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ASSET MANAGEMENT IN RAIL PUBLIC TRANSPORT SECTOR AND INDUSTRY 4.0 TECHNOLOGIES

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ABSTRACT

Industry 4.0 is the concept adopted to refer to new technologies that have been deeply impacting the entire industry, in practically all sectors. The development of technologies associated with the internet of things (IoT) and intelligent systems is driving the industry towards digital transformation. In this scenario, many possibilities arise for the rail public transport sector, mainly for Asset Management, considering that Asset Management represents a significant portion of the operator's efforts and costs to keep the commercial operation running. This work presents the traditional asset management concepts currently used in the public transport sector on rails, as well as some opportunities for using Industry 4.0 technologies in this sector. Then, a methodology for implementing these opportunities is proposed, with the agile methodology being suggested as an implementation strategy, considering a cost-benefit analysis, risk analysis, project plan, implementation plan and financial plan. It is expected that the ideas presented in this work can stimulate other sectors of the industry to move towards Industry 4.0, which is an inevitable trend and will certainly determine in the medium and long term who will survive in an increasingly competitive environment.

KEY-WORDS: Industry 4.0. Big Data. Asset management. Agile methodology. Rail public transport.

RESUMO

A Industria 4.0 é o conceito adotado para se referir às novas tecnologias que vem impactando profundamente a indústria, em praticamente todos os setores. O desenvolvimento de tecnologias associadas à internet das coisas e sistemas inteligentes está impulsionando a indústria em direção à transformação digital. Neste cenário, muitas possibilidades surgem para o setor de transporte público sobre trilhos, principalmente para a Gestão de Ativos, considerando que a Gestão de Ativos representa uma parcela significativa dos esforços e custos do operador para manter a operação comercial em pleno funcionamento. Neste trabalho são apresentados os tradicionais conceitos de gestão de ativos utilizados atualmente no setor de transporte público sobre trilhos, assim como também são sugeridas algumas oportunidades de utilização de tecnologias da Indústria 4.0 neste setor. Em seguida, uma metodologia para implementação destas oportunidades é proposta, sendo sugerida a metodologia ágil como estratégia de implementação, considerando uma análise de custo-benefício, análise de risco, plano de projeto, plano de implementação e plano financeiro. É esperado que as ideias apresentadas neste trabalho possam estimular outros setores da indústria a caminharem rumo à Industria 4.0, que se mostra como uma tendência inevitável e certamente determinará a médio e longo prazo quem prosperará em um ambiente cada vez mais competitivo.

PALAVRAS-CHAVE: Indústria 4.0. Big data. Gestão de ativos. Metodologia Ágil. Transporte público sobre trilhos.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABREVIATIONS

ANPTrilhos	Associação Nacional dos Transportadores de Passageiros sobre Trilhos
APS	Auxiliary Power System
CBM	Condition Based Maintenance
EDCU	Electronic Door Control Unit
IEC	International Electrotechnical Commission
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISO	International Standards Organization
MFC	Multifunctional Cable
MTTF	Mean-time-to-failure
O&M	Operating and Maintenance
PMBOK	Project Management Body of Knowledge
RUL	Remaining Useful Life
SWOT	Strengths, Weaknesses, Opportunities and Threats
Vac	Volts, alternating current
Vdc	Volts, direct current
VLT	Light Rail
UITP	International Association of Public Transport

TABLE OF CONTENTS

1. INTRODUCTION

Railway systems are a strategic theme in main cities of the world. The commercial operation of the Metro, trains, Light Rail or Monorail lines deeply affects the mobility plan of these cities. According to ANPTrilhos, an entity that brings together the main rail public transport operators in Brazil, in the year of 2019, the metro rail systems in Brazil presents the following data, presented in Figure 1.

Figure 1 - Metro rail systems in Brazil in 2019

Source: ANPTrilhos

To play such an important role, metro rail systems need to be interconnected between the different modes of transport existing in the city. The city of São Paulo, for example, which has the most extensive network of urban rail transport in Brazil, has several interconnected systems: metro, passenger trains, monorail and bus lines. Figure 2 presents in detail the metropolitan transport network of the city of São Paulo.

Figure 2 - São Paulo Metropolitan Transport Network
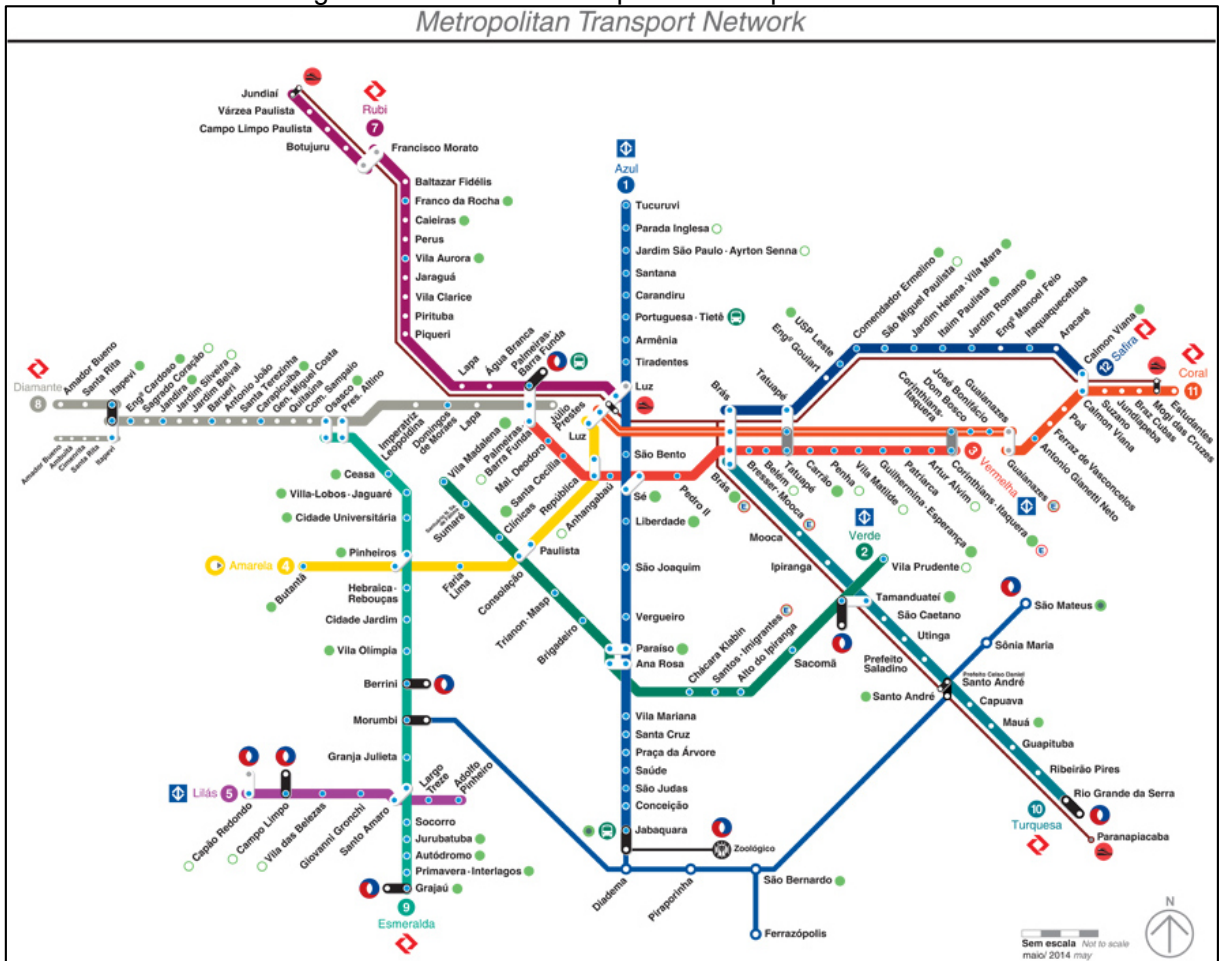
Source: Secretaria dos Transportes Metropolitanos do Estado de São Paulo

The extension and distribution of the lines, which reaches all regions of the city of São Paulo, attests to the importance and great impact that the metro rail systems have in the city. Maintaining the commercial operation with a minimum of interruptions or impacts is a major challenge faced by the Operators. Delays caused by systemic failures that affect an entire line or even a small delay in a busy station can create impacts and delays throughout the city's transportation network. In addition to causing inconvenience to passengers, these occurrences can generate penalties for Operators, as well as eroding the perception of service quality by customers.

In this scenario, the asset management of the systems necessary to ensure the availability of the commercial operation becomes a fundamental tool. The evolution of the technologies available for asset management in the railway systems follows the evolution of the industry in general. Right now, the fourth industrial revolution is imposing transformations in all areas of the industry and bringing new concepts that need to be absorbed by the Operators as a prerequisite to be competitive in the sector.

The evolution of the industry has been accelerating since its emergence in the 18th century, moving from the first steam engines to an environment with interconnected systems and equipment. This evolution allows for a great increase in productivity through the adoption of new technologies and through changes in the way that Operators use the information made available by systems and equipment.

Several opportunities arise from Industry 4.0, many of which require investments for its implementation, others require only existing human resources from the company itself. Some opportunities are described in this work, in order to highlight the applicability of Industry 4.0 technologies in the rail public transport sector. These opportunities are made possible by the technological evolution of the main systems existing on the railway system, such as:

- Signaling system has passed from the era of electromechanical components to the era of highly technological electronic components;
- The trains are operated with the assistance of several electronic systems, drastically reducing the actions of the train operator on board. The automatic lines do not require the presence of not only the train operator, but also any attendant on the train, since all the train's command is carried out remotely from the operational control center;
- Electric traction system incorporated several electronic components that allow real-time monitoring of the system, as well as remote controls. The implementation of these new concepts requires a methodology that considers at least a cost benefit analysis to ensure its real applicability, a risk analysis so that the process has a greater chance of success, a project plan and a financial plan, so that the process fits into the company's strategic planning.

The objective of this work is to present the fourth industrial revolution in the public transport sector on rails, describing some opportunities for adopting new technologies that bring qualitative and quantitative gains, as well as presenting a methodology for implementing these opportunities, taking into account cost-benefit analysis, risk analysis, project plan, implementation plan and financial plan.

2. COVID-19 IMPACT ON RAIL PUBLIC TRANSPORT SECTOR

The Covid-19 pandemic has had enormous impacts on the rail public transport sector. With the adoption of measures to restrict mobility in cities, the number of passengers transported has drastically reduced. Figure 3 shows ridership evolution of the Rio de Janeiro metro when compared to week 10 (ten) of the year 2020.

Figure 3 - Ridership evolution of Metro of Rio de Janeiro
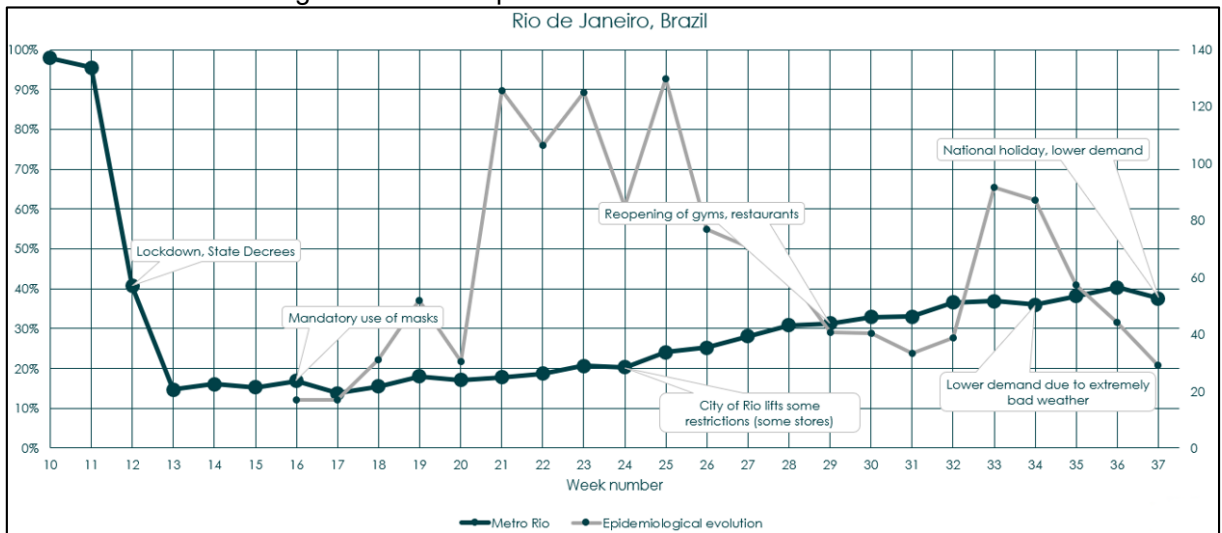
Source: UITP

The reduction in demand shown in Figure 4, in the order of 40% (forty) compared to pre-pandemic levels, demonstrates the great impact suffered by the sector. This behavior of marked reduction in demand is observed throughout the sector in the world. Another aggravating factor is the speed of recovery in demand prior to the pandemic period. A presents the rate at which ridership levels have been recovering after the strictest of the measures put in place have been relaxed in the various cities around the world. After 20 (twenty) weeks, despite the increase in demand, the levels are still well below the benchmark for Operators. This scenario shows that demand recovery is not expected to occur in the short term and the impacts of the pandemic will be long-lasting.

Figure 4 - Speed of recovery - Metros
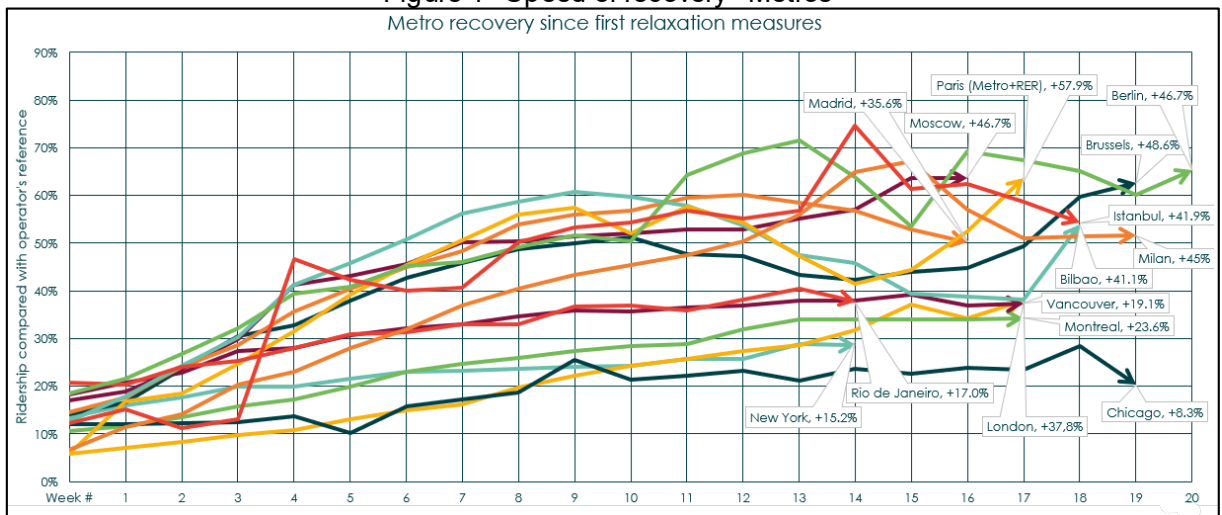
Source: UITP

The impacts of the pandemic described above will certainly contribute to accelerating the adoption of Industry 4.0 technologies in the rail public transport sector, as this scenario increases pressure on companies to reduce costs and optimize resources.

10

3. INDUSTRY REVOLUTIONS

Technological advancement has been profoundly changing the characteristics of the world industry. From the industrial revolution in the eighteenth century, considered as the landmark of its emergence, the industry itself created technologies capable of changing its own characteristics. The main changes experienced by the industry can be grouped into 4 (four) specific moments, called industry revolutions. The main characteristics of these revolutions are presented below.

- Industry 1.0 (eighteenth century) - The beginning of the industry, when the first steam engines to produce consumer goods were built. Its main characteristic is the great demand for labor to perform jobs that required great physical effort.
- Industry 2.0 (nineteenth century) - Marks the appearance of the first large-scale production lines, symbolized by Henry Ford's car production line. Industry productivity increases significantly and working conditions for workers improve.
- Industry 3.0 (twentieth century) - Introduces electronic technological advances and robotization in the industry, reducing the demand for labor. However, automated operations remain isolated from each other and from the industry.
- Industry 4.0 (twenty-first century) - Finally, automated operations start to connect. The concept of connected industry arises from the connection of its industrial assets via the internet. Previously isolated devices now communicate with each other and create valuable insights. The Internet of Things (IoT) brought several advantages such as asset optimization, production integration, intelligent monitoring, remote diagnostics, intelligent decision making. All of this makes it possible to explore predictive maintenance more and more.

Figure 5 summarizes the keywords related to each industrial revolution.

Figure 5 - Industry revolutions
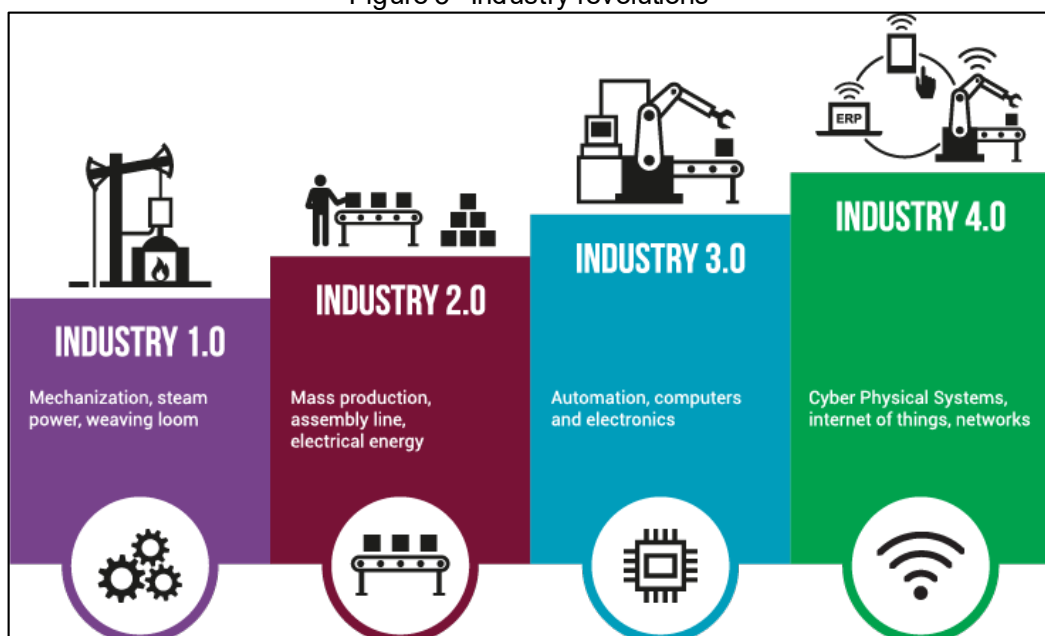
Source: PRNEWWIRE

The viability of industry 4.0 is only becoming possible through the advancement of technologies, the main ones being: Cloud Computing, Systems Integration, Cybersecurity, Internet of Things, Big Data, Additive Manufacturing, Augmented Reality, Autonomous Robots and Simulation.

3.1. Industry 4.0 technologies

The technologies of Industry 4.0 will transform production. Despite a lot of advanced digital technology is already used in manufacturing, the accelerated development of new technologies will be able to profoundly affect the industry, bringing efficiency gains and changing the relationship between suppliers, producers, and customers. Among the main technologies, 9 (nine) stand out that support the concept of Industry 4.0, presented in Figure 6 and briefly described in the following topics.

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Figure 6 - Industry 4.0 technologies
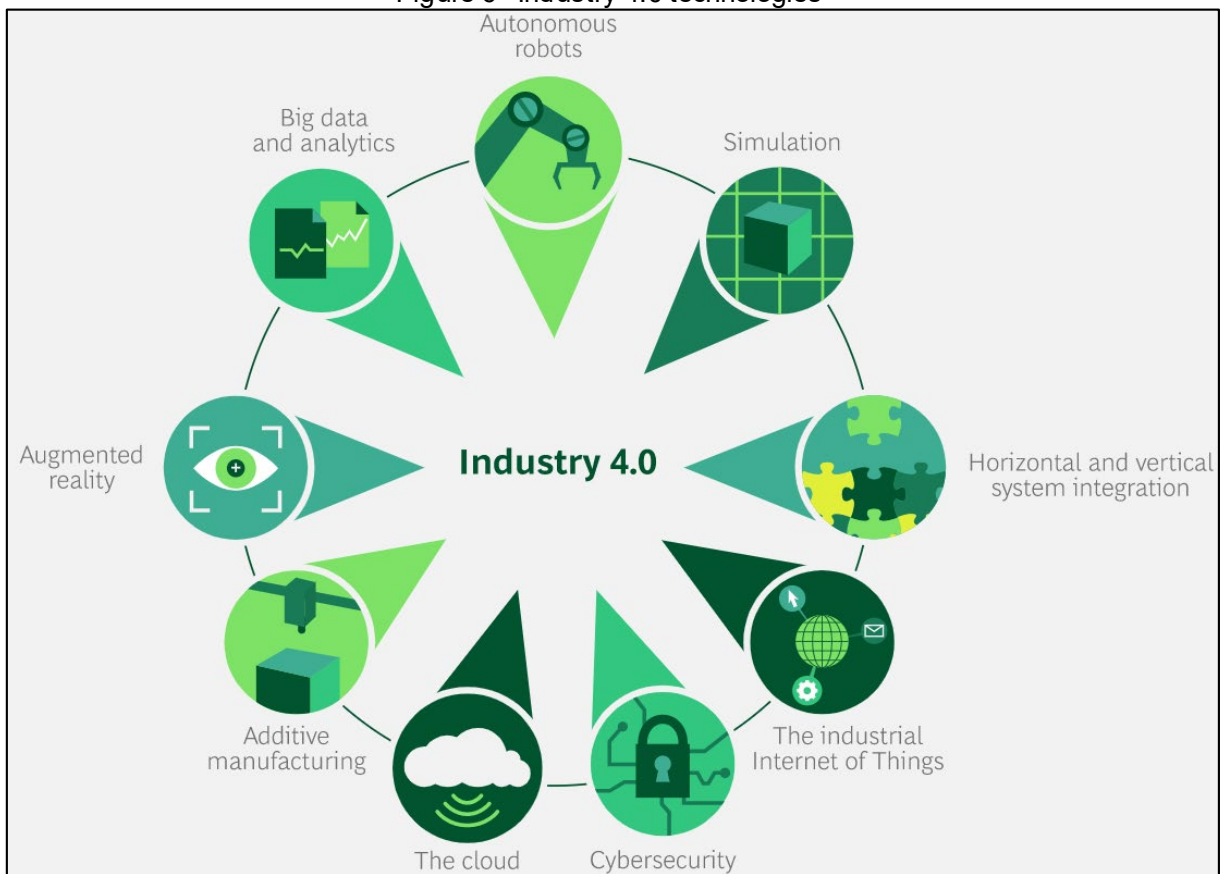
Source: BCG

3.1.1. Cloud Computing

Cloud computing has the characteristic of increasing computing power with investment proportional to the use. The secret behind this is provisioning resources on demand and sharing them. This provisioning requires a low management effort and is done on top of configurable and high-level resources.

For this reason, many Industry 4.0 systems are being developed and delivered with cloud computing. This technology has the benefits of reducing the IT infrastructure

within the industry, which reduces the need for large investments in the acquisition and maintenance of IT equipment and reduces indirect investments such as physical space, cabling, energy costs and operational staff.

In addition, the scalability in which you can increase the computational power proportional to the use and demand is a great differential.

3.1.2. Systems Integration

Normally, each stage of the production process is controlled and monitored by a different system. Systems integration techniques and technologies are necessary for information to flow between the various elements (systems, machines, robots, etc.) and consequently between the areas and people in the process. This intense exchange of information between the elements can directly influence the production processes. Whether through cyber-physical systems or through the people themselves who can act more quickly considering information from several different sources flowing more quickly through integrations. As protocols and integration standards become more abundant and available, the greater the possibility of "conversation" between systems, machines, robots and hardware.

3.1.3. Cybersecurity

Data and information flows traveling through different networks, inside and outside the industry, requires that this information exchange follows security standards to guarantee the 3 main characteristics of the information: confidentiality, integrity and availability. For example, a system in the cloud is sending and receiving information to a network outside the company's domain.

3.1.4. Internet of Things (IoT)

The Internet of Things - IoT - consists of embedding technology that can collect, process and transmit data on any type of object. For example, a shoe that conveys the number of steps you take in a day. In the industrial universe, IoT gained an increase, being known as IIoT - Industrial Internet of Things - where the original concept is kept, but the "things" in this case are the systems and common elements in a production process such as: sensors, collectors, robots, machines, equipment, actuators, readers, etc.

3.1.5. Big Data

The concept of big data emerged in the mid-90s, its main proposal is the treatment of large volumes of data (structured or not), with the advancement of technology this is a concept that tries to be indispensable to companies, after all only having information it is not enough anymore it is necessary to generate value with this information and this can only be done with the use of big data, below the concepts are described in greater detail:

- VOLUME: in big data the volume of data is immense. The data generated is so intense and with the advancement of technology they tend to be even more. The amount of equipment that are now microprocessed and can

generate information about events and alarms, one increasingly moves towards the connected world.

- VARIETY: another factor of great importance, in big data, structured data is treated or not, this means that not only tabular data is considered but others that add a lot of value as well, such as video, audio, log files in different formats (txt, log , etc.), sensor data, etc. This factor is very relevant because it is estimated that only 20% of the data generated are structured, the rest, 80%, are not, therefore, an analysis with only structured data is of worse quality because it leaves a lot of information outside the analysis.
- VELOCITY: the speed of the information presented to the bank can be impressive, the bank must be able to rescue data, store and retrieve at a speed that meets the expectations of those involved in the process, the flow of generation and transmission can be so high that traditional systems cannot handle them.
- VERACITY: for information to be used, it is essential that the information is consistent, for this in the treatment, quality and consistency, origin, veracity, etc. must be verified.
- VALUE: the departure of Big data should add value to the process, either by identifying opportunities, saving costs, improving product quality, or even helping to solve problems.

The maintenance is beginning to embrace the use of big data and analytics to improve performance. In emphasizing the use of "big data", maintenance can establish predictive maintenance programs, which reduce downtime and save on maintenance costs. They can also extend the life of their equipment, reduce unnecessary preventive maintenance tasks, and optimize their spare part inventory.

The role of big data is growing in maintenance, and this trend is improving the way that the maintenance team works. The movement toward data analytics is increasing the effectiveness of the maintenance department, and in turn improving the uptime of operation.

A natural extension of big data in maintenance is a predictive maintenance. By using machine data along with other area data, the operation can truly understand the health and performance of its machines. This is done by installing sensors and utilizing the data to model the equipment performance. Once a model is established, the operation can use real-time data to predict when the machine will see a breakdown.

Obviously, this information is very valuable. With the ability to perceive a future event, the manufacturing line can appropriately plan a response. No more scrambling by the maintenance, operations, and supply chain teams – saving tons of time and hassle for all parties.

A predictive maintenance program not only saves money, it reduces risk and, in some cases, even can save lives by avoiding catastrophic failures of critical equipment.

3.1.6. Additive Manufacturing

Additive Manufacturing is also known as 3D Printing and allows you to manufacture any parts using specific software and hardware. It is called an additive because the "printer" adds material, layer by layer, without wasting them and making the most of the raw material. With this technology it is possible to create parts of any shapes that, for example, are not possible to create with traditional machining or that may be very expensive to do with them.

3.1.7. Augmented Reality

It is the mix of information from the virtual world with visualization in the real world. This technology in operational excellence is more linked to the quality of the work to be done, for example, in an operation or maintenance. Combining virtual elements with the real visualization, it is possible to create an environment where you can visualize what should be done and, mainly, how it should be done.

3.1.8. Autonomous Robots

Robots are already used in industrial environments, which leads many people to say that this is already in "Industry 3.0" so it is one of the most controversial items of technologies listed here. However, in 4.0 this technology differs from traditional robots precisely because of the word "Autonomous", and that makes a lot of difference. The autonomy of robots in Industry 4.0 means that the robot can achieve its goals by making decisions that were not programmed through an algorithm. His actions are based on rules, conditions and learning that he weighs and considers making a decision. Note that among autonomous robots, in fact, there may be different levels of autonomy, with those with higher levels generally having better decision-making capacity and making use of artificial intelligence.

3.1.9. Simulation

Before spending on raw materials, or operationalizing a change in the production process, a series of analyzes and optimizations can be made through simulations that consider different aspects in the product to be manufactured or in the production process to be improved. As, for example, the dynamic, static, thermal, electromagnetic, acoustic influence, among others, avoiding waste, rework and anticipating situations.

4. MAINTENANCE STRATEGIES AND TENDENCIES

Maintenance strategies in the metro rail environment are still very traditional. Basically, only periodicity with time or mileage are the most adopted criteria for preventive maintenance. With the advancement of technology, mainly with the development of electronic systems, the monitoring of variables and parameters of equipment and systems has become feasible, enabling the change of maintenance strategies currently carried out.

From the monitoring and treatment of the data generated by the systems, it is possible to change the maintenance strategy, optimizing resources. Some more complex systems, such as the signaling system and the embedded train control system, generate large volumes of data and information. They are diverse information, that can go from a simple record of opening and closing doors, traveled mileage, until the record of faults and consumption of electric energy. Industry 4.0 is inserted in this context. Several applications that bring direct gains in maintenance service and material costs can be identified through the collection and treatment of this data.

Maintenance processes and methods have been increasingly developed in recent years, becoming more and more linked to the important binomial for any

organization: cost reduction - guarantee of availability of machines and people. The improvements implemented in the maintenance function of a company reflect positively in the areas of quality, reliability and costs, and in the metro-rail transport sector it is no different.

In this sector, where competition and the search for customers is a matter of survival, maintenance is considered strategic, as its absence results in losses and reduced profits, affecting customers, employees, investors and society. Monitoring the maintenance - customer satisfaction interface in urban transport companies is vital for permanence and growth. Controlling the maintenance of strategic assets for Operation is a critical activity in every company in this sector. Keeping regularity in scheduled maintenance, increasingly reducing unforeseen interventions, can provide lower costs, increasing the useful life of these assets, directly impacting the reliability of services.

The maintenance plan is one of the resulting from asset management planning. Its objective is to prevent deterioration in the performance of the assets in use and to manage the risks of failures. In other words, carrying out a good maintenance plan, especially for strategic assets: rolling stock, energy, permanent way is essential for good asset management.

4.1. Maintenance Types

The definition of maintenance can be the combination of all technical and administrative actions to keep or restore a system or equipment it to a state in which it can perform a required function. In case of the railway maintenance, the most common is corrective maintenance and preventive maintenance.

4.1.1. Corrective Maintenance

Corrective maintenance or breakdown maintenance are maintenance tasks that are performed in order to repair faulty systems or equipment after a failure has occurred. The purpose of corrective maintenance is to restore broken down systems or asset to a condition in which it can perform its intended function. Some advantages of corrective maintenance are shown below:

- Minimal planning required: It requires very limited complex planning and consists of very targeted action on specific components of installations or devices that are faulty;
- Lower short-term costs: few administrative or financial costs involved until something goes wrong;
- Simpler process: The process is easy to understand, since you only need to act when problem occurs;
- Best solution in some cases: The amount of time and money invested in preventive maintenance planning and strategy could be a lot more than the simple stop and repair costs.

However, there are several disadvantages to corrective maintenance, as shown below:

- Unpredictability: Can be problematic if the equipment is not monitored, leading to more failures that are highly unpredictable and whose cause is unknown;

- Paused operations: Unexpected failures may be slowed down by not being able to access materials which may lead to increased periods of inactivity.
- Equipment not maximized: Reduces the lifetime of the assets. It simply fixes the asset on a short-term basis;
- Higher long-term costs: A more serious failure can be an extremely costly and slow process to fix. Large periods of inactivity have negative effects on reputation, client satisfaction, safety and on the ability to run a business efficiently and productively.

4.1.2. Preventive Maintenance

Preventive maintenance are the tasks based on interval (time based, or usage based) and the main goal are increase asset lifetime by depreciation and impairment or untimely breakdown. Some characteristics of preventive maintenance are shown below:

- Increases equipment lifetime: Increases return on investment;
- Prevents unpredicted stoppages: Improves the operation of the system;
- Improves equipment reliability: Makes forecasts more realistic;
- Reduces maintenance costs on high-value assets: it is less expensive than corrective maintenance and predictive maintenance currently available;
- Saves resources: Equipment with operational failures tend to spend more energy and lose quality;
- More safety on the facilities: The assets are kept in the best conditions and without wear and tear;
- Requires more time: To plan and to inspect;
- Unnecessary maintenance activities: Since it is not condition-based;
- Higher costs: If applied to assets of lower value or priority;

4.1.3. Predictive Maintenance

Predictive maintenance focuses on predicting when a failure will occur to prevent it. Unlike preventive maintenance, which is scheduled and follows predefined time or usage milestones, it is based on the condition of the equipment. One of the main components that are necessary for implementing predictive maintenance are data collection and preprocessing, early fault detection, fault detection, time to failure prediction, maintenance scheduling and resource optimization.

The predictive maintenance is based on the equipment's physical or operating conditions, so the maintenance will be better-informed to do the necessary and at the correct time than if it were simply performed according to predefined schedules and statistics, as happens with preventive maintenance. This would end up reducing the costs and labor time spent on maintenance. But the implementation of a predictive maintenance needs investment in specific monitoring equipment and training staff to use it and to interpret data correctly. Therefore, it is not a cost-effective approach for lower priority assets, whose failure does not prevent your operations from running normally.

4.2. Condition-Based and Predictive Maintenance

Maintenance of public rail transport assets is based on corrective and preventive maintenance. Industry 4.0 allows new maintenance concepts to be incorporated by the sector. Condition-based maintenance (CBM) and predictive maintenance are new steps towards systems with low failure rates or even zero failures. The Figure 7 presents a brief summary of the evolution of maintenance concepts.

Figure 7 - Preventive to Predictive maintenance

1 INTERVAL-BASED PREVENTIVE MAINTENANCE

Based on predefined intervals such as time, mileage or cycles. **Example:** Change the filter every 15,000 km.

2 CONDITIONAL PREVENTIVE MAINTENANCE

Based on checking the condition criteria and value threshold to assess the need for intervention/replacement at given intervals. **Example:** Check every 15,000 km if the filter needs changing.

3 CBM

Based on real-time checking the condition criteria and value threshold to warn for the need of intervention/replacement. In this case, looking back at past experiences in order to decide on maintenance interventions. **Example:** The system will indicate if the filter needs to be changed.

4 PREDICTIVE MAINTENANCE

Maintenance regime whereby the system smartly analyses asset degradation, and predicts the RUL and supports optimised maintenance duty planning. **Example:** The system will provide the assets RUL and predict the probable date of asset failure.

Source: UITP

To enable these new concepts, it is necessary to perform a more intelligent asset management with systems that learn, diagnose, predict failures and trigger specific maintenance. Data from different equipment and systems are collected and processed, generating a predictive analysis. Based on this analysis, the remaining useful life (RUL) is estimated based on the asset's previous behavior. This allows you to plan maintenance activities for each specific asset, optimizing resources and materials. Figure 8 graphically presents the CBM process and predictive maintenance.

Figure 8 - CBM and Predictive Maintenance process
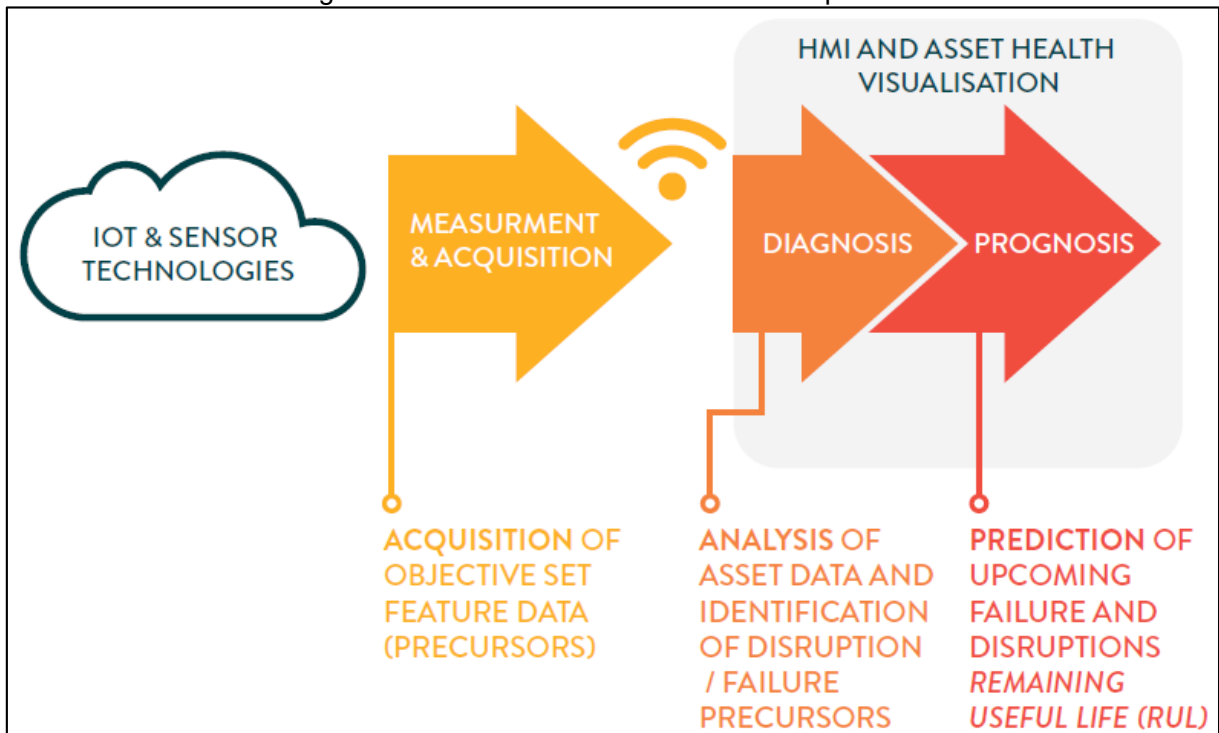
Source: UITP

According to UTIP (Knowledge Brief, March 2020), CBM and predictive maintenance are invaluable tools for optimized asset management decision-making, and they will deliver the following benefits:

- Faster identification and timely qualification of asset deterioration;
- Increased asset availability and optimized maintainability for the operators;
- Improved asset reliability and safety, leading to more trust from passengers and better reputation for the operator;
- Lower system life cycle costs.

5. OPPORTUNITTIES FOR RAIL PUBLIC TRANSPORT SECTOR

The new technologies of Industry 4.0 create several opportunities for the metro rail sector. With the advancement of technology, there is more and more electronic and computational equipment, including systems installed on the train, on the track, in the technical room or at the station. Numerous systems and equipment already have an immense volume of records, alarms, variables and measurements being carried out and stored. The challenges are to enable the use of this existing information to generate value for the company, as well as to generate other information that helps in generating even more value for the company.

Big Data, Industry 4.0 technology that proposes to work with large volumes of data, becomes very useful for the metro-railway sector. This occurs because there are several processes that are repeated up to thousands of times a day during commercial operation, such as: opening and closing doors, point machine movements, traction and braking of trains, uninterrupted electronic monitoring, counting in blockages, etc. The more repetitions or the longer the system remains in operation, the more data is

generated and from these data it is possible to predict failures and thereby optimize resources.

The following describes some opportunities that can be applied to the rail public transport sector.

5.1. Point machine current signature

5.1.1. Context

A point machine is a device responsible for operating the points of a turnout, moving frogs or derailment devices. It is responsible for exerting the force to move the moving parts. In rail public transport lines, its greatest use is in the point of turnout and in movable frogs. Movable frogs are used in turnouts when it is necessary higher speed to pass the train on the branch.

Point machines are typically electromechanical or electro-hydraulic, and are connected to the points through bars that, in addition to exerting the force to perform the movement, have the safety function of detecting the position of the turnout points and reporting this position to the signaling system. Ensuring the safety of the route set. Figure 9 shows a point machine mounted and connected to the points of a turnout.

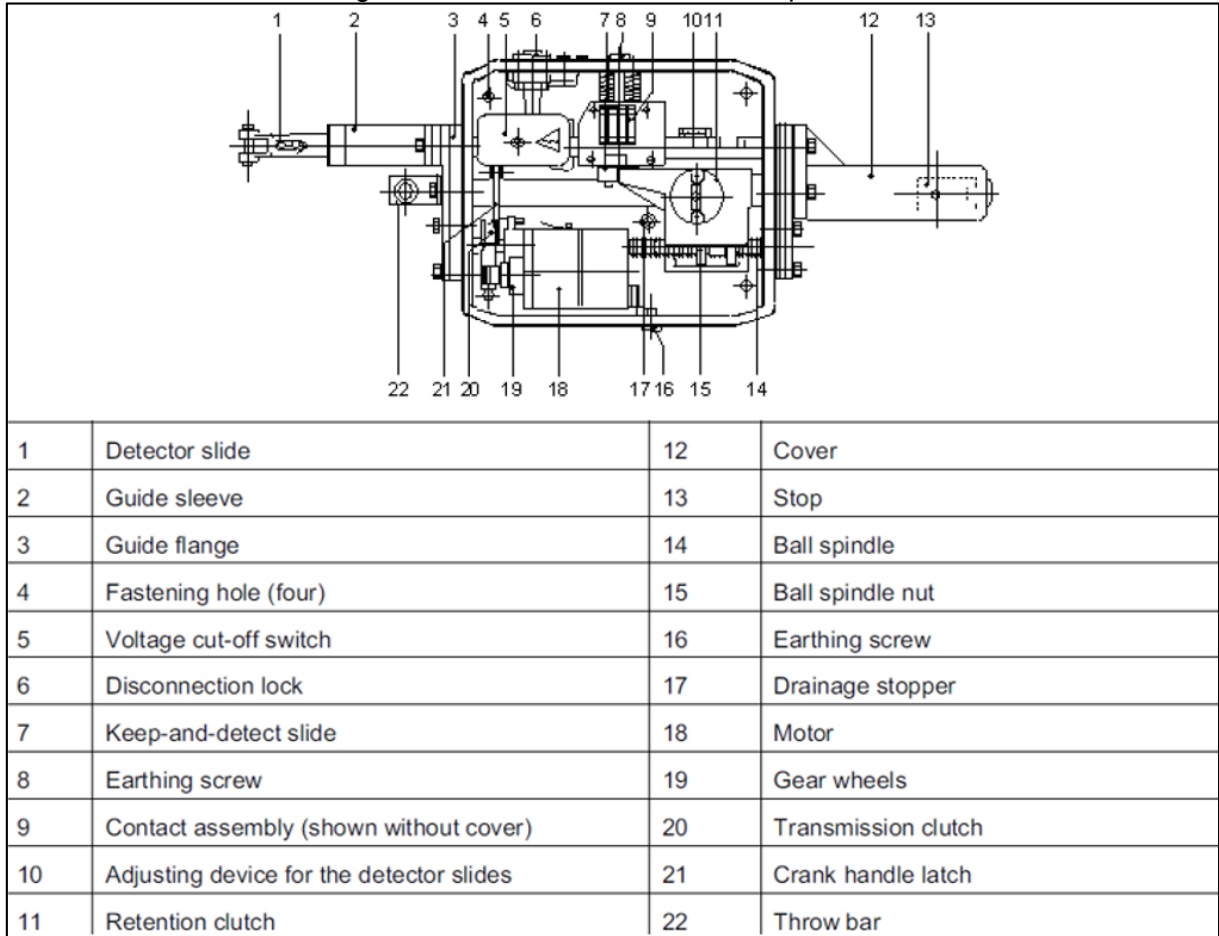Figure 9 - Siemens S700K point machine mounted

Source: CCR Group

5.1.2. System Overview

The Siemens S700K electromechanical point machine is basically formed by the box and the set of bars. The set of bars is formed by a throwing bar that is responsible for exerting force that moves the points and the detection bars. The detection bars are attached to the points and follow movement to detect the points

position. The position of the detection bars indicates via electrical circuits to the signaling system if the points are in the required position and that the required route e set and safe for the train to pass. Figure 10 presents a representation of the components of S700K point machine.

Figure 10 - Point machine S700K components

1	Detector slide	12	Cover
2	Guide sleeve	13	Stop
3	Guide flange	14	Ball spindle
4	Fastening hole (four)	15	Ball spindle nut
5	Voltage cut-off switch	16	Earthing screw
6	Disconnection lock	17	Drainage stopper
7	Keep-and-detect slide	18	Motor
8	Earthing screw	19	Gear wheels
9	Contact assembly (shown without cover)	20	Transmission clutch
10	Adjusting device for the detector slides	21	Crank handle latch
11	Retention clutch	22	Throw bar

Source: CCR Group

The point machine box contains the contacts and electrical circuits responsible for driving the motor and transmitting the command and status signals to the signaling system. There is also the mechanical part formed by gears, spindle and clutch that are responsible for the mechanical movement of the bars. Complementing the set, there is the electric motor responsible for generating the movement that is transmitted to the throwing bar. Figure 11 shows an inside view of S700K point machine.

Figure 11 - Inside view of Siemens S700K point machine

Source: Siemens S700K point machine product brochure

5.1.3. Opportunities Identified

Point machines are not very complex devices. Its operating principle and embedded technology have not undergone much evolution in recent decades. The main variable to be monitored is the electric motor current. The current required to move the points or the movable frog may indicate an abnormal condition on the point machine itself or on the turnout.

The monitoring and recording of each movement performed by the point machine allows the creation of a historical base with thousands of occurrences that will allow the signature of the current of each point machine to be known. From this database it is possible to identify when there is an abnormal condition in the point machine or in the turnout even before the occurrence of a failure. This predictive performance also makes it possible to prevent premature wear of parts and components of the point machine and turnout. Operational impacts will be minimized, considering that the correspondence loss inevitably causes impacts on the commercial operation and delays on the line.

5.2. Rolling Stock – Train door system

5.2.1. Context

Passenger train side door is the first interface between passengers and trains. In mass transportation, such as subway, side doors are used to provide direct access to the passenger compartment. This system allows for the rapid exit and entry for the passenger.

The door system of modern trains is also used as a safety device for operation, as they have sensors that guarantee the movement of the train only with the doors closed. The opening and closing of the doors are done only by the train operator or

automatically by the system, thus ensuring that passengers only embark and disembark in the correct locations, except in cases of activation of emergency devices. It is a highly demanded system during operation, opening and closing all stations. On a typical day of commercial operation, the doors of a train are activated according to the table below:

Table *1* - Average door cycles per day

Line	Número médio de ciclos em 1 dia útil
Salvador Metro Line 1	506
Salvador Metro Line 2	456
São Paulo Metro Line 4	570
São Paulo Metro Line 5	535

Source: Group CCR

The occurrence of failures in this system normally has a great impact on the operation of the trains, causing delays and even interrupting the train's trip. Thus, the reliability and availability of the system is fundamental for the provision of services, especially when considering the practiced headway. Reduced headways require great agility from the operation and maintenance team to minimize impacts to customers and when doors fail, the impact is usually large.

The maintenance of the door system, in its majority, is made preventive, using as parameters the mileage traveled by the train or the time interval. The door maintenance interval, normally, follows the interval of rolling stock maintenance. Below are shown an example of type of maintenance in rolling stock.

Table *2* - Rolling Stock Maintenance Level

Type of Schedule	Interval	Mileage	Locations
Level 'A' Inspection	30 days	12,500km (± 3,000km)	Inspection tracks
Level 'B' Inspection	3 months	37,500km (± 7,500km)	Inspection tracks
Level 'C' Inspection	1 year	150,000km (± 22,500km)	Depot
Level 'D' Inspection	2 years	300,000km (± 30,000km)	Depot
Level 'E' Inspection	4 years	600,000km (± 45,000km)	Workshop
Level 'F' Inspection	8 years	1,200,000km (± 60,000km)	Workshop
Level 'G' Inspection	16 years	2,400,000km (± 75,000km)	Workshop

Source: CCR Group

Each maintenance level contains a list of activities for each subsystem, with the periodicities estimated in the use of the component or equipment during the maintenance interval, as shown below.

Table *3* - Door System Maintenance

Equipment/ Component	Inspect	Clean	Lubricate	Adjust	Replacement	Test	Overhaul	Recommended Interval
Passenger Side Door – Inspection	X	X						A
Motor Assembly – Inspection	X							A
Motor Assembly – Overhaul							X	E
Cable Assembly – Inspection	X							A
Driving Screw Assembly – Inspection	X	X	X					A
Driving Screw Assembly – Overhaul							X	E
Door Closed Switch – Inspection	X			X				A
Door Closed Switch – Replacement					X			E
Lock Out Switch – Inspection	X			X				A

Source: CCR Group

Another form of usual maintenance on the door system is corrective maintenance, which is mostly performed after the failure of the system in operation. Failures in the door system can result in low operational impact, such as failure isolation (system degradation), or high operational impact, with the removal of the train from operation.

5.2.2. System Overview

The passenger side door consists of following components:
- Door Leaves.
- Door Operator.
- Electronic Door Control Unit
- Communication

5.2.2.1. Door Leaves

Each passenger side door consists of two door leaves or one leaf. Each door leaf can be made of metal, like aluminum or stainless steel. In subway its very common to see windows and grip handle in the leaves.

Figure 12 - Door leaves example

Source: CCR Group

5.2.2.2. Door Operator

The door operator is normally located in a compartment above each set of doors, fixed on the car structure, protected by a cover with access by the standard key locker.

The passenger side door most common is a pocket sliding type door system that is operated by a microprocessor base controller is provided with eight sets per car and operated by an electric motor. The door operator contains some microswitch.
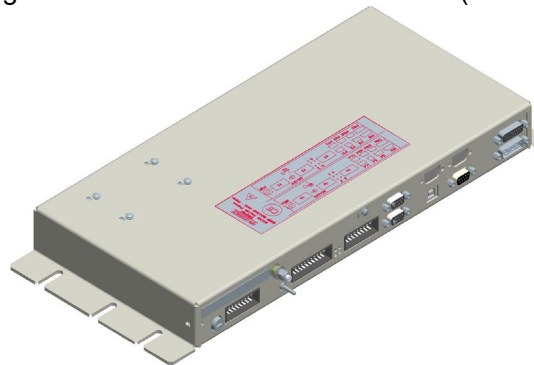
Figure 13 - Door Operator example
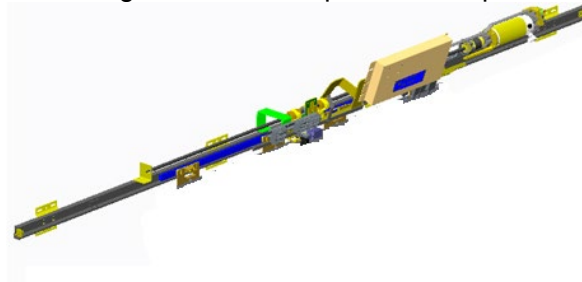
Source: CCR Group

5.2.2.3. Electronic Door Control Unit (EDCU)

The individual controller port EDCU is installed directly in the door operator. The EDCU objective is to control the electrical doors fitted on the train, powered by a supply energy.
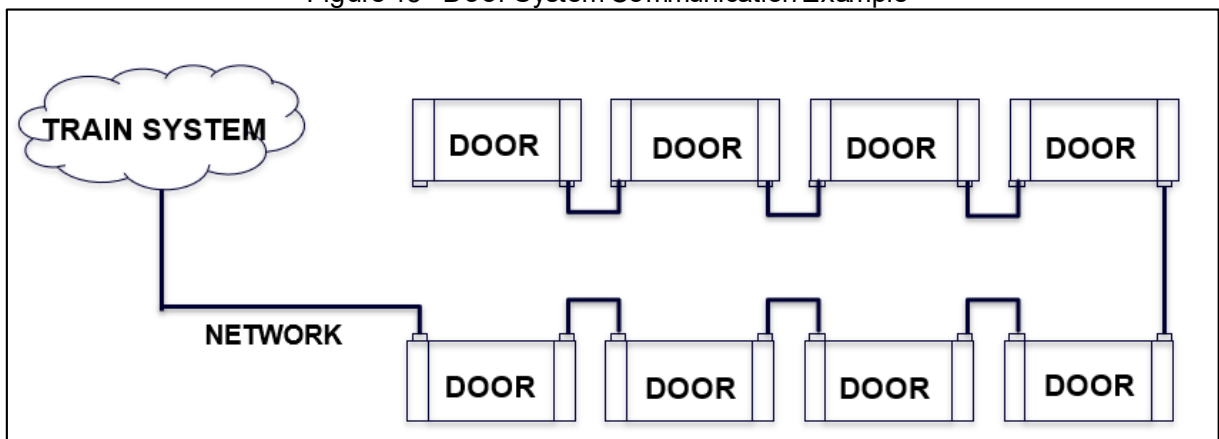
Figure 14 - Electronic Door Control Unit (EDCU)

Source: CCR Group

5.2.2.4. Communication

The door system in modern trains is connected to the train network and provide basic information for the system or the driver, as shown in the figure below.

Figure 15 - Door System Communication Example

Source: CCR Group

5.2.3. Opportunities Identified

Most of the door system is not manufactured / developed by the train manufacturer. Thus, despite the system being interconnected to the train control system, several alarms and records are restricted to the system itself. There is a great opportunity to implement the collection, storage and processing of this large volume of alarms, records and equipment status. To exemplify the volume, there are 32 doors per train in the Salvador Metro and more than 600 cycles per day, which brings more than 19 thousand opening and closing operations. Adopting that 6 door signals would be used, there are a total of more than 115 thousand data in a single train per day of operation. The application of industry 4.0 technologies, especially Big Data technology, has great potential for, for example, changing maintenance strategies.

Currently the preventive maintenance practiced in the door system uses the train's mileage as a counter, which does not directly reflect the number of door opening and closing cycles due to unproductive mileage (train movement other than directly transporting passengers, such as maneuvers, entry and exit of operation, travel without

26

passengers, among others). In addition, when comparing the different lengths of the lines and the number of stations (table 4), the number of cycles per kilometer traveled can vary by up to 38%.

Table 4 - Number of Door Cycles

Line	Length (KM)	Stations	Cycles/1.000km
Salvador Metro Line 1	13	8	615
Salvador Metro Line 2	20	12	600
São Paulo Metro Line 4	12	10	833
São Paulo Metro Line 5	21	17	810

Another opportunity that can be mentioned is the monitoring of the door motor current, as it would allow to identify door leaves with difficulty closing or opening. Lower guide with excessive friction against the door threshold, door sheet vertical parallelism misadjusted and left or right-hand side front gasket deformed are examples of causes, which at the beginning, cause difficulty in closing or opening the door leaves. The initial non-identification will result in the total failure of the door, making it unable to close or open. The implementation of the collection, monitoring and processing of EDCU data can make it possible to anticipate the performance of maintenance before the total failure of the door (inability to open or close it).

Preventive maintenance by use instead of maintenance by time has a great potential to reduce material consumption, avoiding the early replacement of components, as well as the reduction of labor used. The anticipation of the maintenance performance before the failure occurs, that is, a predictive maintenance, has as great potential the reduction of the impact of the possible failure in the operation and the recovery time, since the performance can be programmed.

5.3. Traction Power System – Aesthetic Power system (APS)

5.3.1. Context

The lines of the VLT system were designed in the central area of Rio de Janeiro, to be an integrating modal. The city center was a region of chaotic traffic, many buses, taxis, cars etc. The revitalization of this area took as a premise the modernization without visual impact, improving mobility while promoting traffic reduction. In this context, the tramway was inserted, with the main objective of connecting the different means of transport in the center of Rio, interconnecting the airport, the ferries, the subway, the suburban trains, the cruise ship landing point, even reaching the intercity and interstate Bus Station. In the following figure it is possible to see the tramway network map in the city of Rio de Janeiro.

Figure 16 - VLT Carioca Network Map

Source: CCR Group

In terms of the tramway power supply, two techniques are currently adopted, one being the use of catenary, which in this project was adopted only at the Maintenance Center, and the second, using two technologies. The first, with the longest experience, is known as ground feeding - APS, and the second, more recent, called on-board energy, using capacitor banks, with double insulation layer, and groups of batteries, both of high performance. The so-called Supercapacitors. Both systems were implemented by Alstom.

Due to the directive imposed by the City of Rio de Janeiro, prohibiting the use of aerial networks, due to the legislation that created the Porto Maravilha project, the VLT Rio project adopted the alternative system, with the use of embedded energy (Supercapacitors) and ground feeding (APS – Aesthetic Power Supply), minimizing the visual impact on urban insertion, privileging the beautiful landscapes and historic buildings so present in the center of Rio.

The following figures show the APS rail and the system architecture. The running rails are on the same level as the APS rail segments, which are powered by power boxes, which are power supply boxes located underground in chambers specifically prepared for this purpose. A power box (PB) can power up to two APS rail segments, through underground ducts in which a feeder cable passes that takes energy from the substation to the power box. An electronic connection ensures communication and monitoring of the system, which is SIL4.

Figure 17 - APS Rail

Source: CCR Group

Safety integrity level (SIL) is defined as a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction. In simple terms, SIL is a measurement of performance required for a safety instrumented function (SIF). The requirements for a given SIL are not consistent among all the functional safety standards. In the functional safety standards based on the IEC 61508 standard, four SILs are defined, with SIL 4 the most dependable and SIL 1 the least.

Figure 18 - SIL level according IEC 61508 / IEC 61511

| SIL LEVELS ACCORDING IEC 61508 / IEC 61511			
SIL Safety Integrity Level	PFDavg Average probability of failure on demand per year (low demand mode)	RRF Risk Reduction Factor	PFDavg Average probability of failure on demand per hour (high demand or continuous mode)
SIL 4	$\geq 10^{-5}$ and $< 10^{-4}$	100000 to 10000	$\geq 10^{-9}$ and $< 10^{-8}$
SIL 3	$\geq 10^{-4}$ and $< 10^{-3}$	10000 to 1000	$\geq 10^{-8}$ and $< 10^{-7}$
SIL 2	$\geq 10^{-3}$ and $< 10^{-2}$	1000 to 100	$\geq 10^{-7}$ and $< 10^{-6}$
SIL 1	$\geq 10^{-2}$ and $< 10^{-1}$	100 to 10	$\geq 10^{-6}$ and $< 10^{-5}$

Source: CCR Group

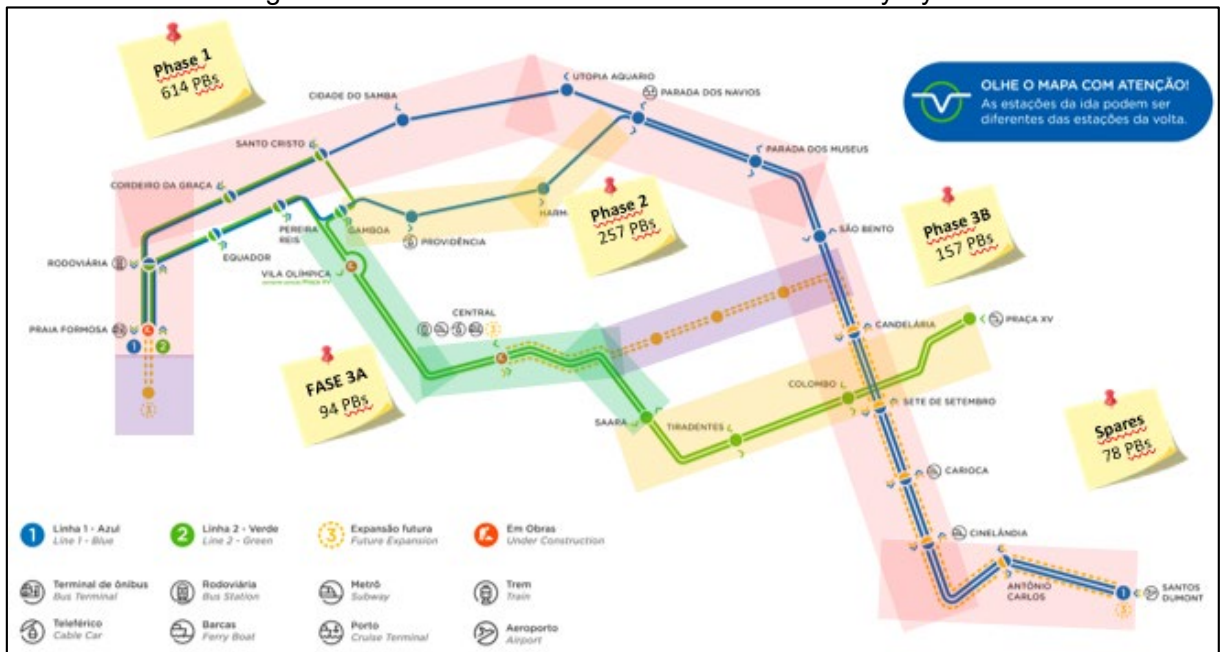Figure 19 - APS System Architecture
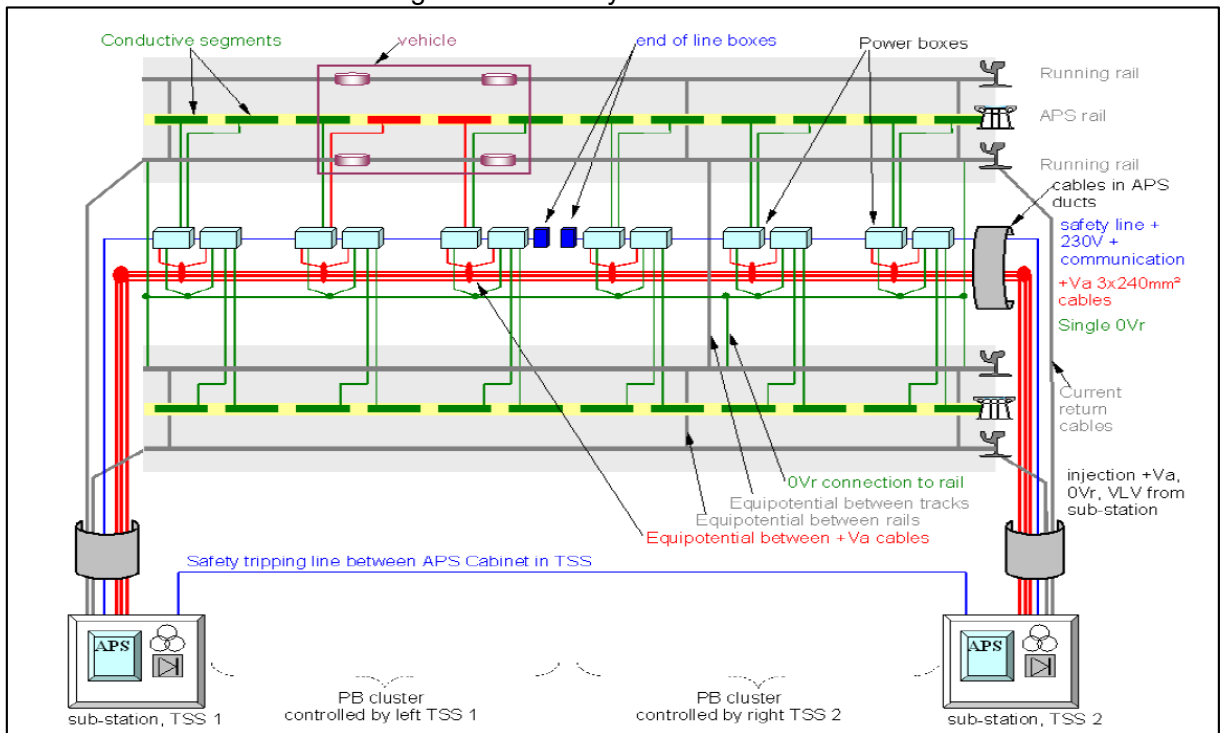
Source: CCR Group

Figure 20 - APS and Supercapacitor
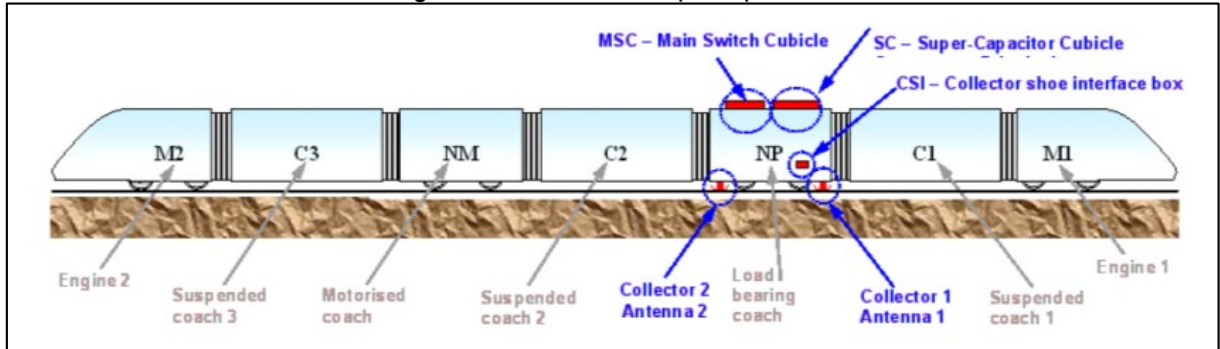
Source: CCR Group

The following figure illustrates the distribution of the PBs in the operational lines of the VLT. 1076 power boxes are distributed throughout the route, divided into 3 lines.

Figure 21 - Distribution of Power Boxes in the tramway layout

Source: CCR Group

5.3.2. System Overview

The APS system is Alstom's intellectual property and was first installed in Brazil in the VLT Carioca project. VLT use electricity as a source of energy, from the distribution network of the local concessionaire, usually at medium voltage, and supplied by rectifying substations, which supply the vehicles and auxiliary substations. The rectifying substations were dimensioned, in terms of nominal power and distance between them, according to the vehicle compositions and the minimum operating intervals adopted in each section of the VLT Network. These substations are powered by an internal distribution ring and transform the alternating medium voltage, lowering it and rectifying it in 750Vdc, supplying the traction power network, which in turn supplies energy to vehicles

Electricity is supplied by 3 external inputs in 13.8KVac, and the distribution is made in a ring to 13 Power Rectifying Substations, being converted to 750Vdc and distributed by the traction system, as shown in the figures below.

Figure 22 - Schematic of Traction Energy distribution
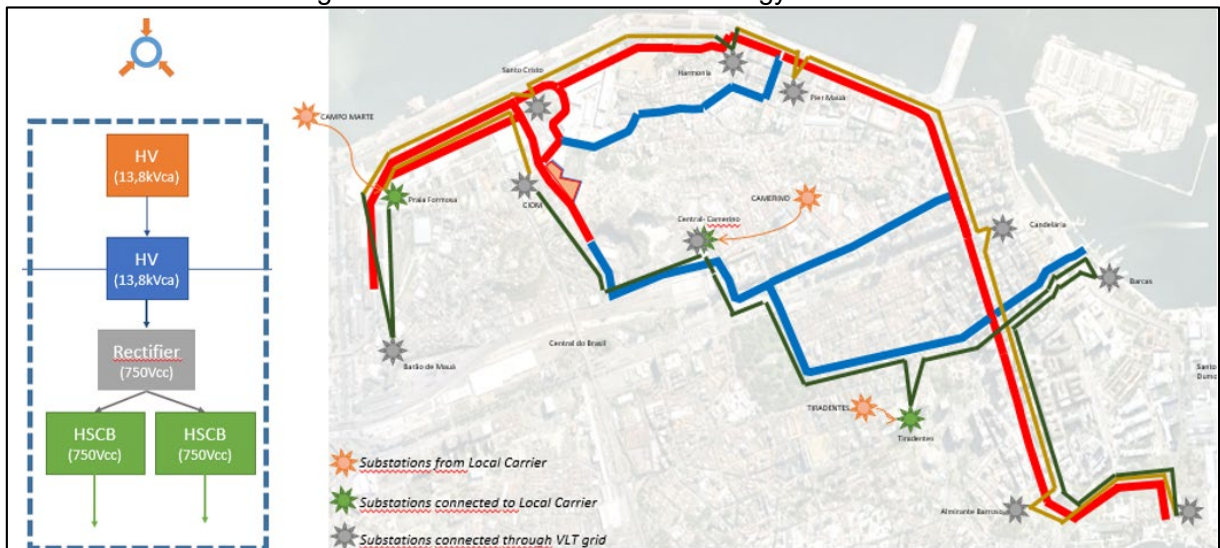
Source: CCR Group

To improve availability, the traction energy was divided into sections and, to control those sections, a technical room was built in each of the substations. As a system premise, each section can have a maximum of 100 PBs.

In the APS system there are many variables that are monitored by a supervisory system on a daily basis. Around 150 variables per power box are monitored at each energization (whenever a tramway passes over a track connected to a PB, it is understood that there was an energization) and the events are loaded into the supervision system. In the VLT Carioca system there are a total of 1176 power boxes, distributed over 3 operational lines that operate 20 hours a day. There are 807 trips (256 trips on line 1, 277 trips on line 2, 274 trips on line 3) with 26 trams, which at peak times, operate with a headway of 7 minutes per line, representing at the end of a business day, approximately 100000 events (disregarding any anomaly).

5.3.3. Opportunities Identified

Rio de Janeiro was the first location in South America where APS technology was installed. Some adaptations were necessary and consequently some problems due to tropicalization also appeared. The maintenance teams working on the system did not have prior knowledge, and as a result, the supplier's manuals and training were the only sources of information that supported the maintenance plan, which today is mainly composed of preventive and corrective maintenance.

The maintenance of the APS is a costly maintenance for the concessionaire, in addition to the fact that corrective measures tend to be very impactful to the system, even generating interruptions in the service that can last several hours, which represents a considerable loss of revenue depending on the time it happens the fault.

In this context, the need arises to implement predictive maintenance in the system, having as one of the purposes the use of the concept of Big Data that for what has been demonstrated would apply very well to this situation.

The system has many digital alarms, however, in order to be able to act in a predictive way, it is necessary to measure analog voltage and current values to monitor small variations that signal the degradation.

An important technical data for understanding the operation of the system and the behavior of failures concerns the frequency used in the APS system cabinets. There are two frequencies: 230V 50Hzs and 230V 60Hzs and that means that the sine wave has its complete cycle in 0.166 seconds (60 Hz) and in 0.02 seconds (50 Hz). The maintainer's challenge is to collect the data as often as necessary and to be able to process the information in a timely manner to take actions before the problem arises.

In the VLT Carioca, several failures have been occurring indicating an accelerated degradation of multifunctional cables (MFCs), which are the cables that connect the electronics of the power boxes. When there is an interruption of this connection, the failsafe system acts, shutting down the entire section, leading to an interruption of service where the failure occurred, until the restoration team acts.

Figure 23 - MFC cable connectors
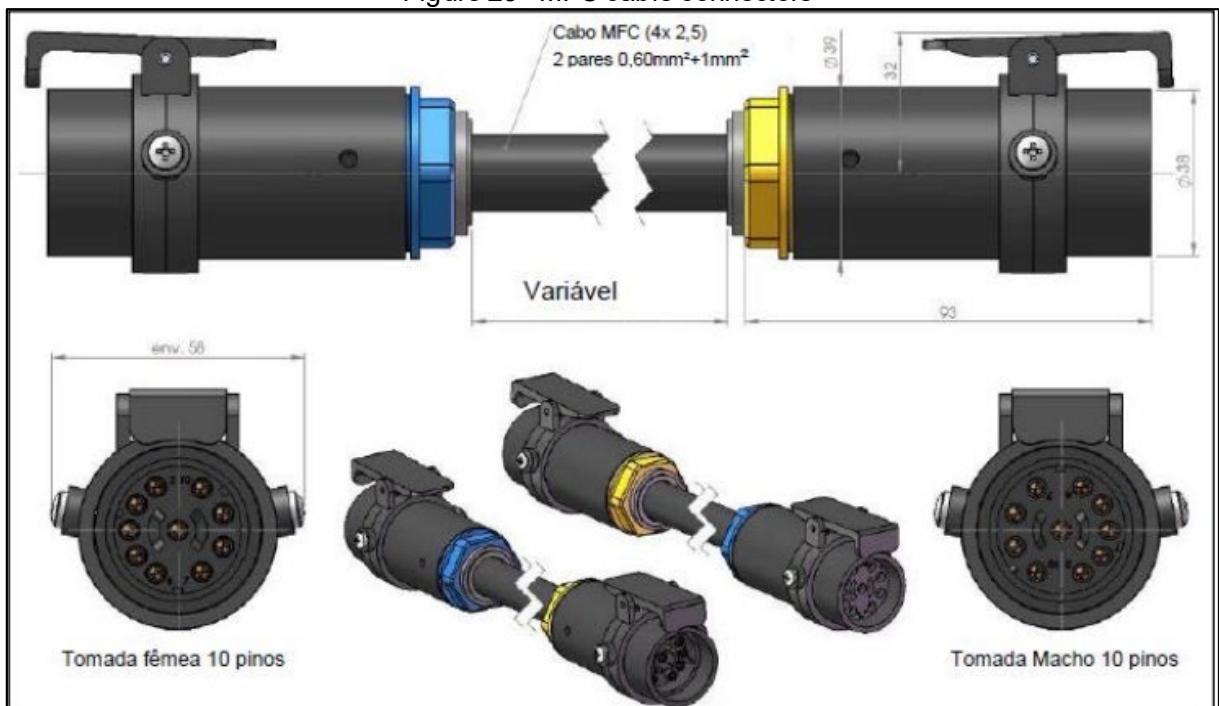
Source: CCR Group

In order to preventively identify failures, it is necessary to identify micro variations in the current of the cables, whose power is given at 50Hz. The purpose of monitoring this equipment is to detect variations in the initial phase so that the material can be replaced before it fails and impacts the operation. The biggest challenge is to analyze the problem through a large volume of data generated.

An example of a signal variation can be seen in the figure below, which allows the identification of abnormal system behavior:

Figure 24 - APS Cabinet Frequency
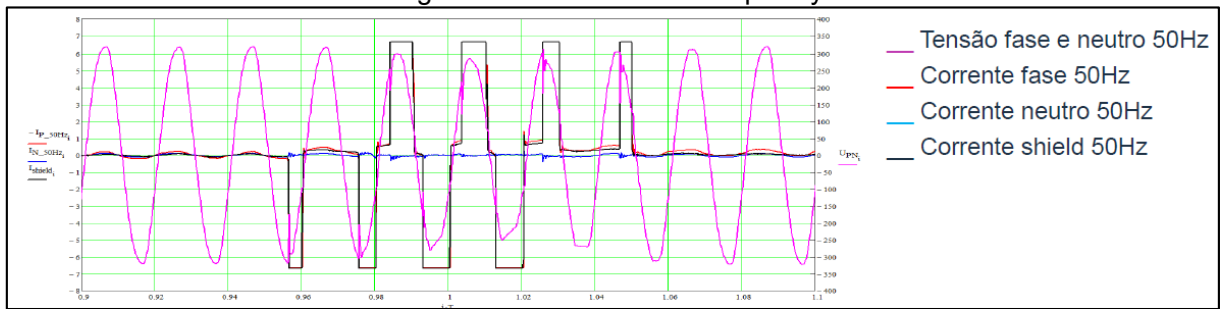
Source: CCR Group

As can be seen, the complete abnormal cycle takes approximately ¼ of the 50Hz cycle, that is, 0.005 seconds to capture such a deviation. The system must have a minimum sampling of 10 points per quarter cycle, that is, a sampling of 2MHz.

The monitoring of the power boxes through the real-time reading of the voltage and current will allow the verification of small variations that will indicate a possible degradation of the MFC cables connected to it. A multifunctional team with representatives from the Maintenance, Planning, IT, Engineering and Quality areas was formed and has been dedicated to the "Maintenance 4.0 Project", with periodic meetings to define and monitor activities.

The work of this multifunctional team based on the concepts of maintenance 4.0 started by searching the market for precision sensors. It was decided to adopt voltage and current sensors connected to a microcontroller with sampling and transmission capacity for storage in a database.

In a second step, to assess the necessary infrastructure, the growth of the records was calculated, taking into account that the measurements should only occur during the commercial operation, with a commercial operation of 20 hours per day and a sample of 2MHz, reaching a value of 2400,000 records per day, per monitored cable. The expectation is that it will be able to monitor at least 30 simultaneous cables, that is, 72,000,000 records per day of operation.

Even considering very small data and low transmission complexity, the database must have a very high recording capacity, being impossible if the network is not compatible. In this case study in the VLT, a fiber optic network with a capacity of 10Gbs is used, which allows data to reach the bank for recording.

In the next step, it will be necessary to process this data in real time. Using a conventional database to record this volume of information, queries are unavailable or extremely slow, and from that moment it is necessary to apply Big Data tools so that the data are processed and made available in a timely manner and the expected result is reached.

Still at this stage, the analysis rules will be loaded into the BIG DATA allowing for the output of reports informing where the maintenance teams should inspect and, consequently, act preventively in the system. The work is at this stage.

With this work, it is initially expected to anticipate the failures that today impact the operation, which will represent a notable gain in system availability, directly reflecting in the revenue. It is estimated a reduction in expenses with materials used during unforeseen remedies, which in these cases are quite significant since the cost of an MFC cable and the repair of a power box is also very significant.

As the project progresses, a drastic reduction in the hours of maintenance teams is expected in corrective activities, prioritizing predictive and preventive activities.

6. COST BENEFIT ANALYSIS

One of the most promising aspects of the rail industry's digital transformation is predictive maintenance – using data collected on equipment during operation to identify maintenance issues in real time. This means repairs can be properly planned, with the benefits that trains and other critical assets, don't need to be unexpectedly taken out of service for emergency or unnecessary routine maintenance.

There is a lot of hype around this topic and several failed cases. The explosion of IoT sensors and platforms – some overpromising what they can achieve – has created a belief that simply plugging in a few devices will give you all the data you need. Several poorly planned investments have become costly and fallen short of the expected business transformation.

This should sound a note of caution about buying into hype, but it doesn't mean predictive maintenance is out of reach. The benefits are there, but they need proper planning and management. As with any promised revolution, there is no magic bullet.

Trains are high value-added assets, so they must have a useful outward link. Thus, the strategic focus should be to keep them in service for as long as possible, in order to obtain a better depreciation of the investment value. This means that technologies that enable predictive maintenance, reducing operating costs and extending fleet life, have the potential to offer great financial rewards. However, it also means that the older trains currently in service, which were not built for modern connectivity, require investments to be able to do so. This extends to other assets that are also strategic on the railroad, such as point machines and traction power system equipment.

Therefore, the cost-benefit assessment must be done before any major investment in predictive maintenance.

7. RISK ANALYSIS

7.1.1. Concept of Risk Assessment

Risk assessment involves many steps and forms the backbone of your overall risk management plan. Although the words "evaluate" and "analyze" are thought to be interchangeable, they aren't the same in the risk management world.

Every risk assessment should consist of three main parts: risk identification, risk analysis and risk evaluation. Each of these components, in turn, comprises several important actions.

A risk analysis is the step in which you determine the defining characteristics of each risk and assign each a score based on your findings. It is a technique that helps you to mitigate risks. There are also tools that can help. It is important, at a minimum, to have a risk tracking tool or to use a risk tracking model to identify and list these risks.

Before being able to analyze a project's risk, you must recognize that the risk will happen in it. When planning for risks, you begin the process of knowing how to identify, monitor and eliminate risks when they appear in your project.

Risks can be assessed at an organizational level, at a departmental level, for projects, individual activities or specific risks. Different tools and techniques may be appropriate indifferent contexts. Risk assessment provides an understanding of risks, their causes, consequences and their probabilities. This provides input to decisions about:
- whether an activity should be undertaken;
- how to maximize opportunities;
- whether risks need to be treated; choosing between options with different risks;
- prioritizing risk treatment options;
- The most appropriate selection of risk treatment strategies that will bring adverse risks to a tolerable level.

Risk management helps decision makers make informed choices, prioritize actions and distinguish among alternative courses of action. Helps allocate scarce resources.

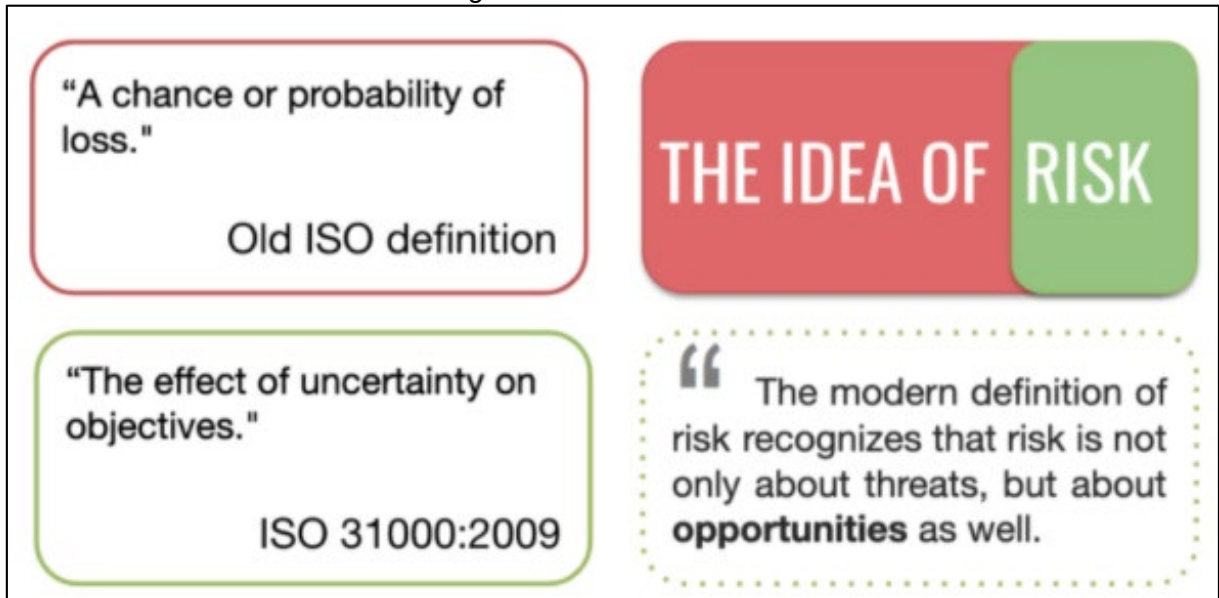Figure 25 - ISO 31000 Risk Assessment Process Overview
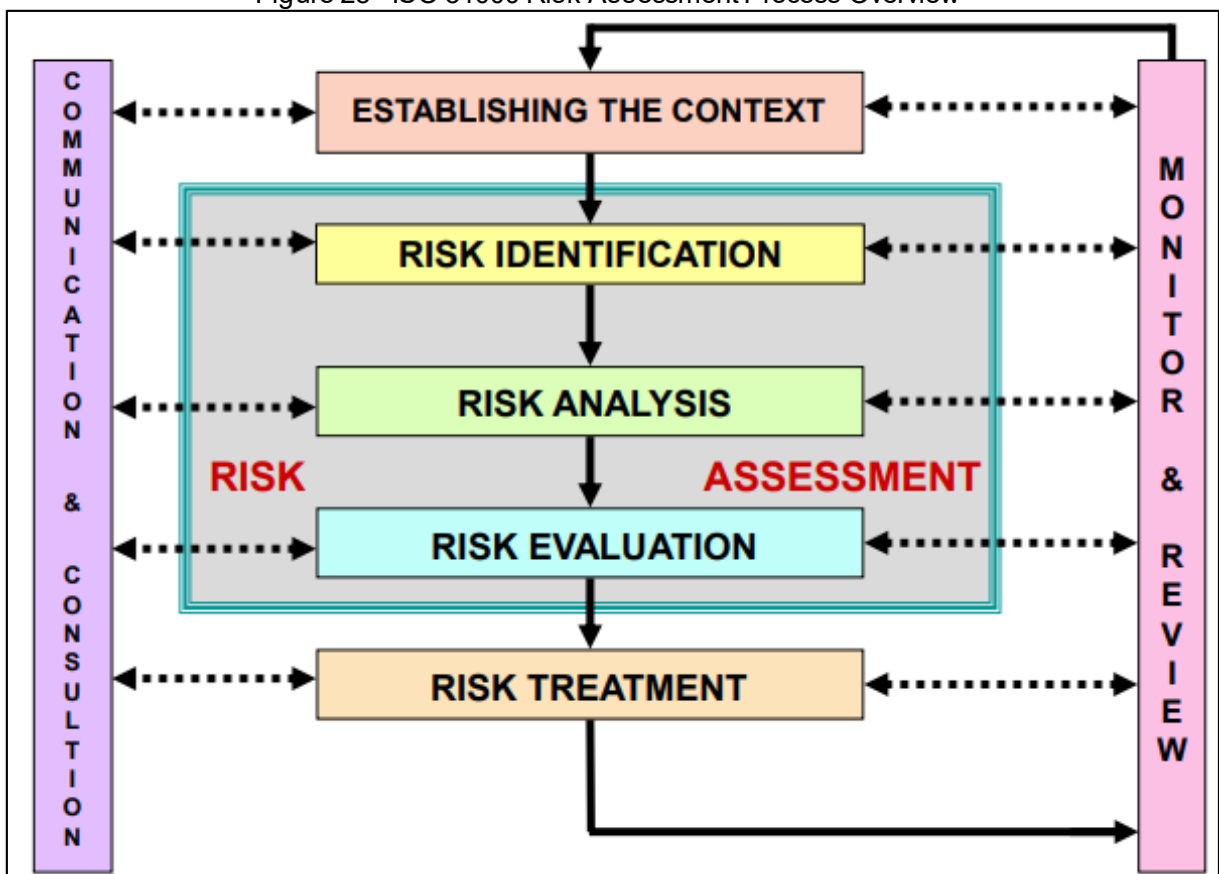
Source: riskwatch.com

36

7.1.2. Definition of Risk

What is risk and how can one measure and control it? Intuitively one understands that risk is something regarding a danger or threat that might happen with a certain probability and result in some type of negative outcomes. This perception is generally correct with one exception: risk doesn't always need to be a threat for a business, it might be an opportunity as well.

Figure 26 - The idea of risk

"A chance or probability of loss."

Old ISO definition

"The effect of uncertainty on objectives."

ISO 31000:2009

THE IDEA OF RISK

" The modern definition of risk recognizes that risk is not only about threats, but about **opportunities** as well.

Source: BSC Designer www.bscdesigner.com

The definition of "risk" used by the authors of A Guide to the Project Management Body of Knowledge (PMBOK® Guide) is consistent with most modern risk management standards. The PMBOK® Guide describes risk as an uncertain event or condition, that if it occurs, has a positive or negative effect on a project's objective. The key element of this definition is that the effect of the uncertainty, if it occurs, may be positive or negative on the objectives of the planned endeavor. Many things are uncertain; risks are, by definition, only those uncertainties that will impact the project should they occur.

The older definition of risk in ISO was a chance or probability of loss, while the latest ISO 31000:2009 defines risk as the effect of uncertainty on objectives. In other words, the modern definition of risk recognizes that risk is not only about threats, but about opportunities as well.

7.1.3. Risk Analysis

Risk analysis is the process that figures out how likely that a risk will arise in a project. Its studies uncertainty and how it would impact the project in terms of schedule, quality and costs if in fact it was to show up. There are two ways to analyze risk is quantitative and qualitative. But it's important to know that risk analysis is not an exact science, it's more like an art.

Risk analysis consists of determining the consequences and their probabilities for identified risk events, considering the presence (or not) and the effectiveness of any existing controls. The consequences and their probabilities are then combined to determine a level of risk.

According ISO 31010:2009, risk analysis is about developing an understanding of the risk. It provides an input to risk assessment and to decisions about whether risks need to be treated and about the most appropriate treatment strategies and methods. ISO31000 was developed with the objectives of providing a generic framework for identification, analysis, assessment, treatment and monitoring of risk.

Organizations use risk analysis to:
- anticipate and reduce the effect of adverse outcomes from adverse events;
- analyze whether risks are outweighed by benefits;
- plan responses and make decisions in case of failure;
- identify the impact and prepare for changes, such as the likelihood of new competitors entering the market or changes in government regulatory policy.

Benefits of risk analysis:

For business success, organizations must understand the risks associated with using their systems, thereby effectively and efficiently protecting their assets and information. Risk analysis can help organizations to:
- identify, classify and compare the overall impact of risks on financial and organizational aspects;
- identify security gaps and determine next steps to eliminate weaknesses;
- improve communication and decision-making processes related to information security;
- improve security policies and procedures and develop cost-effective methods for implementing such processes;
- implement security controls to mitigate risks.

This procedure can be an important tool in the management of costs associated with risks and in the decision-making processes. Its implementation within companies has become increasingly common and essential.

7.1.4. Risk Assessment Methodology

The predictive maintenance process is enabled by predictive analytics, which reduces an asset downtime. By enabling condition based or predictive maintenance railway system availability is maximized.

Traditionally, preventive maintenance relied on industrial or in-plant average life statistics, such as mean-time-to-failure (MTTF), to assist in the scheduling of maintenance events. With preventive maintenance, a service log served as the communication instrument alerting plant or maintenance technicians of machine or equipment breakdowns occurring over time. The log required documenting detailed information on the machine/equipment and its breakdown conditions by the plant or maintenance technicians. Although the process was effective in recording the occurrence after the repair, machine breakdowns were still quite costly.

Today, however, maintenance activities can be effectively minimized by using predictive analytics. With predictive analytics, a machine's system efficiencies and electrical and mechanical conditions can be directly monitored using a variety of non-invasive measuring instruments.

For the implementation of the new process to be effective, it is important to carry out a risk assessment. There are several ways to identify and characterize risks, such as holding brainstorming meetings, obtaining expert opinion or seeking historical information and knowledge accumulated in previous projects of a similar nature. Wikipedia defines risk matrix as "a matrix that is used during risk assessment to define the level of risk by considering the category of probability or likelihood against the category of consequence severity. This is a simple mechanism to increase visibility of risks and assist management decision making".

Risk is the lack of certainty about the outcome of making a choice. Statistically, the level of downside risk can be calculated as the product of the probability that harm occurs (e.g., that an accident happens) multiplied by the severity of that harm (i.e., the average amount of harm or more conservatively the maximum credible amount of harm). In practice, the risk matrix is a useful approach where either the probability or the harm severity cannot be estimated with accuracy and precision.

For more than a decade, the risk matrix has been the go-to decision-making tool for assessing risk. It is practical, easy to use and flexible enough to apply to various risk types and situations, including:
- Assessing risks of a particular asset
- Deciding which investments or projects have the highest importance
- Choosing which risk controls to implement

Although standard risk matrices exist in certain contexts, individual projects and organizations may need to create their own or tailor an existing risk matrix. For example, the harm severity can be categorized as shown in the table below.

Figure 27 - Example of a Risk Matrix

		Impact			
Likelihood		Negligible	Minor	Moderate	Significant	Severe
	Very Likely	Low Med	Medium	Med Hi	High	High
	Likely	Low	Low Med	Medium	Med Hi	High
	Possible	Low	Low Med	Medium	Med Hi	Med Hi
	Unlikely	Low	Low Med	Low Med	Medium	Med Hi
	Very Unlikely	Low	Low	Low Med	Medium	Medium

Source: ARMS Reliability www.thereliabilityblog.com

In this example, the probability of harm occurring might be categorized as 'certain', 'likely', 'possible', 'unlikely' and 'rare'. However, it must be considered that very low probabilities may not be very reliable.

7.1.5. Preparation of the Risk Matrix – SWOT Analysis

For this stage, it sought to involve people with expertise, attitude and a clear understanding of corporate culture, ViaQuatro, ViaMobilidade, CCR Metrô Bahia and VLT Carioca. The SWOT analysis technique was used to collect existing, probable or obvious risks.

First, a SWOT analysis framework was developed that shows the strengths and weaknesses (internal factors) plus opportunities and threats (external factors).

Figure 28 - SWOT Analysis
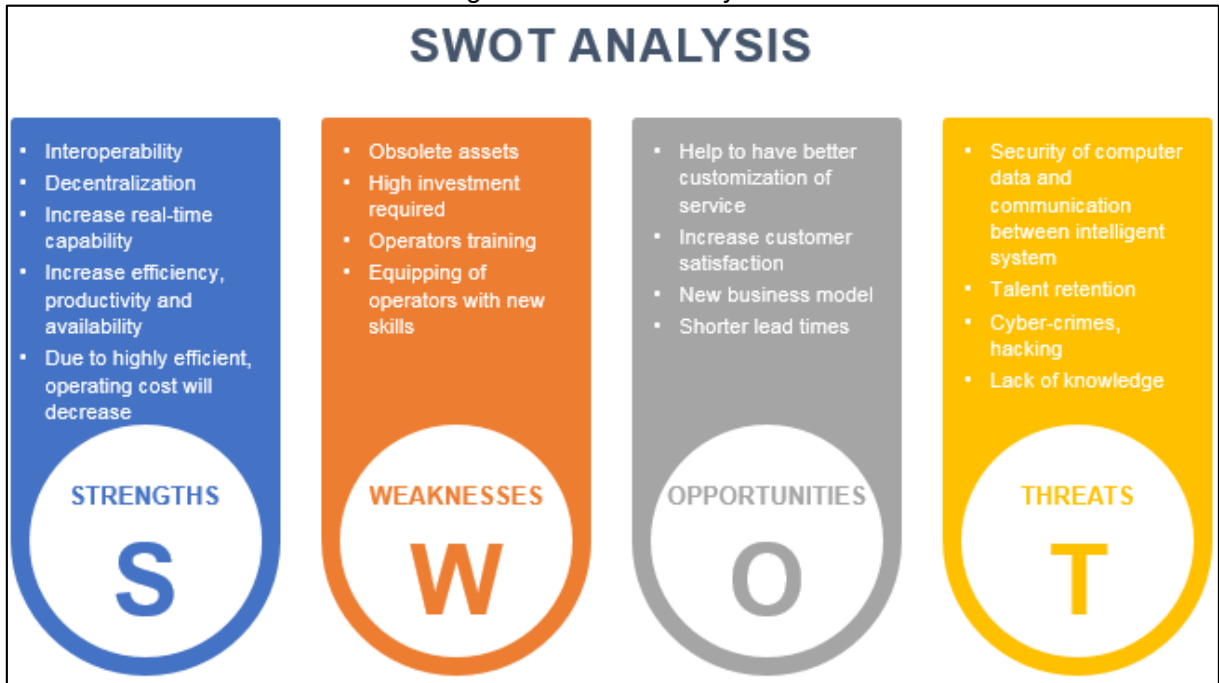
After the SWOT phase, an analysis was made by the specialists, where the risks were defined, together with the respective probability and impact of each one. The Risk Portfolio methodology was used. The following table presents an extract containing 6 risks, and the assessment of the respective impacts and probabilities and then the Risk Portfolio Analysis.

Table 5 - Risk table: impact and probability

Risk	Impact	Probability
Obsolete Assets	1	3
Low Expertise for personnel	3	2
Impossibility to fully integrate with existing systems	2	2
Difficulty on talent retention	2	3
Cyber-crimes, hacking	3	1
High Investment required	3	3

Figure 29 - Risk Portfolio Analysis
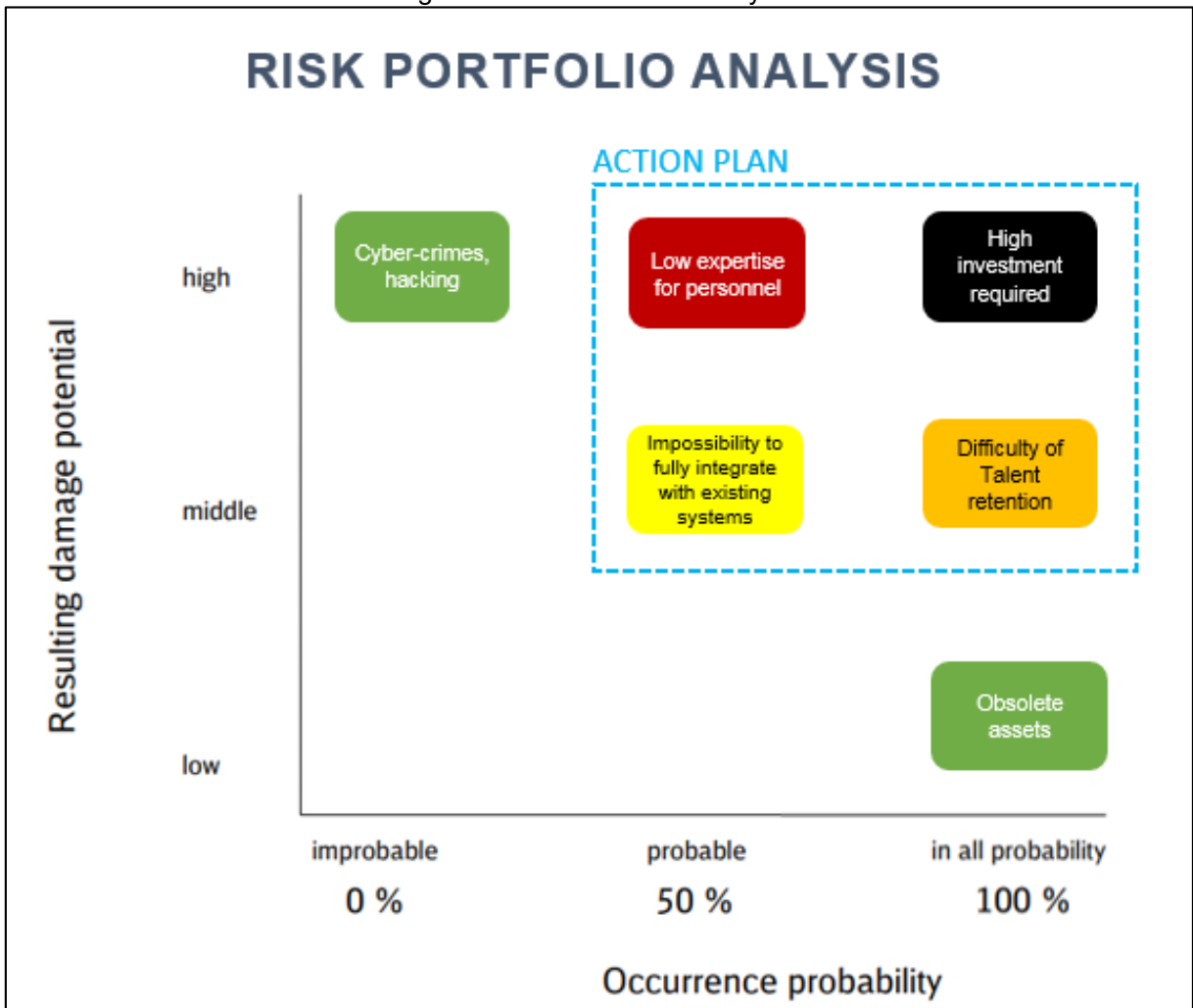
7.2. Project Plan / Implementation Plan

Industry 4.0 is the inevitable future. Over time, all companies will have to adapt or will stay out of the competitive market. The same goes for maintenance. In a world where competitiveness is measured and achieved with details, traditional maintenance has increasingly lost its space, since it only observes the master plan and meets corrective measures. It is necessary to enter maintenance 4.0, integrate supervisory systems, collect information from all sources of information, learn from the results and generate value from all of this, whether saving resources or increasing availability.

There is no recipe for this and following the best practices of those who today are generating results in this business is a good strategy.

1) Define a committee for implementation: a small group of people, but with the power to make necessary decisions;

2) Brainstorming (or another technique) with stakeholders in order to find the gaps where the most significant gain can be obtained with the application of technology. In this work, it was identified some themes common to the railway that are rich in logs, sensors and structured information or not, who would benefit from the application of maintenance 4.0;

3) Prioritize and identify which of the scopes raised will bring profit to the company if they are made. It is worth reinforcing the 80/20 principle, where only 20% of the requirements really add value to the company;

4) Determine the budget for the Project, as this factor will also help in setting priorities.

To be used as a guide, the flow below illustrates the processes to be covered during the implementation of the Maintenance 4.0 project, in a macro way.

Figure 30 - Flow to Implement Maintenance 4.0
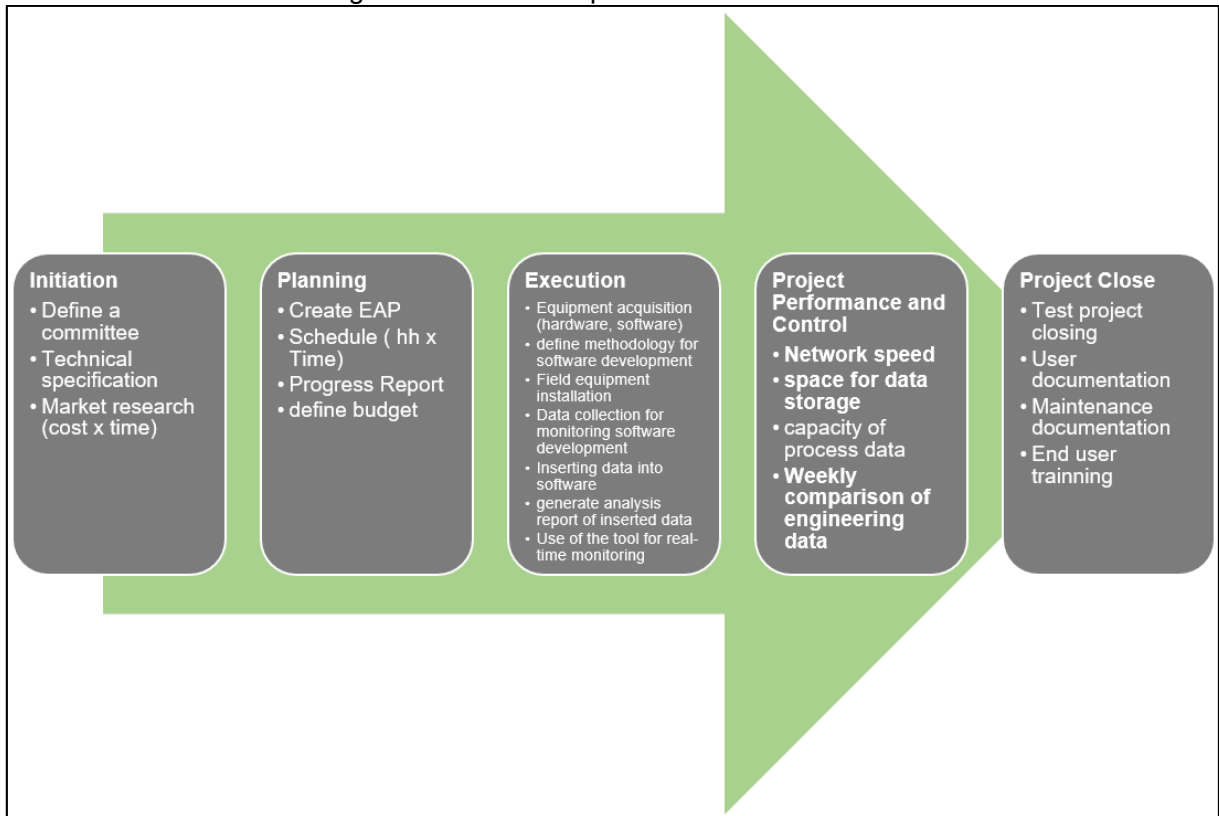
From that point it will depend on the technology to be implemented. In the case of using Big Data, the process is similar to that illustrated below: a step-by-step roadmap to big data implementation.

Figure 31 - Six Milestones of a Typical Big Data Project

Source: https://www.scnsoft.com/blog/big-data-implementation

Big Data implementation plan starts with single steps as described below:

1. Turning business needs into use cases: the project starts with eliciting business needs. The main goal of this stage is to look beyond the needs that stakeholders explicitly voice out and spot even those they might have not even acknowledged yet. Once business needs are identified, they should be translated into use cases (i.e., 360-degree customer view, predictive maintenance or inventory optimization) that a future big data solution is to solve.

2. Designing a big data architecture at this milestone, you should have the main components of your future big data solution, i.e., a data lake, a big data warehouse, and an analytics engine, identified. at this step is necessary to decide on what technologies to base all the architecture components. must have formalize your data sources (both existing and potential), as well as data flows to have a clear picture of where data comes from, where it goes further and what transformations it undergoes on the way.

3. Integrating big data with existing applications and systems: Results obtained during big data analysis must become an input for other systems and applications. To benefit from the synergy and leverage existing applications and processes, is necessary to identify the applications that should be integrated with the big data solution.

4. Working on data quality: Is very important to analyses the 5 main big data characteristics and find a trade-off between the quality level you find acceptable and the costs, efforts, and time required to achieve this level. Besides, an additional attention is necessary during the while devising data quality rules for your big data solution do not ruin the solution's performance.

5. Turning the design into code: At this stage, the big data architecture is deployed either in the cloud or on premises, the applications and systems integrated, and the data quality process running. If the big data solution is powered with data

science, you'll also have your machine learning models designed and trained at this stage.

6. Training users: at this stage to train the users, this propose is to capacity various user groups understand how to use the solution to get valuable and actionable insights.

7.2.1. Agile Methodology

The concept of agile methodologies is relatively new, and emerged from the Agile Manifesto, launched in 2001. The search for the standardization of processes and practices of excellence in project management is constant in companies that want the continuous improvement of their operations. In this type of environment, agile methodology emerges as an advantageous alternative due to its potentials, especially for organizations that operate in sectors related to technology.

Unlike the conventional method, where the customer participates in the specification of requirements and stays for a long time waiting for the completion of the entire process to receive the final product, in the agile methodology a script for partial deliveries is prepared which already add value to the customer until that the final product is done, and in this way the customer, with little project time, can already make use of some of the features for his benefit..

Each sprint for a new delivery defines which scope should be approached, enabling stakeholders and developers to experience the 20-80 thesis, where it is argued that 20% of the requirements will actually be used and make a difference in the product, 80% will not use or will not be effectively relevant. In this way, with a dynamic development, it avoids spending resources on parts of the project that are not relevant.

To understand how to work with agile methodology, the picture bellow shows its use in SCRUM:

Figure 32 - Agile *M*ethodology
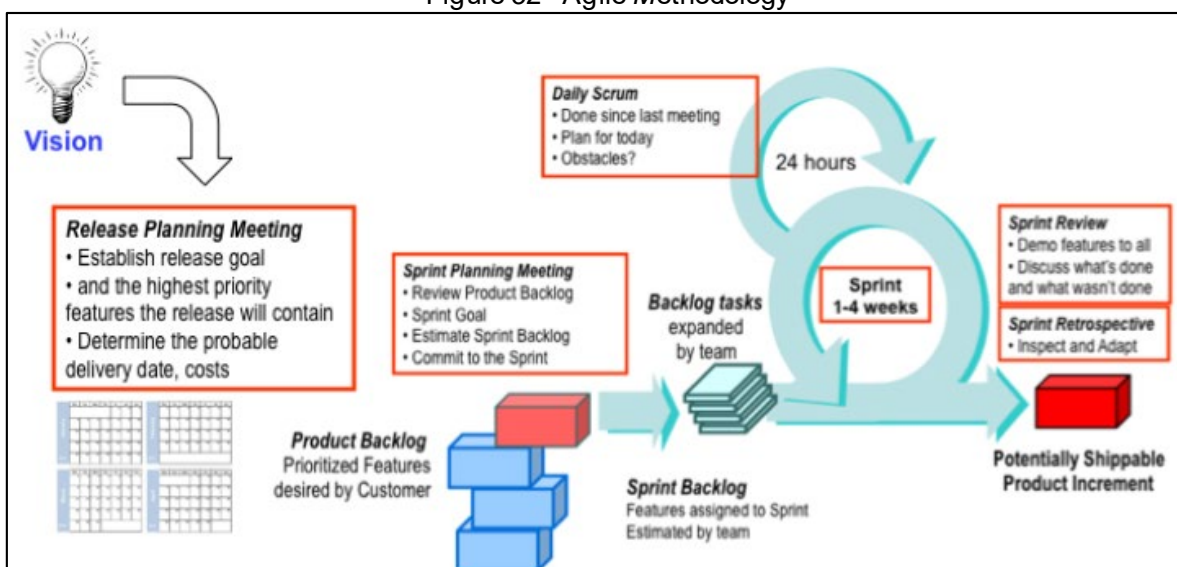
Source: SCRUM Handbook

The product backlog: The Product Backlog is a prioritized list of what's required, ranked in order of value to the customer or business, with the highest value items at the top of the list. The Product Backlog evolves over the lifetime of the project, and items are continuously added, removed or reprioritized.

The sprint: Scrum structures product development in cycles of work called Sprints, iterations of work that are typically 1–4 weeks in length. The Sprints are of fixed duration and end on a specific date whether the work has been completed or not; they are never extended.

Sprint Planning: At the beginning of each Sprint, the Sprint Planning Meeting takes place. The Product Owner and Team reviews the Product Backlog, discuss the goals and context for the items, and the Team selects the items from the Product Backlog to commit to complete by the end of the Sprint, starting at the top of the Product Backlog. Each item selected from the Product Backlog is designed and then broken down to a set of granulated steps.

The purpose of this work is to combine the advantages of Big Data with the development oriented to agile methodology and in this way add value to the maintenance process from the beginning, in addition to making it possible to make it compatible with overcoming the obstacles previously presented in the data collections for the system Big Data (integration of data sources, that is, reports will become richer in data as data from different sources are aggregated).

7.2.2. Financial Plan

The first and probably the most important decision in corporate finance concerns where to invest the scarce resources invested in companies. This type of decision is referred to in academic texts on corporate finance as capital budgeting, and basically refers to the process used by corporations to analyze and choose investment projects.

Thus, the capital budget describes the long-term planning to evaluate, choose the investments to be made and monitor the capital disbursements of the company's projects or programs (Horgren; Sundem; Stratton, 2004).

4.0 technology investments require the same in-depth quantitative and qualitative analysis performed for all other potential major investments. It includes consideration of the short- and long-term costs and benefits—the net value-add to the business.

How, then, to implement the 4.0 maintenance concepts, with new technologies and, at the same time, generate return for the business?

The whole world is experiencing a transition to Industry 4.0. "Turning the key" and adopting Industry 4.0, especially here in Brazil, is not that simple. The obstacles and challenges are greater, especially for small businesses, which do not have such great investment power.

As presented in this work, Industry 4.0 demands the adoption of technologies and systems that allow it to become more autonomous through data collection. Thus, it is possible to monitor processes, make agile and accurate decisions and act more consistently in predictive maintenance. However, this does not mean that the entire industrial park needs to be disregarded and, therefore, there is no need to start from scratch. The implementation and testing cycle must be carried out with small, well-defined problems, gradually being extended. The cases cited in this work suggest this.

The first step to start the changes towards Industry 4.0 is to raise the main bottlenecks and check the opportunities. From there, it is possible to list the priorities and direct investments, so the return obtained from the first changes can finance the next steps.

For each opportunity, it is necessary to create a "flight plan", stages where the result is increased over time, all interested parties must know the plan for a correct alignment of expectations.

After the total implementation, the comparation is possible and the gain to the company is tangible.

Another possibility is to find references, a company in a more advanced stage of using a system / technology similar to the one you want to use, this result is used to base the gain estimate, but you must always plan a "flight plan".

Figure 33 - Flight Plan
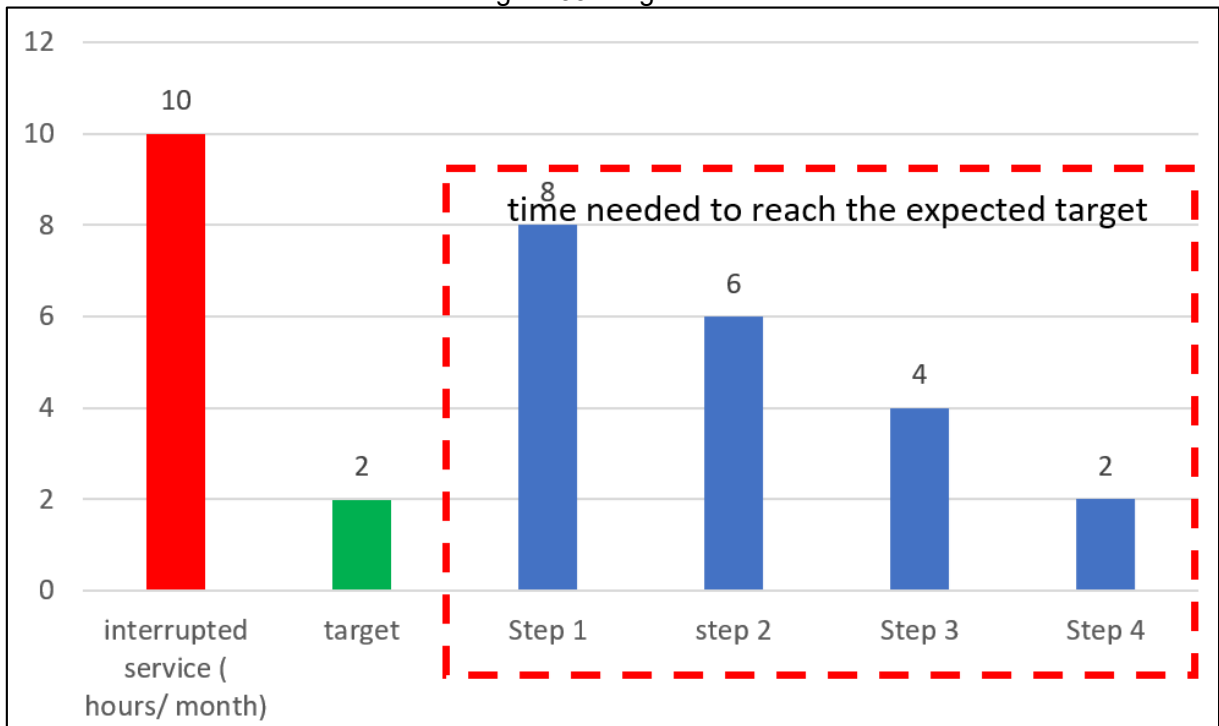
Understanding the results and creating an effective plan and changing the way in which maintenance teams operate are time-consuming activities, it is important that the plan contemplates all phases so as not to frustrate project investors.

8. FINAL CONSIDERATIONS

The impacts of Industry 4.0 technologies are inevitable and profound. Even the rail public transport sector, which can be considered a very traditional sector from the point of view of asset management practices, is being strongly affected by these new technologies. The pressure to optimize resources, whether labor or inputs, is increasing and the sector needs to adapt itself to be able to adopt new practices in line with the trend of Industry 4.0. The good news is that the opportunities are huge and even small initiatives that do not require large investments or efforts can bring significant gains.

The first step is to familiarize employees with the new technologies of Industry 4.0 and its possibilities so opportunities can be identified and then implemented according to the line operator's strategic plan. The opportunities presented in this work

are not limited to the rail public transport sector, since they can be easily adapted and adopted by other sectors of the industry. The proposed implementation methodology aims to highlight the main aspects that must be evaluated, beforehand and throughout the process, by companies that intend to implement new initiatives. In line with the methodology presented, agile methodology is suggested as a way of inserting the process of adopting new initiatives in the company's routine, minimizing the impact on the current processes performed by employees.

This paper sought to identify the most evident opportunities for asset management, the implementation of which is feasible from the use of information already available by the systems or easy to capture. It is characterized as the first steps for the company to enter Industry 4.0. However, many opportunities can be identified by studying the topics of interest in asset management in more depth. There are many possibilities to study in depth initiatives that require initial investments, as the feasibility can be calculated and prove to be quite interesting.

Finally, Industry 4.0 is an inevitable trend that will determine the survival of current companies in the medium and long term. As these new concepts are based on new technologies, it will require efforts to train and adapt companies so that the results will be achieved.

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