UNIVERSITÀ DEGLI STUDI DI ROMA "LA SAPIENZA"

Digital Impact on the Railway Vehicle Maintenance

Impatto digitale sulla Manutenzione dei veicoli Ferroviari

THESIS

Submitted for the degree of Master in Transport System Engineering
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Naga Sai Dilip Kumar Akula
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Chapter 1 Introduction to the Field of Railways

1.1 Chapter wise Case study

In the first part we would be knowing the history of Railways from the early stage in the world and Italy, and its various types of them currently in operation. Then we will look at the Host structure RFI, Trenitalia and in and its functioning. In the Second chapter we would know more about the Roma Smistamento depot in detail and the various assets owned by them for the Regional network, the work structure of the Depot. In Third chapter we would be knowing about the Main Locomotives used for the transportation of Regional passengers i.e. E464, TAF and JAZZ and some of the software's being used for them for maintenance in the plant and in the network. In Fourth chapter we would be seeing the types of Maintenance in Detail, how they are scheduled and maintained generally and in the plant for the locomotive and coaches. In Fifth chapter we would be knowing the next level of advance maintenance tools like diagnostics and tele diagnostics in detail and their functioning in trains, how the failures are known in before and how this would benefit the organization. In the Sixth chapter we would be knowing the advance level of diagnostics named DMMS which is being currently implemented, a revolutionary system which predicts at what time the system may get into failure, making it ready for failure not disrupting it from service and making the fleet more productive. The Seventh chapter lets us know about the IMC pdf Software in Detail, what is it, why it is being implemented in the depot, the advantages and benefits of it. In Eighth chapter we would be dealing with the case study of comparing the advantage of having this software on fleet, how much time it would be saving and economically. In the Ninth Chapter we would be making a case study one of the main components Electric Multiple Unit (EMU) particularly Doors which is having the greatest number of failures and review the correct maintenance methods for the components and propose a new maintenance plan for this by FMECA Analysis. Finally, we would be concluding what we have achieved from studying this, and how it would be benefitting the Organization.

1.2 Scope of Thesis

The main scope of the thesis would be to know in detail the maintenance procedure in in the Roma Smistamento of how the work force works and how the maintenance of railways is carried out without affecting the customer traffic and how digitalization of railways would help the organization in point of maintenance, save time, improve the life cycle and the service time of the fleet.

For this in Trenitalia used the technology of Diagnostics, Tele diagnostics, DMMS and IMC PdP for the maintenance of the fleet and the plant. By the implementation of them we would be knowing what impact they would be making in the plant in carrying out the processes. To achieve this first know the existing methods followed on the depot, and study how the future implementation of software's would help in this process not only in time but also in cost reduction. We would be getting to know in detail of the host structure and its functioning in the Regional Division, the assets being used here, and the type of maintenance used for them in detail. This would let us know more about the digital ways of maintenance, the time that is being saved due to them, how they reduce the costs of maintenance and keeping the fleet more available for services.

We would be concluding with the effect of digitalization of maintenance, the benefits gained from in it in the field of Railways.

Along with it we would be knowing the components which are undergoing failure particularly the Electric Multiple Unit (EMU) train doors, and executing the FMECA analysis for it, and predicting a new maintenance method for this component, who would decrease the number of failures for these components.

1.3 What are Railways?

Railways are a means of transporting passengers and goods on wheeled vehicles running on rails, also known as tracks referred to as train transport. They are run on tracks usually consist of steel rails, installed on ties (sleepers) and ballast, on which the rolling stock, usually fitted with metal wheels, moves where the locomotive runs on electricity or on diesel attached with the compartments.

It is one of the oldest modes of transportation that is suitable for conveying bulky goods over long distances till date. These appeared during Britain's Industrial Revolution and later were constructed throughout the developed world. However, railways were developed during the period of industrial revolution in the 19^{th} century. Modern rail transport commenced with the British development of the steam locomotives in the early 19th century was a major technological advancements in the century. Thus the railway system in Great Britain is the oldest in the world.

The locomotive built by George Stephenson and his son Robert's company Robert Stephenson and Company, is the first steam locomotive to carry passengers on a public rail line, the Stockton and Darlington Railway in 1825. George Stephenson also built the first public inter-city railway line in the world to use only the steam locomotives all the time, the Liverpool and Manchester Railway which opened in 1830. The spread of the railway network and the use of railway timetables led to the standardisation of time (railway time) in Britain based on Greenwich Mean Time.

In the 1880s, electrified trains were introduced, leading to electrification of tramways and rapid transit systems. Starting during the 1940s, the non-electrified railways in most countries had their steam locomotives replaced by diesel-electric locomotives, with the process being almost complete by the 2000s. During the 1960s, electrified high-speed railway systems were introduced in Japan and later in some other countries. Many countries are in the process of replacing diesel locomotives with electric locomotives, mainly due to environmental concerns, a notable example being Switzerland, which has completely electrified its network. Other forms of guided ground transport outside the traditional railway definitions, such as monorail or maglev, have been tried but have seen limited use.

1.4 Different Modes of Rail Transport

- **Metro rail**: It is an underground railway system in a city; it covers a smaller inner-urban area ranging outwards to between 12km to 20km (8 to 14 miles). The usual British word for the underground railway system in London is the tube. The American word is subway.
- **Milk run**: This is a type of train journey with stops at many places before reaching the actual destination.
- **Mono rail**: A railway system in which trains travel on a single metal track.
- **Overground rail**: in this case, the train travels on the surface of the ground, rather than in tunnels underground.
- **Passenger train**: This type of train only carries passengers from one place to another.
- **Freight train:** It is a train that carries only goods from one place to another.

- **Light railway**: It is a railway for small trains, usually one that people ride on for pleasure.
- **Eurostar**: It is a fast train that travels between Britain, France, and Belgium using the Channel Tunnel.
- **Cable rail**: This railway is usually attached to a cable by which it is pulled up a mountain.
- **Boat train**: A train that takes passengers to a port where they can continue their journey by ship, or a train that takes them from a port to a town or city.
- **People mover**: It is a simple railway system, usually in a place such as an airport or a theme park.
- **Commuter rail:** This is also called suburban rail, it is a passenger rail transport service that primarily operates between a city centre and middle to outer suburbs beyond 15km and commuter towns or other locations that draw large numbers of commuter's people who travel daily.
- **Inter-city rail**- This is a fast rail that travels between major cities without stopping at small towns in between.
- **Funicular rail**: This is a railway with carriages that are pulled up a steep slope by a cable.
- **High-speed rail**- This refers to passenger rail systems running at operational speed between 200 and 300 km/h, and above in some cases, it is significantly faster than traditional rail traffic, using an integrated system of specialized rolling stock and dedicated tracks.
- **Regional rails**: these are passenger rail services that travel between towns and cities. These trains operate with more stops over shorter distances than inter-city rail, but fewer stops and faster service than commuter rail.

1.5 Italian Railway History

The origins of the Strada ferrata (Road) are to be found in solco carraio (Groove carriage), native from Pompeii by the Romans around 50 A.D. to ensure the traffic on the Via Magna. These grooves, keeping the wheels of the vehicles within special guides or grooves made allowed to improve the sliding of the wagons and reduce the effort of the horses. It is interesting to note that the distance of approx. 1440 mm between the Pompei's Roman carriage differs only 5mm from the gauntlet of 1435 mm between the two rows of one-line today's iron driveway first implemented from wood wheels to iron which can be seen in Figure 1.

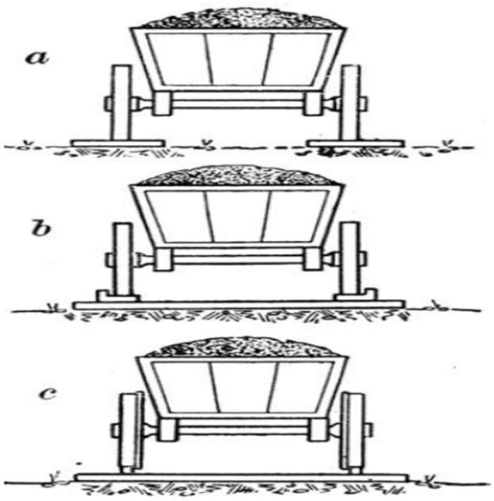


Figure 1 Roman Carriage used in Coalmines

The "Rocket" invented by George Stephenson was a locomotive which, at the time, adopted a new boiler-escapement system. The boiler was tubular with 25 tubes overheated by the hearth, with a separate oven and grill, which allowed the machine to provide more power and above all better performance which can be seen in Figure 2.

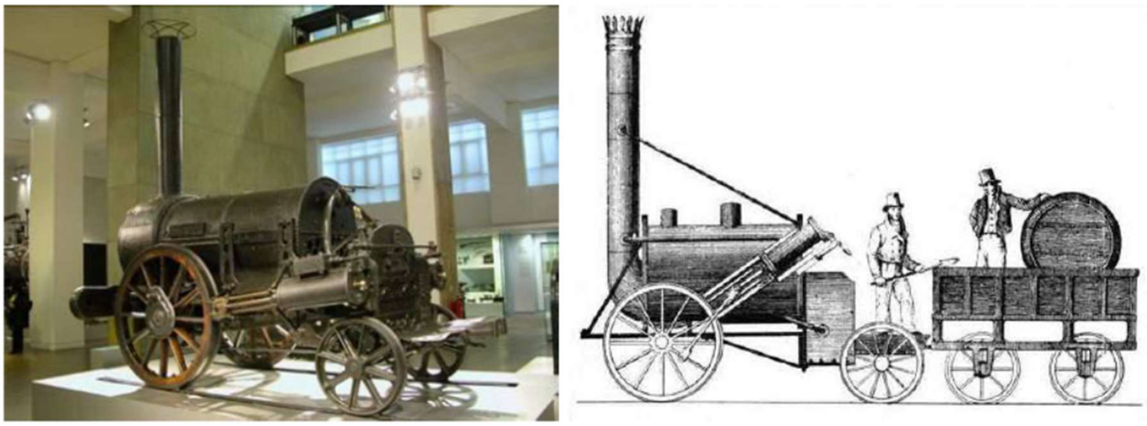


Figure 2 The Rocket

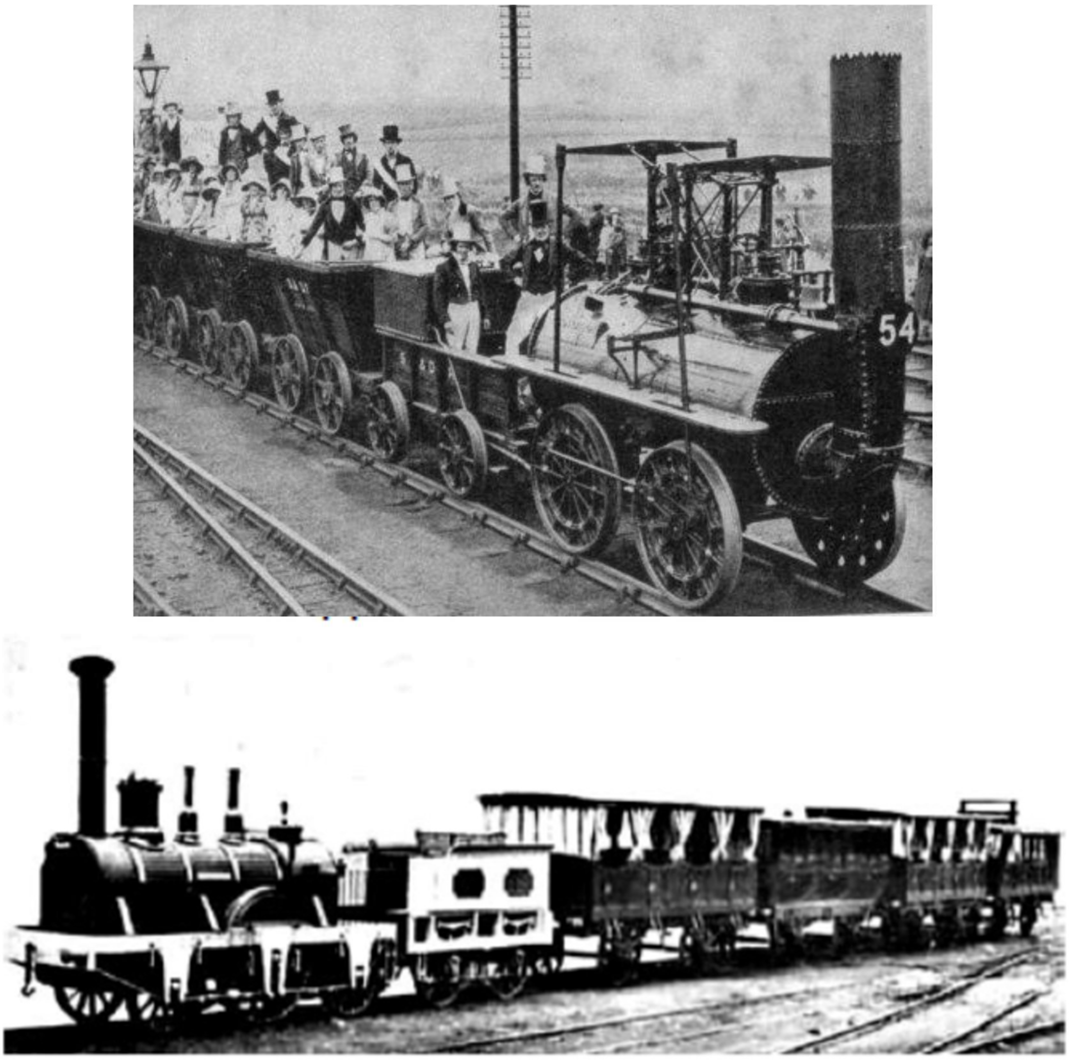


Figure 3 The First Railway line Naples-Portici

The first railway line Naples Portici was inaugurated in Italy in 1839. The line, between Naples and Torre del Greco, met in its path the Granatello station of Portici, then continue for the Forte Colostro, where a temporary stop was opened, and finally reach Torre del Greco which can be seen in above Figure 3. The company's SFAI (Strade Ferrate dell'Alta Italia), SFR (Strade Ferrate Romane) and the Society of the Strade Ferrate Vittorio Emanuele that also included the Sicula and Calabra network used to maintain the railway network. Subsequently, in 1885, with a further reordering, the companies which were previously excluded were also added and the Italian railway operation was such that they were divided between three large companies: the RM (Rete Mediterranea), the RA (Rete Adriatica) and the already mentioned SFR.

On 1 July 1905, after long years of parliamentary research and debates the Ferrovie dello Stato were born and with the nationalization of the railways, an imposing programme of renewal was created, aimed at the improvement of technology and travel comfort, in which the Italian companies Ansaldo and Breda were involved merging all the companies or abandoning them. The far more important aspect of the period, however, was the vast network of electrification of the network, which brought Italy to the European equal in this field. Research was developed on the electrification of the lines already in 1899, producing experiments with accumulator systems and third rail in direct current.

Figure 4 FS E550

With the electrification program, it also passed from the 450 kilometres of the end of the First World War to the 1200km of 1928, until reaching, in 1940, a total of 5170km. The electrification program had privileged international connections with France, Austria and Switzerland, cutting out almost all the South of the country. Before the war, in 1940, the state rail network was over 17,000km, 194 million passengers and around 60 million tonnes of goods were transported, data intended to increase in the first years of conflict for the progressive disappearance of car and truck fuels. An old Trains of the RFI can be seen in Figure 4 and 5.

Figure 5 The Glorious E428

1.6 Management of Train Network in Italy

The Ferrovie dello Stato (State Railways), born in 1905 with the nationalization of the three private railway networks then existed in 1924 in the Ministry of Communications to become then, in 1944, a General Directorate of the Ministry of Transport with three divisions that ensure the transport of passengers on the medium and long distance, the traffic of goods, the transport in the local area

Figure 6 FS Logo

With the creation of the Divisions, and then of the Companies, a radical breakthrough to the organization of the system, creating:

- an industrial strategic company holding, Ferrovie dello Stato S.p.a(Company Logo in Figure 6);
- a company dedicated to the carriage of passengers and freight, Trenitalia, born in 2000, which manages the transport of passengers on medium and long distance, metropolitan and regional traffic and freight transport;
- a company that manages the railway network, RFI – Rete Ferroviaria Italiana (Italian Railway Network), founded in 2001, which is entrusted with the activity of design, construction, commissioning, management and maintenance of the railway infrastructure.

-with the subsidiary TAV, RFI is implementing an impressive programme of investments that has the setting-up of new High Speed/High Capacity lines. The other societies of the group which can be seen in Figure 7.

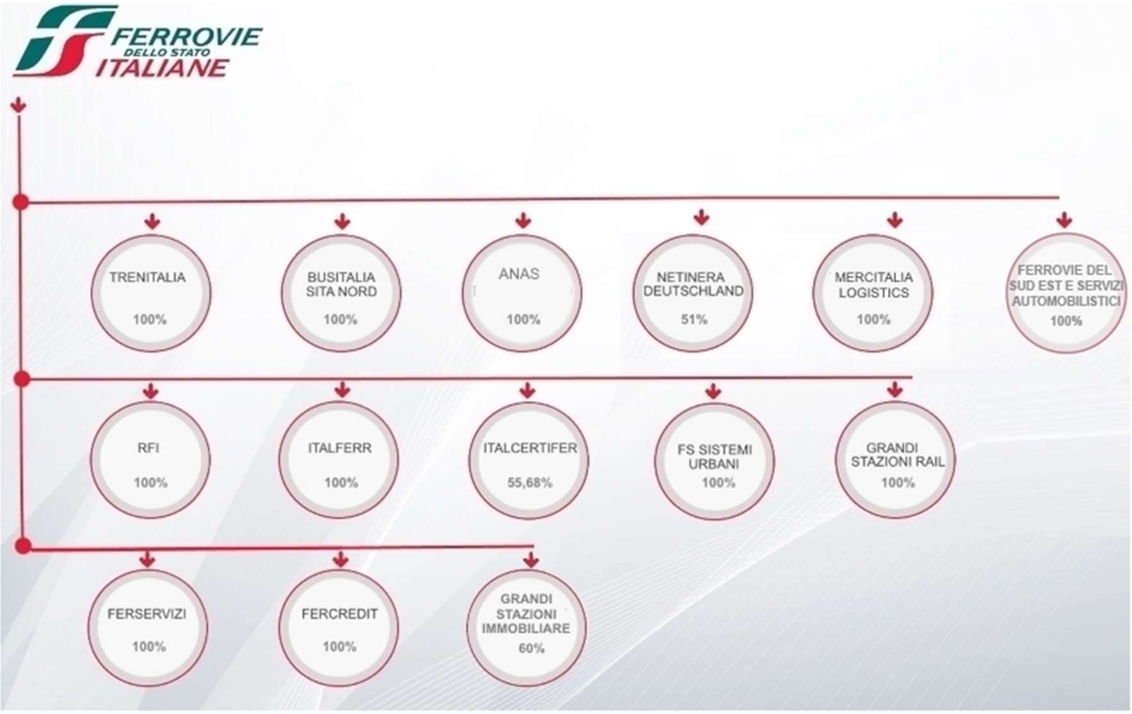


Figure 7 The Network Structure

The Italian railway network consists of:
- 16.200 km of simple binary lines, two thirds of which are electrified,
- 6,300 km double track for a total of 22,500km of total development;
- 1,064 km lines to AV;
- 2,270 passenger service stations and 479 goods service facilities,
- 1,380km of tunnels and 530 km between bridges and viaducts.

1.7 The host structure: Trenitalia S.p.A.

Controlled 100% by the Ferrovie dello Stato S.p.A., Trenitalia operates in the field of services for the mobility of travellers and goods in the national and international field.

Figure 8 Trenitalia Logo

The entire organization of Trenitalia(Company logo in Figure 8), committed to meet the needs of the customer and the demands of the market, always ensures the highest standards of safety and realizes plans of development and modernization in respect of social and environmental sustainability classified into Long Passenger Division Haul where it ensures the activities of national and international passenger transport, including high speed and Regional Passenger division assures metropolitan, regional and interregional services, adapted to the needs of passenger mobility.

Currently the division moves about 1.6 million passengers per day, carrying out a traffic of 6,300 trains per day. The fleet consists of 650 locomotives, 3,800 carriages and 700 light-weight vehicles. The division classified can be seen in Figure 9.

Figure 9 The Organization Structure

1.8 The Directorate Regional (DR) of Lazio

Lazio Directorate Regional (DR) operates around 900 trains per day with 3,00,000 commuters travelling each day in them. The railway lines operated by DR of Lazio which can be seen in Figure 10 come under regional transport and all the fleet used here come under Roma Smistamento for maintenance:

- FL 1: Orte - Fara Sabina - Roma - Fiumicino Aeroporto
- FL 2: Roma - Tivoli - Pescara
- FL 3: Roma - Cesano - Viterbo
- FL 4: Roma - Ciampino - Frascati/Albano/Velletri
- FL 5: Roma - Civitavecchia - Pisa
- FL 6: Roma - Cassino - Caserta
- FL 7: Roma - Formia - Napoli
- FL 8: Roma - Nettuno
- Roma Termini - Fiumicino Aeroporto no-stop (Service "Leonardo express")
- Priverno Fossanova - Terracina
- Avezzano - Sora - Roccasecca
- Orte - Viterbo
- L'Aquila - Rieti – Terni

.

Figure 10 Railway Network Region Lazio

The punctuality and the customer satisfaction are given below. This can be achieved when the trains run on time, are maintained and cleaned properly, less failures and cancellation of services giving a higher customer satisfaction. Thanks to the digitalization in the recent years you can see a good advancement in punctuality and customer satisfaction which can be seen in Figure 11.

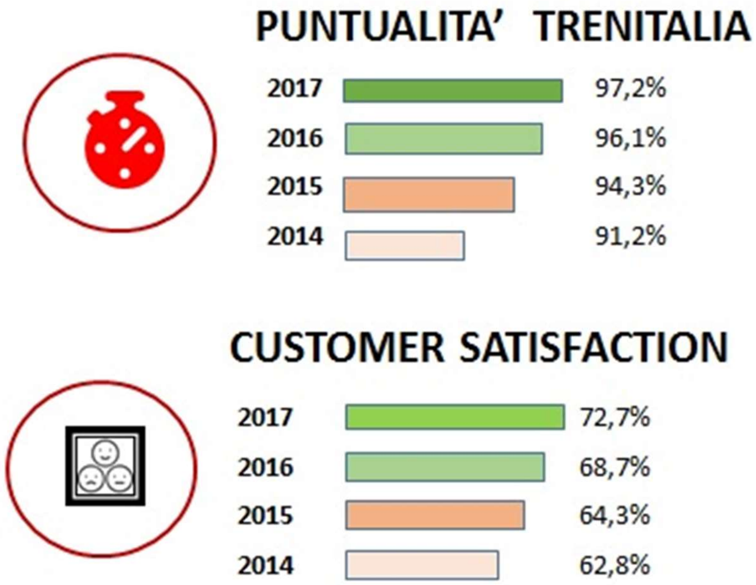


Figure 11 Punctual and Customer Graphs of the Recent Years

Chapter 2 Roma Smistamento

2.1 Depot Sorting

The current maintenance depot in Rome which is an IMC sorting, is represented in Figure 12 below

Figure 12 Aerial photo IMC Roma Smistamento.

This depot together with that of San Lorenzo is the largest in the capital. The IMC of Roma Smistamento is in the north east of Rome near the Grande Raccordo Anulare (Great Ring Road) and has a total area of 233.000 sqm of which 48,230 Sqm is subdivided into which can be seen in Figure 13

- Locomotive Sectors (Settore Locomotive);
- Light Vehicles Sector (Settore Mezzi leggeri);
- Vehicles Sector (Settore Veicoli);
- Technical Area (Locali tecnici);

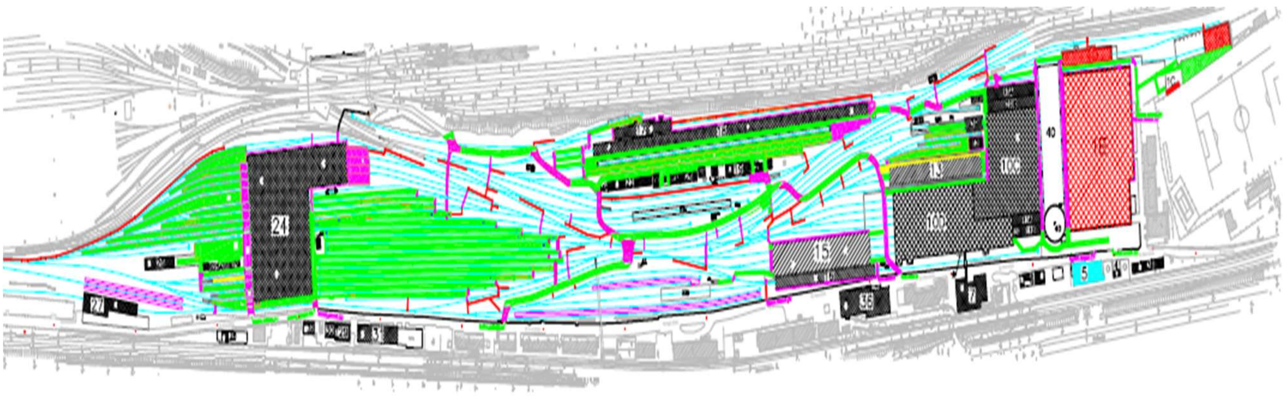


Figure 13 IMC Roma Depot planimetry.

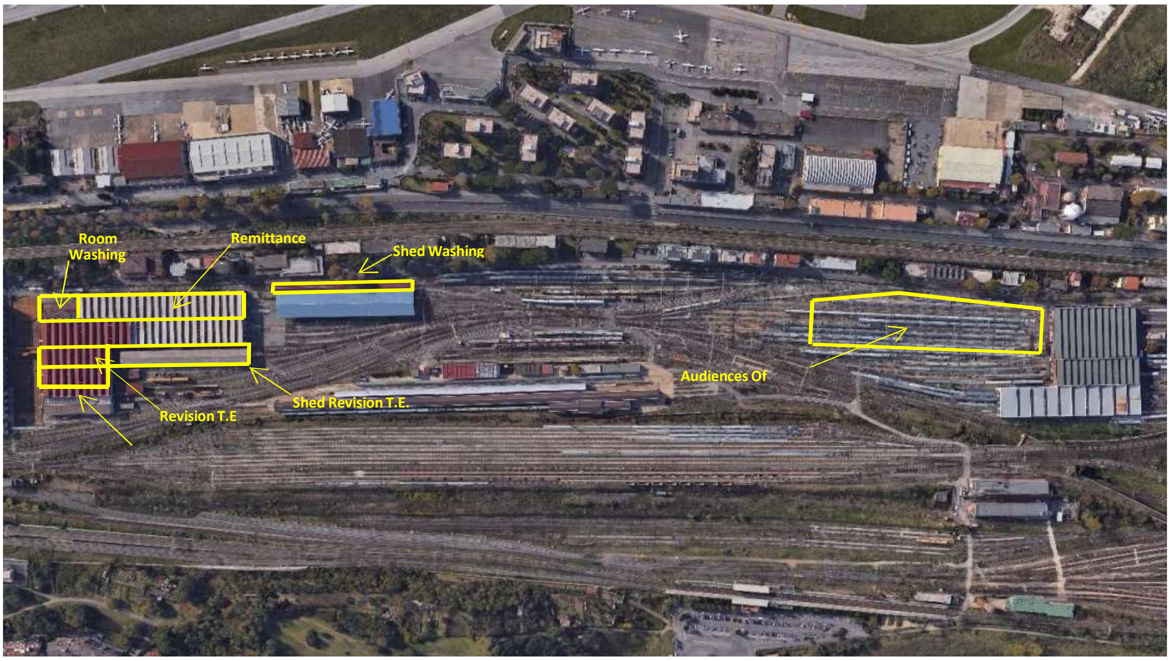


Figure 14 Detailed layout of the depot

The type of Rolling stock managed in the depot is mixed and ranges from old-generation Rolling stock E626 to the new JAZZ (ETR 425). In the coming months it would be hosting the "Rock" the first train built by Hitachi for Trenitalia. It also hosts the vintage trains in its warehouses.

The old trains require more time and skilled persons working which require high maintenance interventions. This generational difference is reflected in the mileage with which the maintenance interventions are performed and in the amount of operations that they require as they are not equipped with sensors which give us the live date to be monitored. The monitoring for the electric trains is executed on a kilometrical and temporal basis, according to the maintenance plans, and shows how, moving from older to more modern and therefore more automated means, the frequency of certain interventions is lower. This clearly shows the digitalization saving time for maintenance, unnecessary change of parts and mainly save of time. Inside depot there are the following technological installations:

- ACC;
- Transporter-wagon and Revolving platform (Carro trasbordatore e piattaforma girevole);
- Wastewater Treatment Depot (Depuratore reflui industriali);
- Axle-Motor Traction Depot (Impianto cala assi-motori di trazione);
- Lathe Machine for Wheels (Tornio in fossa);
- 2 decks for washing coaches underneath (impianti di lavaggio sotto casa);
- 3 decks for external coaches washing (platee di lavaggio esterno cassa);
-

The tracks are equipped with:

- Equipped track for complete train (16 Tracks) and for interventions in the undercut (with openable rail);
- 4 Tracks with walkways for Light Vehicles
- 2 Tracks with walkways for normal vehicles;
- 2 Rails with walkways MAV2 and MAV3.

2.2 Organization Structure

The organization of the Regional passenger division is divided below in the following flow chart in Figure 15.

Figure 15 Organization DPR Lazio

Let's now look at the organisation with focus on DR Lazio inside which you will find the Manutenzione e Pulizia where I got to chance to work with and Ingegneria di Processo. **Manutenzione e Pulizia** (Maintenance and Cleaning): It is the structure that which oversees the activities listed for maintenance. The whole world of maintenance and cleaning bases its processes on the observance of precise deadlines for the planning and management of the maintenance activities to be carried out on the rolling materials and on the system within which the same are carried out. Behind every maintenance activity done or planned it is possible to find a great number of processes that allow the implementation, such as the management of spare parts and consumable materials. The programming, implementation and control of the current maintenance activities on the rolling stock in compliance with the maintenance deadlines and of the ordinary service of the depots, as well as the programming and control of the contracted cleaning services. The whole process can be seen in the following flow chart in Figure 16.

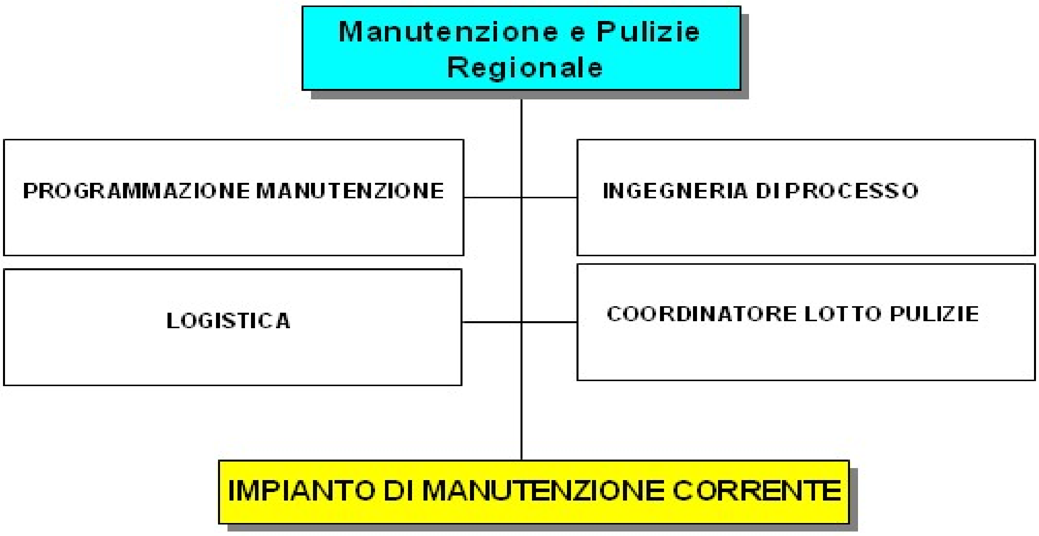


Figure 16 Regional Maintenance and Cleaning Departments in the Depot

2.3 Vehicles in Depot

The current assets of Lazio Region operated by the Trenitalia presently are as follows which all come under Roma Smistamento for maintenance in Table 1:

TAF (Treno Alta Frequentazione)	43	57
Jazz	20	
Loco 464	77	30
Carrozze MD	20	NA
Carrozze Piano Ribassato	136	
Vivalto	97	
Carrozze Vivalto Emilia	244	

Table 1 Total Number of Fleet

The depot consists the listed fleet to which the maintenance is carried out (Preventive and Corrective) to Locomotive E464**,** Coaches of different types like Carrozze media distanza (carriages), Vivalto, TAF And Jazz (Regional and Leonardo Express), Diesel traction**,** Semipilota and hosts the old Steam engines and carriages. Where for the vehicles for E464 and TAF they have 30 and 57 people working in shifts carrying out the respective maintenance works for them where every less one person to look after each three locomotive, and for TAF and Jazz it is almost equal to one person per one train.

2.4 UIC Identification Number

The UIC identification marking for tractive stock is a standard way for identifying train stock like locomotives that supply tractive force. Since the beginning of 2007 locomotives or other traction units in Europe have been given a 12-digit number. Vehicle numbering is now governed by the Intergovernmental Organisation for International Carriage by Rail and in Technical Specifications for Interoperability (TSI) of the European Union, specifically the European Railway Agency's CROPETSI (Conventional Rail Operations Technical Specification for Interoperability). This makes the locomotive clearly identifiable within Europe and parts of Asia and northern Africa. A complete number comprises 12 digits and goes back to the UIC Code of Practice 438-3, Identification marking for tractive stock. Digits 1–2 are the type code, 3–4 the country of origin (where the vehicle is registered), 5–11 are defined by the country concerned, 12 is the check digit calculated via the Luhn algorithm. It is followed by abbreviations for the country of origin and the owner of the vehicle. For Italy the country code number is 83 denoted by the letter “I “. An example of a locomotive can be seen Figure 17 below:

Figure 17 UIC Identification Number

From the above image it can be interpreted that the starting two numbers 50 denote the European code the next two 83 denote the country code Italy, the next five digits denote the Type of locomotive and its identification number for the carriage in Underline (26-78 673- Viv Alto 1st series) and the last digit (3) is the Luhn Algorithm. In the last again we can again see I-TI representing the country Italy.

When it comes to maintenance of Locomotives and Carriages it plays an important role as with the identification numbers only, they are represented and communicated always, not only in this view but also in the Software's used in Total Trenitalia Like RSMS, Mose, Timer.

Chapter 3 Main Locomotives and the Software's Used in Depot

3.1 Introduction of E464

This is the main locomotive that moves Italy. The E464 fleet consists of more than 700 locomotives entirely built at the Bombardier factory in Vado Ligure. The E464 fleet represents the largest fleet dedicated to the transport service as well as being one of the largest locomotive fleets of the same in Europe. The fleet is maintained in 14 workshops throughout Italy.

The E464 locomotive shown in Figure 18 below is a single-cab drive unit of medium power, particularly suitable for fixed and reversible coaches with guide from a semi-pilot carriage or another locomotive if they are equipped with a 78-pin line or a train line with according to the standard TCN/TCN*. The locomotive has a weight of 72 tons and develops an ongoing power to the wheels of 3000 kW which allows the maximum speed of 160 km/h. It is made to operate on lines powered at 3 kV DC but can also be used with a performance powered at 1.5 kV DC. The locomotive is provided with a secondary driving cabin with reduced instrumentation in the rear area, for short range manoeuvres in stations (maximum speed allowed: 30 km/h).

Fully integrated control electronics are based on the technology of the series MITRAC®. The architecture of the control system uses a redundant network of transmissive-MVB data. Using a train network (WTB) according to TCN/TCN* or through the 78-pole line the realization of multiple compositions is permitted. The diagnostic system is structured to implement the automatic exclusion of the failing part for all the redundant components. The defective component is detected and excluded in the automatic and without the machine personnel having to carry out any manoeuvres. The diagnostic system also features operator guidance.

3.1.1 Composition and Characteristic data of the Train

The main performance and mechanical and electrical characteristics of the locomotive E464 are given below in Table 2:

Power Type	Electric
Builder	Bombardier
Build date	1999-2015
UIC Configuration	Bo'-Bo' and UIC 505-1
Gauge	1435 mm
Wheel diameter (new/worn)	1100 mm/1010 mm
Wheelbase (between bogies)	7540 mm
Wheelbase (between axles in each bogie)	2650 mm
Length	15750 mm
Width	3106 mm
Height	4282 mm
Total Mass	72 t
Mass of axis	18 t
Battery voltage	24 V DC (nominal value)
Electric Systems	3000 V DC
Traction Motors	Three phases Synchronous
Transmission	27/55 and 26/44 Gear Ratios
Maximum Speed	160 km/h
Power Output	3.5 MV
Tractive effort	200 kN (starting), 85 kN (braking power)

Max traction power to the Wheels	3500 Kw
Rheostatic Braking power	2350 kW
Transmission Ratio	1/5
Line Voltage	3 kVcc, 1.5 Kvcc
Auxiliary Power Supply Voltage	450 V at 60Hz fixed and Variable
Operators	FS Trenitalia, TiLo, Ferrovie Emilia-Romagna, Trenord
Number in Class	728

Table 2 General Characteristics of E464

Figure 18 Locomotive E464

3.2 TAF (Treno Alta Frequentazione)

The Treno Alta Frequentazione (TAF) shown in Figure 19 is a two-storey electric train in a locked composition of 4 elements, built at the end of the nineties of the twentieth century for Trenitalia and Ferrovie Nord, dedicated to regional services and commuter traffic.

3.2.1 General characteristics of the Train system

The high frequent trains, designed to transport commuters on railways networks of the State railways and Nord Milano, can carry a total of 874 passengers including 476 seated and 398 standing. To obtain such a capacity, motors are used in two floors of High capacity, made of light alloy in order to respect the limitation on the maximum load by 20-ton axle and reduce energy consumption. There is also a reduced painting of external surfaces with positive impacts both in ecological terms and in maintenance and washing.


Figure 19 TAF

The electrical equipment installed on board each of the two engines allows you to develop a power to the axis of 1280kw continuous. The power supply can be carried out either from the catenary to 3 kVcc That from that to 1.5kVcc. Each engine cart is driven by its own traction converter, with its filters and its adjustment. The control system is based on the use of a microprocessor system with the complete redundancy about the common vehicle functions and supports the resident diagnostics functions. The auxiliary Services power system, for its architecture and for the power of every single converter, guarantees the supply of all the loads of the coach also with 1500-line power supply Vcc. The control and low voltage circuits are powered at the nominal voltage of 24 V battery and a low voltage train line achieves the redundancy between batteries of the motors.

3.2.2 Composition and Characteristic data of the Train

The TAF train (high-frequency train) consists of two drive motors Type Ale 506(M-T44) and Ale 426 (MH-T45) positioned at the end of the coach and two towed on 736 (T46). The main characteristics of the train are the following Table 3:

Basic composition	1 Tractor (M) + 2 towed (RH) + 1 motor (MH)
Length	103970 mm
Maximum distance between the end ports (2 coupled Train)	201020 mm
Length of Motor	25895 mm
Centre Motor	26090 mm
Width	2828 mm
Max Height of Vehicle	4300 mm
Minimum Radius at Entry in Curves at 140Km/h	250 m
Clearance on the Lower floor	1915 mm
Clearance on the Higher floor	1910 mm
Side Doors	8
Height of Floor from Platform	650 mm
Motor Pitch	2700 mm
Load-bearing trolleys	2220 mm
Total No of Passengers	841
Total No of Seated Passengers	467
Total No of Standing Passengers	372
For Physically Handicapped Persons	2
Small Seats (Not considered in Capacity)	9
Line Voltage	3000 Vcc
Operating voltage range	2000 ÷ 4000 Vcc
Continuous power to the wheels	2509 KW
Maximum power speed range	58.2 ÷ 100 km/h
Maximum power to the wheels	3640 KW
Tensile stress at Cue	214 Kn
Continuous Traction Force	147 Kn
Traction effort at maximum speed	66.8 Kn
Maximum operating speed	140 km/h
Continuous electrical braking effort	100 Kn

Continuous power to the Electric braking wheels	1150 KW
Maximum power to the braking wheels Electric	3397 KW
Minimum operating speed of the Electric braking	10 ÷ 35 km/h
Total weight at full load	271.60 ton.
Total Weight Empty	208.75 ton

Table 3 General Characteristics of TAF

3.3 Jazz

The Jazz shown in Figure 20, is a vehicle made up of two motorcycle elements, the end with two or three trailer elements (depending on the version). The ETR425 vehicle consisting of 5 elements (engine-trailer-trailer-trailer-engine). It consists of the Basic version, Airport version and the Metropolitan version.

3.3.1 Description and Features

The case structure is of width 2950mm corresponding to the boundary template Provided by Fiche UIC 505-1 (EBO G 1) and is made of lightened steel, in order to comply with the limitation on the maximum axle load of 18 tons. The passenger spaces are of the "salon" type. Possibility of insertion of Baggage seats with limited footprint; Wide internal circulation obtained with large corridors in the areas of intercommunication between the elements and between the seats (640 mm); Safety of the vehicle against fire hazards thanks to the choices made in the definition of the materials and the compartments containing the equipment by a fire-fighting system; Rapid in groaning and evacuation of the vehicle by means of 405 (A From of the version) and large access doors for two-way side panels of which one has access platform for Handicapped wheelchairs, and ascent Board with floor Trampling at 650 mm. Also, low noise level inside the vehicle as a result of the locomotive and the application of mantles for comfort. The vehicle is equipped with a retreat; and a toilet in the centre element which is accessible to passengers.

Figure 20 Jazz Regional (Left) and Leonardo Express (Right)

3.3.2 Description and general characteristics of the vehicle

The main technical features are shown in Table 4 below.

Position (vehicle composed of 5 ETR425 elements)	Two-drive (A41 and A46) at the ends, a re-intermediate motor with pantograph (A43), two Intermediate towed (A42 and A45); 2 Trolleys motor at the ends, 4 carrying trolleys in the Joints area.
Maximum speed	160 km/h (3kv)-125 km/h (1, 5kv)
Rank	C
Vehicle limit Gauge	According to UIC 505-1 (EBO Gl)
Total length (Front wire Auto-coupler Matic)	82,200 mm
Length (excluding couplers)	80,830 mm
Motor length (Front filter Auto-coupler Matic)	19,125 mm
Intermediate towed length	14,650 mm
Maximum vehicle width	2,950 mm
Upper Thread Height from the imperial from the iron plane	4,230 mm
Floor height lowered area	600 mm on A46, A45, A42, A41;650 mm vestibular area A46, A45, A42, A4; 650 the area A43 towed
Floor height lowered area on Intermediate trolleys	800 mm
High floor area height	1,250 mm
Distance between trolley	14,650 mm
Exterior gauge of the halls mounted	1425 mm
Track gauge	1435 mm
Motor Trolley Step	2400 mm
UIC Configuration	Bo' – (2)- (2)- (2)- (2)- Bo'
Carrier pitch step	2700 mm
New wheel diameter	850 mm
Wheel diameter after max wear	790 mm
Min. passable official /exercise	90 m / 150 m
Longitudinal resistance to com- pressure	1,500 kN
Total Mass	189 t
Voltage on Train	24V (Tension from Battery 18-36 V)
Pair	Up to two vehicles
Braking types	Electric, rheostatic and recovery braking; Emergency stops of stationary brake.
Traction	2 pantographs feeding the entire vehicle 4 Asynchronous three phase motors with forced ventilation.

Table 4 Features of Jazz

3.4 Software's being Used

Thanks to the digitalization these days every function is being carried out in computers with dedicated software's for each function. In the work place they ease up the functioning, reduce time and reduce human errors. The programs being used in the Roma Smistamento which I have encountered and learnt to work on are

3.4.1 MOSE

Mose – Monitor on Segnalazione Eventi which tells the running time of the trains, delays, its initial and final destinations, its compositions of the carriages, any problems on them, on general the total functioning on of the train at any time. Works integrated in IE in real time to let us know Stats, Composition, Punctuality of Trains,

3.4.2 Timer Hodie W2 in Sistema Timer

Sistema Timer is a software developed by Almaviva. It is a timer type system for the railway companies with the aim to plan and manage the Train activities. It a system which works on the global network (work from any long distances). To access the central database, it is enough to have an internet connection. Higher transmission fields of data can be received with higher speed connections. Timer Hodie is the module of the Sistema Timer that deals with the real-time management of the shifts of the material. An example can be seen in figure 21. The main operations that the operator performs with Timer are

- Assignment of rolling stock to shifts.
- Changes to scheduled shifts due to greater.
- Control of the circulating of the carriages.

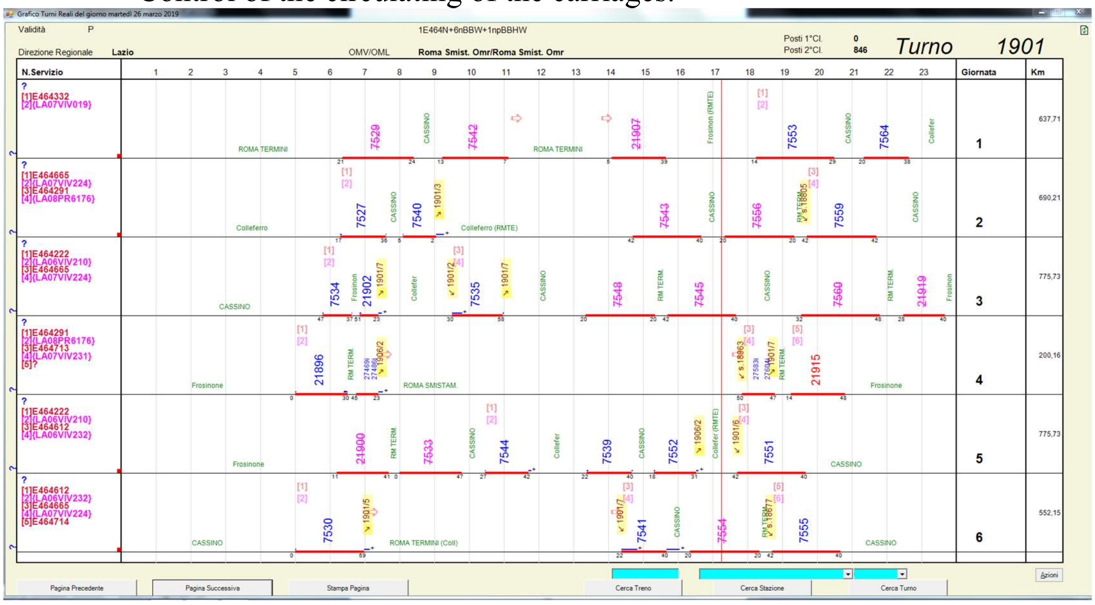


Figure 21 A Screenshot of Programmed Shifts for E464

3.4.3 Diagnostics and Tele diagnostics

Diagnostics: It is a traditional method of analysis where after the train is entered the depot, the data from the Train would be downloaded manually and analysed. For example, TAF don't have tele diagnostics, when it is pulled over for maintenance of diagnostics, data is downloaded from the train by cable into laptop and this is analysed. It is the next locomotive where the Tele diagnostics and DMMS would be installed.

Tele diagnostics: It works with support Predictive and Corrective Maintenance. The system was developed by Bombardier according to Trenitalia specifications in order to increase the availability of the E464 and E405 fleet. It is a fleet diagnostic management system designed and manufactured to support corrective maintenance and predictive activities. In simple words this is the advance form of the diagnostics where the data is stored in cloud, where the signals from the sensors are sent to the cloud from the board of the sensors to the locomotive continuously, from where we can access them from the software and analyse the cause of the problem. We would be going in detail about it the coming chapters.

3.4.4 DISW

For the diagnostics of the fleet this software is used for the knowing the cause of the problems when the vehicle as from here the total values can be seen more in a clear form, taking the values we need to see online, without downloading them. The data here is stored for a span of 120 days.

3.4.5 SAP

Developed by SAP Hana it is the main functional tool being used here for all the main works to be carried out. In the maintenance part of view, it is used first to know when there is a deadline for the deadline in kilometres or time, the inventory of all the stock in the depot, the failures occurred on the locomotive, their current status of maintenance in the depot. It is the mostly used tool in Trenitalia for the maintenance of Railways.

3.4.6 RSMS (Rolling Stock Management System)

It is one of the applications of SAP platform, used for the management of maintenance activities; The basic information that it manages is:

- Vehicles requiring corrective maintenance (Za alerts),
- Maintenance Deadlines (Zac alerts),
- Technical information attached to vehicles,
- Damage,
- Committed materials,
- Ways and causes of faults,
- Activities and work cycle,
- Work orders.
-

This program allows to monitor in a continuous, total and exhaustive way all the maintenance process of each rolling stock, both in terms of programmed and corrective, from the mileage to the working hours discharged on it, from the materials changed to the days of downtime until obviously to reach the economic costs. All this information can be viewed at both local and central level, so you can always be informed about how they are working and if you have any type of problems.

3.4.7 PdP – IMC

The Piattforma di Produzione Trenitalia (Production Platform Trenitalia) with short name PdP aims to achieve a unique integrated and homogeneous platform, with IT services that contribute to the planning, programming and operational management of trains and the resources needed for them in the Depot. Its development programme is aimed to overcome the current system of production systems, and be an innovative solution composed of integrated and rationalized application of modules, covering all the processes that contribute to the production and execution of trains in the depot. It short it completely deals with the Depot Maintenance from the entry of locomotive to the exit, where it must be parked in the depot, depending on the type of maintenance activities it would be needing in the time in the depot. This would not also save time but also eliminate unnecessary movements of trains in the depot.

This was initiated in the year 2011 and implemented in the year 2013 in the Firenze Regional Passenger Division and in the depot of Roma Smistamento it was initiated in the year 2015 and it was implemented in the year 2018. It is still in the Testing Stage and not completely implemented.

3.4.8 DMMS (Digital Maintenance Management System)

The data collected and transmitted by sensors placed on the higher maintenance costs components (engines, batteries, brake systems, etc.) are processed in real time with the application SAP Predictive Maintenance and Service. This system, called DMMS (Digital Maintenance Management System), allows real-time monitoring of the status of vehicles remotely, but also has predictive capabilities. When the threshold values for certain behaviour parameters are exceeded, threshold values indicate an imminent failure, DMMS can trigger interventions before the failure causes stops and service cancellations. The main goal is to reduce the cost of maintenance and service, with both the best availability and levels of service for passengers. We would be discussing about it more the coming chapters. In simple it is the advance form of Tele diagnostics.

Chapter 4 Types of Maintenance

In Italy **52%** [1]of the companies have current maintenance processes based on real-time monitoring using pre-established rules or critical levels, which is higher than in other countries.

4.1 What is maintenance and in trains?[2]

Maintenance means the preserving a condition or maintaining it so that it can be productive in its lifecycle. In the Railways this plays a major role as the different components must be maintained properly not leading to failures as they cost a lot to the company and in the modification or cancellation in the passenger services. They are managed in general in one of the three ways; by mileage, by time or by condition monitoring. Traditionally, maintenance was carried out on a time basis, usually related to safety items like braking and wheel condition. Many administrations later adopted a mileage-based maintenance system, although this is more difficult to operate as you must keep records of all vehicle mileages and this is time consuming unless you have a modern train control and data gathering system. But sometime without the components turning faulty it must be replaced. This system has been overcome by the Condition based system where the components are monitored continuously with the help of sensors. In detail about the types of Maintenance are

After-the-failure maintenance: The oldest type of maintenance that was and still is justified for objects that have a minimal effect on the readiness of the equipment. It represents a disadvantage in the form of unplanned and sometimes longer operational shutdowns of the equipment, which may relate to large financial costs and in when a failure in service causing trouble to the passengers.

Preventive maintenance: It identifies the need for maintenance action based on the current health status of a component. The health status of the component is assessed by correlating one or more physical and chemical quantities to the state of the component and identifying a threshold value, in relation to these quantities, beyond the which the component has a high probability of failing. It usually includes check-ups, inspections. This type of maintenance represents a high level of planned work and usually leads to a reduction in costs compared to the costs of after-the-failure maintenance.

Predictive maintenance: It is a type of preventive maintenance that is carried out following the identification of one or more parameters that are measured and extrapolated using appropriate mathematical models in order to identify the time remaining before the failure. To this end, several methodologies are used, such as the analysis on lubricants, the measurement of vibrations, thermography, the analysis of absorbed currents, the detection of abnormal vibrations and many others. A variation of the measurements made compared to the normal operation state will indicate the increase in degradation and, ultimately, allow to predict the moment of failure. It minimizes the downtime for maintenance.

Condition Based Maintenance: In the condition-based maintenance (CBM) technique one take the condition monitoring results in account and plan the maintenance action by it. The purpose of CBM is to eliminate the breakdowns and prolong the preventive maintenance intervals. With this an increase of availability of an asset will follow. With CBM technique one

[1] GE Predictive Maintenance Digital Full Report 2018
[2] http://www.railway-technical.com/trains/train-maintenance/

wants to analyse the condition monitoring data deep enough to be able to say whether the asset is running at a normal operation condition or not. If the pre-set limits for normal condition exceeds, one also wants to know the reasons behind it and how long before a fatal breakdown will occur. With this information it will be easier to plan the maintenance actions more effectively.

4.2 Maintenance in Trenitalia

Maintenance, as mentioned, is a set of activities designed to maintain a unit in a functional state where it can perform its main function, or to restore that state, in order to ensure the constant integrity of security systems and the conformity. The structure followed in the Trenitalia is which can be seen in Figure 22:

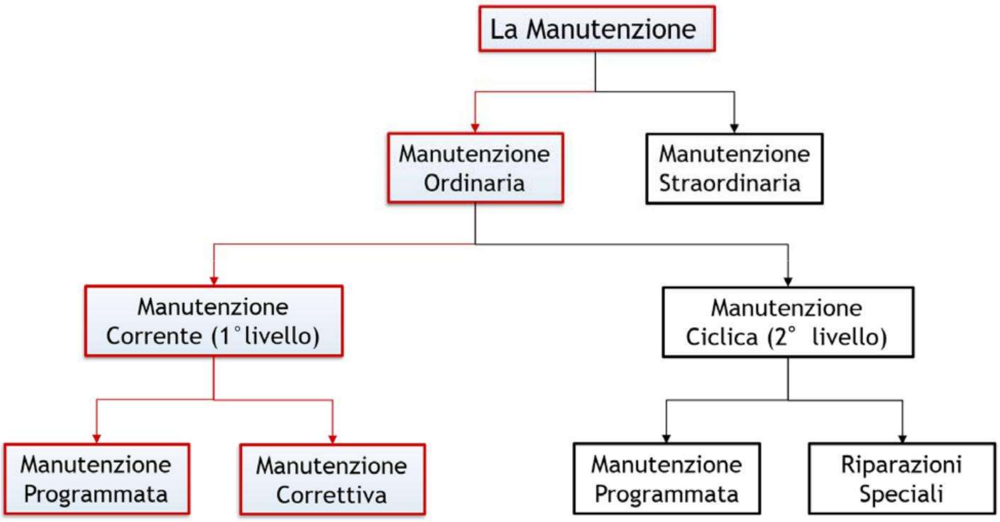


Figure 22 Maintenance in Trenitalia.

The maintenance is distinguished as: Ordinary and Extraordinary. While the first concerns all the rolling stock and is executed in a systematic way, the second one is executed only occasionally and on rolling subject of important modifications and/or which have suffered serious damage and therefore need of restoration interventions. The routine maintenance is in turn organized on two levels:

1st Level Maintenance: It is also known as the Current Maintenance, which provides for operations that can be successfully carried out on board, such as calibrations, alignments, lubricants, substitutions of consumables, inspections and controls on sight or with equipment safety controls, cleaning, minor repairs on equipment or systems.

2nd Level Maintenance: It is also called as Cyclic maintenance, which includes all the interventions which, when exceed the possibility of 1st level maintenance, for example, complex repairs at the depot or in the laboratory, diagnosis and replacement of elements and components, software interventions, etc.

In both levels, maintenance activities can be distinguished in planned (or preventive) and corrective: the first are activities that are performed at predetermined intervals (temporal or kilometrical) or according to prescribed criteria and are aimed to reduce the likelihood of failure or degradation of the operation of components and/or entities; The second, however, are performed only after the detection of a breakdown or failure and are designed to bring the component and/or entity in the state in which it can perform the required function.

4.3 Types of Maintenance Depots and Maintenance Levels

The maintenance is carried out in the depots across Italy which are

i. IMC – Impianti di Manutenzione Corrente (Current Maintenance Depot)- 1st Level Maintenance
ii. OMC- Officine di Manutenzione Ciclica (Cyclic Maintenance Depot) – 2nd Level Maintenance

They are represented below in the following diagram which are spread across Italy shown in Figure 23.

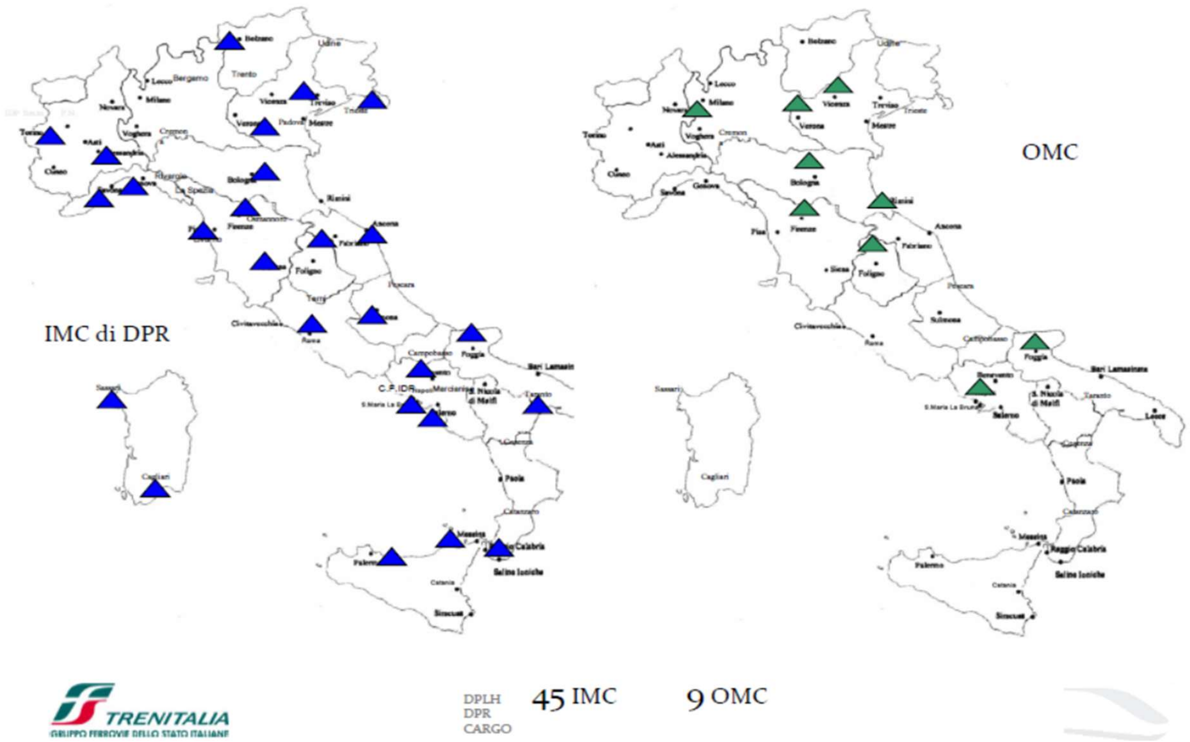


Figure 23 Maintenance Centres across Italy

All rolling stock, in order to guarantee a safe and regular service, requires periodic maintenance, defined by a "Maintenance Plan" (PdM). They are prepared for each type of vehicle and usually based on Kilometre or Time deadlines within which certain checks and replacements must be carried out. The maintenance plan, given by the manufacturer, shows in detail all the operations to be carried out on each rolling stock and the relative periodicity (Kms or Time). In Trenitalia the Preventive Maintenance is carried out in following levels of intervention

- CO – Controllo in Officina – It consists of one examination of the control vision on running gear, carriage, parts underneath the rail and pantograph, after survey finalising the probable failures or abnormalities, so finally to guarantee the safety, the regularity and the maximum availability of the rail for commercial use. This program is effectively carried out in the intervals of every 16.000 km.
- RT – Revisione in Turno – It is carried out in the intervals of 80.000 km.
- CC – Cambio Carello – It is carried out in the intervals of 1.200.000 km.
- RO- Revisione di Officina – It is carried out in the intervals of 2.400.000 km.

The interval of maintenance is carried out, along with the distance travelled or the maximum time, not considering them to be mutually exclusive. This signifies that in the occasion of an interval maintenance program depends on the data of km or time, where the maintenance carried out here is should be done properly checking with the previous maintenance. The maintenance in between the 1.200.000 km and 2.400.000 km includes the same procedure under various deadlines. During this process it involves the assembly and disassembly of various components, getting access to all the mechanical structure, which is carried out by controlled individuals (skilled technicians) for the events of breakdown and failures of the various components. The CC, RO come under second level maintenance where all can be seen in the Figure 24 and Table 5 which can be easily interpreted.

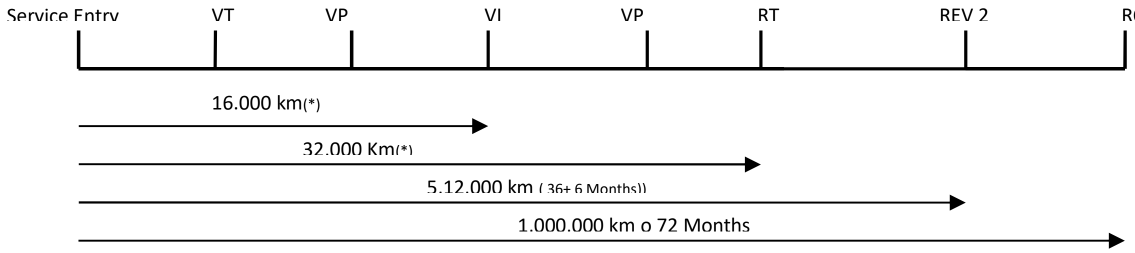


Figure 24 Operating cycle of maintenance interventions (Source: Maintenance Plan).

In the following table we can go through the deadlines with reference to the kms for E464 which is general for all the other trains.

Plant of Maintenance of Locomotive E 464			
Type	**Level**	**Deadline**	**Where the maintenance is carried out**
Kms Deadline	CO	20.000 km	Roma Smistamento
	E464 2CO	40.000 km	Roma Smistamento
	RT	80.000 km	Roma Smistamento
	160.000 km	160.000 km	Roma Smistamento
	Controlli Cretti	160.000 km	Roma Smistamento
	240.000 km	240.000 km	Roma Smistamento
	320.000 km	320,000 km	Roma Smistamento
	borosondo	320.000 km	Roma Smistamento
	480.000 km	480.000 km	Roma Smistamento
	640.000 km	640.000 km	Roma Smistamento
	CC	1.200.000 km	OMC
	RO	2.400.000 km	OMC
Time Deadline	6 Months	6 months	Roma Smistamento
	Manut Appsicu 6 months	6 months	Roma Smistamento
	12 months	12 months	Roma Smistamento
	Manut Appsicu 12 months	12 months	Roma Smistamento
	Before Summer	Once in year	Roma Smistamento
	Before Winter	Once in year	Roma Smistamento
	16 months	16 months	Roma Smistamento
	Pneumatic verification in Plant	16 months	Roma Smistamento
	24 months	24 months	Roma Smistamento
	Tank requalification	10 years	OMC
	Tank substitution	40 Years	OMC
	SC 60 Mesi E 464	60 Months	Roma Smistamento
	6 months E464	Present Program are not active	
	12 mesi E464		
	24 months E464 Trecciole		
	24 months E 464 Battery		

Table 5 Plan of maintenance of E464

The Current maintenance of 1st level, which is carried out in the IMC Roma Smistamento consists of a series of interventions that are carried out in the work on the rolling stock, such as liquid controls, air pressure, lubrication, repair and replacement of consumable materials. They are made, where possible, within the stops foreseen in the Timer Hodie in "Turno", called "Finestre Manutentive" (Maintenance windows), or in the course of stops which have be done forcefully and this time must be subtracted from the intervention time.

The various activities to be performed for each of them are foreseen in the maintenance plans, which in detail prescribe a whole series of checks. It is important to underline how each maintenance activity is carried out as it is marked by a letter: S-Sicurezza (Security), R-Regolarità (regularity), C-Comfort. It is to emphasize what the maintenance operation to be carried out whether on the safety of the exercise, on the regularity or on the comfort of those travelling on board the train. This would help us know which maintenance activities are improving the fleet in which terms ca be seen in Table 6.

TRAMA MANUTENTIVA 1° LIVELLO ELETTROMOTRICI TAF (Treno Alta Frequentazione)		Interventi di MC Programmata			Categoria
Codice	Descrizione lavori	VI	RT	Scadenze	
C.11.05	**Finestrino cabina di guida**				
06	Controllare integrità e regolarità funzionale. Agevolare lo scorrimento ed eventualmente riordinare dispositivio di bloccaggio.	■	■		S
C.12	**PORTE INTERNE E INTERCOMUNICANTI**				
C.12.01	**Porta ritirata HK**				
06	Prova funzionale della porta	■	■		R
28	Sostituzione filtro aria alimentazione impianto porta Blocco valvole di pilotaggio: revisione generale al banco			480	R
C.12.02	**Porte scorrevoli di testata**				
25	Verificare l'integrità ed eseguire le prove funzionali della porta nelle modalità di funzionamento normale, manuale ed esclusione dal servizio.			240	S
28	Prova funzionale generale. Pulizia e lubrificazione della piastra. Pulire il filtro posto sulla piastra porta apparecchiature. Controllo tenuta apparecchiature pneumatiche e tubazioni. Sostituzione dello spazzolino dell'anta. Controllare ed eventualmente sostituire l'elettrovalvola di isolamento. Verificare il buono stato dei cuscinetti			480	S
C.14	**PORTA SALITA PASSEGGERI**				
06	Prova apertura/chiusura porte salita passeggeri. Controllo integrità guarnizioni porta e della protezione del pulsante di apertura esterno. Verificare l'integrità della porta, delle guarnizioni (interna, esterna e paramano) e provare il funzionamento	■	■		S
10	Prova funzionamento bordo sensibile		■		
20	Prova funzionale della porta nelle modalità normale, manuale ed esclusione dal servizio Verifica funzionale chiavistello ed eseguire la pulizia e la lubrificazione. (Verificare, dopo aver tolto lo sportellino di protezione, che a porta bloccata il chiavistello, di entrambe le ante, entri perfettamente nelle apposite sedi di ritegno. Provvedere inoltre alla pulizia e lubrificazione con grasso specifico.) Verifica regolazione albero laterale con 2 supporti. Lubrificazione catena gruppo guida assiale. Lubrificazione leva comando blocco porta Pulizia filtro aria Controllo presenza e integrità dei tamponi di battuta.			120	S
22	Lubrificazione guida a sfere. Controllo stabilità ed integrità di serraggio delle viti a testa interna esagonale che bloccano la guida a sfera alla cassa. Qualora le viti siano lente procedere allo smontaggio, alla pulizia del foro filettato tramite maschiatura in modo da asportare definitivamente i residui del frena-filetti (loctite). Applicare il frena filetti nuovo (loctite) e stringere con sforzo adeguato.			120	S
25	Controllo tenuta apparecchiature pneumatiche e tubazioni.			240	S

Table 6 The 1st level maintenance plan of TAF.

4.5 Planning of the programmed maintenance in Roma Smistamento

The "Officina di Manutenzione Rotabili" (Rotatable maintenance workshop), does the following operations:

- Planned maintenance deadlines for the train;
- The distances travelled by the train;
- The average daily distance by type of train, derived from the turno carried out in operation;
- The data derived from the Rolling Stock Management System (RSMS)
- In touch with the Sala Operativa Regionale (Regional operative room) (SOR);

In short, the Time or No of Kms run can been seen in the Timerhodie and RSMS and when a train is near scheduled maintenance it automatically emits an alert that is ready for cyclic maintenance. With collaboration with the SOR the activity is planned. It can be simply depicted from the flow diagram below in Figure 25.

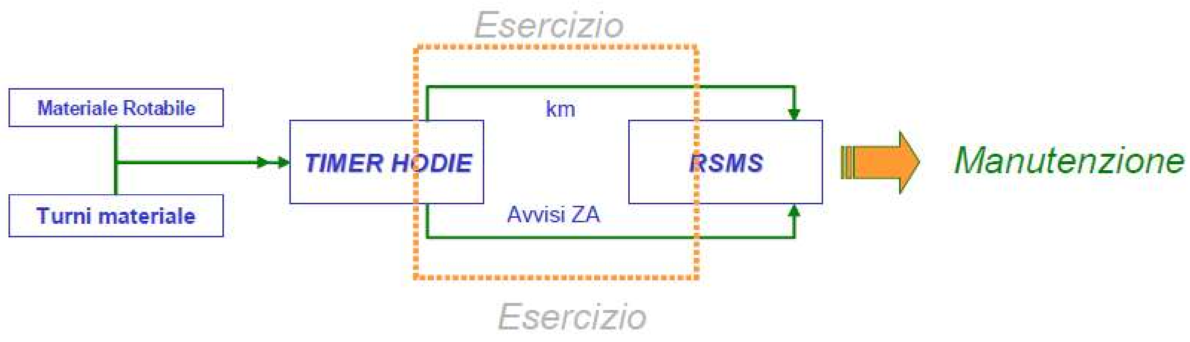


Figure 25 Data flow for communication deadlines or maintenance notices.

4.5.2 Maintenance of the Carriages or Coaches

Not only for the Locomotive E464 and Light Vehicles on the other part of the IMC the maintenance activities for the Passenger carriages are also carried out along with the Semipilota. It consists of mainly cleaning the rolling stock, maintain the interior and exterior neatness of the material performing commercial Service, cleaning activities and preparing to maintenance processing on a weekly basis and programmed interventions of ordinary disinfestation. There are workstations located for the under-carriage washing too like locomotives.

This cleaning activity is to ensure maximum comfort and the best conditions of hygiene, through the restoration and constant maintenance of a certain standard imposed by Trenitalia on the contractor, which include:

- Periodic interventions that take place cyclically, according to the shifts in use of the material;
- Occasional interventions due to operational requirements;
- Extraordinary and emergency interventions.

The periodic interventions are divided in 4 levels of “Pulizia Radicale” (Radical cleansing activity) (PR) and they are classified according to the depth level of the range to be carried out and according to the frequency with which these interventions are carried out on the materials as follows: -

- **PR 1:** It is the less thorough intervention, carried out in the station systems on board of the rolling stock in the intervals between the execution of two services of train. It is a brief targeted and systematic cleaning, removal of solid waste. They are programmed on every rolling stock is subject to interventions of PR1 several times in a day, in order to guarantee a good maintenance of the conditions of cleanliness and quality of the carriage.
- **PR 2:** It is the second intervention for the depth level of the work and is carried out daily in the station, but mostly at night during which train halts for several hours in the evening to the next morning. In this case we foresee the same operations contained in a PR1, with the addition of cleaning and washing of the floors of the carriages, with focus on vestibules.

- **PR 3:** It is basic intervention carried out in the platform of washing areas. It foresees a thorough cleaning of the interiors of the material, with the washing of the floors of vestibules, retreats and corridors with use of water, the systematic cleaning of windows, seats, armrests and headrest in the carriages, and washing of sides of the vehicles, including the pilot carriages. They are carried out weekly as they require more materials and time for maintenance.
- **PR 4:** It is the programmed cleaning operation carried out at a lower frequency, once a month, and is carried out on rolling stock, providing the same operations of PR3 carried out with a higher level of depth, to which are added interventions targeted cleaning on every surface of the interior (floors, walls, windows, top cover, seats, overhead...).

In addition to these programmed cleaning interventions, a series of specific interventions are added in order to perform on condition or characterised by much more extensive temporal deadlines like the activities for the removal of writings and graffiti made on the exterior of the carriages, for which particularly aggressive chemical products are used that require the use of special acid-resistant sheets for the collection of effluent, activities of periodic disinfestation of the interior of the carriages with which the antibacterial conditions of the vehicles are periodically restored, the interventions of radical disinfestation, carried out with a cadence of about 2 times a year, in which a thorough overhaul of the carriage is effected at the hygienic level, dismantling and reassembling all the components of the interior, the activities of water supplies and removing wastewater.

Chapter 5 Diagnostics and Tele Diagnostics

5.1 Introduction

The tele diagnosis system implemented in Trenitalia, which is active on E464 locomotives and on all Jazz trains that travel in the various regions of Italy, is the first significant step towards dynamic and predictive maintenance (Dynamic Maintenance Management System). It represents the crucial step towards an innovative type activity based mainly on predictive analysis and on conditions.

Indeed, during the future project phases, advanced ground-based diagnostic systems will be available with evolved functions to calculate the wear on components, predictive algorithms to identify any malfunction and optimisation instruments needed to carry out a service which increasingly meets the demands of commuters throughout Italy. The installation of the tele-diagnosis system is scheduled to be extended to the entire regional fleet.

The "Telediagnostica" system is to check the quality of train-rail interaction, which can connect to a central location to communicate in real time the indicators and alarms for exceeding certain levels, which can show problems on board the train itself or on the ground.

It is a case of system to support Predictive and Corrective Maintenance. The system was developed by Bombardier according to Trenitalia specifications in order to increase the availability of the E464 and E405 fleets. The Research Project was initiated from 2005 and in 2011 the implementation of them on locomotives came into existence. It is an intelligent system which has the task to control and manage the train tools. Tele diagnostics is a fleet diagnostic management system designed and manufactured to support corrective maintenance and predictive activities. The future installations of the Tele diagnostics are on Minuetto, TAF, which have been ready for implementation soon.

Main objectives

- The fleet can always be controlled from the Control Room. The Diagnostic technicians always check out the status of the fleet all time, to support the locomotive for critical sections when an alert occurs, whether the train must be stopped or can be used for the run. In short it can be seen in Figure 26.
- The actual point of the failure can be known, before the vehicle returns to the maintenance point, analyse how the vehicle had a failure from which components.
- The additional diagnostics of the vehicle help us in calculating the residual life of other components and these signals can be used for specific surveys of the vehicle.

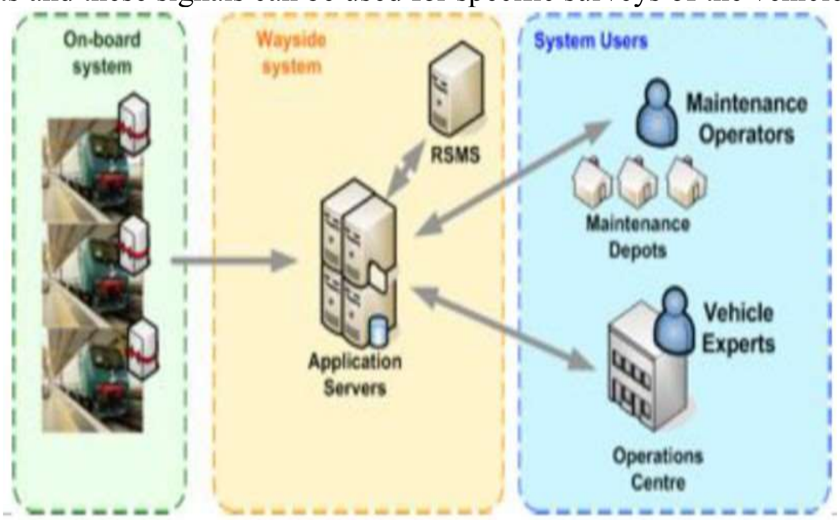


Figure 26 Working of Diagnostics

5.2 Basic Functioning Procedure

Bombarider built the **"**Mitrac TCMS**"** which monitors all the components where sensors are mounted to give live readings to the system which is saved for furthur use.It is platform designed as a distrubuted, modular, scalable solution which is a fully integrated solution which includes major necessary functions to design, implement, valiadate and maintan vehcile control systems for all type of trains. The major function for us here is to control and management of a train to fulfill its mission with efficent fleet opeartion with providing existing diagnsotics with high reliabilty and availabilty. It contniously emits all the sensors data to the cloud server. When a reading goes wrong due to the failure of the components or temeperature differences, the system automatically generates a "Avissi" stating a problem has occurred on the dashboard and automatically an alert (Mail and SMS) to the concerned authorities which can be seen in the software like Figure 27 if it's a major problem. The Train Driver can also look this on the SCMT. The Diaganostic technician would check out what caused the problem to occur from the Diagnostics software in "Eventi" checks out what is the problem in detail and downloads all the data of the train at the failure time before and after. The data can be downloaded data is stored in Area Allbus where this is stored for future reference or for much analysis for the the cause of the program. Depending on the type of failure the parameters required for it are taken and the cause for it is found out stating whether it was a temporary problem or requires a change of the component . Depending on the severity, if is a small one the train is run for its full course and later called back for maintenace, a critical one the train is called back into the depot as early as possible. By selecting the Lazio all the trains can be seem at once or else for total vehicles in the list.

Figure 27 Train having problem shown in Display in software

This error would be entered in the TV31 Elenco Table a module in Mose and updated, which by the time the locomotive enters for maintenace , the regarding technicians know which parts have to be maintained, as depending upon from the type of failure from the downloaded values from the software which have been analyzed already which would save time by reparing or chaging the components which are needed for maintenace making the train fit for run in a very short time.

Rule Definition Process (Diagnostic Algorithms): Rules (based on knowledge of vehicle design) correlate diagnostic information in order to detect defects and/or degradation of vehicle components. The rules are verified and validated based on the return from the field and then put into operation. Tele diagnostics allows to translate the maintenance experience into diagnostic algorithms. The given output values are classified into certain parameters predefined like 0,1 or certain values with each having a respect command. They would be checked and would be used for the analysis of the failure. Not only this the life and health are monitored from here of each component.

Example: If we take compressor as an example some of rules set for it are

- When the pneumatic value of the compressor reaches 2.5 bar it gives an alert and allows the control of the pressure switch by autorotation.

- The reaching of this value of 2.5 bar whether reached within 5 seconds or more is controlled by the Logica di Veicolo and the pressure control switch. If there is any change here, we could see it in the tele diagnostics as an alert.
- When the oil reaches the critical temperature 110±5º C it shuts down the compressor by giving an alert.
- A sensor in the filter area of air when it is blocked giving an alert.
- In the main Gruppo Viti which is considered as the heart of the compressor is a sensor which determines the increase in the pneumatic ducts and air reservoirs.

5.3 Impact and Benefits of Tele diagnostics

The benefits of the Tele diagnostics are

1. When in Exercise: Operating rooms have a tool that makes the clear real-time vehicle status, decreasing the probability of stopping it when a problem occurs, help in analysing data online when stoppage and increase availability.
2. In Maintenance: This system improves corrective maintenance and allows predictive maintenance based on detection of Condition Based Maintenance (CBM) through data. The system tends to save the time of the logistics for repair by issuing an automatic report of the fault in Tele diagnostics System, as by the time the vehicle enters the spare part is made ready and equipped and put into use as early as possible.
3. In Engineering: The vehicle engineering and maintenance features a series of tools that allow you to perform operations (extension of the diagnostics of edge, monitoring of process variables) that in the past needed months and costly interventions on vehicles by checking all the parts manually.
4. Economically: For Trenitalia, thanks to the impacts in terms of reduction of maintenance time and costs and the increase in availability of vehicles for service profitability from these more services.
5. Social: The fleet E464 with more than 700 locomotives in operation serves regional traffic throughout the Italian territory and consequently the increased availability of vehicles can improve the national mobility service.

Impacts of tele diagnostics:

- Issuing of management and operational procedures, maintenance procedures, guidelines and operative methodologies
- Inspection Planning and procedures to monitor safety parameters
- Test activities and reporting for systems and vehicles
- Technical specifications, terms of contract, evaluation framework editing
- Design compliance check activity
- Cost benefit evaluation, to be applied when purchasing new rail vehicles or revamping existing vehicles
- Risk evaluation and risk management

5.4 Sensors

The most effective enabler for the system would be monitoring of critical components that have been identified as major causes for derailments and delays, and for causing deterioration in rail infrastructure. The sensors installed on board on the components of will time to time let us know the defects based on the Condition Based Maintenance (CBM) for timely detection of defects with the aim to enhance the safety and security of the locomotive. The information system will be constantly updating the health of the locomotive from oscillatory behaviour, its diagnostics and heating, ventilation and air conditioning and many other components.

The on-board sensors constantly record vibrations and temperatures. Anomalies in vibration are the earliest indicator that something may be wrong for example with the bearings in the wheels of a locomotive. This allows for operators to mark those bearings out for careful observation, thus preventing any further damage. Detection of bearing fault at this early stage will help prevent incidents and maintenance schedules can be planned accordingly. We can also call them the Smart Locomotives with the wireless sensor modes that, once fitted on every component, help monitor the health of the wheel and its bearings.

"Once deployed in volume, these sensors would also be able to monitor track health on a real-time basis, resulting in improved safety, higher utilisation and reduced operation costs by enabling predictive maintenance and reduction in sudden catastrophic failures of the Railway's assets." So, the diagnostics which is carried out on the train is with the help of sensors which work continuously emitting data which can be assessed from the system. They are Battery, Compressor, Pantograph, Bearings of Brakes, Distributor of Brakes, Electric cabins, Driving Cabin, Wheel Frame, Voltage frames, Imperial, Semipilota etc. which can be seen in Figure 28.

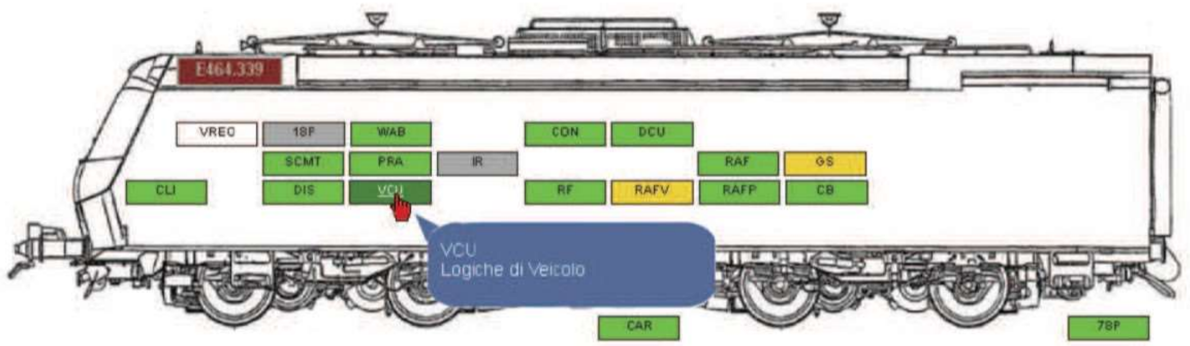


Figure 28 Sensor Functioning Visibility in Teledianostica Software

The live functioning of any components can be seen from like this in the software, where green means it the sensors are all functioning good, yellow means there the sensor is not functioning well, red means there is a failure in the component.

Chapter 6 Dynamic Maintenance Management System (DMMS)

6.1 Introduction to DMMS

Trenitalia devised a new form of maintenance with Big data and IOT becomes which is a crucial step in digital transformation which is the real-time monitoring of locomotives and carriages which highlights the components at risk of failure preventing service disruption m which is estimated to reduce the maintenance costs by 8-10%. It's an advance form of the platform Tele diagnostics.

A project was initiated in 2014, to develop a model of dynamic and predictive maintenance, based on the technologies of Internet of Things and Big Data Analytics of SAP. The Concept was simple; intervene on the components of locomotive and carriages and when the data collected, from the sensors (from 500 to 1000 per train) and properly analysed, anticipate when a problem is going to occur. A revolutionary method compared to the classic model based on interventions at fixed deadlines for number of kilometres or years of service. In summary, the data collected and transmitted by sensors placed on the prices of higher maintenance costs (engines, batteries, brake systems, etc.) are processed in real time with the SAP application Predictive Maintenance and Service, based on SAP Hana platform, through special algorithms, developed with SAP and two Italian universities, the "Politecnico di Milano" Scuola Superiore Sant'Anna of Pisa".

This system, called DMMS (Digital Maintenance Management System), allows real-time monitoring of the status of vehicles remotely, but also has predictive capabilities. When the threshold values for certain behaviour parameters are exceeded, threshold values indicate an imminent failure, DMMS can trigger interventions before the failure causes stops and disservices with the main goal is to reduce the cost of maintenance and service and provide the best availability and levels of service for passengers.

The interconnection between real objects that communicate with each other, access information or transmit data through connectivity, software and sensors which allows the dynamic processing of big data thanks to the numerous sensors present on the new trains. The anomaly or the end of the life cycle of a component are reported in advance, completely transforming the way to manage maintenance, making it from reactive to predictive. The last-generation distance-to-end diagnostics system, applied in the initial phase to high-speed trains, has also been extended to the regional Jazz trains, in order to reduce failures and breakdowns during service and to reduce maintenance costs, for the benefit of the millions of commuters who choose the train every day for their journeys. Among the significant awards resulted in a strong reduction in the cancellations of regional races for technical problems. In the first half of 2016 cancellations affected the 1% of the programmed course, and only 0.4 %[3] for reasons attributable to Trenitalia. The index has more than halved within two years.

The diagnostic system experimented and implemented, active on the E464 and all the Jazz that travels in different Italian regions, is the first meaning step in the direction of a Dynamic Maintenance Management Systems (DMMS). It constitutes, in fact, the crucial passage towards an activity of after innovative based mainly on predictive analyses and on condition. In fact, in the subsequent phases of the project will be available advanced diagnostic systems of earth, functions, evolved for the calculation of the wear of the components, Predictive algorithms to identify any malfunctions and planning optimization tools necessary to perform a service that responds increasingly to the demands of commuters throughout Italy.

[3] Trenitalia, la manutenzione con Big Data e Iot diventa predittiva. (Un passo cruciale della trasformazione digitale)

6.2 General Overview of the DMMS

The main aim of the DMMS is to estimate the life span or health of the components. Various parameters from previous data for each component are monitored continuously. It uses some of the elements of the use of advanced diagnostic techniques and Telediagnostica.

Objectives: The main objectives of the project DMMS is the reduction of the costs of maintenance, increasing the affordability and the available of the rolling stock, with five direct principles

1. Improvement of the monitoring of the state of fleet.
2. Identifying and improving the management of failures and process maintenance.
3. Reducing the failures by utilizing predictive maintenance.
4. Overcoming the deadline of time and kilometres, with structural modification of the Implementation Plans.
5. Efficient management of the materials of the Rolling Stock, installations, removing of the parts, taking in the results of the previous points.

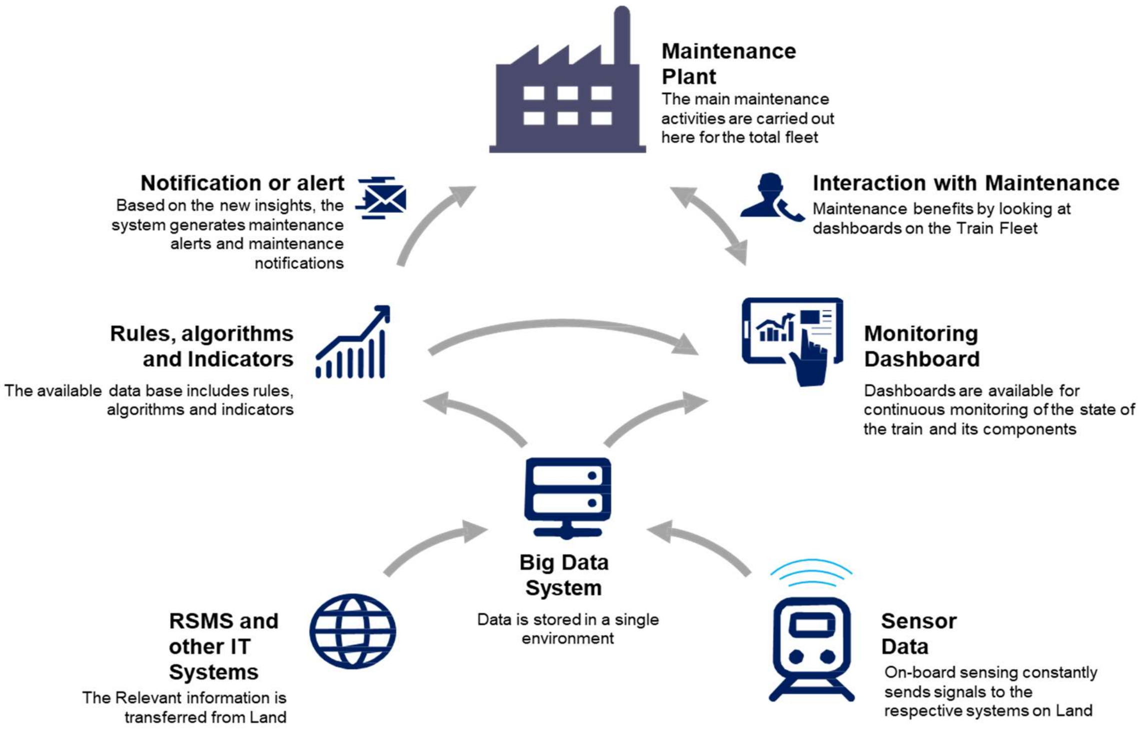


Figure 29 DMMS Functioning

The main actions and results going in this system continuously are as seen from Figure 29 are

- **Big Data Infrastructure -** Managing all the points of interest information in the Big Data infrastructure.
- **Monitoring the State of Fleet -** In real time monitoring the state of Rolling Stock through dashboards.
- **Managing the Rules and Actions -** Generation of actions (by sending an SMS, Email by creating maintenance alerts) that follow the fulfilment of the rules defined here.
- **Algorithms, Indicators and Rules-** Modelling and implementing the Algorithms, Indicators and Rule, relative to one subset of points of interest.

- **Maintenance of Components:** As of now the components the maintenance of the components is not in full scale but is monitored on the components of Battery, Compressor, Pantograph, Bearings of Continuous Breaks, Distributor of Brakes.

Present Scenario in Roma Smistamento

This program would be in future installed on the entire regional fleet. As of now this is implemented on E464 in the Roma Smistamento and other depot locomotives on the following components

1. Battery
2. Compressor
3. Pantograph
4. Bearings of Continuous Breaks
5. Distributor of Brakes

Where it is being planned to implement on the other Rolling Stock like TAF and JAZZ as early as this surely is a better way which can be used for the maintenance of Railways making the best example for Digitalization of Railway Maintenance.

Chapter 7 PdP - IMC

7.1 Introduction

As stated in the Introduction chapter the PdP-IMC suite the Piattaforma di Produzione Trenitalia (Production Platform Trenitalia) with short name PdP aims to the planning, programming and operational management of trains and the resources needed for them in the depot with the main objectives of the software being

- Programming and managing depot operations for blocked convoys and ordinary trains using standard models of operating cycles;
- Manage system operations for "non-approved" material;
- Manage and controls associated with ordinary maintenance services of interest for the train material;
- View the details of compositions and the main information from the RSMS system;
- View maintenance alerts and maintenance deadlines associated with rolling stock;
- Use the master instance that is fed by: RSMS for the information, technical, composition of the blocked material (Light Coach, etc.)
- TIMER for unlocked material composition information.

The main features of the PDF IMC Program are

- Program and manage the operations in the depot for blocked coaches and ordinary material using standard models of the operating cycles;
- Manage depot operations for ' non-approved ' material;
- Manage and control counters associated with ordinary maintenance services of interest for the decoration of the material;
- View the details of the compositions and the main data from the RSMS system;
- Display maintenance alerts and deadlines associated with rolling stock;
- Use the RSMS for information, technical, composition of the blocked trains (light convoys, etc.)
- TIMER for material composition information not locked for exit and entry.

7.2 Procedure in PdF/IMC

In the earlier days when a regular maintenance has to be planned the from the Timer the free time of the train form the shifts is taken noted down , intimating the concerned department the arrival time of the train , the type of maintenance it needs from the RSMS depending on Kms or Time , the short time for maintenance has to be planned for the total activities and the exit of the train with the manoeuvre team. For a simple plan like this too would take at least one hour informing all the concerned persons about this. From the time of entry of the plant , the area which has to be parked depending on the type of maintenance, the service materials needed for it , the additional maintenance activities it would be needing, the service number it has to be assigned , the number of coaches needed, the position of the train to be with locomotive in rear or front , the time for the activities or scheduling them till the exit of the train from the plant. In simple words the maintenance activities of all locomotives can be controlled from the software reducing time and effort and, limiting the errors made by humans. The time and allotment of the activities for a convoy of train in general which needs to be updated generally to the concerned authorities of the progress made and its availability time continuously which can be seen in Figure 30.

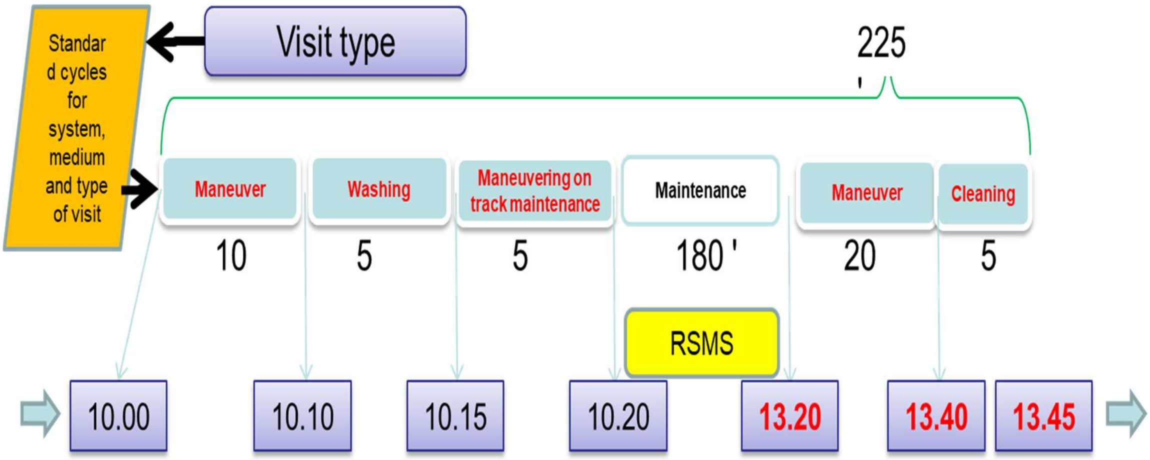


Figure 30 Example of General Maintenance Schedule Time

But with the PdP/IMC program implementation from timer it takes in the time free for maintenance , from RSMS the type of maintenance it would be needing and it would automatically plan the time needed for all this type of activities along with the entry exit of the a train, and the service materials associated along with the area it has to be parked for maintenance not needing time more than five minutes which if the future of planning maintenance in the depot. It can be updated automatically by the application GEMMA from which the status can be updated time to time in the application linking to other services reducing time for calls an informing authority as seen in Figure 31.

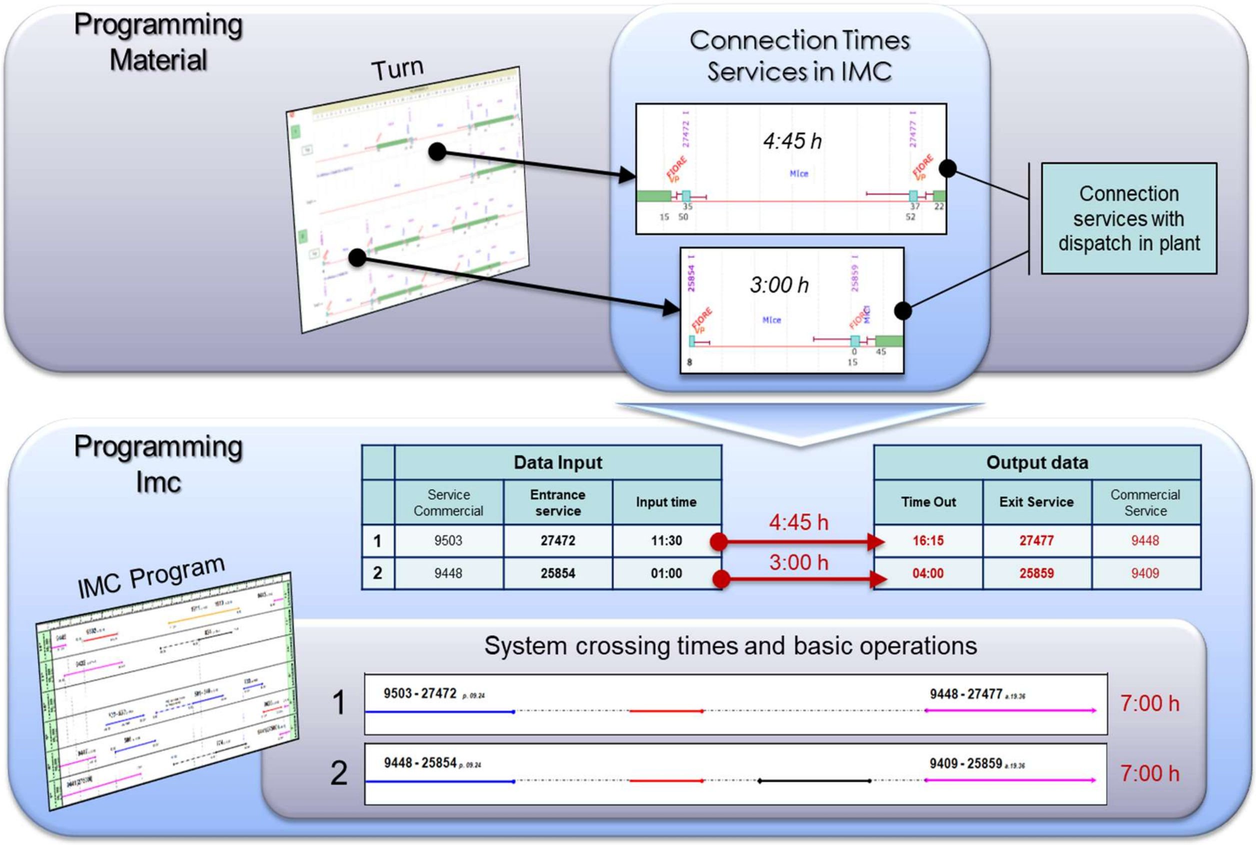


Figure 31 Interlinking operations in IMC

With Pdp/IMC when these services all can be managed at once leading to saving time of not using multiple software's at once to enter information. One person can handle all this task with reducing the chance of human errors and when data is entered simultaneously from other programs. It reduces the manpower required for various operating systems. This information once updated in one point will function in collaboration and updating the other software's systems parallelly with each click carried out in the system.

Chapter 8 Case Study: Evaluation of EMU Passenger Door System Failures by FMECA Analysis

EMU is the High frequent train which daily connects the regional services in Lazio. The Lazio region has 44 trains per day making more than 300 trips a day in the regional region serving operations in most of the Lazio Regional lines. The people board them planning to go to school, offices or for some regular works or leisure travel or we may be having visitors to visit the around places around the City. Imagine this type of daily service being cancelled due to unavailability or a problem on the train. The trouble it would be resulting in the passengers at that time, resulting to arrange them a temporary mode of transport or making them to wait for the next service. EMU is the mostly monitored train in the depot as they don't have extra trains in reserve when a train has a breakdown or a failure. So, this train was taken for our analysis.

In this case study we would first see the total data and what are the major causes of failures in EMU for a timespan of six months. We can see here the main types of failures which have occurred and the countermeasures for them together in the Riserva Accudienze file where these data would be saved. A failure and the counter measure over here would be written which can be seen in Figure 32:

INFORMAZIONI IN ENTRATA PER IL CICLO LAVORATIVO						INFORMAZIONI IN USCITA DAL CICLO LAVORATIVO													CONCLUSIONI TAVOLI TECNICI
TRENO	DATA EVENTO	GRUPPO	MATERIALE ROTABILE	CAMPO EFFETTO DA TV 31 (1 - 8)	INFORMAZIONI DA TV 31	RISCONTRI IN IMPIANTO	APPARATO COINVOLTO	SINGOLO COMPONENTE INTERESSATO O COINVOLTO	CATEGORIA	AZIONI DI RECUPERO	COMPONENTE SOSTITUITO SI	NO	COMPONENTE PRESENTE IN MAGAZZINO SI	NO	COMPONENTE CANNIBALIZZATO SI	(prelevato da)	EMESSA NON CONFORMITA' SI	NO	RESPONSABILITA'
7421	02-07-18	TAF	ALe426054	Richiesta di riserva	malfunzionamento UR,UR4,UR3. reset negativi	RISCONTRATO CONNETTORE UR7 PARZIALMENTE SFILATO. DOPO IL RIORDINO OK	LDV	centralina	944787	Serrato connettore		X							Tecniche DP
7413	02-07-18	TAF	ALe506033	Richiesta di riserva	mancata chiusura porte di tutto il convoglio.	eseguite prove in deposito non si riscontrano anomalie. eseguito scarico dati	LDV	NULLA RISCONTRATO		NESSUNA		X							Tecniche DP
22059	03-07-18	TAF	ALe426001	Richiesta di riserva	PERDITA AZIONAMENTO EFFETTUATO TRASBORDO	DA SCARICO DATI SI EVIDENZIA SOLO UN AVARIA DI MASSIMA CORRENTE FASE R RICONDUCIBILE ALLA MANCATA TENSIONE DI INEA	AZIONAMENTI	Modulo principale	943982	NESSUNA		X							Tecniche DP
22073	03-07-18	TAF	ALe426033	Richiesta di riserva	QAT RIMASTO APERTO PROVOCAVA AVARIA GRUPPO STATICO E AZIONAMENTO CON NUMEROSE APERTURE IN	controllati sezionatori. riscontrato sezionatore 1QAT in falsa posizione. materiale non presente in magazzino	IR	IR guasto	944701										Tecniche DP
21791	03-07-18	TAF	ALe426055	Richiesta di riserva	AZIONAMENTO AUTOESCLUSO PER AVARIA GRUPPO STATICO	RISCONTRATI 2 RELE' CORAZZATI BRUCIATI	GRUPPI STATICI	RELE' CORAZZATI	544351	Sostituiti relè MT	X								Tecniche DP
21928	03-07-18	TAF	ALe506026	Richiesta di riserva	mancata abilitazione per batterie basse	VERIFICATA INCONGRUENZA LDV, RISCONTRATE BATTERIE SCARICHE	BATTERIE	BATTERIE BASSE	544302										Tecniche DP
24039	03-07-18	TAF	ALe506036	Richiesta di riserva	le porte non si aprono le portedalla cab M con blocco efficenteeffettuate tutte le prove con esito n	TROVATA SCATOLA DI DERIVAZIONE 1ASSE CON INFILTRAZIONE D'ACQUA E OSSIDO. SOSTITUITA SCATOLA E CONTROLLATO CABLAGGIO CAVI	Scatola di derivazione Antipattinante/Locopar	Scatola di derivazione	982081	Sostituita	X								Tecniche DP
22025	03-07-18	TAF	ALe506048	Acc. con ritardo	mancata configurazione, guasto a bordo. dopo reset regolare	IN IMPIANTO SI RISCONTRAVANO LE VENTOLE DI RAFFREDDAMENTO INTERVENUTE PER TEMPERATURA ECCESSIVA. NON SOSTITUITE PER MANCANZA SCORTA	SCMT\STB	VENTOLE ARMADIO ALA	385014										Tecniche DP
24052	04-07-18	TAF	ALe426050	Acc. con ritardo	contattore 2K02 in avaria.	SOSTITUITI RELE' 3K11 E 3K13 MH	IMPIANTO ELETTRICO	CONT.2K02 MEDIA TENSIONE	544351										Tecniche DP

Figure 32 Riserva Accudienze Sheet

Next in this period a list is made for the most type of failure activities is taken where they were total 265 failure maintenance activities in total that occurred in span of six months which equals to 1.44 failure everyday which is a not good number to the company. Every failure is an important thing as it must be properly analysed stating why the failure has occurred, from which component and how it can be prevented in the next time of usage. As of whole the total number of accidents that took place for the whole time can be seen below in the Figure 33:

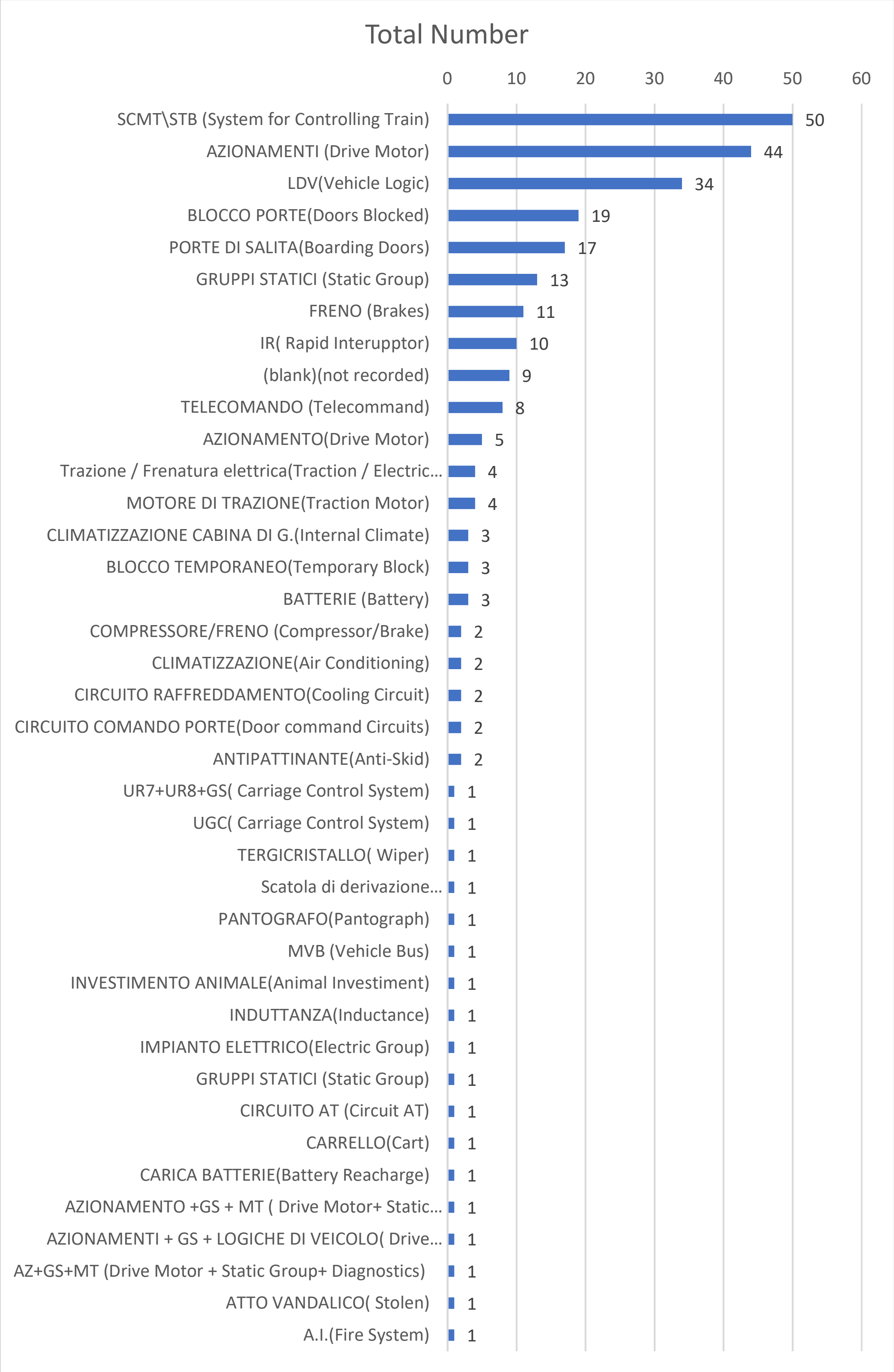


Figure 33 Total Failures Graph for EMU for the period of six months

The list is taken from TV 31 a module in the software Mose which shows the registered total failures. This are known by the diagnostics carried out on the EMU or from the "Libro di Bordo" (Book on board in Train) where the Train driver writes the down the problems. This list doesn't include the regular maintenance activities carried on the convoy. And finally, they are updated here.

When the maintenance activities of all the components were elaborated with respect to each of them were the first three that stood up were "Azionamenti" (Drive Motor) were 52, SCMT were 50 and for Porte was 38. For doors this factor is a high one as in the span of 6 months a failure here occurred for every 5 days.

I was more interested to work in doors as this are the mostly used components in the train for the boarding and deboarding of passengers takes place, where if malfunction here would be a great discomfort to the passengers. If it is a major one the service is cancelled or if a minor one, where the door would be blocked for opening and closing in operation manually. The main causes of failures would be as passengers stand in between when closing at the time of boarding or deboarding so that other passengers too can get in or out. This effect the closing of the door, affecting the linear guide rails inside them or the referral chain. This type of damages can't be seen immediately but can be seen in the long run. This would cause "Blocco Porte" (Door Blocked) which everyone using the service can face it. This delay makes the train halt at the stations and increasing the delay time of the service.

First lets us look at the functioning of them and the inbuilt security and advance features.

8.1 Basic Functioning of Doors

The basic functioning of the EMU door works on the principle of Plug doors which are like external sliding doors they retract along the exterior of the train which works on the pneumatic principle. However, as the edge of the doors meet at the mid-point, they move into the threshold closing off the edge of the door flush with the exterior of the carriage, effectively 'plugging' the door aperture with the advantage of the sliding door that is hung externally to the train and simply closes in the same plane. Doors that slide across the exterior of the train and seal themselves into the door aperture which works in less than 6 seconds for the total opening and closing. Coming to the disadvantages it is more complex mechanically, with issues in on cost and maintenance.

In general, in the first and last compartment and the middle two compartments where the motor is there the dimensions change for the ports. They are equipped with four external passenger ascent doors, two in two different sizes; for both with the basic function of the door is to allow the entrance and exit of the passengers, ensuring an adequate separation of the internal compartment from the external environment in the condition of know. The door system is electrically regulated by the UGC carriage management unit, while its pneumatic system is powered by that of the vehicle with its own tank (one for each vehicle).

On the motor carriages the passage of each door is 1200 mm while on the centre carriages is 1800 mm. Opening and closing times are approx. 3 seconds, with a drag force on the doors of less than 15 kg. At speeds of less than 5 km/h the door that during closing encounters an obstacle reopens. Under normal operating conditions, the door is operated by the passengers from inside and outside through two buttons on a leaf. A command for closing door and all the unattended doors of a side is at the Guiding Cabin. The door system meets the requirement for "intrinsic safety", i.e. a fault or a and/or pneumatic malfunction has because of closing the door, if it is open, and its locking automatically and displaying an error symbol.

8.1.1 Movement of Doors

The motion of the slide doors is made possible by linear ball guides and transmitted and synchronized by a referral chain. The ejection motion involves, in addition to the doors, the upper mobile plate with the control cylinder and all the suspension system of the door. In this way, despite the ejection of the doors, the cylinder exerts the strength with constant movement. In the Figure 34 we can see how the door looks when it is closed an open.

Figure 34 Door leaf's when closed and open

8.2 Safety Criteria

To meet the safety requirements laid down, the following solutions have been adopted in the doors. The system is equipped with two mechanical locking blocks, one active upper by a spring and unlocked by air pressure supply, the other lower with opposite operating modes.

All the solenoid valves in the pneumatic circuit cause, in the case of electric disalimentation and locking of the door. At speeds exceeding 5 km/h the carriage management unit cuts the power supply to the solenoid valves. This prevents the partial reopening of the door on the drive of the emergency handle to the train, avoiding hazardous situations and when exceeding the vehicle's limit gauge. In additional to this in the pneumatic circuit there is a pressure switch detector which marks the lower pressure in the circuit below 4 bar.

At the time of failure, the door can be opened and closed by keeping a special key at the key slot provided side of the door from inside the train, and from outside at the below of the door area or to the side and pushing the door side with a little effort.

It is also important to evaluate the behaviour of the door system in case of power supply; the following is what is expected in the absence of electric or pneumatic power supply:

- No power supply with closed door - The door is closed and blocked.
- No power supply with open door closes and blocks it. In the event of an obstacle between the doors, there is no sensitive edge. The effort on the obstacle will still be limited by the presence of pressure reducer.
- No pneumatic supply with closed door - The door is closed.
- Absence of pneumatic power and door open - The door remains open and can only be used manually.

An acoustic warning signal is installed on the carrier plate that emits a signal when the door is about to close. Also, two red light scripts inside, one in front of each door from inside and outside indicated when the door is about to close. We can understand that, in all the situations listed, the emergency handle does not lose the its own functionality. After the occurrence of the above situations, the maintenance operations of the door concerned is performed.

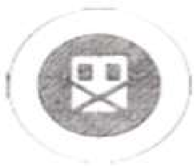
8.2.1 Diagnostics and reports

The control and function of the door diagnostics which is carried out by the carriage management unit UGC with 11 inputs from the electrical circuit of the door and 5 outputs towards it. It can highlight the following states and malfunctions by processing the return signals by the system ports where Port functioning state is monitored by the flowing factors

- Closed door,
- Locked door,
- Isolated door,
- Emergency door or open command from outside,
- Open door,
- Pneumatically not powered door with the malfunctions being monitored as Microswitch contact failures,
- Interruption of coil valves,
- Failure connection system of the doors.

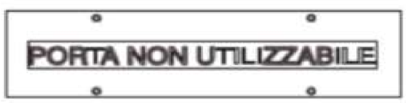
In case of failure to a door, or for any reason of service, the train staff can exclude the same from any use by acting on a command by square key manually. This causes the port to be electrically excluded from any manoeuvre while the air pressures in the pneumatic circuit, which works in the maintenance of the door to be closed and locked. An insulated and locked door is signalled by a red light inside the vehicle, also visible to its exterior.

Door Status Signals which can be seen in the Figure 35



"Key and Blocked door" (colour green when you have access)

Visible signal from outside, indicator when closing in all the doors



This signal "Door out of service" (red colour when on and flashing)

Figure 35 Door Indicators

8.3 CCU

CCU which stands for "Unità di Controllo Centrale" (Central Control Unit) is a software device which works on the collection of all the train data to know the functioning of the train vehicle and if there any failures. The CCU essentially consists of electronic boards for data acquisition, data processing and piloting of apparatus under the control of the Central Unit for the treatment of normal state, alarm and diagnostic codes. These tabs are intern connected by CGS, TCU, MD, MS and CCU redundant in stand-by state, are connected to CCU using the MVB Vehicle Bus as shown in figure 36. The CCU mainly consists of 2 STA microprocessors names STA 01 and STA 02. The STA 02 receives the data from the MVB and does the software functions of diagnostics and dispatching. The STA 01 hosts the "Logico Di Veicolo" works with Dual Port Ram and Dispatcher. If the signals are not registered for one component of them then it indicates the failure of the sensor which would be replaced by the net run.

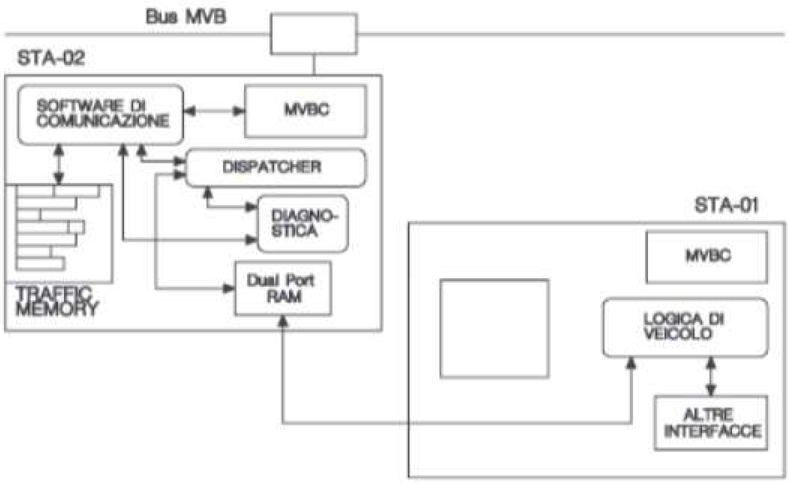


Figure 36 Design of the Software

It works principally on Drive Motor, Static Group, Carriages where it monitors and diagnoses this data. In short, we can see it functioning below in figure 37:

Figure 37 CCU Software Chart

8.3.1 Signal Analysis

The signals which are transmitted are stored in the CCU which are later downloaded for analysis. The emitted signals for doors are for all the ports are Emergency Door, Failure of Door, Door open unduly.

CODICE	4101
DESCRIZIONE	Porta salita 1 in emergenza
Verificare localmente lo stato della porta e provvedere a riarmarla	
CODICE	4123
DESCRIZIONE	Porta 1 indebitamente aperta
GUIDA OPERATORE	Provvedere a controllare localmente lo stato della porta. In caso di necessita' provvedere al suo isolamento

Table 7 Values of Failures wrt Door

The failures of them can be analysed by many like RCA, FMECA analysis which here we will be working in the FMECA analysis and getting to know about it below:

8.4 FMECA Analysis

It means Failure modes, effects and criticality analysis which a method used to identify all the potential modes in the system, and the effects of them and how these failures can be avoided which was the first type of failure analysis. Initially it was called FMEA (failure modes and effect analysis) where criticality was later introduces where both mean the same type of analysis. The analysis which we would be making is the process FMECA where problems in the maintenance are taken into consideration and a bottom up approach where all the components are considered which is also called as hardware approach. Let's carry out the process in the following steps:

Step One: Selecting a component for study

The EMU mainly consists of car body and the bogie parts. The main risk analysis study for the components is the "Door Unit" where the train doors are opened and closed at each station which allow the passengers to allow to enter or leave the coach.

Step Two: Collecting the component function information

For the analysis it is always required to have a good analysis of the components of all the parts, where the functioning and the characteristics of the components have been read before the analysis. This can be shown in the "Reliability Block Diagram" (RBD). It is a diagrammatic method showing all the components reliability contributing to the success or failure of the system, where each component has its own probability of failure. For doors, how the information is collected and stored, it's functioning we have already read them above. The blocks are given out in a structure, where the whole structure fails if any one of the components fails. For door unit the RBD can be seen below:

Figure 38 Door Functioning Flow Chart

Step Three: Determining the main potential failure modes to the component from past failures

The main type of failures modes is identified from past failures and inspection records. Where the main type of failures in doors are due to

Decreased air pressure that can lead to a velocity loss which is detectable by the door opening /closing time measurement deviation. It could be detected using two sensors where one indicates the door fully open and the other that the door is fully closed,

- Drive roller wear, swivel bearing wear,
- Spring wear,
- Sliding door track worn,
- Sensor malfunction,
- Door open /close buttons wear (passenger exposed component in constant use),
- Door panels misalignment i.e. caused by loose door arm roller guide assembly
- Door closing or opening too fast/slow

Step Four: Identify the root causes of analysis from various fields

After all the main failure modes have been identified, the analysis is carried out by Root Cause Analysis (RCA) where it identifies the root causes of failure and Fault Tree Analysis (FTA) which is a deductive failure analysis method where all factors and events that lead to failure are analysed.

Step Five: Assign a rating for each failure mode

The failure data is analysed using statistical techniques like regression models, data mining to create models for the estimation of models. The likelihood of occurrence of failure is estimated from the previous data. It is given by the following formula

$$\lambda i = \frac{Total\ No\ of\ Failures\ resulting\ form\ i\ installation\ time}{Duration\ of\ time\ in\ opearation}$$

Equation 1 Likelihood of occurrence in failure

On the rating obtained it is assigned to a on a 10-point scale where 1 represents "remote" and 10 indicates "almost certain".

Step Six: Assign a severity rating to each failure mode

Each of the failure has its own different modes on train safety, transport operations and environment which can be linked to Economic costs, Passengers dissatisfaction, Safety impacts and environmental impacts. Here too we would be evaluating with the scale from 1 to 10 where 1 represents "no effect" and 10 indicates "dangerous without warning" shown in Table 8.

Rate	Likelihood	Criteria	Failure rate (/year)
1	Remote	Failure is unlikely to occur	1 in 1500,000
2	Very low	Very few failures occur	1 in 150,000
3	Low	Few failures occur	1 in 15,000
4	Moderate	Failures occur occasionally	1 in 2000
5			1 in 400
6			1 in 80
7	High	Failures occur frequently	1 in 20
8			1 in 8
9	Very High	Failures occur persistently	1 in 3
10			1 in 2

Table 8 Likelihood failure ratings of Rolling Stock

Step Seven: Evaluate the failure levels and prioritise them in descending order

The criticality is given by the risk factor(R) calculated by multiplying likelihood rating(O) and the impact rating(S) given by

$$R = O * S$$

Equation 2 Risk factor

Since the rating and occurrence have values between 1 to 10, the risk factor has the values in between 1 to 100. The factors obtained are prioritized in descending order where the most critical ones would be the most frequent leading to more losses.

Step Eight: Categorizing the failure modes into five types of cruciality

The failure modes can be classified into very low, low, medium, high and very high critical. They can be shown in the picture below which can be interpreted very easily shown in Table 9.

	Criticality level	Risk Factor (R)	Recommendation
	Very low	$1 \leq R \leq 4$	Almost unnecessary to take the improvement actions
	Low	$5 \leq R \leq 9$	Minor priority to take the improvement actions
	Medium	$10 \leq R \leq 25$	Moderate priority to take the improvement actions
	High	$26 \leq R \leq 49$	High priority to take the improvement actions
	Very high	$50 \leq R \leq 100$	Absolute necessary to take the improvement actions.

Table 9 Five classes of failure and its recommendations

Step Nine: Potential Measure to prevent Occurrences

In order to enhance the reliability of the system, the improvement methods can be suggested depending on medium, high and very high critical failure components. Where the general protective measures can be to increase the reliability of the components, to calculate the mean time between failures, planning the maintenance activities, sensor technology to monitor these technologies, minimising the repair times.

The whole process in short can be shown below in the figure 39: -

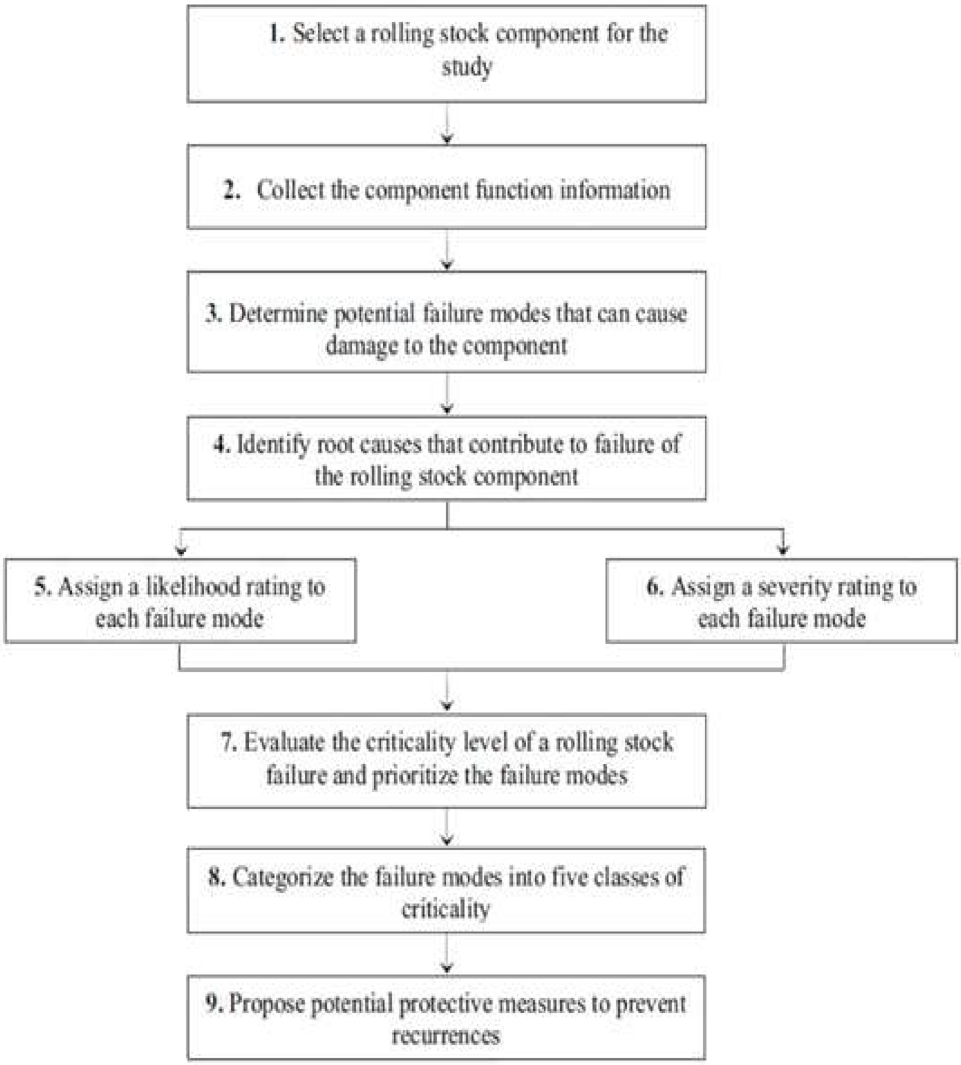


Figure 39 Risk evolution Methodology

Now going into the analysis of them in detail:

Let's get to understand the total 38 failures which have occurred in the short span of 6 months. Of all the problem there where 6 were in the motor carriages where the passenger movement would be less in the starting and end, the rest 32 were in the centre two carriages where there would be a high moment of passengers.

Let us study the total accident data for the span of six months which was 265 in which the door reported failures accounted to 38 which is 6.97% of the total failures. First let us calculate the total number of failures per train where the total number of trains are 44.

$$MNF = \frac{Total\ no\ of\ Train\ failures}{Total\ No\ of\ Trains} = 0.86.$$

Equation 3 Mean number of Failures

The mean failure between failures is given by

$$MMBF = \frac{Total\ Length\ of\ kms\ run\ by\ trains\ in\ operation}{No\ of\ Trains}$$ [4] =19404.22 km

Equation 4 Mean Mileage Between Failures

Depending on the severity of the condition of the cause they can again be classified in when the train has a problem whether it has been called back to depot early or with delay. The emergency failures are called back to the plant without much delay. For the Doors this can be seen below where we had 33 normal failures, 4 emergency repairs along with the cancellation of the service and 1 no signal one meaning no proper info which can be seen in the Figure 39.

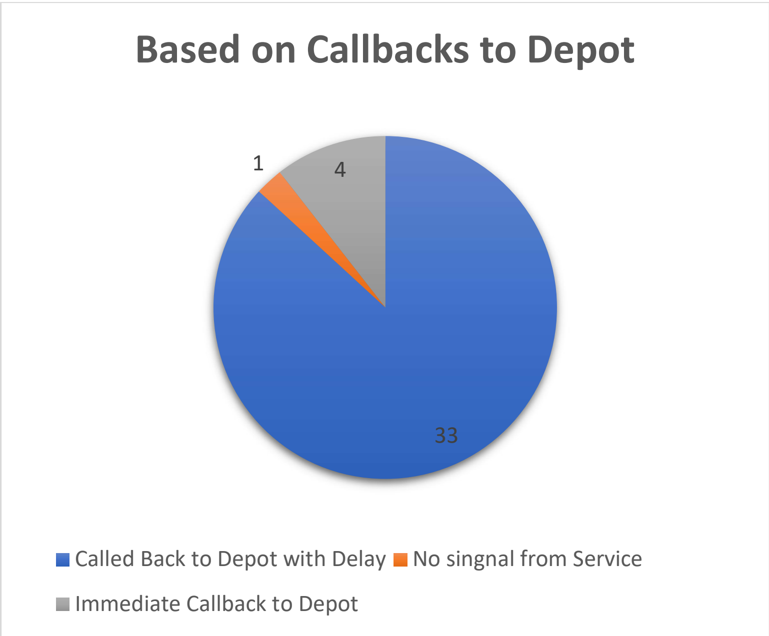


Figure 40 Pie chart based on Call-back

[4] Risk Evaluation of Railway Rolling Stock Failures Using FMECA Technique: A Case Study of Passenger Door System by Fateme Dinmohammadi • Babakalli Alkali • Mahmood Shafiee •Christophe Be´renguer • Ashraf Labib from France and UK in the year 2016

Depending on the type of components that have undergone failure we can see them in the below combo chart w.r.t failures in the figure 40 below.

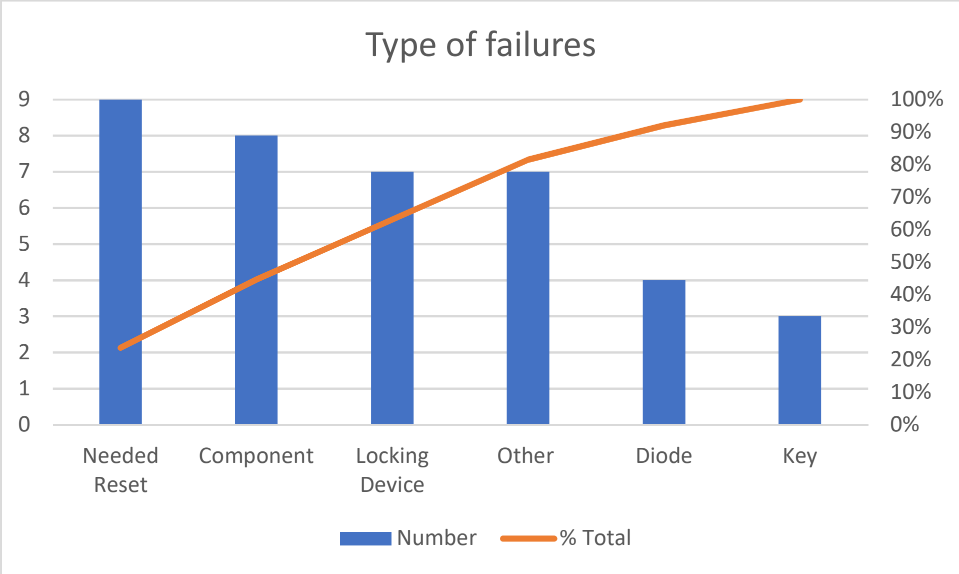


Figure 41 Bar Graph and scatter line chart showing total failures

Every component may malfunction for a short period which later we can find nothing due to a small glitches in the Command Unit, MVB or LdV; the second where there were problems in the closing of the door component ("Valvola a Tasto") in the closing of the door mainly which is locking device , and followed by Components, Key and Diode failures. Eliminating the first three problems means that more than 80% of the problems are solved. The causes of them would be learnt more in the FMECA analysis further below.

No	Item	From Period		Function	Failure Mode	Potential Causes	O	Potential Effect	S	R
1	Door Drive	A	Locking Devices	To lock/unlock the door leaf	Locking Not possible	Deformation of it or Structural Failure	7	Door not closing, does not open even in emergency, door blocked in closed	8	56
					Unlocking not possible	Deformation of it or Structural Failure	7	Door blocked in closed position, difficult door opening putting it in out of service	8	56
		B	Valvola a Tasto	To provide door movement during open and closing	Seized at door opening/closing	Mechanical Failure	8	Excessive noise, door leaf vibrations, excess opening closing times	7	56
					Fractured at door opening/closing	Pollution U Shape	8	Difficult door movement, excess opening and closing	7	56
2	Door Control elements and switches	A	Switch left and right door closed S32,S33, S34	To Transmit door closed information to DCU	No Transmission	Sensor defect, loose fixings, oxidisation of contacts	3	DCU has no closed signal , door must be locked manually, door must be locked out of use	6	18
					Permanent Transmission	Sensor defect, shot circuit, external voltage	3	Door has closed signal and also door open signal , door must be locked manually, door must be locked out of use	6	18
3	Other									
		A	Door Level Adjustment	To see that the doors are properly placed in position when locked	Door not Closing properly in fixed position	After continuous use, loosing of the holding chain, or due to external pressure or internal pressure moving out of alignment	3	Door not opening and closing properly, taking much time to open and close the door	4	12

Figure 42 FMECA Analysis

For the components let's look at the Present maintenance activities which are being followed show in Table 10:

Task	Task Description	From Period	From Kms
Current Maintenance Programme			
1	Passenger Doors- Unit Functional Check	3RT	120.000
2	Electrical Components	Dedicated Not Present	
3	Side Key for opening	After failure	
4	Door Adjustment	After failure	

Table 10 Current Maintenance Procedure

To reduce these failures and to have a better functioning of the components, the following maintenance plan is proposed shown in the below Table 11

Task	Task Description	From Period	From Kms	For Days
Proposed Maintenance Programme				
1	Passenger Doors- Unit Functional Check	2RT	80.000	144
2	Electrical Components	3RT	120.000	216
3	Side key for opening	RT	40.000	72

Table 11 Proposed Maintenance Program

The current maintenance plan is taken by the EMU manual given by the manufacturer Ansaldo Breda. The proposed method is an taken into consideration by the collected information which was analysed and with the main components identified, it was proposed with talks with the EMU Maintenance Engineer about the feasibility of it as his experience helped me frame it.

8.5 Conclusion for Analysis

In the current study, a failure mode, effects and criticality analysis FMECA based approach was presented to identify, analyse and evaluate the potential risks associated with unexpected failure of door component failures. The criticality level of a door component failure was calculated by multiplying the likelihood of occurrence of the failure mode (O) and the severity of damage caused by the failure (S), each being rated with a number from 1 to 10 (1 = lowest, 10 = highest). The failure modes according to the level of their criticality were categorised into five classes, namely very low, low, medium, high and very high critical. The most critical failure modes in the system with respect to both reliability and economic criteria were identified. Some components link up with the door functioning components in CCU and LdV of the vehicle. These were not taken into consideration as they refer to their functioning but not directly deal with the Doors. For the components which are undergoing failure a proposed and feasible plan is given. The results of this study were used not only for assessing the performance of current maintenance practices, but also to plan a cost-effective preventive maintenance (PM) programme for different components of rolling stock. To avoid the recurrence of the failure modes, a new mileage-based preventive maintenance (PM) programme including 3 tasks was proposed. These proposed tasks must be carried out so that we can know the effectiveness of the analysis or it would be needing further changes.

Chapter 9 Conclusion

The thesis was mainly focused on knowing about the digital maintenance methods being implemented and executed in the host structure Trenitalia S.p.A. For this we got to know about how the Italian Railways has been formed and some facts about the work structure of the host group.

We have learnt in detail the more about the Maintenance Depot in Roma Smistamento, how its geometry would be helping to facilitate the different type of maintenance activities carried out depending in the kms run and time and how the organization structure is in the depot for the process. We have gone through some of the main technical specifications of the Fleet used in the plant for the Lazio Region Passenger Services, and the software's that are being used like Mose, DISW, SAP, Timer Hodie, Pdp-IMC, DMMS which are used for the management and planning of the maintenance activities in the plan are an example of the recent technical advancements in technology.

We would be coming back to our main aspect of our thesis, studying the different types of existing maintenance methods implemented, and the new methods like DMMS which are being implemented for the Train Maintenance and Pdf-IMC for Plant Maintenance. To understand the functioning of them better we need to know the functioning of the existing methods , how the fleet is being is maintained where we will get to know the terms like 1st level and 2nd level maintenance, and how they are carried out in the different levels of IMC and OMC Depots of the host structure and the type of activities that are carried out here depending on Kms run by the fleet and Time. The inspection activities are carried out for the functioning of the components with reference to the Maintenance Manuals provided by the fleet manufactures, also knowing the types of maintenance activities for the carriages.

The main aspect for the digitalization of railways in the field of maintenance is whenever a fault occurs when the train is in motion, we can immediately analyse it online, whether it may cause a serious problem , or it can resolved when the train enters into the depot for maintenance and if it a particular component failure, before the train enters into the depot, the technician and the spare parts required for it would be scheduled.

Not all types of maintenance activities can be carried out in one area and each require a different type of materials, and apparatus. Before the train enters the plant, these all activities must be planned, so that the unnecessary movements of the train in the depot can be eliminated as it requires a lot time to change the binaries for it. These all is planned in the Pdf-IMC, the entry and exit of the plant, the type of service materials it would be needing, activities it must be carried out and according to it, assigned the designated parking area in the plant. This saves a lot of time, and data assigned here is updated in the other software's being used in the plant which saves a lot of time and increases the depot efficiency making the fleet available on time.

To sum it up, nowadays the environment advancing forward into the 21st century with a lot progress in globalization and rapid advancement in the ICT specially in the field of railways. For this reason, it is important to go beyond the boundaries of existing railway technologies like "Tele diagnostics" and with R& D activities successfully implanting the new level of technology like "DMMS" we can revolutionize the field of Predictive Maintenance which not only saves time in the maintenance activities carried out, but also saves a lot time, and makes the fleet available for disposal making it need less maintenance halts summing up with a better programmed depot.

We have carried out FMECA analysis for the Door failures in the EMU train listing out the main factors for the failure, carrying out the Likelihood factor, Risk factor and impact rating. We have seen the existing method available for maintenance of these most failure components, and we have proposed a new maintenance plan, taking with the maintenance engineer in the plant checking out the feasibility of it. More analysis can further be calculated to check out the costs incurring be this change and whether there is a change in the failure levels of this components.

We can conclude finally by saying that maintenance is always on of the higher costs for the company that owns a fleet of vehicles where it has an important aspect Quality of Service. An intelligent maintenance policy by innovative methods in the digital era has positive effects on costs reduction and increase of quality of service making the customers happy for and choosing the service again. Not only this it increases the lifespan of the components and putting into service for a longer duration.

The application of the digital methods would cause a platform to support maintenance, with a self-growing knowledge base and impressive maintenance costs and great growing of availability, reliability and security levels.

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Acronyms

- TCN/TCN* -Telecommand (Telecomando)
- GT0- Controller switch for on/off (diodo con accezione e spegnimento comandati)
- WTB- Wire Train bus (bus di treno)
- MVB- Multifunction Vehicle bus (bus di veicolo)
- Kn-Kilonewton
- Kw- Kilowatts
- Km/hr – Kilometre per hour
- IMC-Impianti Manutenzione Corrente
- RSMS-Rolling Stock Management System
- PdP- Trenitalia Production Platform
- IMC- Impianti di Manutenzione Corrente
- OMC – Officine di Manutenzione Ciclica
- PR- Pulizia Radicale
- RFI- Rete Ferroviaria Italiana
- RSMS-Rolling Stock Management System
- RT-Revisione di Turno
- SOR-Sala Operativa Regionale
- IMC- Impianto Manutenzione Corrente
- DRP-Direzione Regionale Lazio
- CCU- Unità di Controllo Centrale
- LdV-Logico di Veicolo
- STA- CCU Micro processor
- TAF-Treno Alto Frequentazione
- SCMT- Sistema di Controllo Marcia Treno
- EMU- Electric Multiple Unit