for example the entire day is deleted or assigned trains don't run during that day.
- Not assigned services: they are services created by the middle term planner of drivers. They include also services that shape the shift but allocated to drivers that are unavailable (for example drivers are on vacation, are ill, are occupied in refresher courses, etcetera).
- Difference between available drivers and not assigned services: in most cases it is a negative number. It means that available drivers are less than not assigned services.

Therefore the objective of short term planner of drivers is to continue the optimizing phase that started middle term planner of drivers. The short term planner knows other trains that will be delated and, modifying not assigned services, he tries to eliminate the negative gap between available drivers and not assigned services.

Another important aspect is to study the previous and following working days of the driver with respect to the day in which the operator assigns the

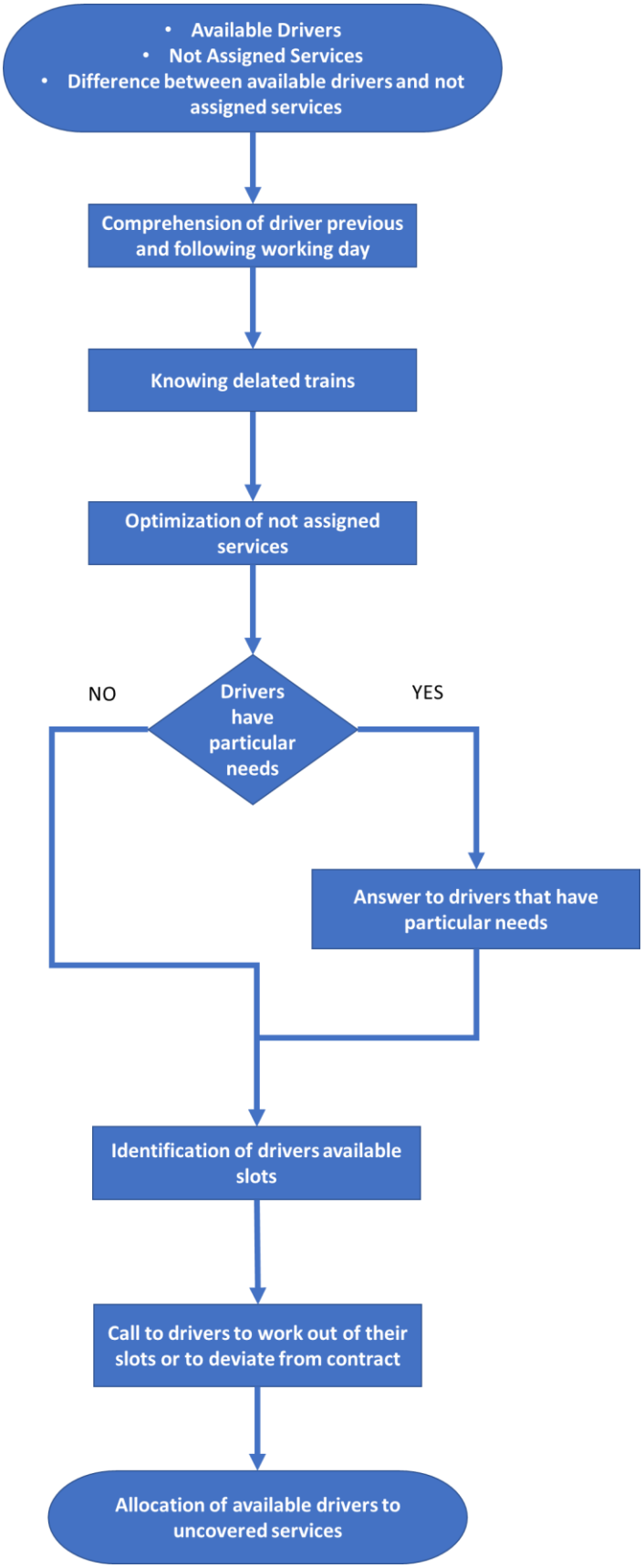

Figure 24 Flow chart of short term planner of drivers

services. This is done to understand the available slot of each driver (when a drive can work). For example considering a short term planner of drivers that works today and assigns a services for tomorrow, he studies drivers situation on today and on day after tomorrow. But he considers also a wider range because if for example the day is during the end of the week, he must check some constraints like number of night services and RAFH fulfilled by available drivers. If drivers have problems (for instance in their private life) for the next day, they call the operator to explain their issues and to define together slot in which driver is available. When it is possible to allocate a service that corresponds to driver availability, operator is sure that driver accepts the day, otherwise short term planner of drivers calls driver to ask if it possible to go outside available slot or to deviate from contract (Appendix 2). At the end of his day, the operator books hotel (one room per each driver) to all drivers that has RAFH inside the service. Rooms are booked for services that are assigned to both available and on turn drivers.

In order to sum up, activities related to medium and short term phases are carry out inside an Impianto Operativo. It means that during the planning phase an Impianto Operativo deals with requests concerning additional trains, cancellation of scheduled trains and allocation of available drivers to not assigned services. Operators that are involved inside an Impianto Operativo are shown on *Figure 26.* The first that starts the process is the responsible of planning that continuously is in contact with other operators in order to edit P&GO and to communicate delated trains.

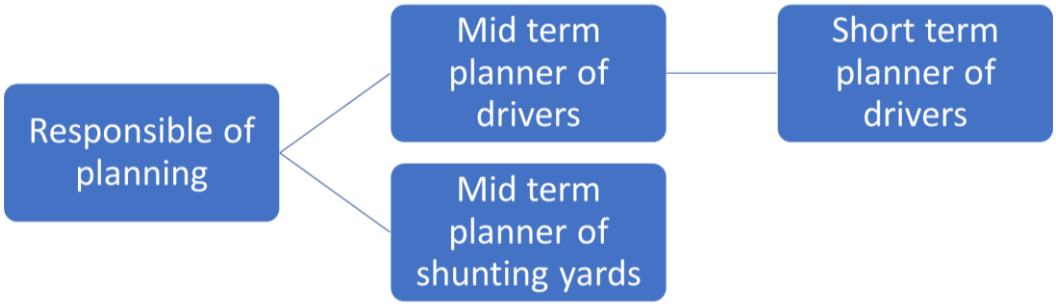

Figure 25 Planning operators inside an Impianto Operativo

Then there are middle term planner of drivers and middle term planner of shunting yards that support responsible of planning. In particular the middle term planner of drivers is the operator that organizes services that the short term planner of drivers assigns to available drivers.

6.2.1.1.2. Operative Management (Real Time)

Considering the real time phase there are three operators:

- Train dispatcher (Coordinatore trasporto)
- Locomotives dispatcher (Coordinatore locomotive)
- Train drivers dispatcher (Circolazione 303[25])

Train dispatcher

He is the coordinator and the responsible of real time activities. He is the operator that supervises all actions. He is one of the most experienced people inside an Impianto Operativo because it is important that he knows in depth all phenomena that characterized a traffic control room. For example when it is necessary to delete trains, he is the responsible of the decision. Since he knows which train is less important, he can choose which train can be deleted or postponed producing as little damage as possible.

[25] 303: the number comes from the paper form that was used to allocate drivers to services

He is the representative of the entire structure. Indeed when there is a problem, he is the person that speaks with external entities like police or judiciary. He is also the only operator that speak directly with the infrastructure manager. In fact he is the only one that can request to create or delete a train path. He can also see the trend of all trains in order to understand when it is higher the probability that the train path will be accepted. During his activity, he gives a particular attention to special trains carrying dangerous goods and exceeding loading gauge.

Locomotives dispatcher

He is the operator that manages locomotives of all trains that departure and arrive in shunting yards of his territory. The objective of this workstation is to balance locomotives. It means that each locomotive that arrives must be allocated to departing trains using the easiest and the most efficient way. The easiest and the most efficient way is that a locomotive that arrive in a station is assigned to a train that departure from the same station. But this is not always possible because for example the number of arrives is less than the number of departures or the back trip needs two locomotives instead of one because of weight reasons. In this case it is necessary to take the locomotive from another rail yard if it is not available in the departing station. In order to bring it, the locomotives dispatcher has to plan all operations. For instance he allocates the locomotive in composition[26] to another train or he organizes a trip for a single locomotive[27]. In the last case it is also necessary to ask a train path for the locomotive therefore he, through the train dispatcher, send a train path request to the infrastructure

[26] Locomotive in composition: it means that it is not the locomotive that is the leader of the train. It is put after the principle locomotive.
[27] Single locomotive: it means that a train is composed by only locomotives. Locomotives carry any wagons.

manager. He contacts also train drivers dispatcher that has to organize the service for two drivers. The locomotives dispatcher is constantly in contact with representative of each rail yard. This is important to verify that locomotives are in the same place that is specified by the software and to check how locomotives are parked. This is because they must be chosen in order to guarantee the minimum number of manoeuvres and the minimum time to put locomotives in front of trains. The operator when assigns a locomotive to a train must also consider skills of each driver. Since locomotive fleet is various, there are drivers that are not able to drive all locomotives. The allocation of a locomotive to a train must also consider the maintenance point of view. This is because each locomotive has mileage and temporal deadlines. When expiry deadline has passed, locomotives can't pull a train. Therefore it is necessary to send a locomotive to the nearest maintenance centre just before the expiration.

The activity of locomotives dispatcher is organized in two phases that are carry out simultaneously:

- Planning phase: the operator organizes the allocation of arriving locomotives to departing trains few hours before the departure.
- Real time phase: the operator checks the real arrival time in order to be sure that locomotives are ready for the departure time of the next train.

Train drivers dispatcher

He is the operator that manages drivers in real time. The objective of this workstation is to supervise all drivers that are allocated to trains that run along the rail network belonging to this workstation. For example the operator checks that, when a train has delay, if driver hours remain inside

labour parameters (rest time, break time, lunch time) and if drivers are able to take the outbound train. For example as it shown in *Figure 27*, the outbound part of the service is made up by the train 2724. But if the delay is more than 2 hours it is necessary to postpone the departure of train 51637 (when it is possible) or to send other drivers.

Figure 26 Example of a service

Other activities that are carried out by train drivers dispatcher are:

- Reorganization of services due to last minute unavailability in order to allocate them to other drivers. Examples are sick drivers or delays that don't safeguard the minimum rest time.
- Booking of *Vetture* where drivers doesn't have free access. They are taxi and Freccia Rossa, Freccia Argento, Freccia Bianca and Euro City trains. Instead drivers can have free access to all other kind of trains (Regionali and Intercity).
- Booking or cancellation of rooms to drivers that are subjected to service variation.
- Flexibility[28] registration on a form.
- Rail Skid[29] registration on a form
- Coupling-uncoupling[30] registration on a form.

[28] Flexibility: it is a reward to each driver that allow to deviate from CCNL/AF to CCNL/AF MIR

[29] Rail skid: they are used to stop the train where there is not electric power. For this kind of operation there is a reward

[30] Coupling-Uncoupling: it is an action that usually is carried out by the shunting team. But when the shunting team is not available, drivers couple or uncouple the locomotive from wagons. For this kind of action there is a reward.

7. The case study: Impianto Operativo Verona

The organization inside the Impianto Operativo located in Verona follows the general layout. Therefore there are operators that are related to planning phase and others that concern with real time situations (operative management). Considering the planning phase there is one *responsible of planning*, one *middle term planner of shunting yards* and one *middle term planner of drivers*. Working hours of planning phase operators are shown in *Figure 28.*

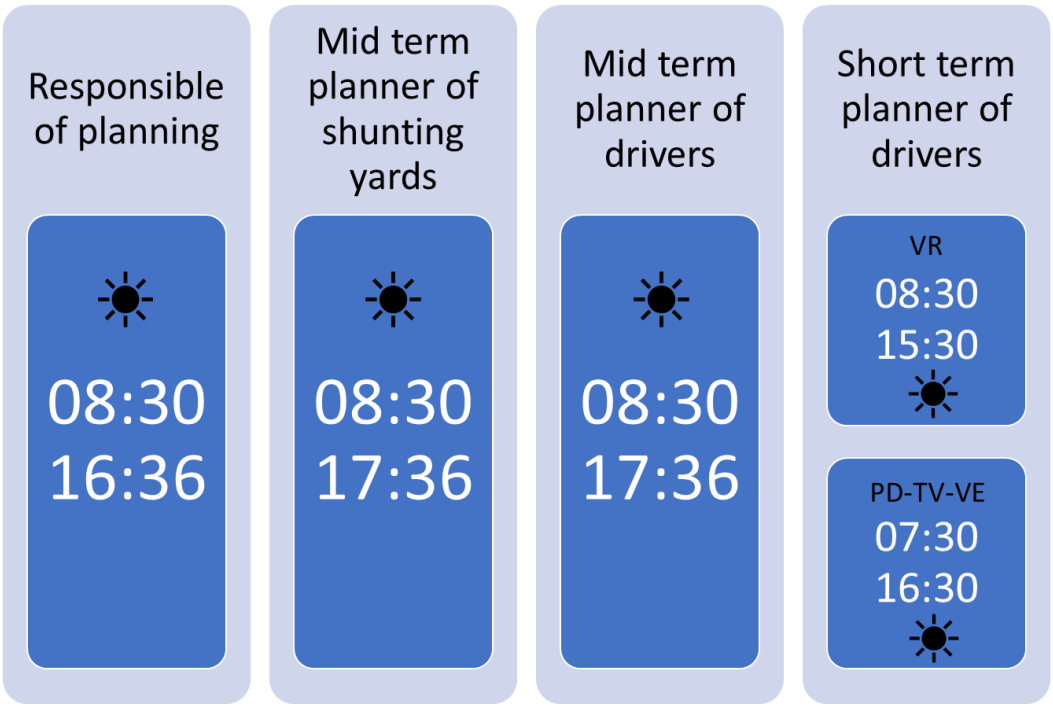

Figure 27 Planning phase operators working hours

The responsible of planning carries out his activities from 08:30 to 16:36. It means that he works for 7 hours and 36 six minutes with 30 minutes of lunch in the middle from Monday to Friday. Instead mid term planner of shunting yards and mid term planner of drivers work with same parameters with the only exception of lunch. It means that they finish their work at 17:36. About

short term planner of drivers there are two operators: one manages all available drivers that belongs to Impianto[31] Verona (VR) and the other that manages available drivers belonging to Impianti of Padova (PD), Treviso (TV) and Venezia Mestre (VE). The first carries out his activity from 08:30 to 16:30 instead the latter from 07:30 to 15:30. This is the configuration from Monday to Friday. Instead during weekend there is one operator that manages together drivers belonging to Impianti of Verona, Padova, Treviso and Venezia Mestre. Related to real time phase there is one *train dispatcher*, one *locomotives dispatcher* and one *train drivers dispatcher.* The first and the second carry out their activities for 24 hours that are divided into three parts:

- 06:00 – 13:00 → Morning
- 13:00 – 21:00 → Afternoon
- 21:00 – 06:00 → Night

Instead the train drivers dispatcher works during two slots:

- 06:00 – 14:00 → Morning
- 14:00 – 22:00 → Afternoon

Management of drivers during the night is fulfilled by locomotives dispatcher. In this way during the night slot the latter manages both locomotives and drivers. Working hours of real time phase operators are shown in *Figure 29.* Real time operators manage the movement of trains over Veneto and Trentino Alto Adige.

[31] Impianto: inside an Impianto Operativo there are branches (Impianti) in order to have an higher distribution inside all territory. For example Impianto Operativo Verona has the headquarter in Verona but there are also other Impianti (Padova,Treviso and Venezia Mestre)

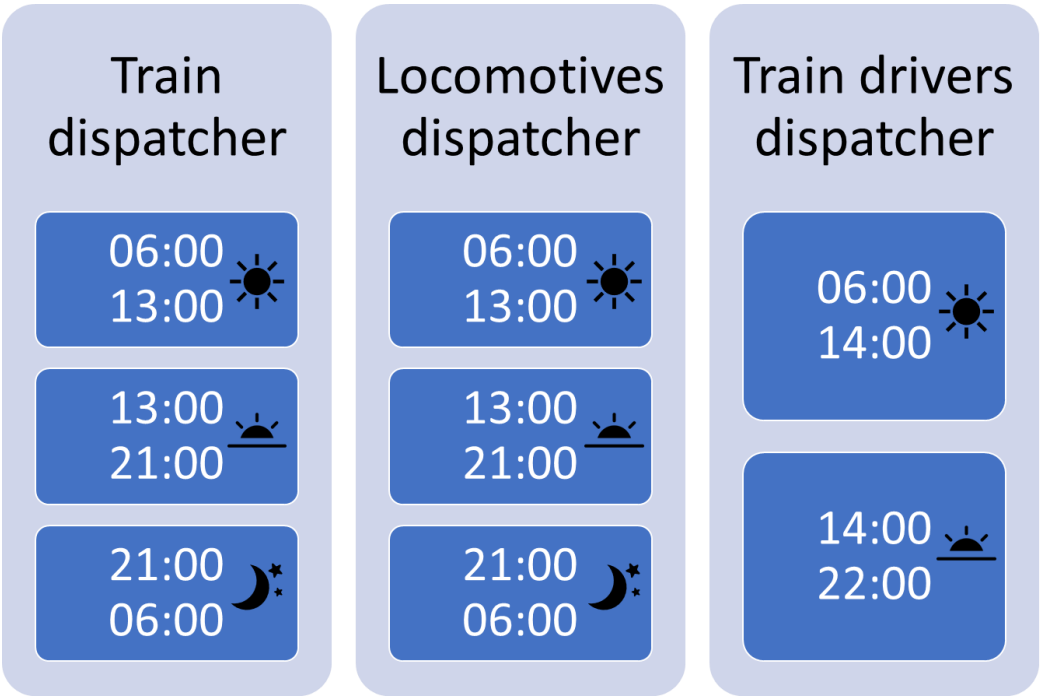

Figure 28 Real time phase operators working hours

7.1. Numerical analysis of workloads of traffic control room operators in Impianto Operativo Verona

The analysis has the objective of quantifying workloads of traffic control room (Sala Operativa) operators. It is done in order to understand which days and which part of the day are more critical. But the main problem lies in the fact that each operator carries out actions of different nature and different weight that are difficult to compare. An instrument that allows to solve this kind of problems is the Multicriteria Analysis [40] [41]. It is based on a dimensionless confrontation of criteria that are characterized by different nature (levels) and by different values (judgments) during each alternative *(Figure 30)*. In fact the goal (objective) is influenced by evaluation criteria (they regulate the final score) and how they are defined in each alternative.

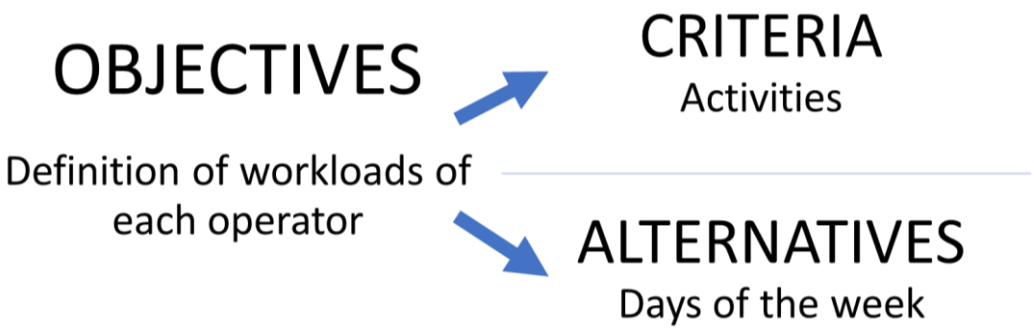

Figure 29 Multicriteria Analysis structure

But how it is possible to define each criterion in order to estimate how many times one criterion is larger than another? The issue is that criteria, that represent activities carried out by operators, have different nature and the comparison is not easy. Therefore the only way to define the relative magnitude between criteria is based on researcher feelings and experience. The scientist uses his interpretation of reality also to sort elements in groups that have similar influences on objective. Hence activities are organized into levels where one level is made up by activities that have the same effect on the objective. In order to define which criterion is more important and to define the weight of each element, each activity is evaluated through a paired comparison. It means that higher is the level and higher is the weight on the final evaluation.
Criteria assumes different values during each alternative (days of the week) and they are classified through the definition of a scale. The scale is determined by a graphic analysis that allow to specify a judgment for each value. In this way it is possible to homogenize points that have different values but the same judgment. The combination of judgments and weights of each criterion (activity) defines workloads of each operator during each alternative (days of the week).

The entire process is made up by 5 steps (*Figure 31*):

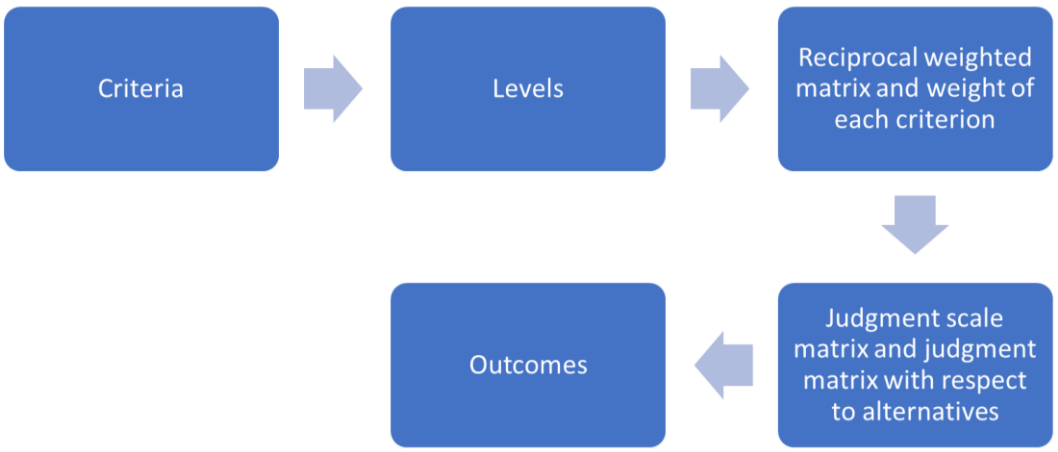

Figure 30 Analisi Multicriteria steps

- Step 1: definition of criteria. Each criterion is an activity fulfilled by the operator.
- Step 2: definition of the level of each criterion. All criteria of each operator are divided into three levels:
    1. I level or **green level**. It is the level that has the lowest weight. It includes fast activities (not more than few minutes) where the operator for example filled out a table.
    2. II level or **yellow level**. It is the level that has a medium importance. For all operators this category is described by the number of incoming and outgoing calls. They are put in the middle because there are calls that bring a problem to solve instead others are simple information.
    3. III level or **red level**. It is the level where there are the most important activities. They are activities with the highest weight.
- Step 3: definition of reciprocal weighted matrix and definition of weight of each alternative. The reciprocal weighted matrix is a

square matrix with criteria on both rows and columns. It represents the paired comparison between criteria. Each element a_{ij} of the matrix can assume three values (*Figure 32)*:

Figure 31 Relationship between levels

1. **-1** if criterion i has a level that is lower than the level of criterion j;
2. **0** if criterion i and criterion j have the same level;
3. **1** if criterion i has a level that is higher than the level of criterion j.

Table 1 shows a general reciprocal weighed matrix where the generic element c_{ab} represents the level of criterion a with respect to criterion b.

		Criteron j (j=a,b,..,n)			
		a	b	…	n
Criterion i (i=a,b,..,n)	a	c_{aa}	c_{ab}	…	c_{an}
	b	c_{ba}	c_{bb}	…	c_{bn}
	…	…	…	…	…
	n	c_{na}	c_{nb}	…	c_{nn}

Table 1 Reciprocal weighted matrix

The weight of each criterion i (w_i) is defined by the following procedure:

$$w_i = \frac{\left(\sum_{j=a}^{n} c_{ij}\right) + C}{\sum_{i,j=a}^{n} c_{ij} + nC} * 100$$

- All elements that are in row i are added together $\left(\sum_{j=1}^{n} c_{ij}\right)$.
- The sum is added by the same constant (C) that is chosen in a way that all w_i are positive numbers.
- Each score is divided by the sum of each row that is added by n times the constant C. Then it is multiplied by 100 $\left(\frac{100}{\left(\sum_{i,j=a}^{n} c_{ij} + nC\right)}\right)$. $\sum_{i,j=a}^{n} c_{ij}$ is the sum of all elements of reciprocal weighted matrix.

Weight of criteria are expressed by the vector *w* where the element w_i is the weight of criterion i

$$w = (w_1, w_2, \dots, w_i, \dots, w_n)$$

- Step 4: definition of judgment scale matrix and definition of judgment matrix. All values, that assume a criterion for each alternative, are evaluated through a scale that is made up by three ranks. Each rank is decided by a graphic analysis (*Figure 33).* The lowest rank is identified by 1, the middle by 2 and the highest by 3. The line *Rank 1-2* is the border between rank 1 and rank 2 instead the line *Rank 2-3* is the border between rank 2 and rank 3.

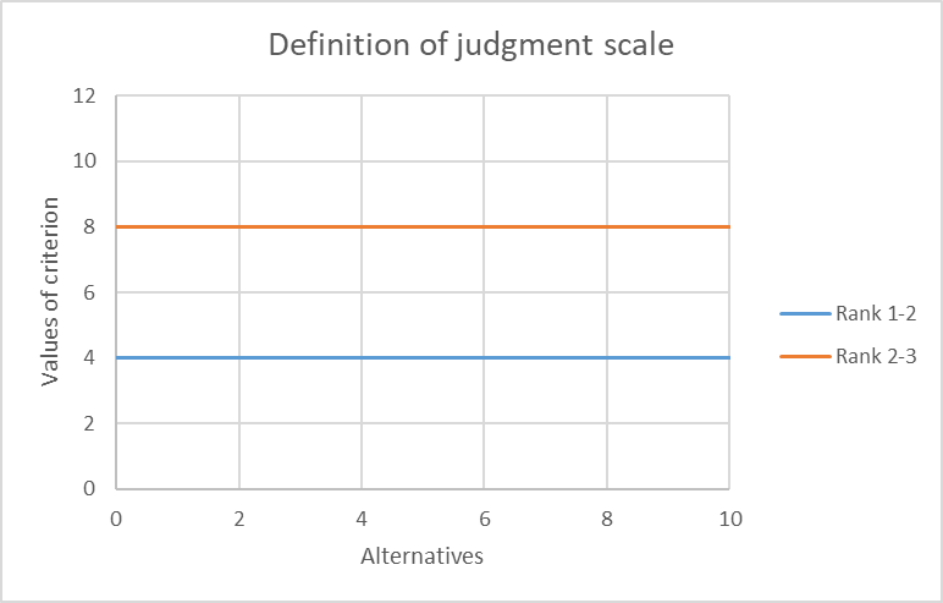

Figure 32 Definition of judgment rank matrix

An example of judgement scale matrix is shown in *Table 2* where criteria are on rows and ranks are on columns. The generic element a_1 defines slot in which criterion a is classified by 1.

		Ranks		
		1	2	3
Criterion i (i=a,b,..,n)	a	a_1	a_2	a_3
	b	b_1	b_2	b_3
	...	...	...	...
	n	n_1	n_2	n_3

Table 2 Judgment scale matrix

All values of each criterion are homogenized in a scale through which a criterion can assume only a value that is variable from 1 to 3. Therefore the judgment matrix, shown in *Table 3*, is made up by elements that can assume only 3 values (1-2-3 according to slot defined in judgment scale matrix). Columns of table 3 are given by alternatives that represent days of the week. They are from 1 to 5 because the analysis is done from Monday (1) to Friday (5). Days of the week are alternatives because of criteria assumes different values

during each day. Hence observing figure 33 if for example the criterion i has value 6, it assumes 2 for a specific day of the judgment matrix. The generic element α_{a1} represents the rank of criterion *a* during the day 1 of the week (Monday) and it can assume values of 1, 2 or 3.

		Alternatives j (j=1,…,5)				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criterion i (i=a,b,..,n)	a	α_{a1}	α_{a2}	α_{a3}	α_{a4}	α_{a5}
	b	α_{b1}	α_{b2}	α_{b3}	α_{b4}	α_{b5}
	…	$\alpha_{...1}$	$\alpha_{...2}$	$\alpha_{...3}$	$\alpha_{...4}$	$\alpha_{...5}$
	n	α_{n1}	α_{n2}	α_{n3}	α_{n4}	α_{n5}

Table 3 Judgment matrix

- Step 5: definition of outcomes. The final score represents the workload of the operator during each day of the week. It is represented by the vector *r*

$$r = (r_1, r_2, \dots, r_j, \dots, r_5)$$

where the generic element r_j is the workload of the operator during the day j

$$r_j = \sum_{i=a}^{n} w_i \cdot \alpha_{ij}$$

w_i is the weight of criterion i and α_{ij} is the rank of criterion i during day j. In other words, the result is given by the weighted sum of each rank of each criterion.

7.1.1. Multicriteria Analysis of short term planner of drivers

The analysis is done for both short term planner of drivers that are presented in Impianto Operativo Verona. Therefore one analysis is done for

operator that deals with drivers inside Impianto Verona and the other deals with drivers of Padova, Treviso and Venezia Mestre.

7.1.1.1. Impianto Verona: existing scenario

Activities fulfilled by the operator are defined by 5 criteria that are divided into 3 levels (see *Table 4)*. Inside level 1 (green level) there is the activity related to *hotel reservation*s of drivers. It is a fast operation that lasts few minutes where the operator books a room for each driver that has a RAFH. In the level 2 (yellow level) there are the number of incoming and outgoing *calls*. They are put in the middle because there are calls that bring a situation that the operator has to solve but others are simple information. Then there are the most critical activities (red level) that describe this operator. They are *not assigned services* (services defined by P&GO settimanale and giornaliero), *available drivers* and the *difference between not assigned services and available drivers.*

	criterion i		unit of measure
I level	1	hotel reservations	number of bookings
II level	2	calls	number of calls
III level	3	not assigned services	number of services
	4	available drivers	number of people
	5	difference between 4 and 3	\

Table 4 Criteria of short term planner of drivers VR

Therefore it is possible to define the reciprocal weighted sum and the weight of each criterion (see *Table 5)* that is expressed by the vector *w*. Obviously the weight is higher for criteria that belong to III level (each criterion has 28% of the total weight). The additive constant is equal to 5. It is chosen in order that the smallest sum (-4) becomes positive.

		Criteria				
		1	2	3	4	5
Criteria	1	0	-1	-1	-1	-1
	2	1	0	-1	-1	-1
	3	1	1	0	0	0
	4	1	1	0	0	0
	5	1	1	0	0	0

Sum		w
-4	1	4.00%
-2	3	12.00%
2	7	28.00%
2	7	28.00%
2	7	28.00%
	25	

Table 5 Reciprocal weighted sum and weight of each alternative – short term planner of drivers VR

Judgment scale matrix is shown in *Table 6*. It represents slots in which values of each criterion are homogenized. For example if criterion 1 (hotel reservations) is equal to 10 (10 hotel reservations) it has a judgment or rank that is equal to 2.

		Ranks		
		1	2	3
Criteria	1	<9	9-15	>15
	2	<50	50-70	>70
	3	<40	40-60	>60
	4	<28	28-39	>39
	5	<15	15-25	>25

Table 6 judgment rank matrix – short term planner of drivers VR

In order to understand more easily how the table 6 is edited, graphs of each criterion are shown. On the y-axle there are values of the criterion instead on the x-axle there are days of the week (from Monday to Friday). *Figure 34* shows values of Hotel Reservation criterion. The scale, chosen through a graphic analysis, is organized into three ranks:

1. Less than 9 hotel reservations.
2. Between 9 and 15 hotel reservations.
3. More than 15 hotel reservations.

Each day has more than one value because it is represented by the average value of that day ± the standard deviation. The observation was carried out from Monday 24th September 2018 to Tuesday 6th November.

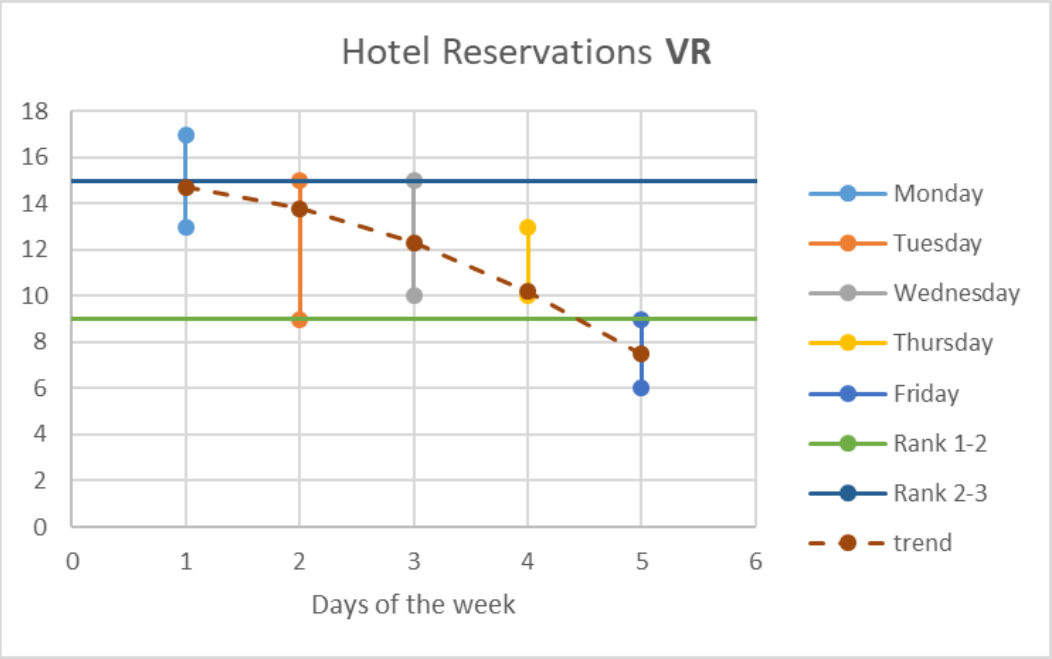

Figure 33 Hotel reservations – short term planner of drivers ***VR***

Therefore there are 6 or 7 values per each day. Values observed on Monday are between rank 2 and rank 3, hence on Monday hotel reservations criterion has value 2.5 in the rank matrix (*Table 8)*. Tuesday, Wednesday and Thursday are entire in rank 2, instead Friday is in rank 1. *Figure 35, 36 37* and *38* shows values of other criteria. Criterion 1 during the week assumes a parabolic trend.

Calls are described by only one point per each day because one observation is made per each day.

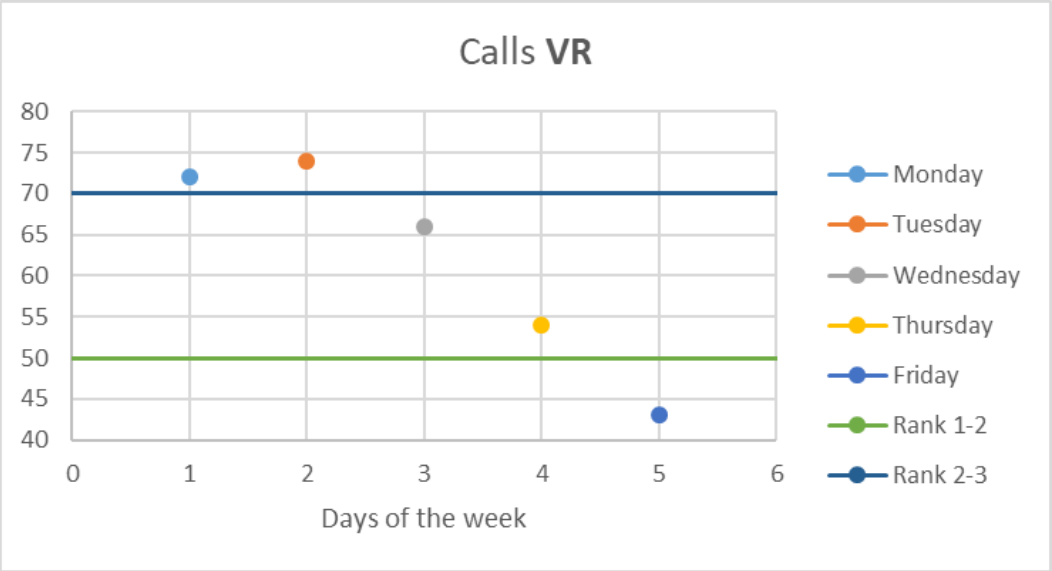

*Figure 34 Calls - short term planner of drivers **VR***

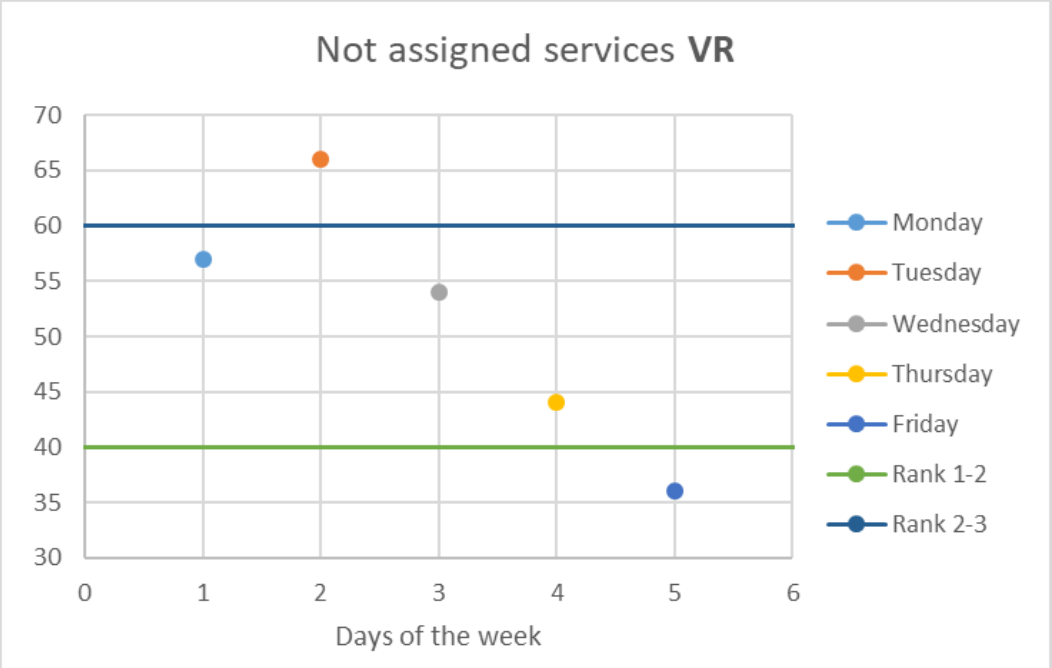

*Figure 35 Not assigned services - short term planner of drivers **VR***

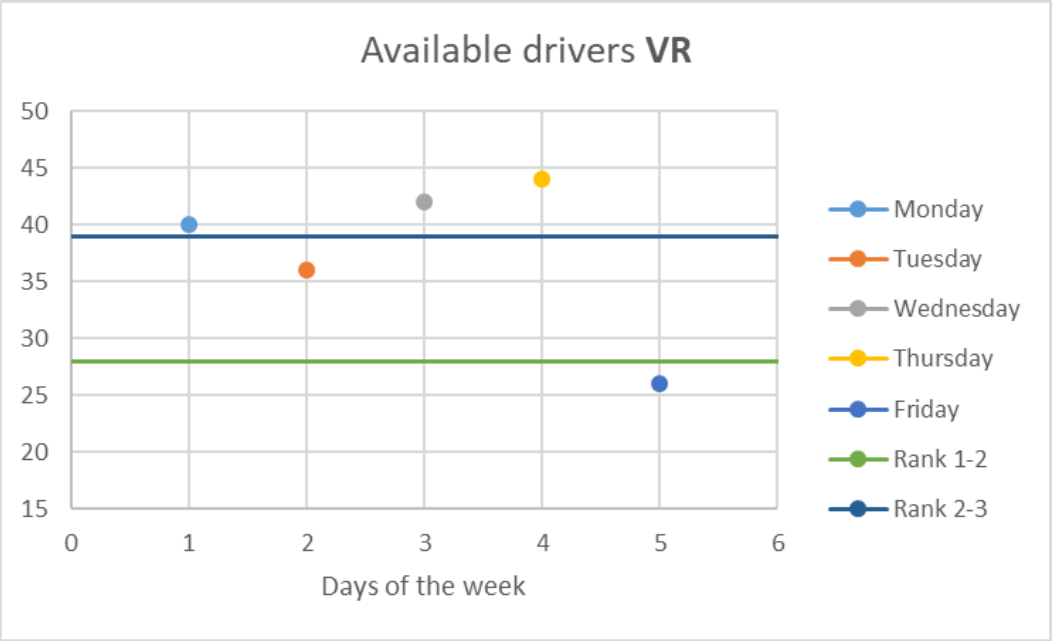

*Figure 36 Available drivers - short term planner of drivers **VR***

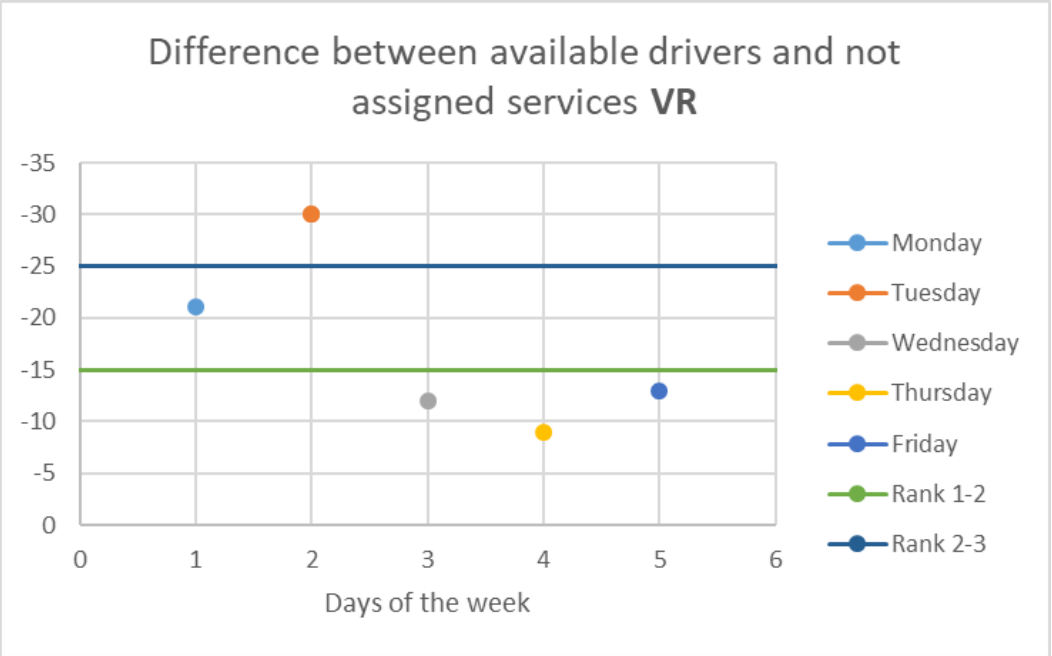

*Figure 37 Difference between available drivers and not assigned services - short term planner of drivers **VR***

Figure 36,37 and 38 are described by one point for each day. It is because per each day at maximum three observations are fulfilled. The point represents the most critical situation. In fact in the case of available drivers

and not assigned services it is the maximum number instead, considering the difference between available drivers and assigned drivers, it is the minimum. This is because the result is negative and the most critical situation is given by the highest difference between available drivers and not assigned services. How it is possible to observe, points that shape figure 38 are not the difference of values observed in figure 36 and 37. In fact, as it is shown in *Table 7*, on Monday three observations are made but values of available drivers and values of not assigned services aren't chosen in the same observation of criterion 5. Indeed the point of criteria 3 and 4 is chosen by the second observation, instead the point of criterion 5 is taken by observation 3.

observation	Available drivers	Not assigned services	Difference
1	35	47	-12
2	40	57	-17
3	32	54	-22

Table 7 Observations of criteria 3,4 and 5 during Monday - short term planner of drivers ***VR***

All points that are shown in previous graphs are clustered in *Table 39*. It represents values that are assumed by each criterion during each day of the week.

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	13-17	9-15	10-15	10-13	6-9
	2	72	74	66	54	43
	3	57	66	54	44	36
	4	40	36	42	44	26
	5	-22	-30	-12	-9	-13

Table 8 Values of each criterion during the week - short term planner of drivers ***VR***

Therefore now, making a comparison between table 8 and table 6, it is possible to check the rank of each value. Each rank is shown in *Table 9* (Judgment matrix).

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	2.5	2	2	2	1
	2	3	3	2	2	1
	3	2	3	2	2	1
	4	3	2	3	3	1
	5	2	3	1	1	1

Table 9 Judgment matrix- short term planner of drivers ***VR***

Knowing the vector *w* and the judgment matrix, it is possible to define workloads of short term planner of drivers during the week. Outcomes, shown in *Table 10,* are described by elements of vector *r*. A general element of the vector varies between 1 (all criteria belongs to rank 1) and 3 (all criteria belongs to rank 3).

	Monday	Tuesday	Wednesday	Thursday	Friday
r	2.42	2.68	2.00	2.00	1.00

Table 10 vector r - short term planner of drivers ***VR***

Results are presented in *Figure 39.*

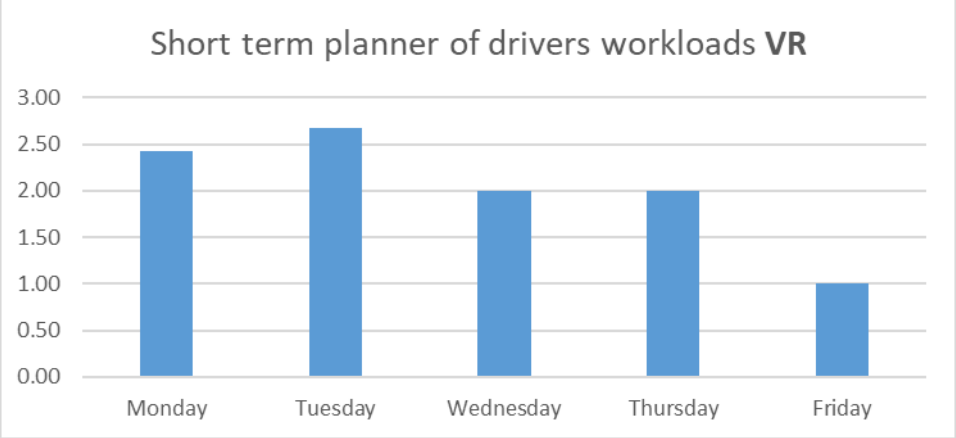

Figure 38 Short term planner of drivers workloads - ***VR***

The most critical day is on Tuesday. This is because on Tuesday the operator works on trains than travel on Wednesday. During this day is higher the flow of trains. The other critical day is on Monday. This is because during Saturday and Sunday the middle term planner of drivers has weekly rests. The last works trains before the short term planner of drivers and when he is at work he starts to solve criticalities. Instead Friday is the lowest day because on Saturday the flow of train is low.

7.1.1.2. Impianti Padova, Treviso and Venezia Mestre: existing scenario

The short term planner of drivers, that manages all drivers belonging to Impianti of Padova, Treviso and Venezia Mestre, carries out same activities of operator that manages Impianto of Verona. The only difference is that operators supervises different drivers and different services. Therefore criteria and weight are the same but scale (*Table 11)* and values of each criterion are different.

		Ranks		
		1	2	3
Criteria	1	<3	3-6	>6
	2	<30	30-50	>50
	3	<20	20-30	>30
	4	<20	20-27	>27
	5	>0	0-12	>12

Table 11 judgment rank matrix – short term planner of drivers ***PD-TV-VE***

Because of the scale is different, it is not possible to compare outcomes of two operators.

Figures 40-44 shows values of all criteria.

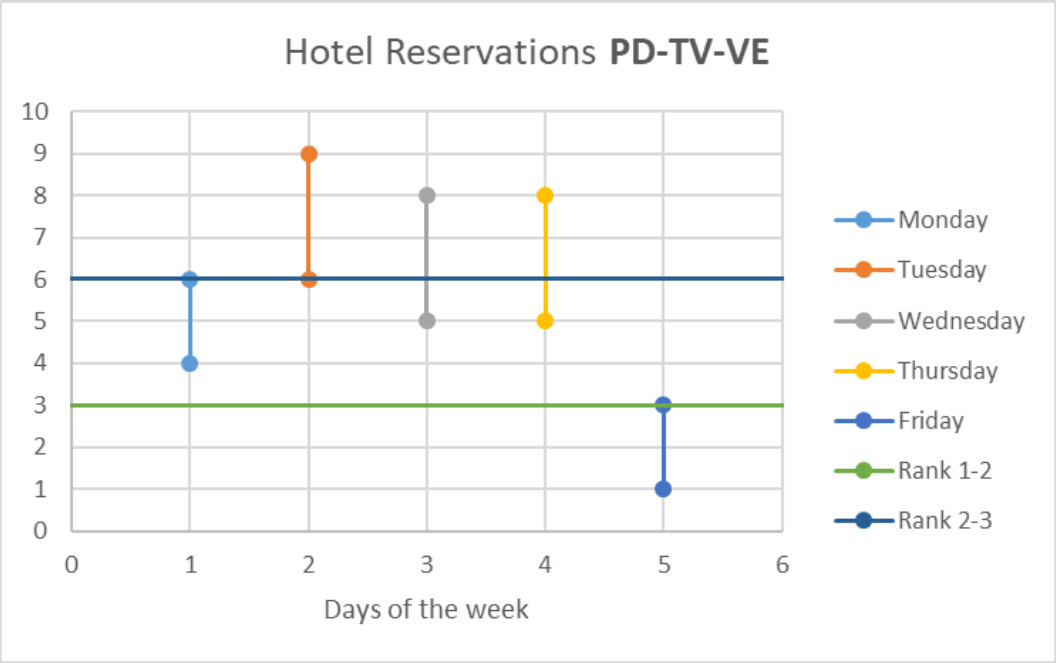

Figure 39 Hotel reservations - short term planner of drivers ***PD-TV-VE***

With respect to other short term operator, hotel reservations are more or less half.

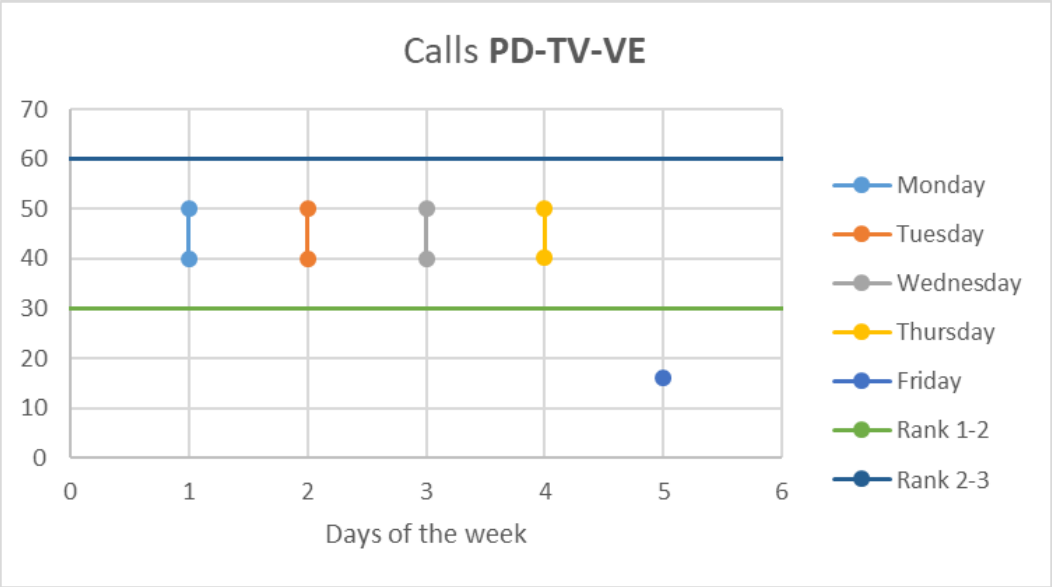

Figure 40 Calls - short term planner of drivers ***PD-TV-VE***

Since there are few observations regarding calls, it has been decided to keep constant the value of calls in the slot 40-50. The slot has rank 2.

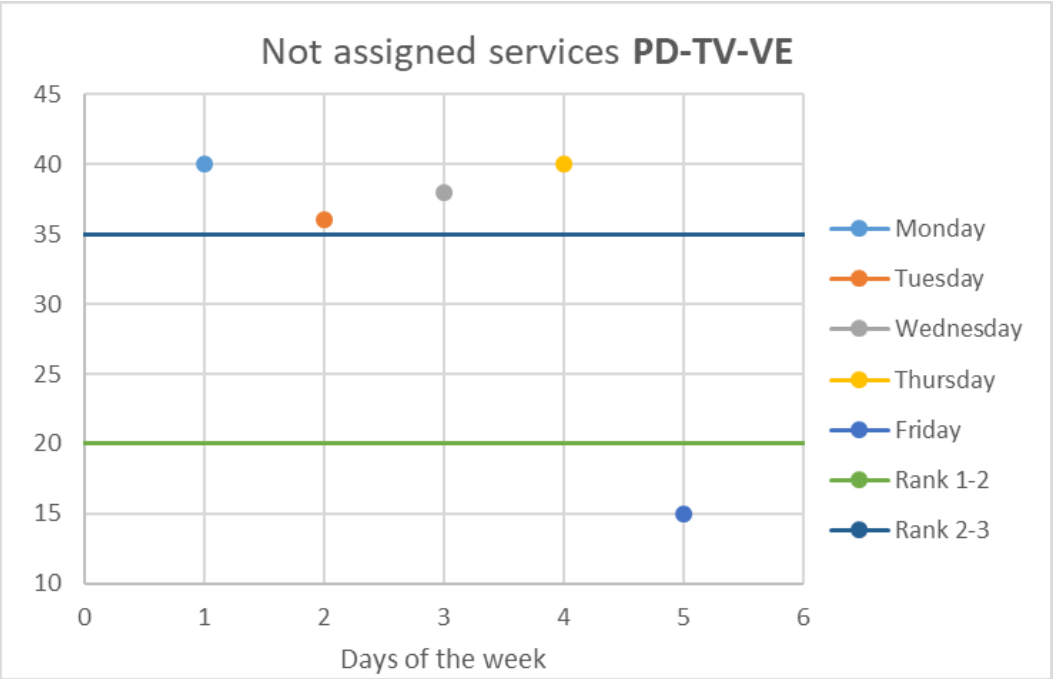

Figure 41 Not assigned services - short term planner of drivers ***PD-TV-VE***

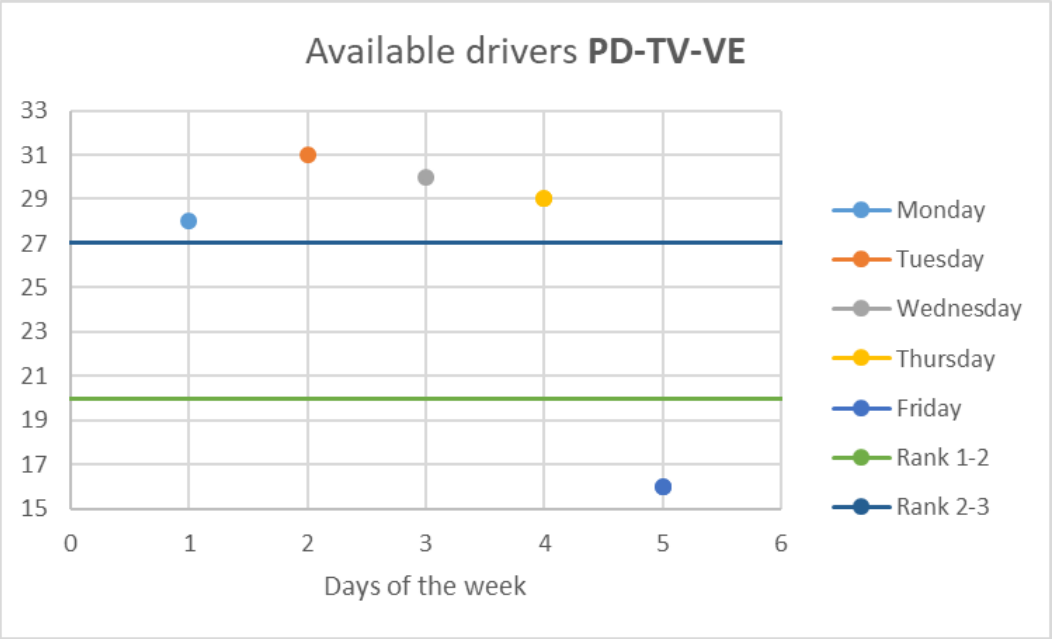

Figure 42 Available drivers - short term planner of drivers ***PD-TV-VE***

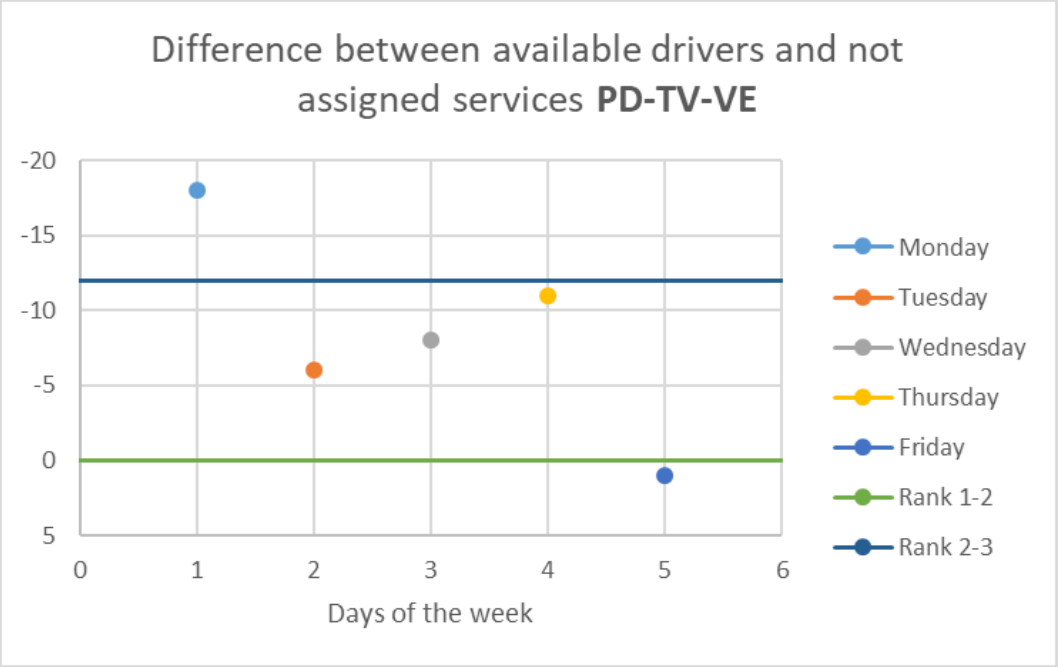

Figure 43 Difference between available drivers and not assigned services - short term planner of drivers ***PD-TV-VE***

With respect to other short term operator, not assigned services and available drivers are reduced by approximately of 30%-40%. But this fact doesn't mean that workloads are reduced. It is because there are less

services and drivers to manages but possibilities are reduced to move a driver from a part to another or to modify a service.

All points that are shown in previous graphs are clustered in *Table 12.*

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	4-6	6-9	5-8	5-8	1-3
	2	40-50	40-50	40-50	40-50	16
	3	40	36	38	40	15
	4	28	31	30	29	16
	5	-15	-6	-8	-11	6

Table 12 Values of each criterion during the week - short term planner of drivers ***PD-TV-VE***

Now, making a comparison between table 12 and table 11, it is possible to check the rank of each value. Each rank is shown in *Table 13*.

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	2	3	2.5	2.5	1
	2	2	2	2	2	1
	3	3	3	3	3	1
	4	3	3	3	3	1
	5	3	2	2	2	1

Table 13 Judgment matrix - short term planner of drivers ***PD-TV-VE***

Outcomes are shown in *Table 14* that describe elements of vector *r.*

	Monday	Tuesday	Wednesday	Thursday	Friday
r	2.84	2.60	2.58	2.58	1.00

Table 14 vector r - short term planner of drivers ***PD-TV-VE***

Results are presented in *Figure 45.*

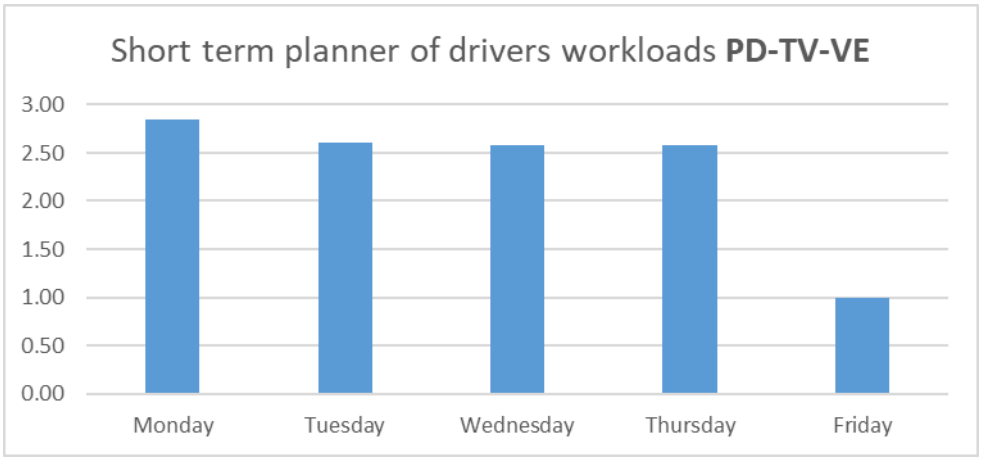

*Figure 44 Short term planner of drivers workloads - **PD-TV-VE***

The most critical day is on Monday. This is because during Saturday and Sunday the middle term planner of drivers has weekly rests. The middle term planner of drivers manages services and drivers before the short term planner of drivers and when he is at work he starts to solve criticalities. Instead Friday is the lowest day because on Saturday the flow of train is low. From Tuesday to Thursday workloads can be considered constant.

7.1.1.3. Impianti Verona, Padova, Treviso and Venezia Mestre: hypotethical scenario

In the hypothetical scenario it is assumed that short term planner of drivers of Impianto Verona and short term planner of drivers of Impianti Padova, Treviso and Venezia Mestre are clustered together as it is shown in *Figure 46*. Therefore instead of 2 daily operators there are 2 operators (*Figure 47)* with one that works during the morning from 06:00 to 14:00 and the other from 14:00 to 22:00. Working hours are the same in both scenarios: 2 operators that work per 8 hours. The exception is Friday when only one operator is necessary. He works from 08:30 to 16:30.

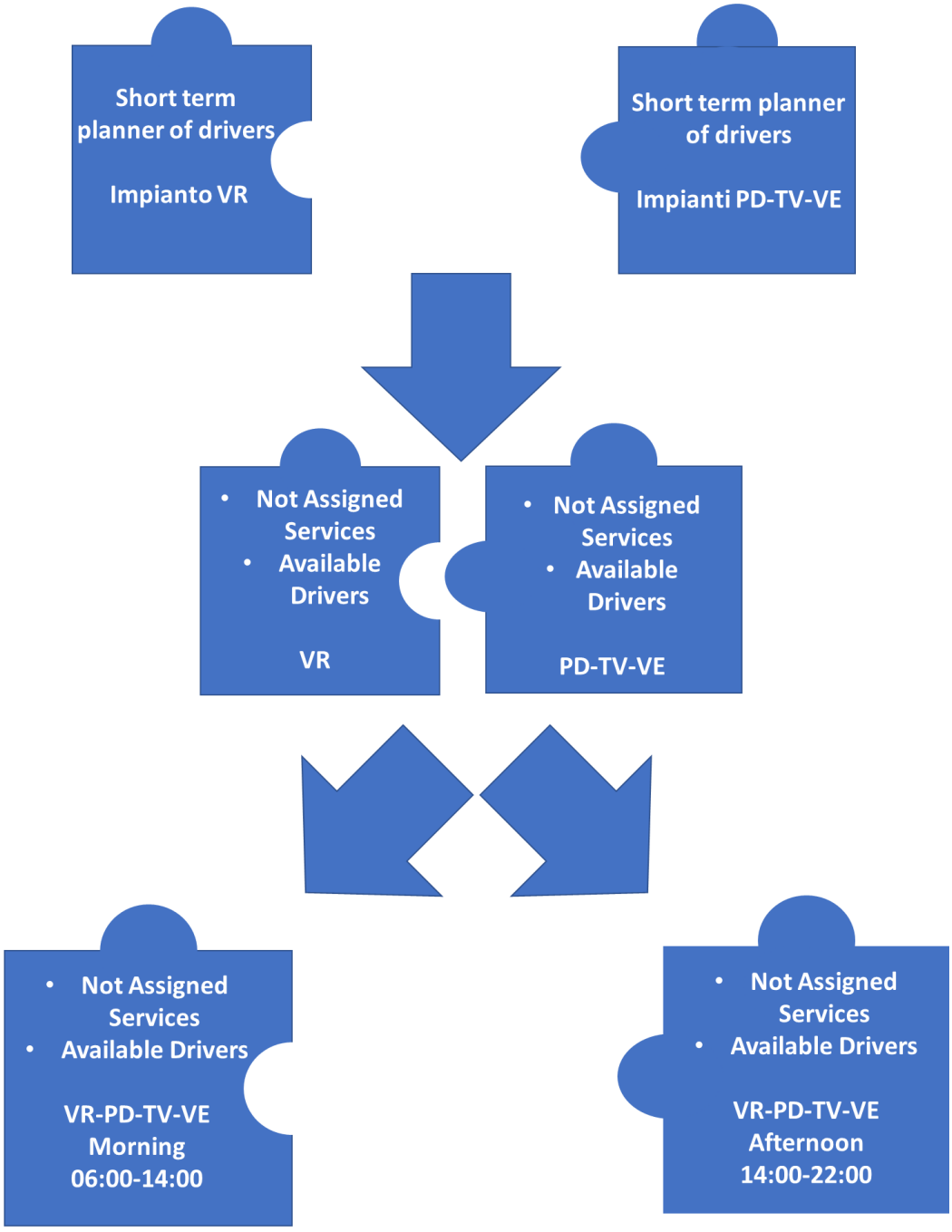

Figure 45 Short term planner of drivers - hypothetical layout

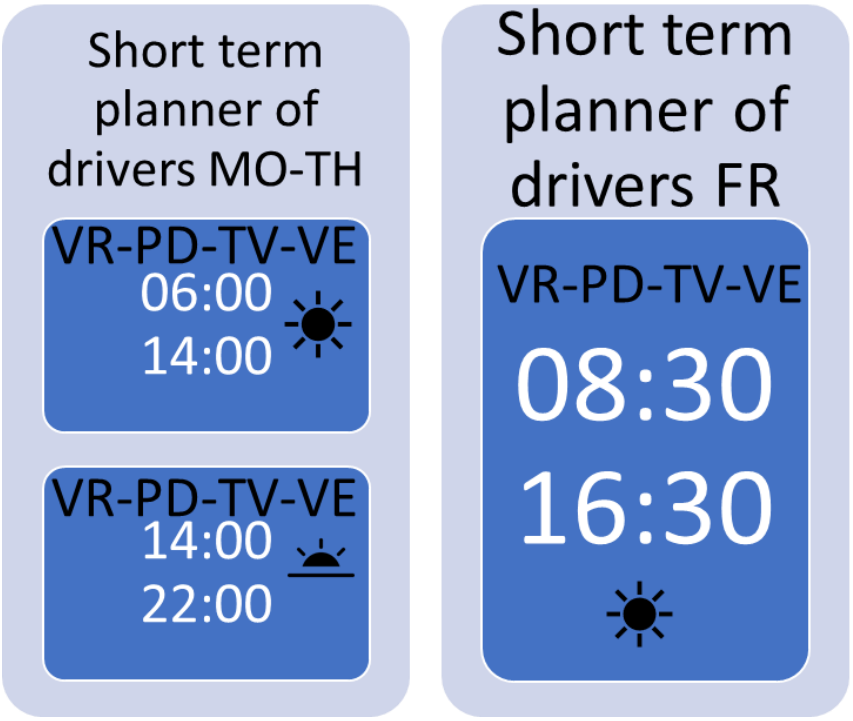

Figure 46 Planning phase operators working hours- hypothetical layout

The evaluation of the hypothetical scenario is carried out using the same methodology that is fulfilled for existing scenarios. In particular criteria are equal for all short term planner of drivers. But obviously values of each criterion are different. The scale must be the same in order to allow a comparison between hypothetical and existing scenarios.

Before to go in depth in the values that characterized each criterion of the hypothetical scenario, it is necessary to make some assumptions. The hypothetical scenario is described by grouping activities of two operators. Therefore values of all criteria are defined making the sum. For example if the short term planner of drivers of Impianto Verona manages 40 available drivers and the short term planner of drivers of Impianti Padova,Treviso and Venezia Mestre manages 57 available drivers, grouping all Impianti short term planner of drivers manages 97 available drivers. But it is necessary to split this value between morning and afternoon operators.

Data, that are shown in *Table 15*, were observed on Thursday 13th December 2019. Therefore they are values of drivers that work on 14th December.

	available drivers		not assigned services	
	number	wrt tot	number	wrt tot
tot	49		56	
0:00-12:59	36	73.5%	38	67.9%
13:00-24:00	13	26.5%	18	32.1%
0:00-7:59	36	73.5%	21	37.5%
08:00-24:00	13	26.5%	35	62.5%

Table 15

The total number of available drivers is 49 instead the total number of not assigned services is 56.

Criteria are the same but they are divided in the following way:

- Hotel reservations: they are done only by afternoon operator. This is because hotel reservations are one of last activities carried out by the operator. They are done when all not assigned services are allocated to available drivers.
- Calls: inside calls are defined other categories (Appendix 3 calls in depth)
    1. Communication info availability:
        - Incoming →100 % morning
        - Outcoming →73.5% morning, 26.5% afternoon
    2. Availability >24 hours:
        - Incoming → 100% afternoon
    3. Allocation/variation to the service:
        - Incoming →32.7% morning, 67.3% afternoon
        - Outcoming →37.5 morning, 62.5% afternoon
    4. Communication with other traffic control rooms:

        - Incoming/outcoming →67.9% morning, 32.1% afternoon
    5. Unanswered calls: not considered
    6. Other
        - Incoming →100% morning
    7. The last category considers calls that in existing scenario are made to train drivers dispatcher. This is because after 16:30 there is any operator that manages services and drivers of next day. Therefore this activity is assigned to the real time operator. It is observed that on average train dispatcher receives 9 calls for issues regarding short term planner of drivers operator. 9 calls are added to afternoon calls.
- Concerning activities that defined III level the border line between morning and afternoon is drawn by 13:00. Therefore the operator that works on the morning deals with all not assigned services and available drivers with starting time before 13:00. Operator that works on the afternoon carries out his activities with all other available drivers and not assigned services.

In order to allow a comparison between hypothetical and existing scenarios, the scale of hypothetical scenario is the same of the scale of existing scenario. Therefore, afternoon workloads are defined through the scale of short term planner of drivers that manages Impianto of Padova, Treviso and Venezia Mestre (*Figure 48)*. In this way it is possible to compare outcomes of hypothetical scenario during morning with Impianto Verona and outcomes of hypothetical scenario during afternoon with Impianti of Padova, Treviso and Venezia Mestre.

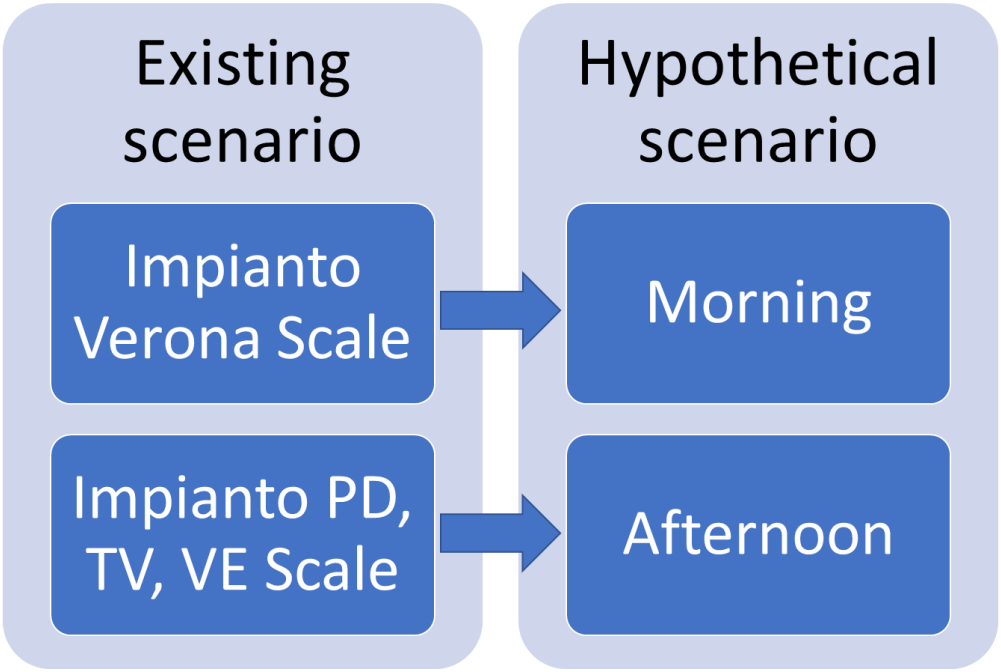

Figure 47 Comparison between scales of existing and hypothetical scenarios

Scales are unvaried but where necessary a judgment (rank) is added. For example the rank with value 7 is added in the scale of hotel reservations and the rank with value 4 is added in the scale of available drivers during the morning. Graphs of all criteria are shown from *Figure 49* to *Figure 57*. They represent values of both morning and afternoon operator. On the y-axle there are values of criteria instead on the x-axle there are days of the week. But there is a difference on x-axle between morning and afternoon. It is because graphs that represent morning operator go from 1 (Monday) to 5 (Friday) even if on Friday there is only one operator for the whole day (from 08:30 to 16:30). Instead graphs that represent afternoon operator goes from 1 (Monday) to 4 (Thursday). Friday is not present because there is not the second operator.

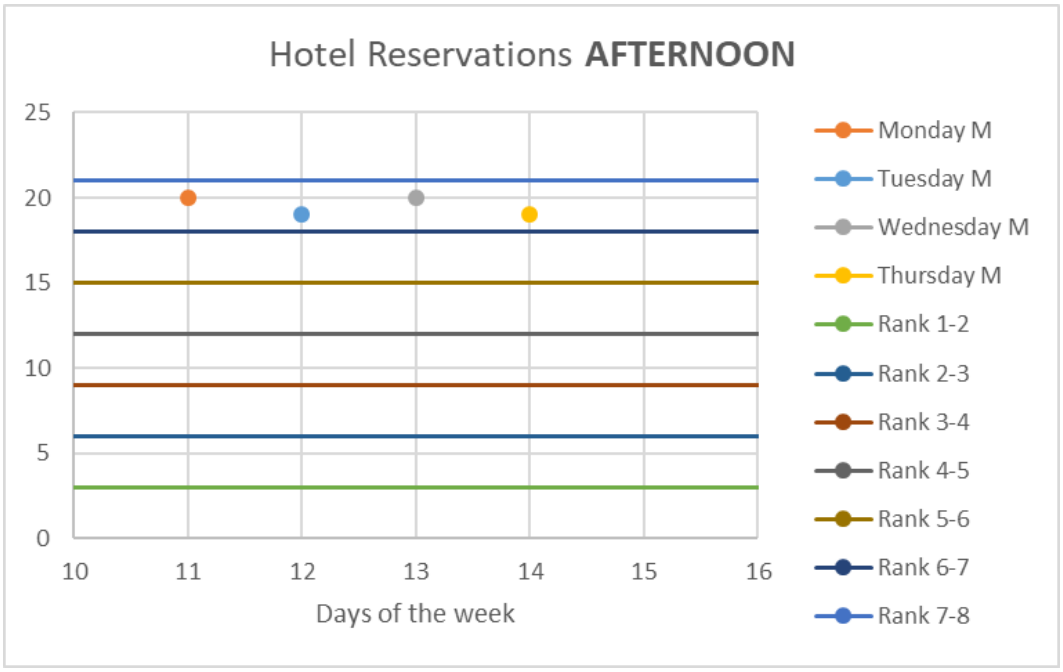

Figure 48 Hotel reservations- short term planner of drivers ***Afternoon***

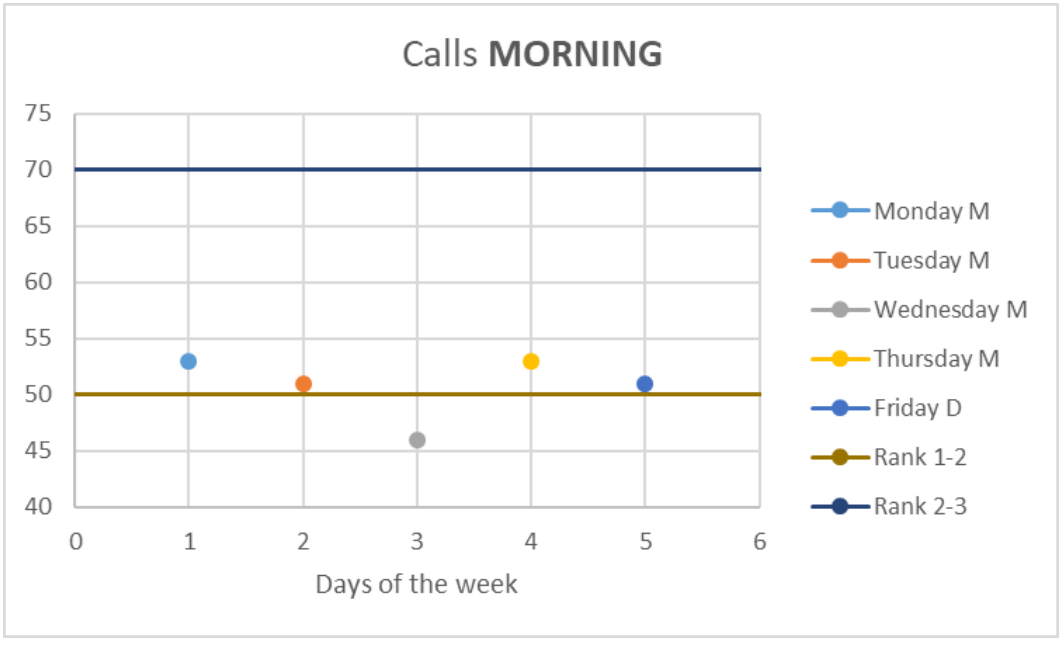

Figure 49 Calls - short term planner of drivers ***Morning***

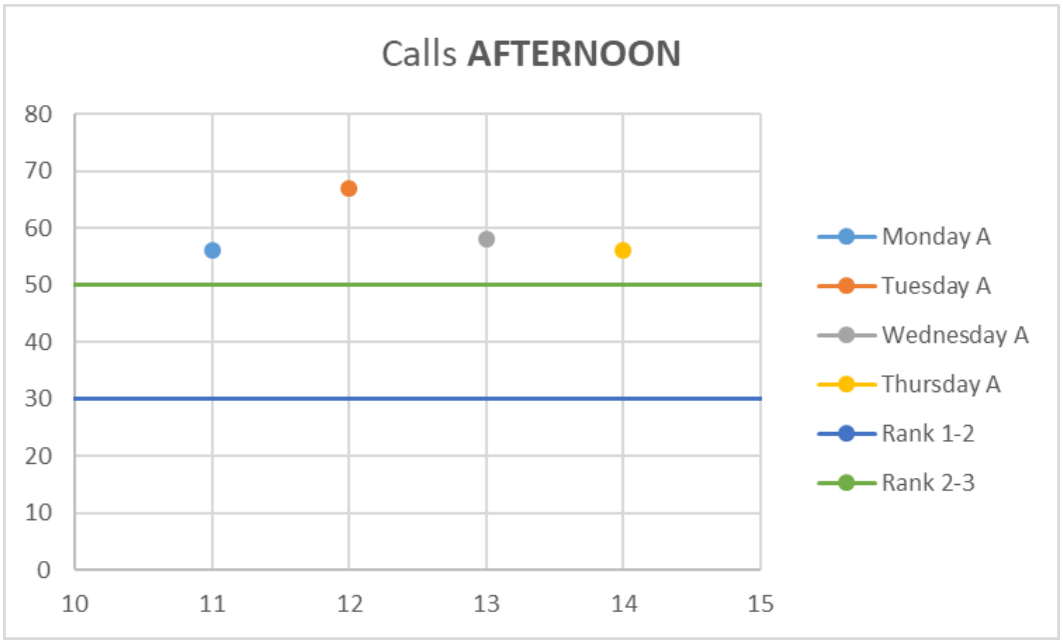

*Figure 50 Calls - short term planner of drivers **Afternoon***

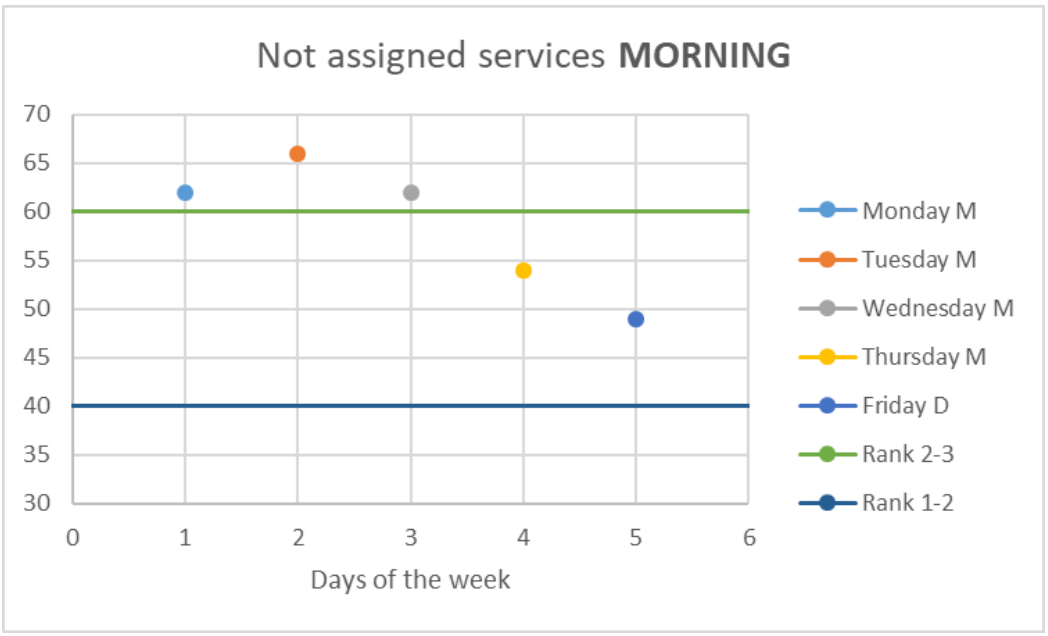

*Figure 51 Not assigned services - short term planner of drivers **Morning***

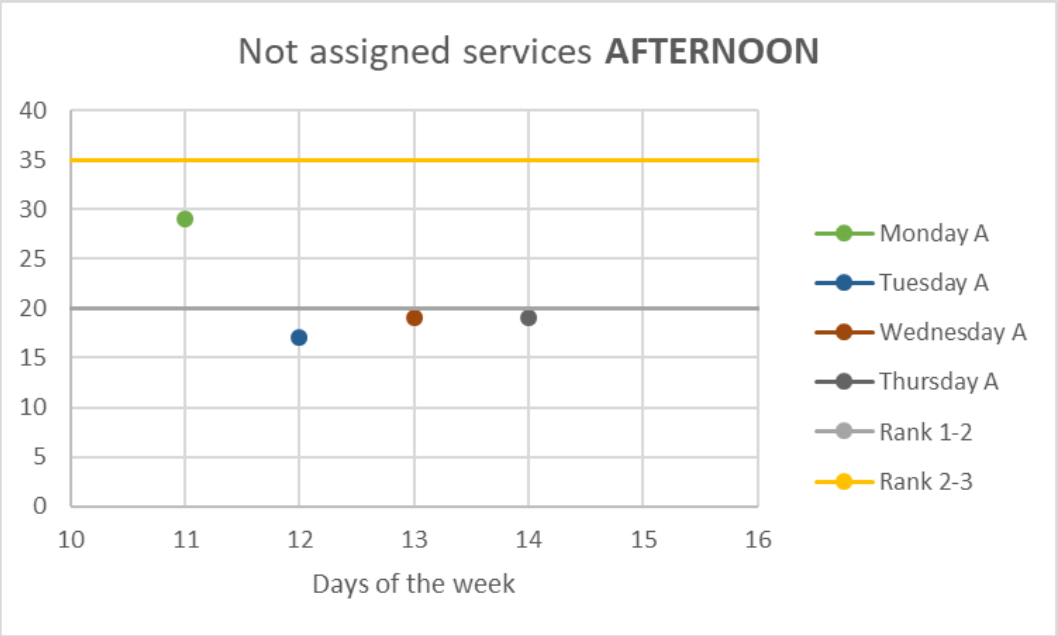

*Figure 52 Not assigned services - short term planner of drivers **Afternoon***

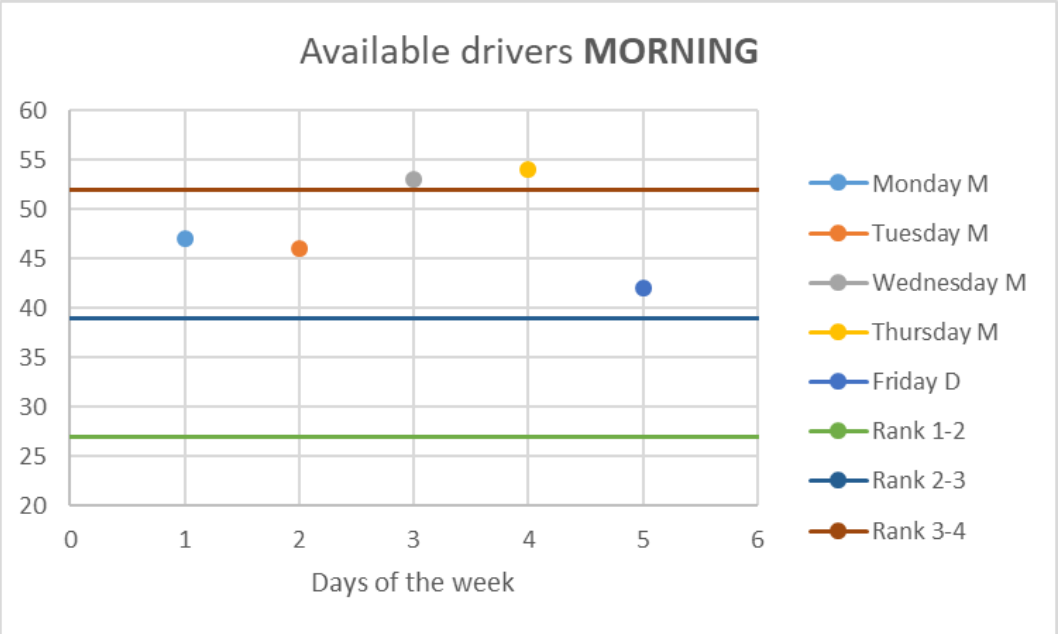

*Figure 53 Available drivers - short term planner of drivers **Morning***

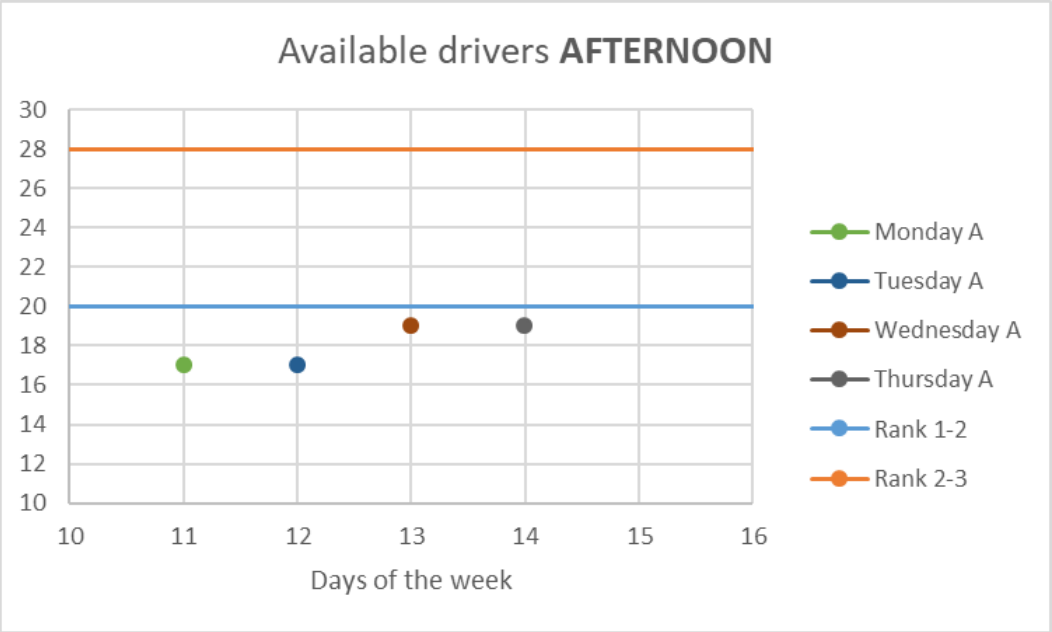

Figure 54 Available drivers - short term planner of drivers ***Afternoon***

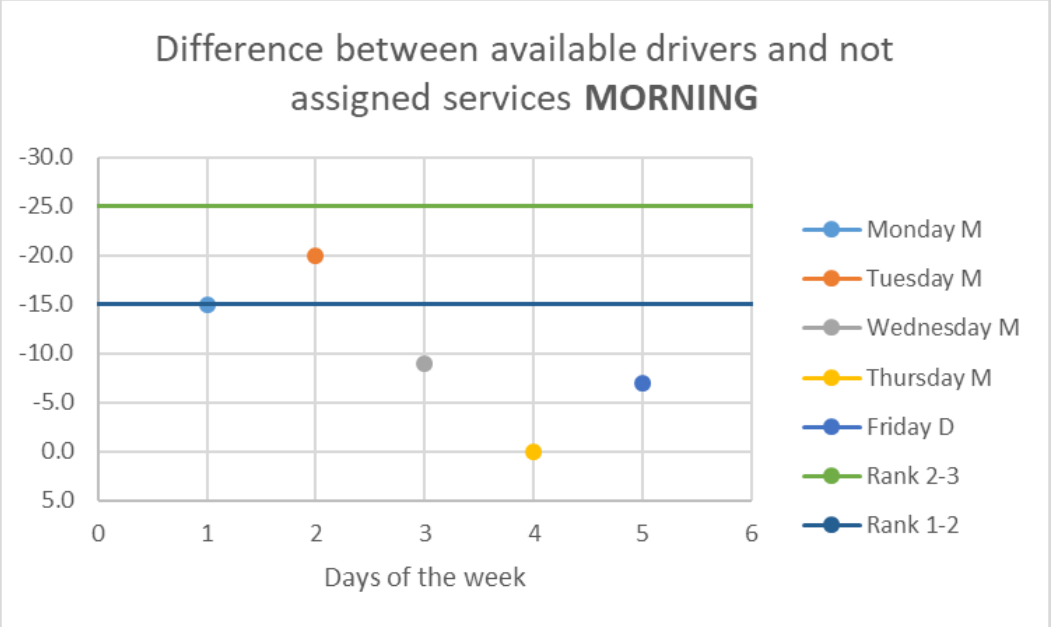

Figure 55 Difference between available drivers and not assigned services - short term planner of drivers ***Morning***

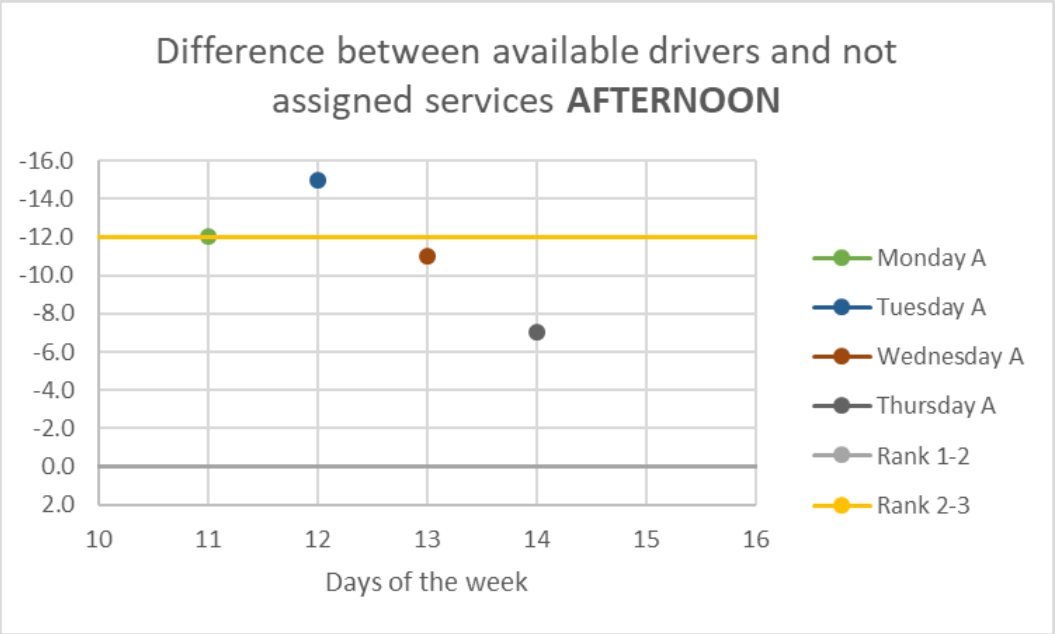

*Figure 56 Difference between available drivers and not assigned services - short term planner of drivers **Afternoon***

Outcomes are shown in *Figure 58* and *Figure 59*.

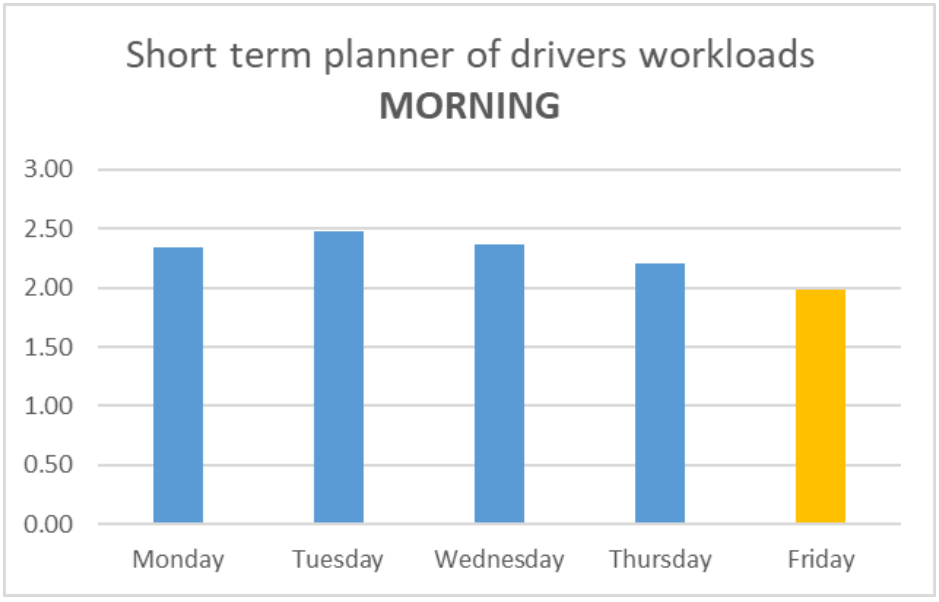

*Figure 57 Short term planner of drivers workloads - **Morning***

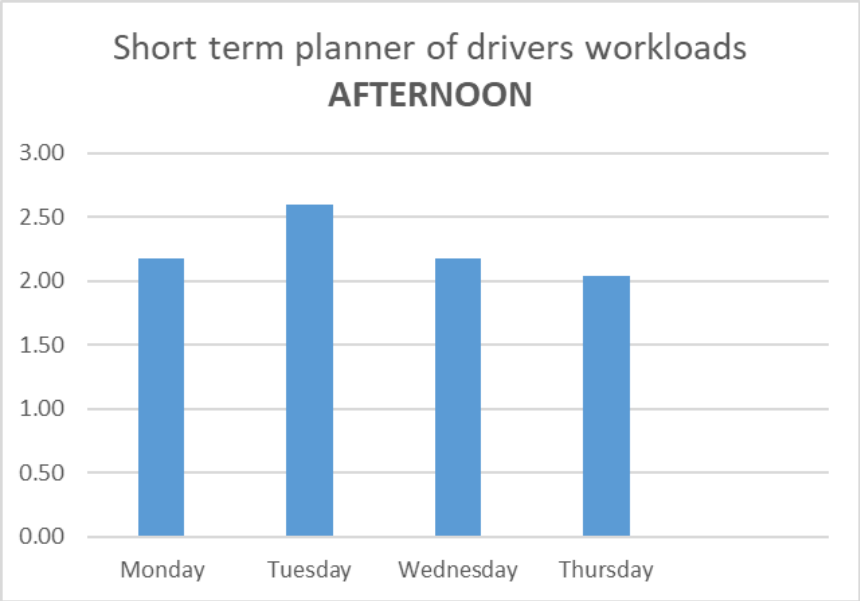

*Figure 58 Short term planner of drivers workloads - **Afternoon***

In conclusion it is possible to say that the hypothetical scenario is feasible. The busiest day is on Tuesday for both morning and afternoon operator. Then there are Monday and Wednesday. The most important aspect is that values of workloads are more or less constant. There is not a big difference between the busiest day and the least. On Friday only one operator is necessary instead of two but anyway workloads are lower than other days of the week.

7.2.1. Multicriteria Analysis of locomotives dispatcher

Activities fulfilled by locomotives dispatcher are defined by 6 criteria that are divided into 3 levels (*Table 16).* Inside level 1 (green level) there is the *number of arrivals.* It is the number of trains that arrives in rail yards managed by the operator. They are put in the lowest level because they define a passive activity: the operator can only check if the train is arrived.

	Criterion i		unit of measure
I level	1	number of arrivals	number of trains
II level	2	locomotives for workshop	number of trains
	3	single locomotives	number of locomotives
	4	calls	number of calls
III level	5	number of departures	number of trains
	6	number of delays (>120 min)	number of trains

Table 16 Criteria of locomotives dispatcher

In the level 2 (yellow level) there are *locomotives for workshop, single locomotives* and *calls*. They are activities that belong to the intermediate level. Locomotives must be sent to workshop when temporal and mileage deadlines are closed. Single locomotives are organized in order to balance arrivals and departures. Then there are the most critical activities that shape level 3 (red level). They are *number of departures* and *number of delays (more than 120 minutes).* They are most important activities because the objective of locomotives dispatcher is to allocate locomotives to all trains that start from rail yards over the assigned territory. Usually the minimum gap for a locomotive between the arrival and the departure with the next train is 2 hours. Therefore when the arrival delay is higher than 2 hours, the operator must check if the locomotive is able to departure in time. Therefore it is possible to define the reciprocal weighted sum and the weight of each criterion (*Table 17*) that is expressed by the vector *w*. The additive constant is equal to 6. It is chosen in order that the smallest sum (-5) becomes positive.

		Criteria					
		1	2	3	4	5	6
Criteria	1	0	-1	-1	-1	-1	-1
	2	1	0	0	0	-1	-1
	3	1	0	0	0	-1	-1
	4	1	0	0	0	-1	-1
	5	1	1	1	1	0	0
	6	1	1	1	1	0	0

Sum		w
-5	1	2.78%
-1	5	13.89%
-1	5	13.89%
-1	5	13.89%
4	10	27.78%
4	10	27.78%
	36	

Table 17 Reciprocal weighted matrix and weight of each alternative – locomotives dispatcher

Judgment scale matrix is shown in *Table 18*. The analysis is carried out for both morning and afternoon operators. The scale is the same therefore it is possible to compare workloads during the morning with workloads of the afternoon.

		Ranks		
		1	2	3
Criteria	1	<40	40-53	>53
	2	<1.5	1.5-2.5	>2.5
	3	<10	10-15	>15
	4	<30	30-40	>40
	5	<39	39-51	>51
	6	<1.5	1.5-2.5	>2.5

Table 18 judgment rank matrix - locomotives dispatcher

Graphs of each criterion are shown from *Figure 60* to *Figure 64*. One graph shows both values on the morning and on the afternoon. Morning is described by points on x-axle from 1 (Monday) to 5 (Friday) instead afternoon is described by points on x-axle from 11 (Monday) to 15 (Friday). The locomotives dispatcher carries out both planning and real time phases hence during his duty he manages both trains that run during his working hours and trains that run when he doesn't work, In fact in order to define the number of arrivals, departures and isolated trains are considered with following slots:

- Morning: from 06:00 of working day to 12:00 of following day.
- Afternoon: from 13:00 of working day to 24:00 of following day.

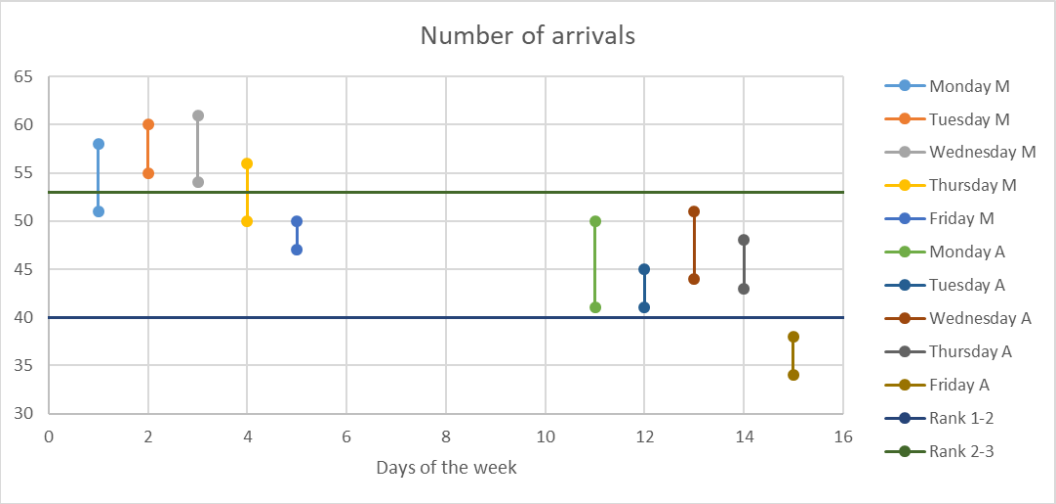

Figure 59 number of arrivals – locomotives dispatcher

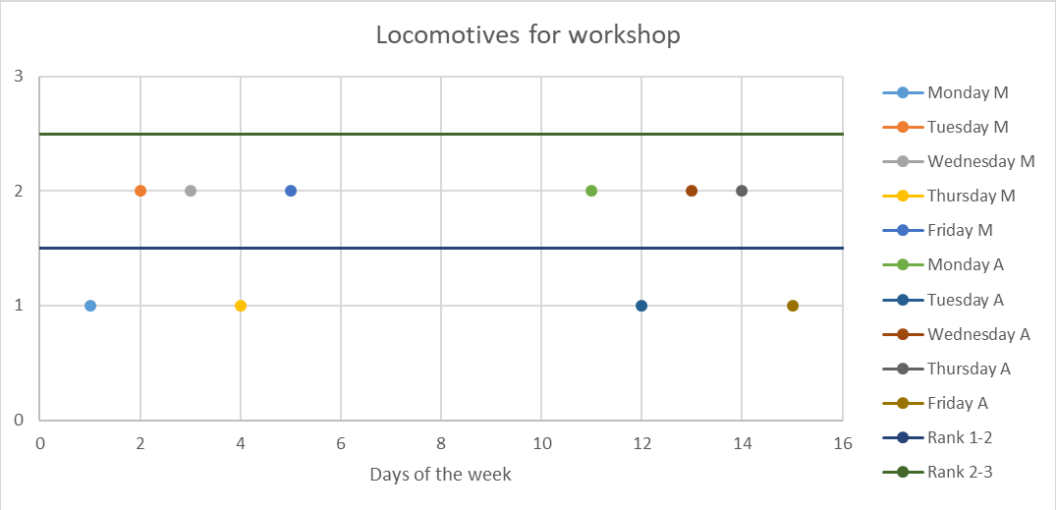

Figure 60 locomotives for workshop – locomotives dispatcher

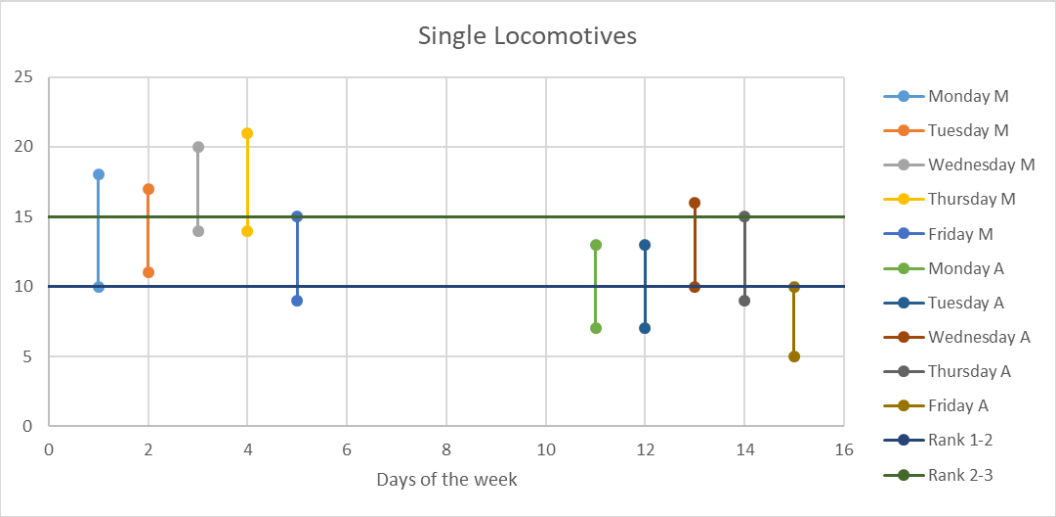

Figure 61 single locomotives – locomotives dispatcher

The graph of calls is not shown because the number is supposed constant during all days for both morning and afternoon. The values is between 30 and 40 calls.

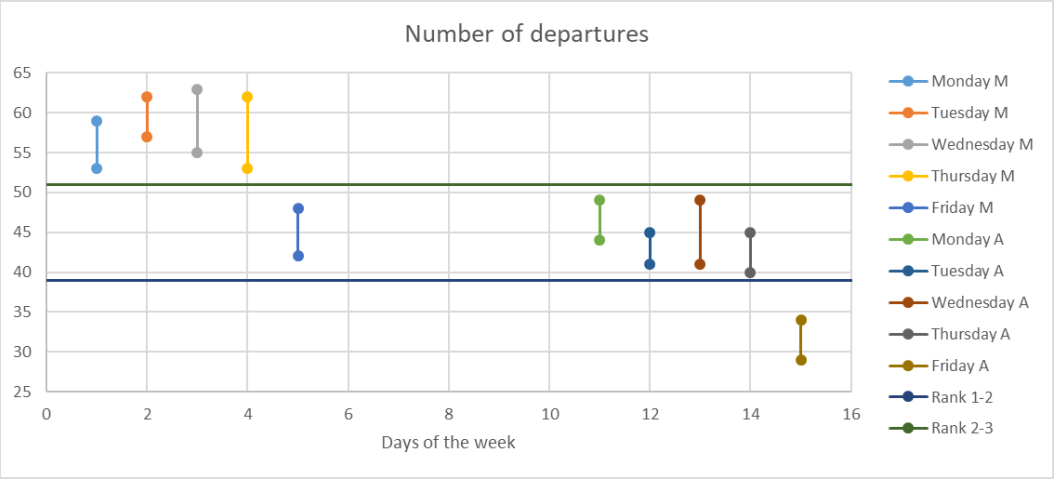

Figure 62 number of departures – locomotives dispatcher

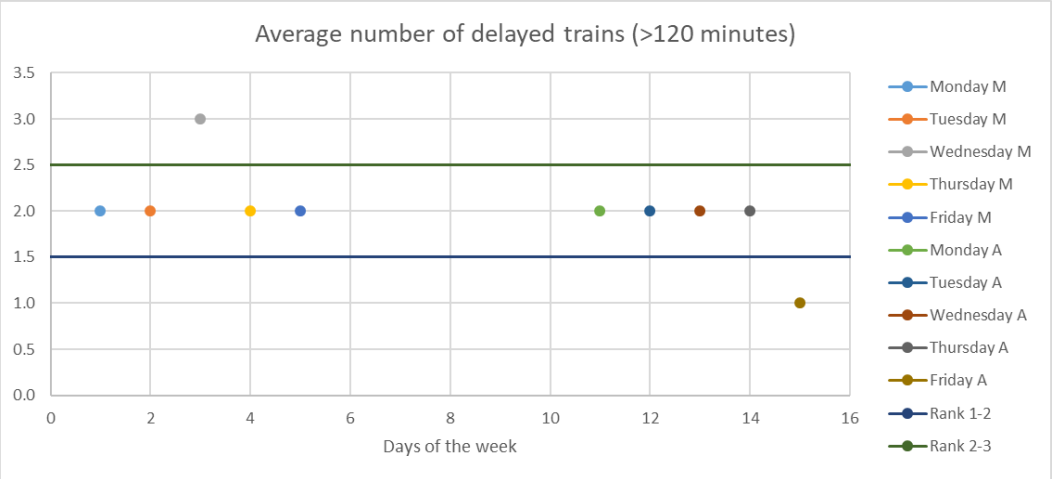

Figure 63 average number of delayed train (>120 minutes) – locomotives dispatcher

The number of delayed trains is defined considering trains that run during working hours of the operator.

All points that are shown in previous graphs are clustered in *Table 19* and *Table 20*.

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	51-58	55-60	54-61	50-56	47-50
	2	1	2	2	1	2
	3	10-18	11-17	14-20	14-21	9-15
	4	30-40	30-40	30-40	30-40	30-40
	5	53-59	57-62	55-63	53-62	42-48
	6	2	2	3	2	2

Table 19 Values of each criterion during the week – locomotives dispatcher ***Morning***

		Day of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	41-50	41-45	44-51	43-48	34-38
	2	2	1	2	2	1
	3	7-13	7-13	10-16	9-15	5-10
	4	30-40	30-40	30-40	30-40	30-40
	5	44-49	41-45	41-49	40-45	29-34
	6	2	2	2	2	1

*Table 20 Values of each criterion during the week – locomotives dispatcher **Afternoon***

Now making a comparison between table 19, table 20 and table 18, it is possible to check the rank of each value. Each rank is shown in *Table 21* and *Table 22*.

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	2.5	3	3	2.5	2
	2	1	2	2	1	2
	3	2.5	2.5	3	3	2
	4	2	2	2	2	2
	5	3	3	3	3	2
	6	2	2	3	2	2

*Table 21 judgment matrix – locomotives dispatcher **Morning***

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	2	2	2	2	1
	2	2	1	2	2	1
	3	1.5	1.5	2	2	1
	4	2	2	2	2	2
	5	2	2	2	2	1
	6	2	2	2	2	1

*Table 22 judgment matrix – locomotives dispatcher **Afternoon***

Knowing the vector *w* and the judgment matrix, it is possible to define workloads of locomotives dispatcher during the week. Outcomes, shown in *Table 23* and in *Table 24*, are described by elements of vector *r*.

	Monday	Tuesday	Wednesday	Thursday	Friday
r	2.22	2.38	2.72	2.29	2.00

*Table 23 vector r – locomotives dispatcher **Morning***

	Monday	Tuesday	Wednesday	Thursday	Friday
r	1.93	1.79	2.00	2.00	1.14

*Table 24 vector r – locomotives dispatcher **Afternoon***

Results are presented in *Figure 65* and *Figure 66*.

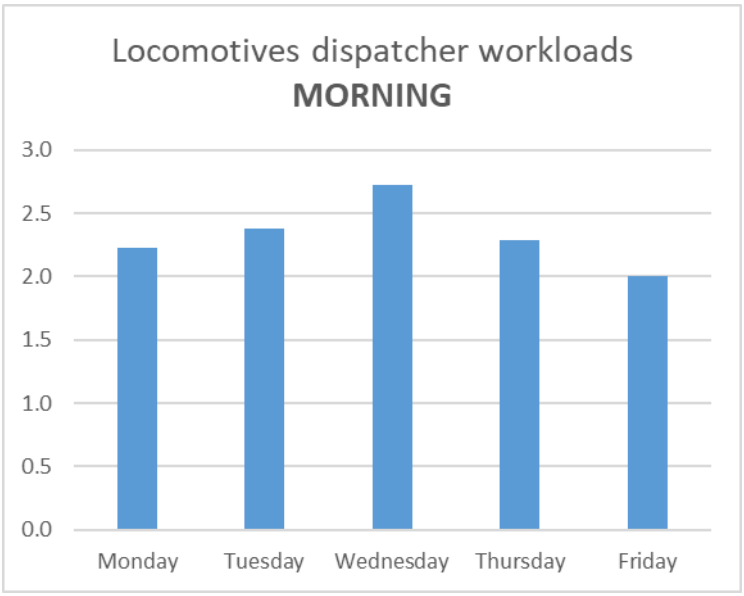

*Figure 64 Locomotives dispatcher workloads - **MORNING***

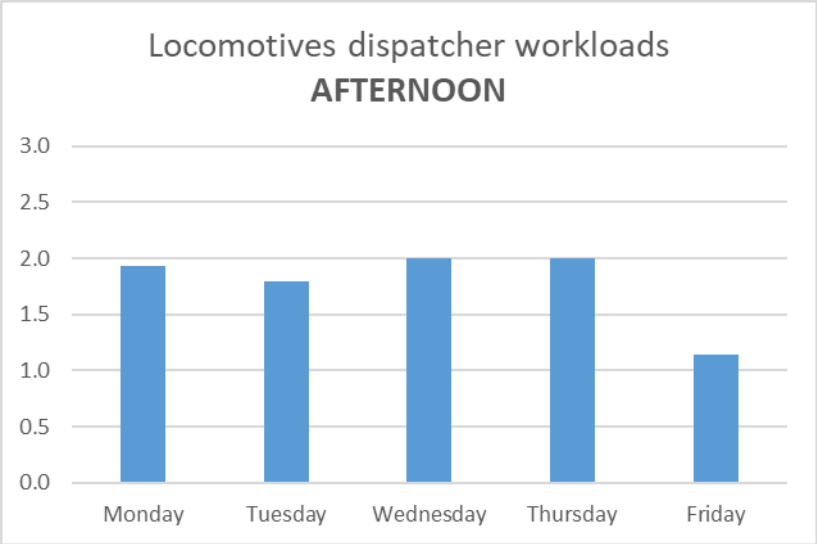

*Figure 65 Locomotives dispatcher workloads - **AFTERNOON***

In conclusion it is possible to say that Wednesday is the busiest day. It is because there is the highest flow during this day. Then morning is always the most critical part of the day. As in the previous analysis, Friday is the day in which workloads are the lowest.

7.3.1. Multicriteria Analysis of train drivers dispatcher

Activities carried out by the train drivers dispatcher are defined by 7 criteria that are divided into 3 levels (*Table 25*). Inside level 1 (green level) there are *Coupling-Uncoupling, Skidding and Flexibility* and *Eurostar Bookings.* They are simple activities where the operator edit form or make few clicks. In the level 2 (yellow level) there are *circulating trains, calls* and *single locomotives.* Circulating trains are all trains that run on assigned territory for which the operator may have a situation to solve. Then there are single locomotives. They are organized by the locomotive dispatcher but the drivers dispatcher has to allocate them to drivers. These criteria are in the intermediate level because they don't take many problems. Then there are the most critical activities that are in level 3 (red level). They are *illness drivers* and the *number*

of delays (>120 minutes). They are important because each illness driver must be substitute by another one driver instead trains with a delay of more than 120 minutes take the risk of abandonment. It is an average value because a train may be abandoned after 1 hour (if the driver has a service that is closed to maximum working hours) or not before 3 hours. Therefore it is possible to define the reciprocal weighted sum and the weight of each criterion (*Table 25*) that is expressed by the vector *w*. The additive constant is equal to 6.

		Criteria						
		1	2	3	4	5	6	7
Criteria	1	0	0	-1	-1	-1	-1	-1
	2	0	0	-1	-1	-1	-1	-1
	3	1	1	0	0	0	-1	-1
	4	1	1	0	0	0	-1	-1
	5	1	1	0	0	0	-1	-1
	6	1	1	1	1	1	0	0
	7	1	1	1	1	1	0	0

Sum		w
-5	1	2.38%
-5	1	2.38%
0	6	14.29%
0	6	14.29%
0	6	14.29%
5	11	26.19%
5	11	26.19%
	42	

Table 25 Reciprocal weighted matrix and weight of each alternative – train drivers dispatcher

Judgment scale matrix is shown in *Table 26*. The analysis is carried out for both morning and afternoon operators. The scale is the same therefore it is possible to compare workloads during the morning with workloads of the afternoon.

		Ranks		
		1	2	3
Criteria	1	<9.5	9.5-12.5	>12.5
	2	<10	10-15	>15
	3	<30	30-40	>40
	4	<60	60-90	>90
	5	<10	10-15	>15
	6	<0.5	0.5-1.5	>1.5
	7	<5	5-10	>10

Table 26 judgment rank matrix – train drivers dispatcher

Graphs of each criterion are shown from *Figure 67* to *Figure 69* and from *Figure 72* to *Figure 74*. Each graph shows both values on the morning and on the afternoon. Morning is described by points on x-axle from 1 (Monday)

to 5 (Friday) instead afternoon is described by points on x-axle from 11 (Monday) to 15 (Friday).

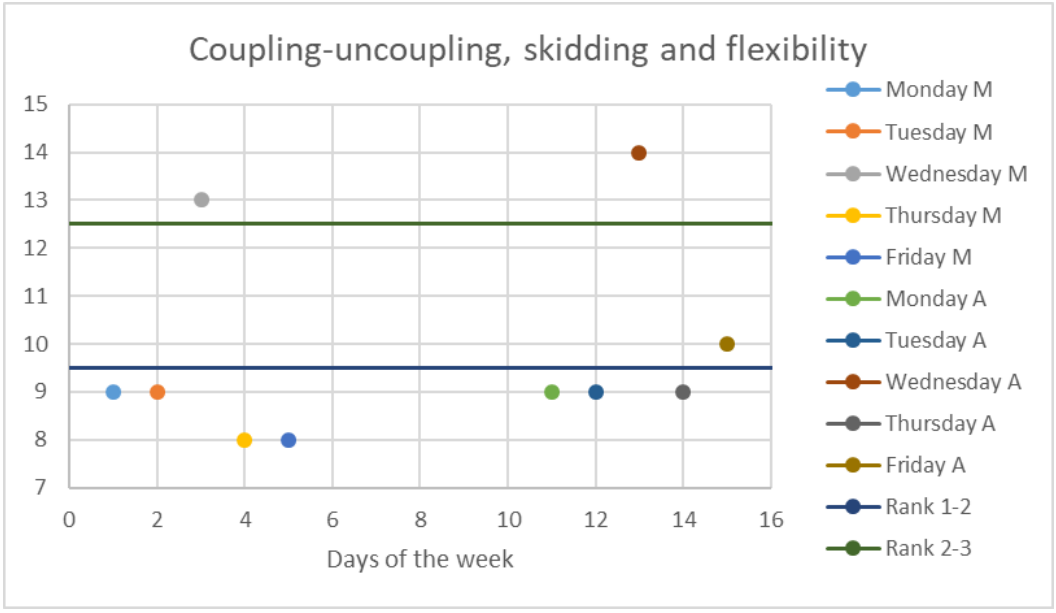

Figure 66 Coupling-uncoupling,skidding and flexibility – train drivers dispatcher

Values that are described in Figure 67 are given by the sum of rows that are edited in three forms (one for coupling-uncoupling, one for skidding and one for flexibility)

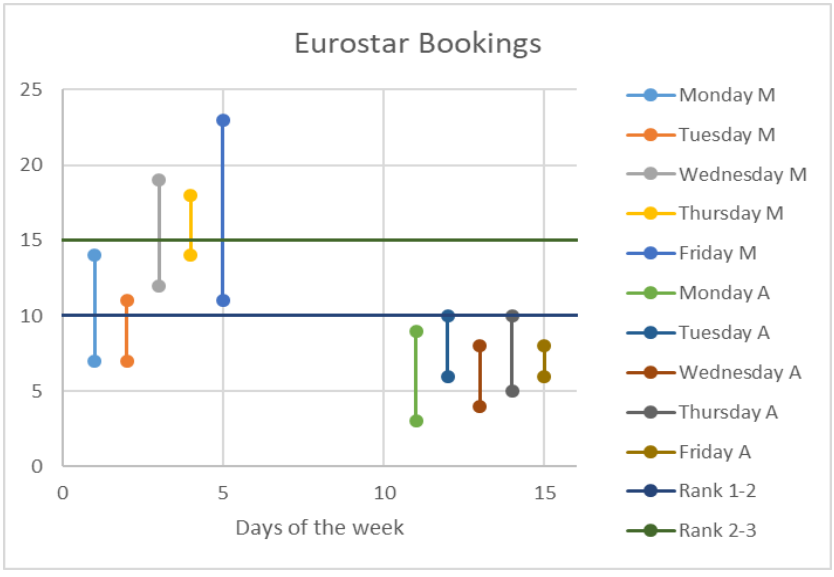

Figure 67 number of Eurostar Bookings – train drivers dispatcher

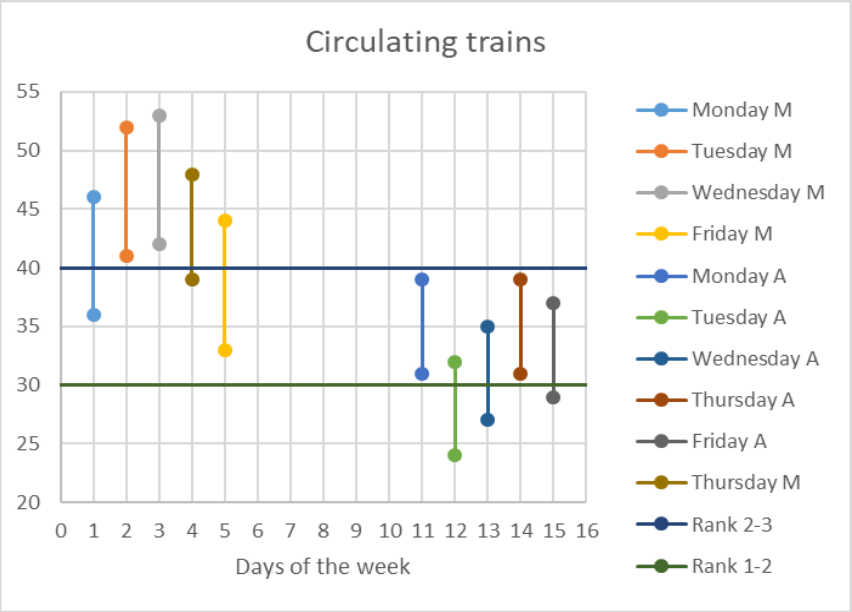

Figure 68 Circulating trains – train drivers dispatcher

Instead considering incoming and outcoming calls, due to the poor number of observations it is not possible to define the distribution during the week. But it was possible to define the number of hourly calls taking into account maximum values observed. Results are shown in *Figure 70* and *Figure 71.* The total number of calls during the morning are 110 instead they are 80 during the afternoon.

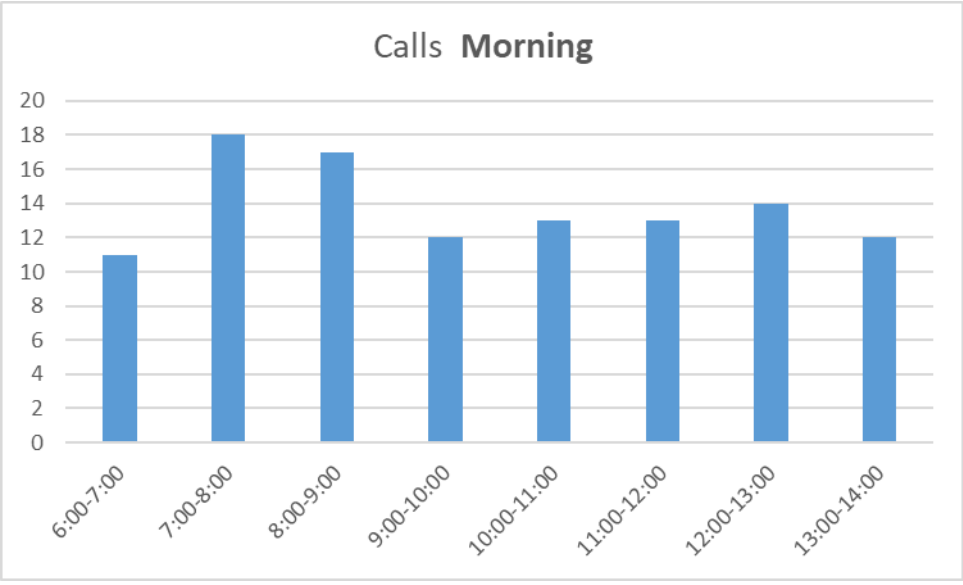

*Figure 69 Calls – train drivers dispatcher **Morning***

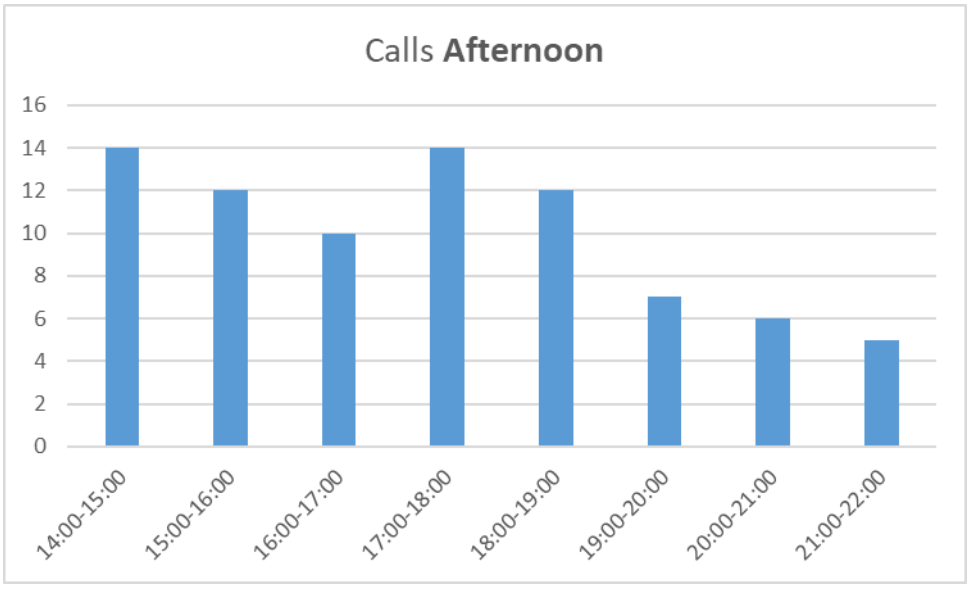

Figure 70 Calls – train drivers dispatcher ***Afternoon***

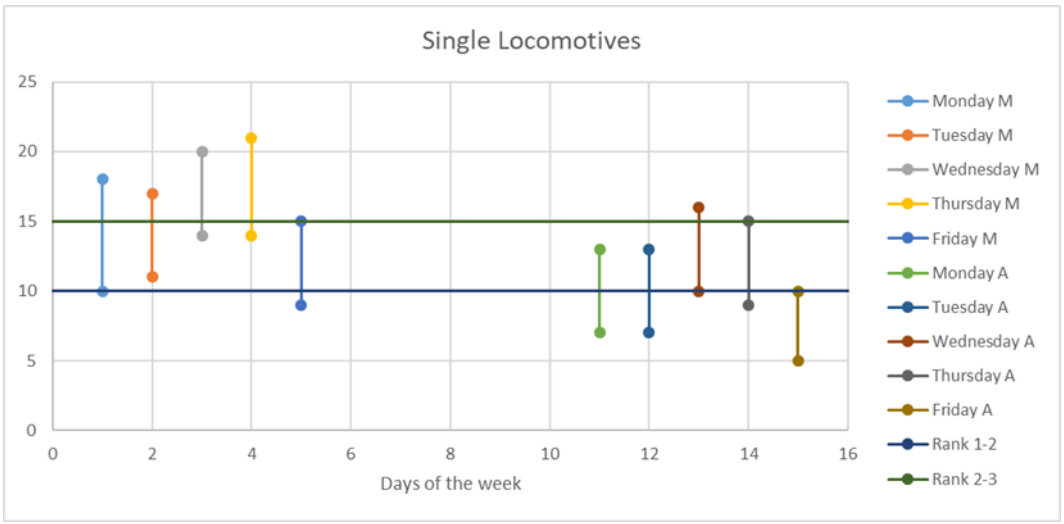

Figure 71 Single locomotives – train drivers dispatcher

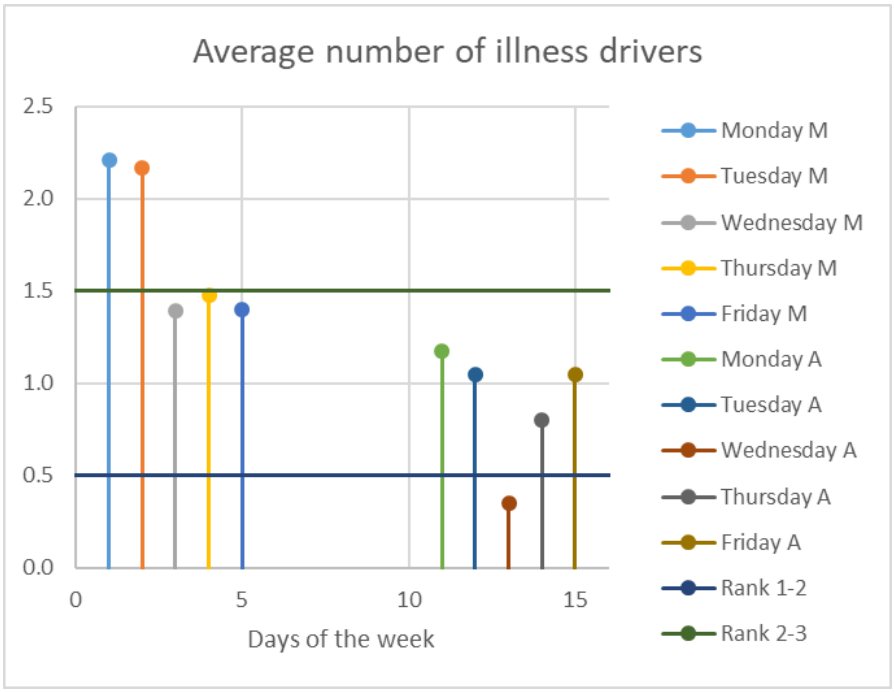

Figure 72 Average number of illness drivers – train drivers dispatcher

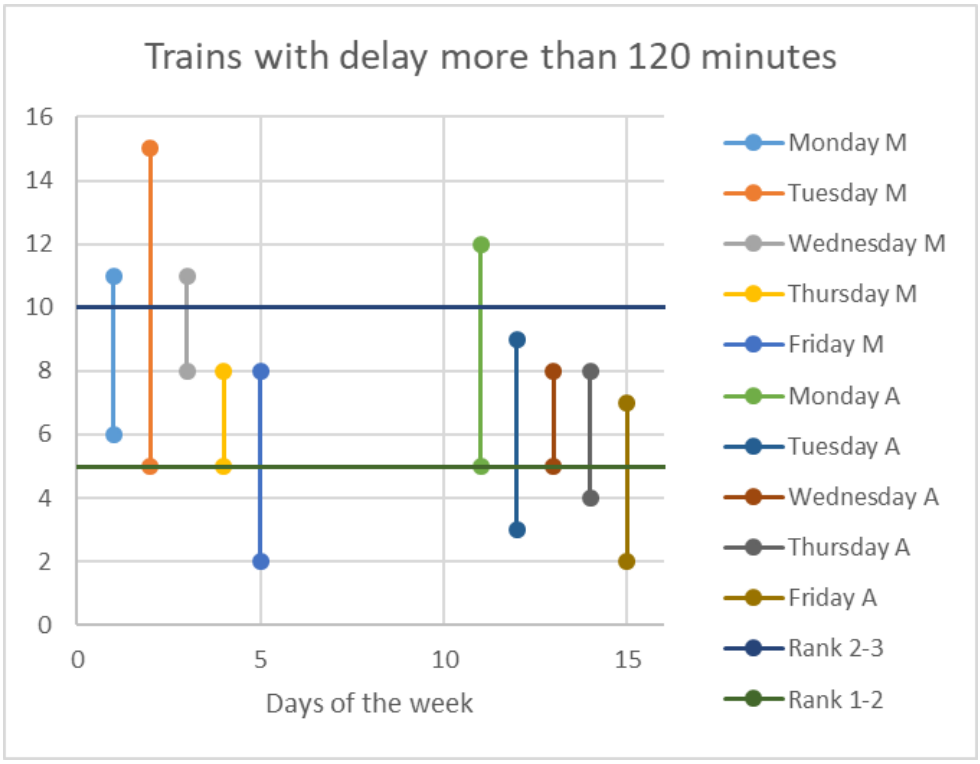

Figure 73 trains with delay more than 120 minutes – train drivers dispatcher

All points that are shown in previous graphs are clustered in *Figure 74* and *Figure 75*.

		Days of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	9	9	13	8	8
	2	7-14	7-11	12-19	14-18	11-23
	3	36-46	41-52	42-53	39-48	33-44
	4	110	110	110	110	110
	5	10-18	11-17	14-20	14-21	9-15
	6	0-2.2	0-2.2	0-1.4	0-1.5	0-1.4
	7	6-11	5-15	8-11	5-8	2-8

*Table 27 values of each criterion during the week – train drivers dispatcher **Morning***

		Day of the week				
		Monday	Tuesday	Wednesday	Thursday	Friday
		1	2	3	4	5
Criteria	1	9	9	14	9	10
	2	3-9	6-10	4-8	5-10	6-8
	3	31-39	24-32	27-35	31-39	29-37
	4	80	80	80	80	80
	5	7-13	7-13	10-16	9-15	5-10
	6	0-1.2	0-1.0	0-0.35	0-0.8	0-1.1
	7	5-12	3-9	5-8	4-8	2-7

*Table 28 values of each criterion during the week – train drivers dispatcher **Afternoon***

Now making a comparison between table 27, table 28 and table 26, it is possible to define workloads of train drivers dispatcher during the week. Outcomes, shown in *Table 29* and in *Table 30,* are described by elements of vector *r*.

	Monday	Tuesday	Wednesday	Thursday	Friday
r	2.51	2.70	2.60	2.43	2.00

*Table 29 vector **v** – train **drivers** dispatcher **Morning***

	Monday	Tuesday	Wednesday	Thursday	Friday
r	1.88	1.61	1.67	1.82	1.57

*Table 30 vector **v** - train **drivers** dispatcher **Afternoon***

Results are presented in *Figure 75* and *Figure 76*.

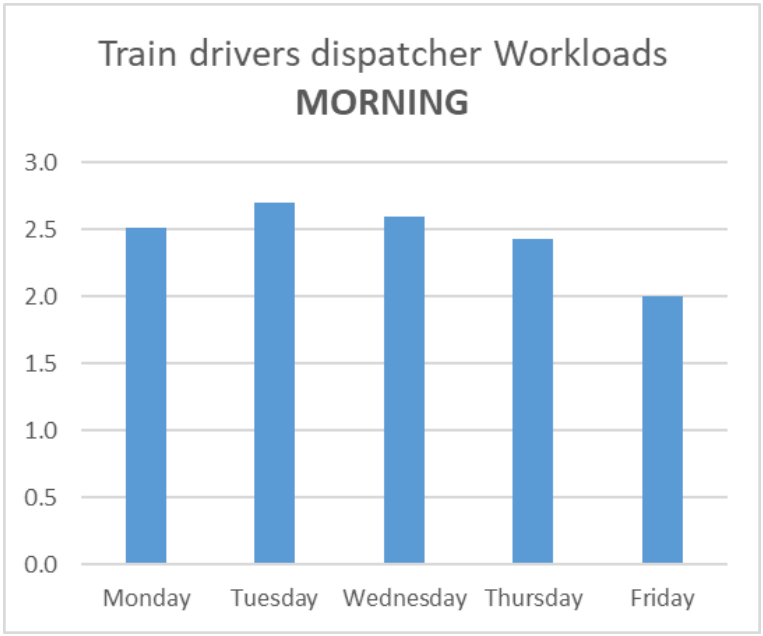

*Figure 74 train drivers dispatcher – **MORNING***

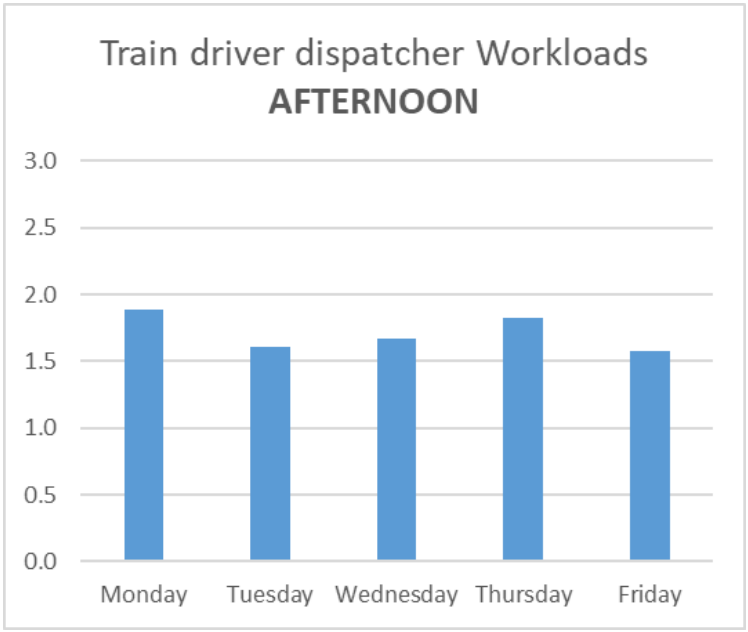

*Figure 75 train dirvers dispatcher **AFTERNOON***

In conclusion it is possible to say that Tuesday morning is the busiest roster. During the morning maximum and minimum values are not so much different. It means that the operator has an almost constant workload during the morning. Instead during the afternoon workloads are reduced. The most important element of this operator with respect to others, is that Friday the lowest day but it is not so far from workloads of other days of the week.

8. Conclusions

In conclusion it is possible to say that the hypothetical scenario is feasible. Moreover it is better than the current configuration. This is because on Friday only one operator is necessary instead of two and during other days (morning phase) workloads are more constant with respect to the previous configuration (*Figure 77)*. In this way it is possible to avoid that in one day the operator is too busy and others in which it is less busy. It means that values of peak are reduced and values of minimum are increased. In fact if the real situation changes from 2.68 to 2.00, the new scenario varies from 2.48 to 1.98. That is the difference between maximum and minimum is reduced of 26.5%.

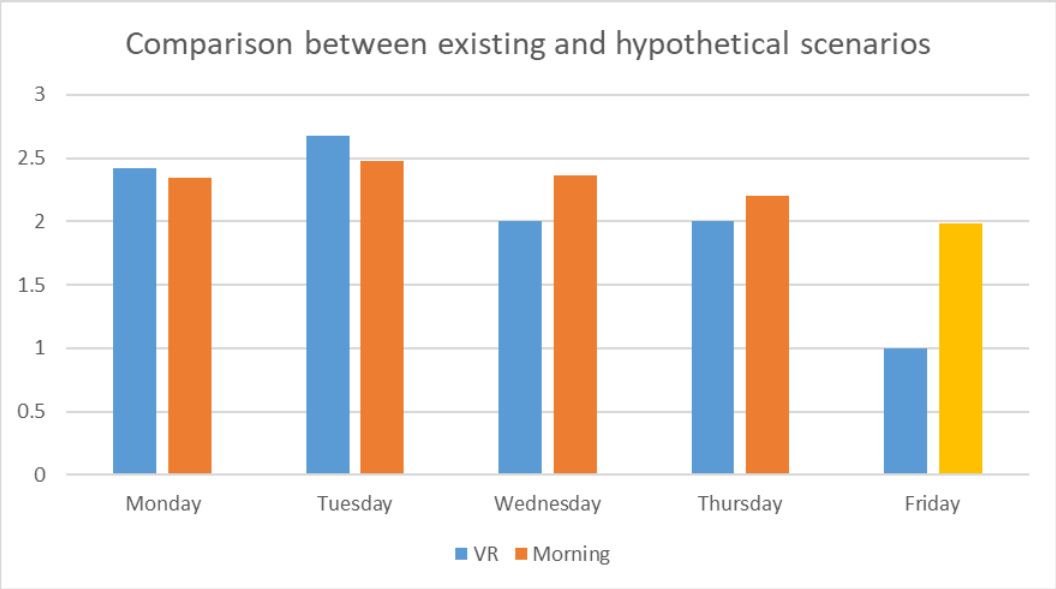

*Figure 76 Comparison between real and new scenario. **VR/Morning***

Whereas considering the comparison between existing and hypothetical scenarios during the afternoon phase, the difference between maximum and minimum is increased of 4.5 times. But this is produced by Tuesday where peak is about 25% bigger than workloads of other days. Instead

considering only other days, the variation has a trend that is similar to the real configuration (*Figure 78*).

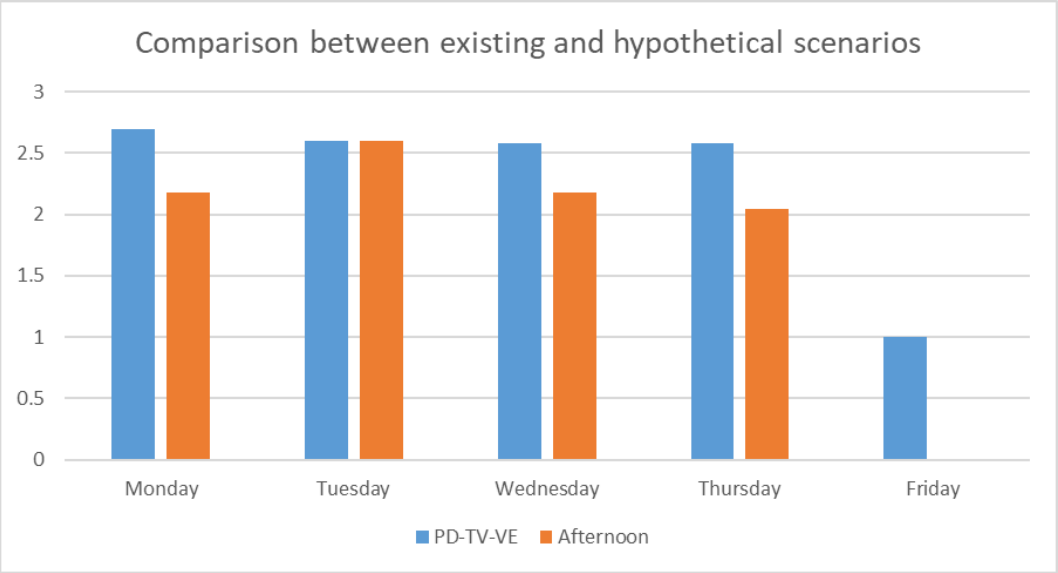

Figure 77 Comparison between real and new scenario. ***PD-TV-VE/Afternoon***

Obviously results are affected by the sensitivity of the researcher but anyway they reflect reality. For this reason it is possible to say that the model is reliable. In fact for all operators morning is busier that afternoon. Then one of the most important days is Wednesday. It is in the middle of the week and it is the week day in which the flow of train is higher. The exception is the short term planner of drivers but he works 24 hours before the departure of the train. Therefore the peak of Tuesday means that the most critical situation there is on Wednesday. An other important day is Monday because during Saturday and Sunday there is the rest time of few operators. Hence the operator that works on the first day of the week has more criticalities to solve because they were not solved during previous days. Instead Friday is the less busy day. It is because during the end of the week the number of circulating trains reduce.

In Italy the most diffused service is the FTL (Full Train Load). But how would workloads change in the case that the most common service is SWL (Single wagon load)? SWL service means that there are more circulating trains because a train is used to make the entire shipping. More circulating trains are synonymous of more services, more drivers and more locomotives therefore all operators will be subjected to a higher flow of information. Moreover SWL means that a train during its trip has stops in order to couple or uncouple wagons. This fact will increase travel time and delay because of more human behaviour will affect all activities.

Appendix

Appendix 1: Chapter 6.2.1.1. Driver shift and legislation on working hours [38] [39]

All trains set up by Business Direction and published on annual and periodic timetable are grouped together. Then they are divided in order to create shifts for each Impianto Operativo and each branch inside an Impianto Operativo. Each shift is made up by days where one day is also called service or link[32]. One day is a combination of two parts:

- The first part is the *productive part (*when drivers are in the cab). It means that drivers lead a train along railway network or inside a rail yard (for example to move wagons or locomotives). It is also the case where they prepare the train[33]. Trains assigned to a day are whole trains[34] and/or piece of trains[35].
- The second part is the *inactive part* (when drivers are not in the cab). It means that drivers don't lead a train but they move as passengers from a station to another by a taxi, a passenger train or by another mode. Inside this category there is also the rest time namely when drivers eat and sleep and the waiting time when they wait the arrival of the train.

[32] Day, Service, Link: in Italian "day" is *Giornata*, "service" is *Servizio* and "link" is *Allacciamento.*

[33] To prepare a train: in Italian language it is called *Accessori.*

[34] *Whole train* means that in a day drivers bring the train from the first station to the last one (whole train path). *Intera Stecca* is Italian railway slang.

[35] *Piece of train* means that in a day drivers bring the train between two intermediate stops (only a part of the train path).

The objective is that in one day the *productive part* is as big as possible and the *inactive part* is as low as possible according to legislation on working hours.

The example of a day is shown in *Figure 79.*

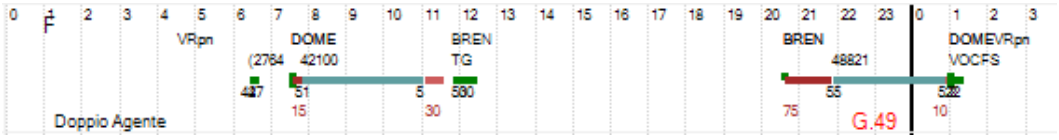

Figure 78 Single day of a driver shift

Each day is a round trip where the starting point must be in the same city of the arriving point. In fact the departure station is VR PN (Verona Porta Nuova) and the arrival station is Verona Porta Nuova. In this case the arrival and departure stations coincide but it is not mandatory. The first part of the service (green line) is from VR PN to DOME (Domegliara) but drivers don't lead the train. They are passengers[36] of the train number 2764. Then from DOME to BREN (Brennero) they drive (sky blue line) the train number 42100 with departure at 7:51 and arrival at 10:05. The train doesn't start in Domegliara therefore 15 minutes are added (marrow line) that is the time to relieve[37] to other drivers that lead train 42100 until Domegliara. When they arrive in Brennero there are 30 minutes to park the locomotive and then 40 minutes (green line) from 11:50 to 12:30 to move locomotives of other trains[38]. From 12:30 to 20:40 there is the rest time. Since it is not in drivers' country, it is call RAFH (Rest Away From Home)[39]. It means that an operator of Impianto Operativo has to book an hotel in order to allow

[36] The Italian slang is *Vettura* when drivers move from a point to another as passengers.
[37] The Italian slang is *Cambio Volante* when drivers lead a train not from its starting station. It is 15 minutes in departing phase and 10 minutes in arriving phase.
[38] The Italian slang is *Traghetto (TG)* when drivers move locomotives to prepare trains that are led by other drivers.
[39] The Italian slang is *RFR (Riposo Fuori Residenza).*

the rest of drivers. In the second part of the day there is the back-train number 48821 (sky blue line) from BREN to DOME that starts at 21:55 and arrives at 00:52. It is anticipated by 75 minutes to prepare the train and it is followed by 10 minutes of *Cambio Volante.* The last line of the day is used to bring drivers as passengers to their starting city. But because passenger trains are not available, it is necessary to book a taxi[40].

Each day is assigned to two drivers that when finish it, they go to the next one. Therefore between one day and the following must be ensured the rest time at home. All parameter fixed by corporate contract are shown in *Table 31.*

		Module	CCNL AF	CCNL AF MIR	Note
Weekly working time	Avg		38h		It doesn't consider RAFH time
	Min/Max		30h/44h		
Daily work	T&B[5-24]	MEC 2	max 10h	11h	
		MEC 3	max 8h30'	10h	
	T&B[0-5]	MEC 2	max 8h	9h	
	T&RAFH&B		max 16h		16h is calculated substracting RAFH
			max 24h		Considering also RAFH. If 24h<T&RAFH&B<28h B=only active part
Productive part	[5-24]	MEC 3	max 6h30'		MEC 2 no limit. It can be equal to DW
Night work	week		max 3		1 light night [0-1]
	month		max 12		
	year		max 79		
Weekly rest			min 48h		
			VI day	IV day<WR<VII day	
	year		min 3538h	min 3394h	
				min 12 weekend	each lasts 60 h during Saturday and Sunday
				min 12 qualiquantitative	each lasts 60 h during Mon-Fri
RAFH			min 7h		only [0-5]
	week		max 2		between 2 weekly rest
	month		max 5	max 6	1 RAFH must be [5-24]
Daily rest at home			min 16h	14h	After DW [5-24]
			min 18h		After DW [0-5]/Between DW [0-5] and DW [0-5] if 2nd DW is followed by RAFH
			min 22h		Between DW [0-5] and DW [0-5]
Meal			min 30'		Only if DW is during the entire [11-15] or [18-22]
Break			min 15'		Only if productive part > 6h continuously

Table 31 Parameters for driver shift

The guideline is defined by Mobility National Collective Agreement inside Contractual Area of Railway Activities[41]. It is valid for each railway undertaking that carries out its business in Italian country. Anyway in order to increase production efficiency, it contains opening clauses that enable

[40] The Italian slang is *VOC (Via Ordinaria Comandata)*

[41] In Ialian it is Contratto Collettivo Nazionale di Lavoro della mobilità/Area contrattuale Attività Ferroviarie (CCNL/AF).

company-level bargaining on specific points. Therefore each railway undertaking has an own corporate contract. The contract in force was stipulated on 16th December 2016. In the table there are two columns: first is CCNL/AF that represents contract valid for each railway undertaking instead second one is CCNL/AF MIR that represents Mercitalia Rail adjustments.

From a railway point of view, one day is divided into two parts:

- Day: from 05:00 to 24:00
- Night: from 00:00 to 05:00

It is necessary that the service is for only 1 minute between 00:00 and 05:00 that the working day is considered night work. Then there are two kinds of services:

- There and Back (T&B): it is a pure round trip without rest time in the middle
- There and Back with Rest Away From Home (T&RAFH&B) in the middle

During a week a driver can work for a time that is between 30 and 44 hours but in average it must be 38 hours. Weekly working time considers all time that driver is not at home without including RAFH time.

Considering only There and Back services, the daily work in slot [5-24] can last at maximum 11 hours if the module is MEC 2 or 10 hours if the module is MEC 3. But in the last case the break is at least 30 minutes instead of 15 minutes. During the night the module MEC 3 is not possible therefore a night service with module MEC 2 can last at maximum 9 hours. Instead a service with RAFH in the middle can last at maximum 24 hours. But it is possible to reach 28 hours only if return trip is made up by productive part

without the inactive one. A T&RAFH&B service can last at maximum 16 hours without counting RAFH time. Anyway it is possible to reach 18 hours but the There or the Back can't go over 10 hours.

The productive part of a MEC 3 service can last at maximum 6h 30 minutes. Instead there are no limits with module MEC 2.

During one week (week is the time between two weekly rests) night services can be at maximum 3 but 1 must be light. It means that the driver for 1 night can work only for 1 hour from 00:00 to 01:00. Night services are 12 during one month and 79 during one year.

Weekly rest can last minimum 48 hours and normally it is on the sixth day after the previous weekly rest. But anyway it can be from forth to seventh day. During one year the weekly rest time must be at least 3538 hours. This time includes 12 weekend weekly rests (weekly rests that last at least 60 hours and they must be during Saturday and Sunday) and 12 qualiquantitative weekly rests (weekly rests that last at least 60 hours and they must be during 2 days from Monday to Friday).

Rest Away From Home is only in slot [0-5] and it can last at least 7 hours. During one week 2 RAFH are possible instead during one month they are 5. Anyway it is possible to add one RASH in daily slot (from 05:00 to 24:00).

The daily rest at home is the rest time at home between two services. It lasts 14 hours in the better condition. It means that the previous service was a daily day ([5-24]). Instead if the previous work day is a night service (it cuts slot [0-5]) the rest time must be at least 18 hours. In the case that the daily rest time is between two daily works that cut night slot, the rest time is at least 22 hours. But it is possible to reduce the daily rest time to 18 hours if the daily work after the rest time is made up by another RAFH.

A meal is assigned if the daily work is during entire slots [11-15] or [18-22].

A break is established if during the service the productive part lasts more than 6 continuous hours.

Coming back to figure 23, it shows a T&RAFH&B service whit Module 2. The ongoing trip lasts 7 hours that are less than 10 hours, the RAFH lasts 7 hours that is equivalent to the minimum and the ingoing trip (night service) lasts 6 hours that is less than 9 hours. The entire day has a length of 20 hours that is less than the maximum (24 hours) and subtracting the RAFH it lasts 13 hours that is less than 16 hours.

Appendix 2: Chapter 6.2.1.1. Deviate from contract

Considerations, that are made in Appendix 1, concern parameters that must be respected to create a shift. But considering short term and real time phases it is possible to use wider parameters. However they are limited by drivers acceptance. Anyway there are 4 indicators that must be guarantee in any case:

- Rest at home: minimum 11 hours
- RAFH
    - Minimum 6 hours (if 4 hours are between 0:00 and 05:00 or if T&RAFH&B is between 05:00 and 24:00.
    - 7 hours (cases that are not considered in the previous point)
- Weekly rest: minimum 35 hours but 24 hours must be in the same day.

Legislation considers also trains with delay to allow to drivers to abandon the train. A driver may abandon a train after 1 hour (if the service is very closed to maximum working hours) or not before 3 hours. Anyway the driver must highlight his intention of abandonment at least 2 hours before. This is in order to give the possibility to the train driver dispatcher to find another driver.

Appendix 3: Chapter 7.1.1.3. Ingoing and outgoing calls of short term planner of drivers

One of activities carried out by short term planner of drivers is represented by incoming and outcoming calls. It is possible to make a deep analysis to calls that involved operator that manages drivers belonging to Impianto Verona. It is because for all observed days, values are not far from an average point. Incoming and outcoming calls are divided into six categories:

1. Communication/info availability: calls where the driver asks which is his available slot. Operator asks to drivers their availability in the case that there is a strange situation. During these kinds of calls there is any allocation to the service.
2. Availability > 24 hours: drivers with special needs ask the service or their availability for a day that is not tomorrow.
3. Allocation/variation to the service: calls where drivers are allocated to services.
4. Communication with other traffic control rooms: calls that are made when there is a problem. Other operators are contacted to ask for help in order to solve criticalities.
5. Unanswered calls.
6. Other: calls related to hotel reservations or wrong calls.

Percentage of each category are shown in *Figure 52.* Instead the percentage of incoming and outcoming calls of each category is shown in *Table 16.* The most important category is the *allocation/variation to the service*. It is because the telephone is the only mean that available drivers have to know the service of the next day. Incoming and outcoming calls have more or less the same value. Then the other relevant category is the *communication/info*

availability. Incoming calls are 92% because it is the category where drivers call to communicate their availability when they have a special need. Instead 8% of outcoming calls are because the operator needs a clarification about the availability of the driver.

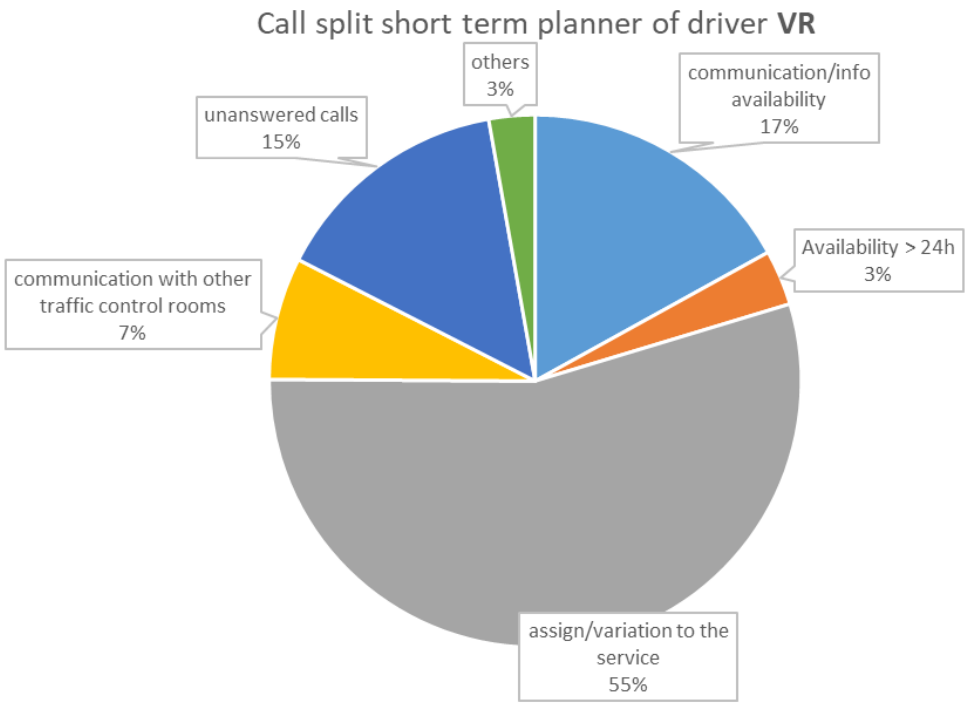

Figure 79 Percentage of each category – short term planner of drivers **VR**

	Incoming	Outcoming
communication/info availability	91.4%	8.6%
Availability > 24h	100.0%	0.0%
assign/variation to the service	51.6%	48.4%
communication with other traffic control rooms	48.6%	51.4%
unanswered calls	0.0%	100.0%
others	100.0%	0.0%

Table 32 Incoming/Outcoming percentage- short term planner of drivers **VR**

The third category is represented by unanswered calls. They are represented only by outcoming calls. It means that the operator answers to all incoming calls. Then there are calls used to *communicate with other traffic*

control rooms. They are used only when there is a particular problem that the operator is not able to solve. The number of incoming calls is more or less equal to outcoming calls.

The percentage of calls is used to define the number of calls in the hypothetical scenario. These data are observed for the short term planner of drivers that manages drivers belonging to Impianto Verona but they are supposed valid also for the other operator. Therefore it is possible to assume that percentages are reference values of operators that manages together Impianti of Verona, Padova, Treviso e Venezia Mestre.

In order to go in depth with the percentage of calls that characterized the hypothetical scenario, it is necessary to see the table 15 set out below:

	available drivers		not assigned services	
	number	wrt tot	number	wrt tot
tot	49		56	
0:00-12:59	36	73.5%	38	67.9%
13:00-24:00	13	26.5%	18	32.1%
0:00-7:59	36	73.5%	21	37.5%
08:00-24:00	13	26.5%	35	62.5%

1. Communication/info availability:
    a. Incoming →100 % morning. When a driver has a need, he calls in the morning. It is because during the morning the possibility to change available slot is higher.
    b. Outcoming →73.47% morning, 26.53% afternoon. For example this category is used to ask to driver if he wants to work out of his availabile slot. Therefore the morning operator may make a call to all drivers that he manages. They

are drivers with available slot that start before 13:00 (73.5% of all drivers).

2. Availability > 24 hours:
    a. Incoming → 100% afternoon. Drivers, with special needs for a day that is not tomorrow, call during the end of afternoon. It means that the allocation to tomorrow services is almost completed.
3. Allocation/variation to the service:
    a. Incoming →32.65% morning, 67.35% afternoon. The morning operator receives calls of drivers with available slot that start before 7:59.
    b. Outcoming →37.50 morning, 62.5% afternoon. The morning operator calls drivers in order to allocate them to all services that start before 7:59.
4. Communication with other traffic control rooms:
    a. Incoming/outcoming →67.86% morning, 32.14% afternoon. The morning operator manages not assigned services that start before 13:00. Therefore it is possible to make a call to another operator regarding 67.9% of all not assigned services.
5. Unanswered calls. Unanswered calls are not considered in the hypothetical scenario.
6. Other:
    a. Incoming →100% morning

List of Figures

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