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POINT MACHINE MONITORING

BRASÍLIA-DF

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Final project of the course Certificação Internacional em Gestão de Sistemas Ferroviários e Metroferroviários

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Contents

LIST OF ABREVIATION

CT Current transducer
ETA Event tree analysis
FTA Failure tree analysis
IoT Internet of things
OCC Operation Control Center
OCC Operation Control Centre
PLC Programmable Logical Controller
UPS Uninterrupted power supply
VPN Virtual private network
VT Voltage transducer
WBS Work Breakdown Structure

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1 Brief description of the chosen topic

Metro systems plays a key role on passenger mobility on big cities across the globe, the operational standard of these enables the city to transport hundreds of thousands passengers every day are very high and only achievable by the automation of many process. One of them is the operation of point machines, which are responsible for changing the route of the train and keeping the carrousel of metro lines running.

Point machines is a device for operating railway turnouts, it is also known as: point motor, switch machine or switch motor. On the beginning of the era of the railway lines this devices were operated manually by levers. With the increase of the traffic and thus the design complexity of the railway lines, the operation of point machines were centralized on signal boxes that could control remotely a few point machines. It was first controlled by means of wires or rods, which limited the distance between the signal box and the point machine to hundreds of meters. Later new technologies, such as: electric motor, hydraulic or pneumatic actuator; enable the power operation of the point machine and thus operate it from a greater distances even kilometers.

The industrial revolution of the 18th century changed the world drastically and since then the development of new technologies, machines and process never had stopped. The second decade of the 2000’s are being described by social scientist as the dawn era of the fourth industrial revolution characterized by technologies that are blurring the lines between the physical, digital, and biological spheres. One of the emerging technologies is the Internet of Things (IoT), the network of devices such as vehicles, and home appliances that contain electronics, software, actuators, and connectivity which allows these things to connect, interact and exchange data.

The focus of these educational project is to study means to implement sensors on a point machines to collect its operational data, these will be further processed and analyzed in order to monitor the operation condition of the device in order to better understand the operational conditions and reduced the potential down time of the asset, thus increasing the operational availability of the metro line. The educational project is based on a project of online

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monitoring of point machines developed by the metro line operator ViaQuatro (line 4 – yellow – of Metro Sao Paulo).

2 Railway turnout and point machines

Turnout, also known as railroad switch (on North America), Fig 1, is a mechanical installation enabling railway trains to be guided from one track to another. It consists of a pair of linked rails, known as points (switch rails or point blades), lying between the diverging outer rails. These points can be moved laterally into one of two positions to direct a train coming from the point blades toward the straight path or the diverging path. Another component of the turnout is the frog, also known as common crossing, it is the crossing point of two rails. This can be assembled out of several appropriately cut and bent pieces of rail or can be a single casting of manganese steel. On lines with heavy or high-speed traffic, a movable-point frog may be used. As the name implies, there is a second mechanism located at the frog. This moves a small portion of rail, to eliminate the gap in the rail that normally occurs at the frog. A separate switch machine is required to operate the movable-point frog switch.

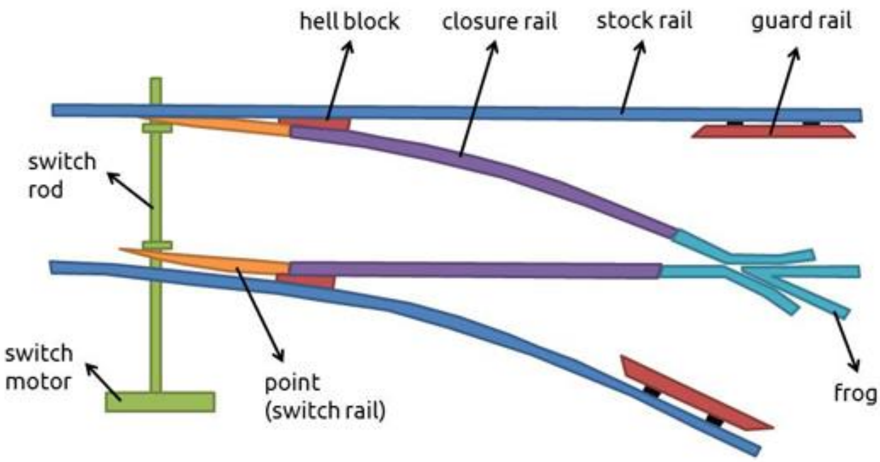

Fig 1: Turnout diagram

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Unless the switch is locked, a train coming from either of the converging directs will pass through the points onto the narrow end, regardless of the position of the points, as the vehicle's wheels will force the points to move. Passage through a switch in this direction is known as a trailing-point movement.

A mechanism is provided to move the points from one position to the other. Historically, this would require a lever to be moved by a human operator, nowadays most are operated by a remotely controlled electric motor, by pneumatic or hydraulic actuation, called a point machine. This both allows for remote control and for stiffer, strong switches that would be too difficult to move by hand.

Generally, switches are designed to be safely traversed at low speed. However, it is possible to modify the simpler types of switch to allow trains to pass at high speed. The conventional way to increase turnout speeds is to lengthen the turnout and use a shallower frog angle. If the frog angle is so shallow that a fixed frog cannot support a train's wheels, a moveable point frog will be used.

3 Internet of Things (IoT)

According to Margaret Rouse on the article on the internet site https://internetofthingsagenda.techtarget.com the internet of things is: a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. A thing in the internet of things can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an IP address and is able to transfer data over a network. Increasingly, organizations in a variety of industries are using IoT to operate more efficiently, better understand customers to deliver enhanced customer service, improve decision-making and increase the value of the business.

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An IoT ecosystem consists of web-enabled smart devices that use embedded processors, sensors and communication hardware to collect, send and act on data they acquire from their environments. IoT devices share the sensor data they collect by connecting to an IoT gateway or other edge device where data is either sent to the cloud to be analyzed or analyzed locally, Fig 2. Sometimes, these devices communicate with other related devices and act on the information they get from one another. The devices do most of the work without human intervention, although people can interact with the devices - for instance, to set them up, give them instructions or access the data. The connectivity, networking and communication protocols used with these web-enabled devices largely depend on the specific IoT applications deployed.

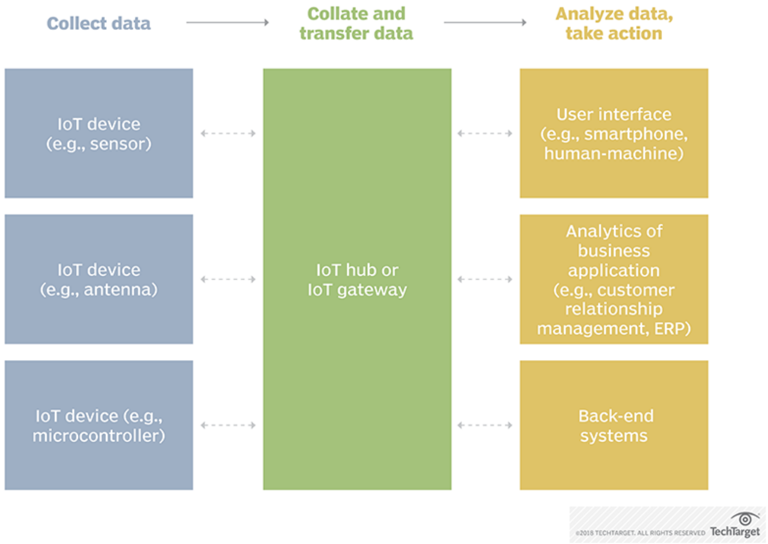

Fig 2: Example of an IoT system.

4 Overview of passengers railway lines of São Paulo metropolitan region and Porto Alegre metropolitan region

Sao Paulo metropolitan region comprehends 21.5 million habitants, just the city of Sao Paulo concentrate 12.1 million habitants with a population density of 8.005 habitants per km². The city metro system, which operates only within it, has 96km of rails divided in 5 lines. Sao Paulo metropolitan region has a suburban train network of 273km, Fig 3, that reaches many of the neighborhood cities and is integrated, with no extra fee, on the metro network. The whole system (suburban trains and metro) transports daily circa 4.5 million passengers.

All metro lines uses advanced railway signaling and are automatic operated. During normal operation the point machines are automatically operated, as the headway could be as short as 100 seconds.

As the system is fully integrated delays in any of the lines would lead to delays on the whole system, as a cascade effect. And on a, worst case scenario, the whole system could be shut down. During rush hours the busiest lines could reach 10 passengers per m² and any delay would cause huge inconvenience for the passengers.

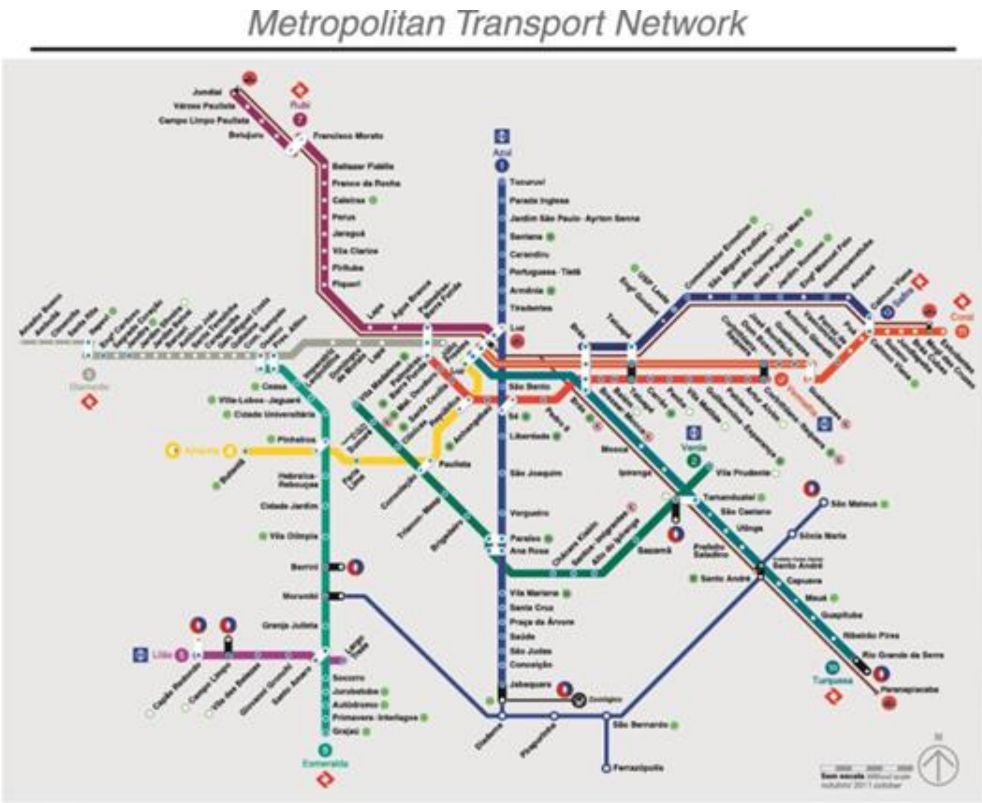

Fig 3: Map of Sao Paulos railway network

Porto Alegre metropolitan region comprehends 4.3 million habitants and has a suburban train line that reaches almost 60% of its population. The system consists of 22 stations, a 43 km double track line equipped with ATC/ATS signaling system, connecting Porto Alegre to Novo Hamburgo. Daily circa 170 thousand people are transported.

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The line construction started in 1982 and has been extended twice, it has 122 point machines, 32 hydraulic-electric and 90 electric. On the initial implementation it was installed 76 electric point machines produced by Kyosan, 55 on the main line of the model 1206F (non- trailable) and 21 on the yard of the model 1211L (trailable). On the first expansion 14 electric point machines of the model JEA 73 produced by Bombardier were installed on the main line. On the last expansion 32 hydraulic-electric point machines of the model Unistar HR produced by Contec (a subsidiary of the company Voestalpine), this machines has moveable frogs.

The train is a key means of transport, a great portion of the population use it for the day-to-day transportation, and any failure that could cause operation restrict can lead to huge traffic jams on the adjacent roads causing huge inconvenience for the passengers.

5 ViaQuatro (line 4 – yellow) overview

Line 4 is a 12.8 km underground metro line with 11 stations and it is the first Brazil driverless metro line, Fig 4.

Fig 4: Line 4 map, circles indicates integration with other railway lines.

Apart from power supply supplied by Metro Sao Paulo on the stations Luz, Republica, Paulista; the line does not share any system with other metro lines.

The line main characteristics are:

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- Stations equipped with Platform Screen Doors (PSD);
- Length of platforms: 132m
- Track: Gauge: 1.435m, Rail profile: UIC-60;
- Power supply through catenary (1500 VDC);
- At the end of the track, mobile self-braking bumpers capable of absorbing the impact of a train without passengers at the speed of 15 km/h;
- The line is completely underground with a single tunnel and the yard (at station Vila Sonia) is at the surface;
- More information about the line on the Fig 6.

Maximum operating speed

- 80 km/h on the main line;
- 25 km/h on secondary tracks and Yard;
- 65 km/h for passing by the platforms;
- 40 km/h for passing diverted point on the main line;
- 40 km/h in case of imposition of speed restriction;
- 37 km/h on the test track.

Trains operates in full automatic mode (MTO), without any necessary operating personnel in the train and in station. Turn back operations at terminal stations and most of the movements in yard are operated in full automatic mode (MTO), except for the transfer between yard automated zone and workshop zone. System operations and supervision are performed from the Operation Control Centre (OCC). The control and vital functions are mainly performed either by on-board or wayside train control equipment (ATC and interlocking).

Whereas trains remain protected even auxiliary vehicle are moving in the automated area, operating rules for auxiliary vehicle have to be specified in an operating procedure in order to avoid operation to be disturbed by auxiliary vehicles. For that purpose, the auxiliary vehicle need to be detected by AC Track Circuit and TCM100 Systems. If not, their use in automated area is strictly prohibited during commercial operation, Fig 5.

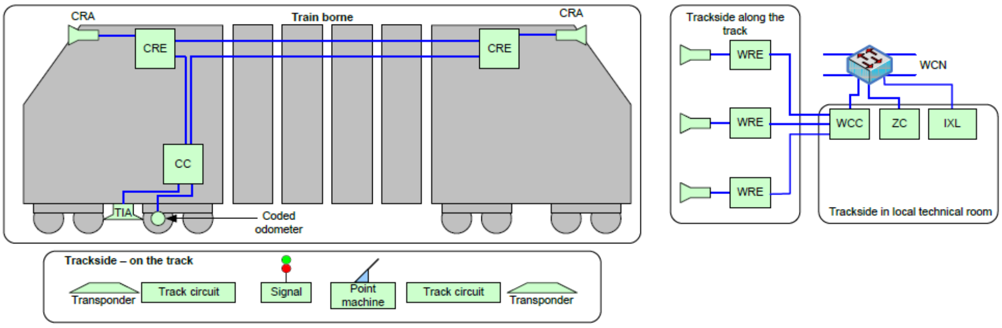

Fig 5: train control system architecture on the line.

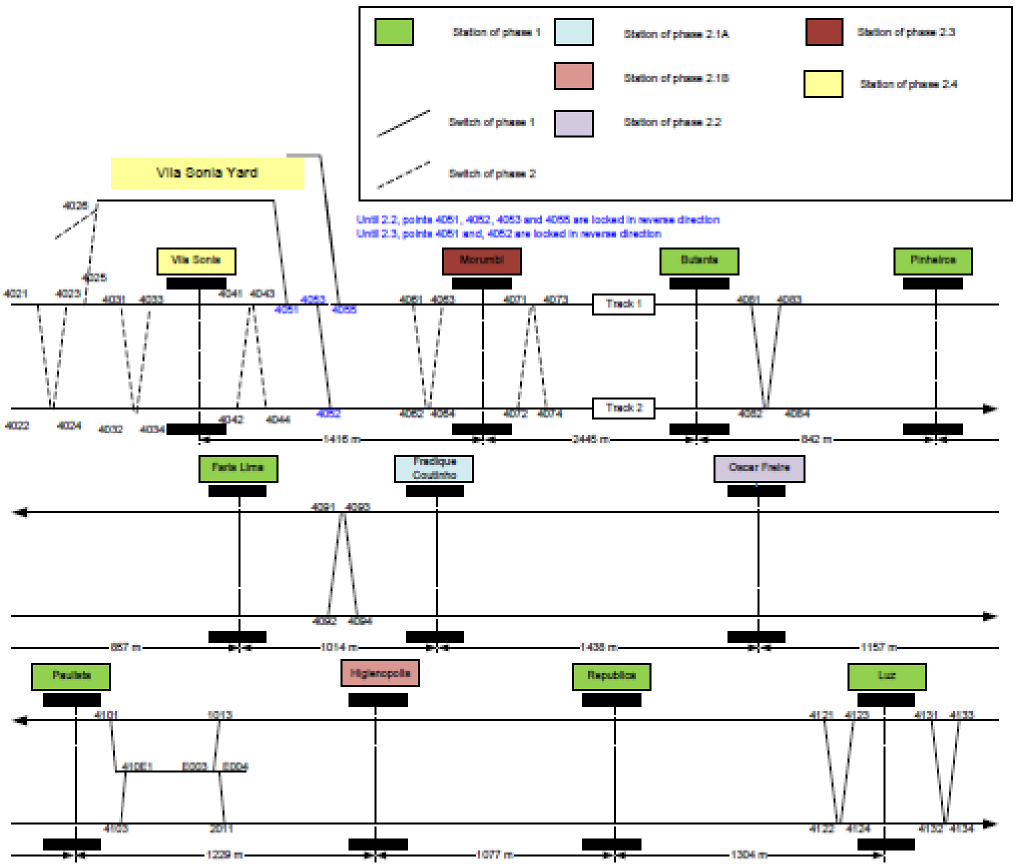

Fig 6: Line synoptic

Interlocking system of the main line and yard composed of:

- Signals;
- Point machines and position detectors;
- Track circuits;
- IXL cabinets installed in technical rooms equipped with two local operation workstations: on for maintenance operation of the

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interlocking and another for local routes command in case of communication malfunction between IXL and ATS;

- Emergency IXL remote control located in OCC, to send commands to an IXL from the OCC;
- More information on the Fig 7.

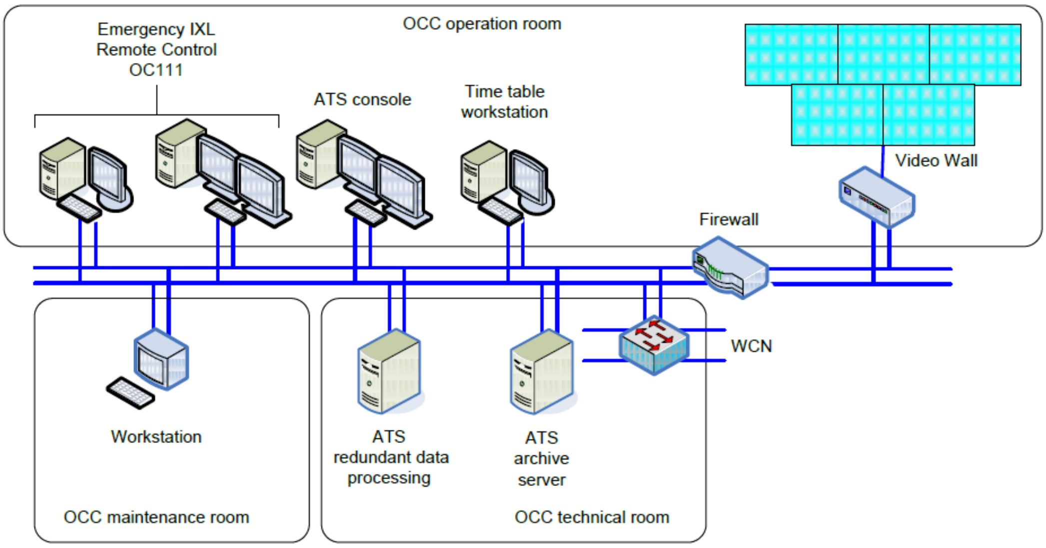

Fig 7: Train control system architecture in OCC.

On the main line are installed 70 electric point machines S 700 K produced by Siemes, Fig 8, it is used both on the moveable frogs and on the point (switch rails). On the switch rails the trailable version is used and on the moveable frog the non trailable is used.

Fig 8: point machine for the switch rail (far) and for the moveable frog (near).

The signaling system indicates for the OCC operator a failure of a point machine, Fig 9, however the indication is very succinct: limited to an ERROR message and the indication of the point machine related to the failure. The

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fault could be an issue related to the power supply, a mechanical issue, a failure on the sensor… The lack of further information difficult the prompt re-establishment of the operation condition by the maintenance gang.

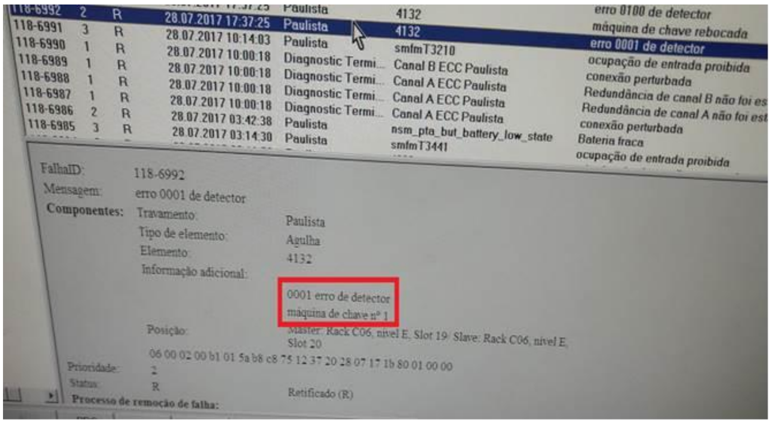

Fig 9: Point machine failure message.

6 Hypothesis

As the percentage of the population living on the cities and the demand for public transportation are increased exponentially during the final half of the last century it is worth to take actions to increase the availability of the metro lines, especially on older metro lines, on which a greater rate failure due to the aging of the infrastructure is expected.

Metro lines are usually double track lines with a set of point machines on the line extreme, which are crucial for the line operation as it are responsible to direct the train from one line to the other. On some lines there could be also multiple carrousels and thus point machines on the middle of the line would also be very important. It is worth to mention that another very important point machine are the ones on the entrance of the maintenance yards or parking yards, a failure on it could lead to severe operational restrictions, especially during peak hours. A single failure on a critical point machine for the system could lead to a line stop, which could lead to a

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significant incident if the duration is longer than three times the planned headway.

At Brazil the commercial operation of metro lines are from 4:00 until midnight, circa 20 hours per day, leaving just a 3 hours window during the night for the maintenance to work on the line. And within this period the travel time from the maintenance yard to the line equipment must be also encompass. As it turns out the interval is extremely short, and it is worth to note that in some cases the preventive/predictive maintenance, which are actions to keep the equipment healthy, must be postponed due to the necessity of a corrective maintenance, due to the equipment failure. On the other hand, some activities needs more than three hours and must be performed on successive nights and, unfortunately, could impose during the period restrictions on the system operation.

At ViaQuatro on 2018 the point machine rate of failures were relatively low in comparison to past years, Graph 1, however the lack of predictive maintenance and some failures on the scope of the preventive maintenance lead to two significant incident, which stoped the line commercial operation for a while. It is worth to notice that on 2017 many corrective maintenance took place.

At Trensurb on 2018 were registered 108 failures on the point machines, almost 80% of the point machines failures were related to uncertain position on straight or diverted position, the stratification for the different types of machines is on the Graph 2. The corrective action taken on 26% of the failures were lubricate and clean the point machine, follow by adjustment of the sensor rod with 17%.

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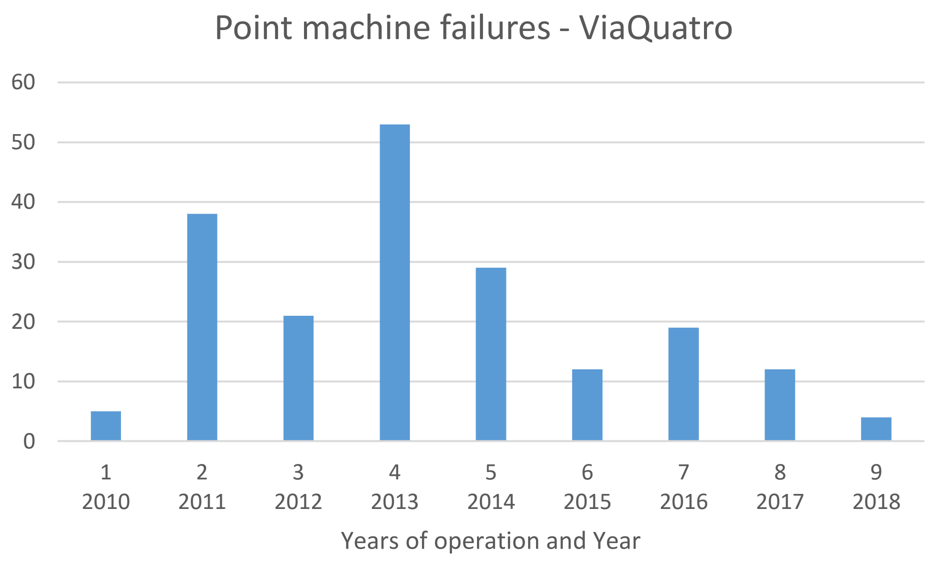
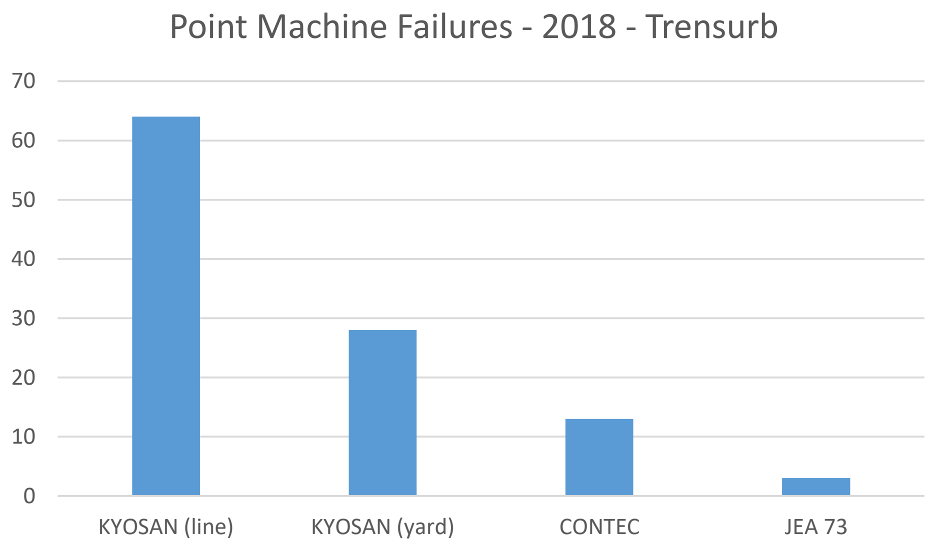


Graph 1: Point machines failures - ViaQuatro



Graph 2: Point machine failures 2018 - Trensurb

At ViaQuatro the preventive maintenance of the point machine takes circa 1 hour, on the whole system during a year circa 370 hours are spent on it. As the maintenance gang has four member it takes circa 1.488 hours of the maintenance team. At Trensurb the preventive maintenance of point machines consists of: visual inspection of the equipment, current measurements, sensor inspection and lubrication. For the critical point machine the inspection interval is a month for the others the interval is three months. The inspection of each point machine takes circa 45 minutes, so yearly circa 400 hours are spent on point machines preventive maintenance.

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As the maintenance gang has four member it takes circa 1.600 hours of the maintenance team.

A system that could online monitor the condition of the point machine would increase the available information about the behavior of the point machine and improve the predictive maintenance. The analysis of this information could lead to alerts of possible failures and avoid corrective maintenance, thus increasing the availability of the asset. The data could also optimize the preventive maintenance schedule, enabling the company to better use the human resources.

7 Generate ideas

Point machines on metro lines are remotely controlled from the OCC, the command to change direction is sent by means of a logical network until the signal box, there relays will energize the engine of the point machine and a device will monitor the movement of the machine. When a command to change the direction is sent and the machine does not change the direction within a certain amount of time or the PLC could not detect that the machine is in position and locked an error message will be sent to the OCC and trains could not use this route, because it is unsafe.

The energy necessary to change the direction of the point machine from straight to diverted, or vice-versa, is strictly correlated to the effort needed to move the components and to overcome the resistance of the movement, as the resistance to the movement increase the energy necessary increases.

Electrical energy can be easily measured by a CT (current transducer) and a VT (voltage transducer) that can be installed on the relay room and plug into a PLC, that will receive the information, process and send the data to the OCC by means of a logical network, where it finally can be processed and stored. On electrical-hydraulic point machines a pump, driven by an electrical

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motor, pressurized an oil that by its turn will move the switch rails by means of a hydraulic actuator. On these types of machines it is also necessary to monitor the oil pressure.

There is an additional aspect of this: over the years railway lines have upgraded the logical network that connect the relay room to the OCC; in the past the data transmission rate were extremely low and the network throughput were also low, nowadays fiber optic connection became a common standard and there is huge capacity for data transmission. The price of electronic devices are also decreasing exponentially over the years, making possible the massive acquisition of hardware such as CT, VT and PLC.

All equipment related above, to be used on the online monitor system, are promptly available on the market and with accessible prices. The idea is to use those in order to scale the project to all point machines installed on the metro line. It is also important to notice that some companies specialized in railway assets monitoring also commercialized system specifically for point machine, on this educational project a commercial system will also be assessed.

The idea is to enable the maintenance to monitor online the operation condition of the point machine and storage this information to analyze broad trends. This analysis could detect deviations on the point machine behavior before a failure occur, therefore improving the maintenance approach on the asset by optimizing the predictive and preventive maintenance.

Maintenance could gain a lot with assets online information and even more with the analyses of the historical data of the equipment, such gains could lead to improvement on the predictive and preventive maintenance activities by reducing the corrective maintenance interventions, increase the maintenance team productivity, optimization of the preventive maintenance cycles and scope, the analysis of the historical data could also improve the maintenance on the verification of intermittent failures. Actions that would reduce the maintenance intervention on the assets and deepen the maintenance equipment know how. Regarding the point machine, it is forecast

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a reduction of circa 50% on the preventive maintenance time with the elimination of the current verification procedures.

8 Theoretical foundation

Point machines can be online monitored by the energy consumed during the changing of direction, as the machine is electrical the energy consumed is proportional to the current consumed by it and the voltage of the power supply. As the energy supplied is stable, with minimal oscillation, it is possible just to measure the current with a current transducer. On the market, there are plenty of current transducers available with different sizes and features for many applications. In order to select a current transducer it is necessary to define the range of the current that will be measured the available space to mount the device and how it can be assembled.

As mentioned before, the energy necessary to change the direction of the point machine is strictly correlated to the effort needed to move the components (rail, rods, gears…) and to overcome the resistance of the movement. The resistance of the moving parts can be controlled with suitable lubrication (usage of grease and oil), with the removable of dirties or objects that can interfere the movement, keeping the alignment of the parts within the tolerance inform by the supplier as well as the clearances, gaps, flush… If any of these factors are out of control the machine will increase the energy consumption in order to overcome the resistance.

On hydraulic-electric point machine the electric motor drives a hydraulic pump to pressurize a fluid that will move the switch rails (or the moveable frog). On this type of machine it is necessary to monitor the electric motor consumption and the hydraulic system pressure in order to verify the behavior of the point machine.

The current consumption curve of a point machine during a normal operation consists of a peak (due to intrinsic characteristics of the electrical

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motor), which the maximum value is the “in rush” current of the motor, and a relative flat line. The characteristics of these graph varies a little bit between operations, so it is possible, on a machine with optimum adjustment, to detect the signature of the point machine operation, or its normal behavior. It is important to detect the signature of each machine, as none is equal due to innumerous factors related to its assembly and installation. Perturbation on the system causes deviations from the normal behavior, some are acceptable as it will not cause a failure and some are unacceptable because it will probably cause a failure on the system. It is important to detect the last one in advance and avoid the related operational retracements.

Regarding all the required work force necessary to perform these measurements manually, it is clear that the company would have a high labor cost and the process would be slow and not very effective, making an automation system the only viable option to establishing a reliable process and efficient.

The first step must be to define the hardware needed to perform these measurements continuously and accurately, without any human intervention during the process.

Once the hardware has been tested and defined, all measurements need to be addressed, and then to develop an easy-to-understand HMI system that show possible faults accurately, thus allowing a predictive maintenance performance.

The final part of this project will be the creation of a management tool, allowing the storage of all information, reporting and automatic fault handling, generating alarms for triggering predictive maintenance.

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9 Scope and limitations

The macro scope of the project is to improve the maintenance strategy of the point machines, from a time based preventive and predictive maintenance plus corrective maintenance to a more accurate and sophisticated preventive and predictive based on the actual machine condition and minimal corrective interventions by the analysis of the machine historical data and the remote verification of the point machine condition or the online verification of the machine parameters on friendly user interface. The scope is further divided in mini scopes:

- Data acquisition: scope relative to the data acquisition on the field (precisely on the relay room), the point machine current consumption must be measured without any interference on the system and the measurement devices must be non-invasive (no interference on the point machine electric circuit) due to the fact that the system security certifications might be invalidate with and invasive measurement system;
- Data transfer: the data acquired on the field must be transferred to the OCC using the available logical network, optic fiber connection with high throughput, without any interference on the network traffic;
- Data storage: A server, connected to all data acquisition devices through the data transfer system, will receive all the data acquired on the field and storage it;
- Data visualization: The storage data consists of numbers (current measurements) related to a point machine on a given time, in order to access this information on a productive way it is necessary to process and show it on graphs, detect deviations between different periods, generate alarms and so on. This will be achieved using a commercial available platform to develop a visualization software.

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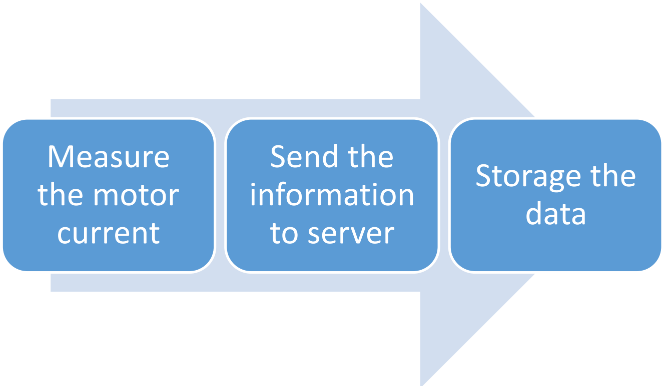
10 System for point machine data acquisition

On this chapter two different approaches are analyzed to acquire data from the point machine, the first approach is the internal development of a system and the second is the acquisition of a system commercially available.

The data acquisition process flow can be summarized as:



Than the data can be analyzed either by a software that will detect deviations or by a human on a graph or a table.

10.1 System design with market available components (System 01)

All devices of the system are standard devices, which reliable and easily available on the market devices. These characteristics makes it especially a good choice for a first tryout, in order to validate the idea.

On the field it is necessary to install the current sensors, the devices that will receive this information and another device to send it to the OCC.

After an analysis of the options available on the market it was selected a C series I/O model 9206 and a cDAQ Chassis model 9191, both devices produced by the company National Instruments. The first equipment has a series of analog inputs and outputs (I/O) that are used to receive the information from the current sensor and the second equipment, which is connected to it, sends the information to a PC over an Ethernet connection.

The chassis cDAQ model 9191 features also wifi connection (IEEE 802.11), which is not in use. So for further developments the similar chassis cDAQ model 9181, which does not features wifi connection can be a cheaper option.

The chassis C series I/O model NI 9206 features 32 isolated inputs with –10 / +10 V range, which makes it suitable for the monitoring of 16 point machines.

Fig 10: cDAQ chassis 9191 model for ethernet connection.

Fig 11: chassis C series I/O model 9206.

The first current sensor used on the system was the current clap I1010 from the supplier Fluke, which can measure current on a range between 0 and 1000 Amperes and has an output signal of 1mV/A. This sensor was chosen because it was promptly available on the company. After successive unsuccessful attempts to read the current it was clear that this sensor did not suit well the application due to:

- Too much noise on the reading signal due to the intrinsic characteristic current sensor and the National C Series I/O, which requires at least 200mV, for a satisfactory signal reading;
- Difficult to install the current sensor on equipment rack due to its size (200mm x 78mm x 48mm), which was too big for the available space.

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Fig 12: Current clamp I1010 produced by Fluke. Current range 0 to 1000 Amperes.

In cooperation with the supplier of the I/O module, National, a more suitable current sensor was selected, its minimum requisites were:

- Range of 0 to 5 Amperes, at least;
- Clamp type sensor, in order to not insert a device on the point machine electric circuit;
- Compatible with the C Series I/O module input;
- Reduced size, suitable for the equipment rack.

After an extensive search on the market the current sensor i5S from the supplier Fluke was chosen for tests. The sensor range is 0 to 5 Amperes and the output rate is 400mV/A, suitable for the application and the I/O module. Just one sensor was bought for test due to its extremely high cost, which could deter the whole project. Some test were performed on a laboratory, supervised by National application team, with successful results and the sensor was installed on the point machine number 436 on the line. Due to the different sensor output, in comparison to the I1010, some adjustments on the software were necessary.

The test on the field was extremely positive:

- The current sensor clamp prove to be easy to install;
- Data acquired by it was free from noise;

Fig 13: Current clamp i5S from supplier Fluke. Current range 0 to 5 Amperes

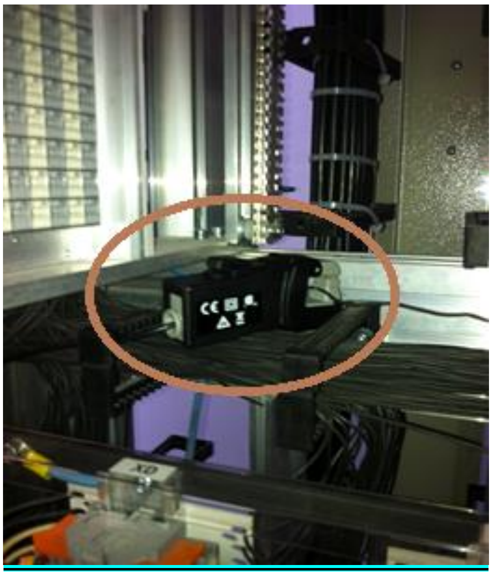

Fig 14: Current sensor i5S during the field test.

During the test the acquired data was storage on a data base and compared to the current measured by a Fluke 325 True RMS Clamp Meter installed on the same line. The current measured by both devices were very similar.

DATA	E HORA	CORRENTE
18/12/2014	09:03:02	1,927410
18/12/2014	09:03:03	1,271914
18/12/2014	09:03:03	1,269241
18/12/2014	09:03:04	1,269682
18/12/2014	09:03:05	1,271240
18/12/2014	09:03:06	0,787413
18/12/2014	09:03:24	1,734519
18/12/2014	09:03:25	1,253282
18/12/2014	09:03:26	1,251236
18/12/2014	09:03:27	1,253706
18/12/2014	09:03:27	1,256531
18/12/2014	09:03:28	0,907859
18/12/2014	09:03:35	1,484729
18/12/2014	09:03:36	1,298595
18/12/2014	09:03:37	1,272181
18/12/2014	09:03:38	1,269899
18/12/2014	09:03:39	1,270394
18/12/2014	09:03:39	1,272091
18/12/2014	09:03:40	0,650698
18/12/2014	09:03:46	1,677971
18/12/2014	09:03:47	1,252957
18/12/2014	09:03:47	1,252619
18/12/2014	09:03:48	1,253264
18/12/2014	09:03:49	1,256040
18/12/2014	09:03:50	1,007417
18/12/2014	09:03:57	1,489071
18/12/2014	09:03:58	1,298110
18/12/2014	09:03:59	1,272207
18/12/2014	09:03:59	1,270190
18/12/2014	09:04:00	1,269725
18/12/2014	09:04:01	1,272172
18/12/2014	09:04:02	0,649411
18/12/2014	09:04:20	1,410827
18/12/2014	09:04:21	1,261957
18/12/2014	09:04:22	1,252819
18/12/2014	09:04:23	1,251722
18/12/2014	09:04:23	1,254855
18/12/2014	09:04:24	1,257446
18/12/2014	09:04:25	0,454410

Fig 15: Data acquired during the first test with the current sensor i5S

As the architecture (current sensor + I/O module + Ethernet connection) was defined, further actions were taken to find a cheaper and suitable current sensor on the market. After an extensive search the sensor YHDC model SCT013-010 was selected, the sensor range is from 0 to 10 Amperes with a sensitivity of 100mV/A.

The final setup for the monitorement of 8 point machines is on the Fig 16, this setup was installed during one night.

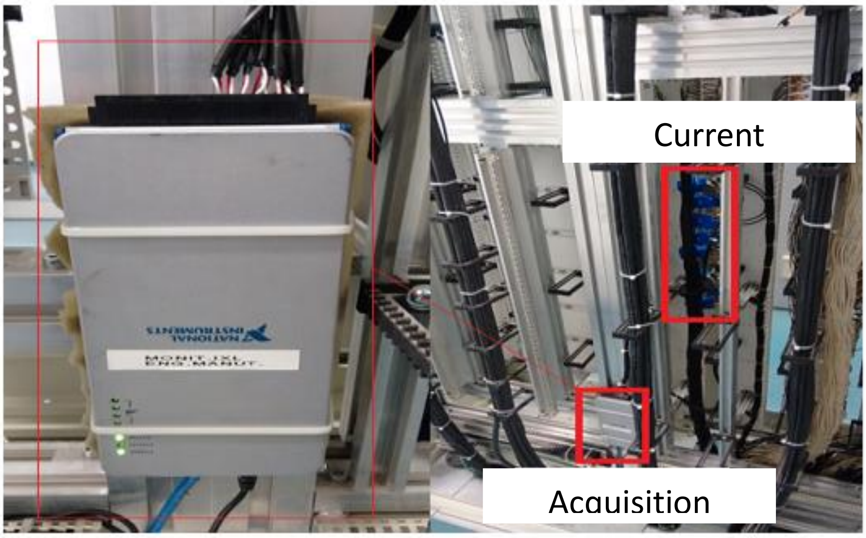

Fig 16: Setup for monitoring XYZ point machines

The server is connected to the chassis cDAQ 9191 through the available logical network and the free software NI MAX (National Instruments Measurement & Automation Explorer), Fig 17. The software is developed to provide access to innumerous National Instruments application: It is used to configure the chassis and used to check if the chassis is connected to the network, in a case of a failure that disconnected the chassis it can be reconnected using the software.

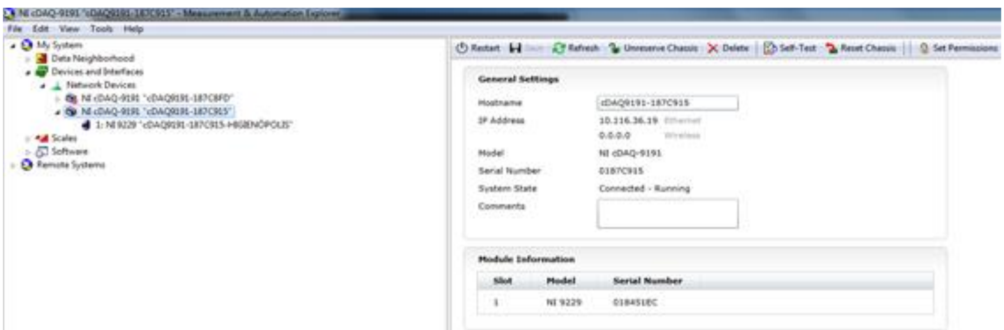

Fig 17: NI MAX screen. On the left panel it is possible to see that two cDAQ 9191 chassis are connected on the newtork

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Every computer on the enterprise network can connect to the chassis and even external computer, through a VPN access, can also connect to it. The equipment layout for two stations are described on the Fig 18 and Fig 19.

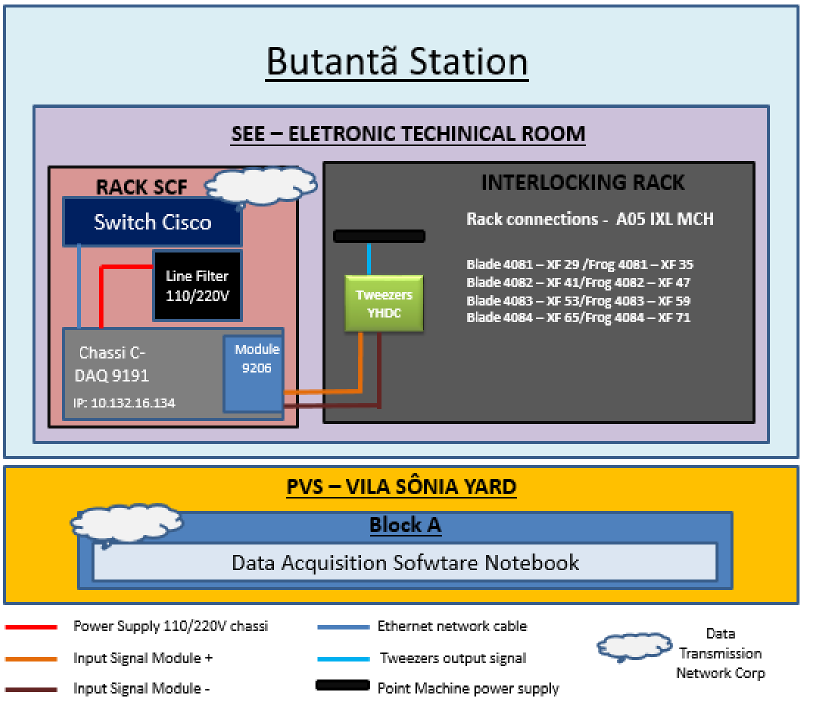

Fig 18: Butantã station equipment layout

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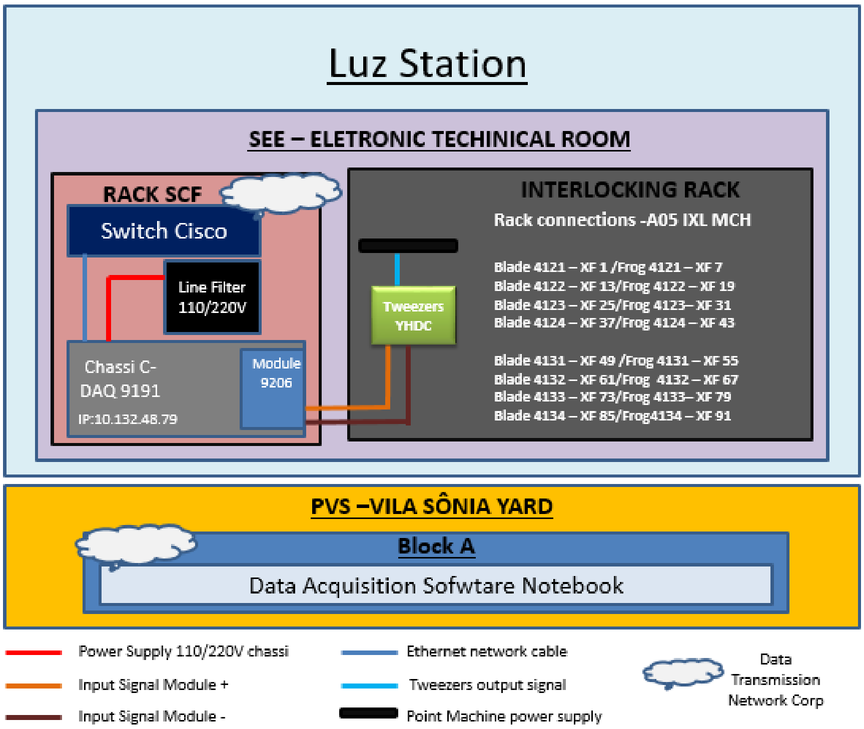

Fig 19: Luz station equipment layout

The data visualization software was developed on the LabVIEW software, a commercial software developed by National Instruments to visualize aspect of an application, including hardware configuration, measurement data, and debugging; represent complex logic on the diagram, develop data analysis algorithms, and design custom engineering user interfaces. On the visualization software, on its actual stage of development, is possible to visualize the point machine engine current online and also the historical data, the visualization can be zoom in, in order to visualize important nuances of the current, Fig 20 and Fig 21. The software has a very friendly user interface and as it access the data of the server it can be run on any computer, it is possible to use it on the offices and on the computers on the signal box.

Fig 20: Visualization software

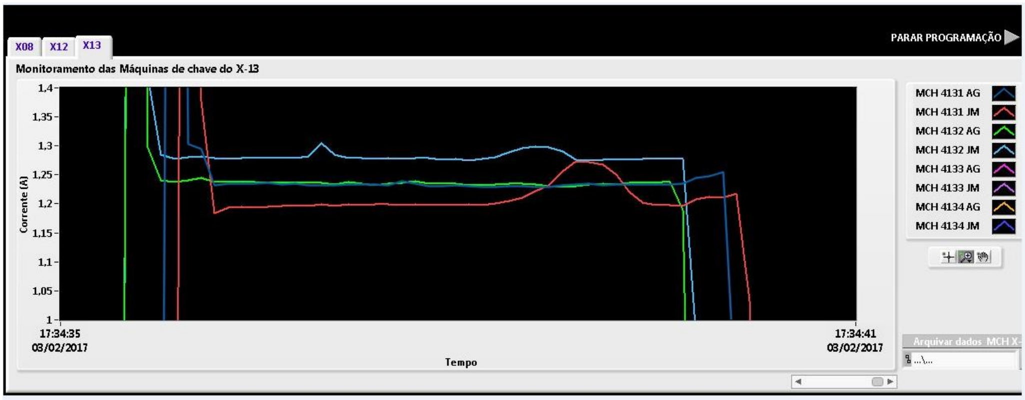

Fig 21: Zoom in on a point machine movement.

For a route definition on the ViaQuatro metro system four point machines are moved, on one track the switch rod and the frog (which are moved by independent point machines) are positioned and on the other track the switch rod and the frog must be also moved, thus four point machines are maneuvered, Fig 22. On the Fig 21 each line represents the motor current of a point machine, it is possible to see the current peak on the beginning of the movement and variations during the movement of the components.

The analysis of the data to identify trends or anomalies on the point machine behavior is done by an engineer. As the system acquires more data and the technical team acquires more expertise about the components failures and the effects on the point machine behavior it will be possible to design a software that can generates mail alarms based on the point machine condition. This further development can be made “in house” or by a third part with a fairly low price.

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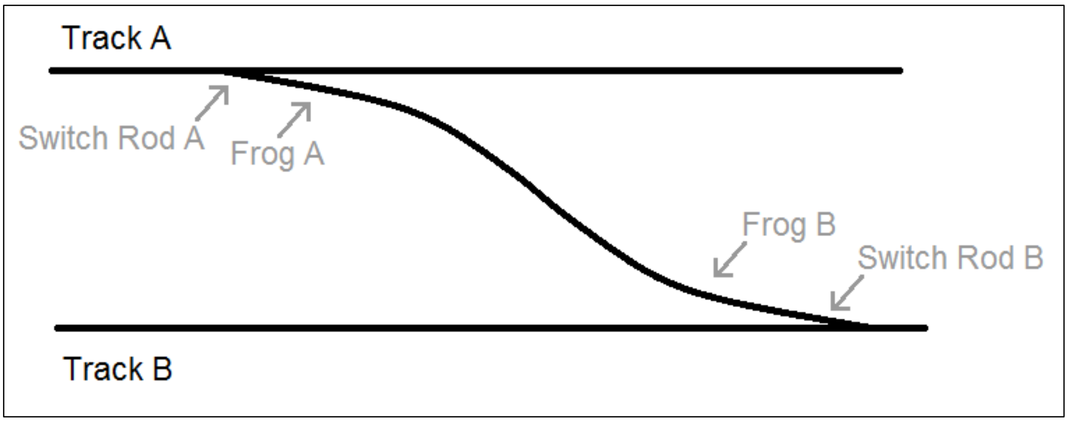

Fig 22: Components of two turnouts with moveable frog.

10.2 Commercial point machine monitoring system of VAE Brasil Produtos Ferroviários LTDA (System 02)

VAE is a Brazilian subsidiary of the company Voestalpine company base in Austria, the company core business is railway turnouts and related equipment for monitoring, diagnosis… The company represents in Brazil the company CDSRails, subsisdiary of the group Voestalpine and specialized in solutions for health & performance of a wide range of railway assets.

The company propose a monitoring system for point machines that comprehends:

- Software specifically developed for point machines monitoring;
- Current transducers with 4-20mA output, Fig 24;
- Clamp type current transducer (noninvasive system);
- Mini logger with current inputs;
- Free data base for one year.

The Mini Logger, Fig 23, used on the application has a wide range of communications: fixed network, GPRS; an SD card slot and 8 analogue inputs, suitable for 8 eight electric point machine monitoring. All the equipment on the field are installed on the relay room.

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The system software is specifically developed for point machine monitoring, all the incoming data is analyzed to determine the asset condition and if a deviation or anomalous behavior is detected an email or SMS is send to specific users. The software also plots the historical data on graphs with possibilities to quickly zoom in to an area of interest, changing the axis scaling to show more detail, stage of the point machine plotting: unlock, movement and lock.

This system was successful tested on a yard point machine during one day and prove to be a good option for point machine monitoring.

Fig 23: Mini logger

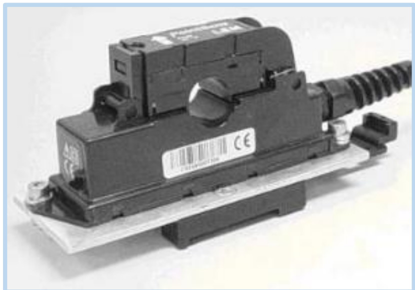
Fig 24: Current transducer

10.3 System costs

The costs of the system are divide in two categories:

- Cost of the data acquisition equipment (which are installed on the field);
- Cost of the licenses, database, software and training.

The cost of the first depends on the number of point machines that are monitored; on the other hand, the cost of the other remains constant.

System 01 costs for the point machine are described on the Table 1.

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System 01 - Point machine monitor for 8 point machine			
	Quantity	Unitary cost (R$)	Total cost (R$)
C-DAQ	1	R$ 1.700,00	R$ 1.700,00
Módulo 9206NI	1	R$ 5.875,00	R$ 5.875,00
Transdutores YHDC	8	R$ 2.000,00	R$ 16.000,00
		TOTAL	**R$ 23.575,00**

Table 1: System 01 data acquisition costs for eight point machines.

As the employees develop the system there is no charge for licenses, database, software and training.

System 02 costs for the point machine are described on Table 2.

System 02 - Point machine monitor for 8 devices		
	Quantity	Cost (R$)
Mini logger	1	R$ 14.956,00
Current transducer	8	R$ 25.044,50
	TOTAL	**R$ 40.000,50**

Table 2: System 02 data acquisition costs for eight point machines.

This system also requires the acquisition of software, license, training and database, which are described on Table 3.

System 02 - Visualization/Storage		
	Quantity	Cost (R$)
Software	1	R$ -
License	1	R$ 25.044,50
Training	1	R$ 59.757,00
Data Base	1	R$ 500.000,00
	TOTAL	**R$ 584.801,50**

Table 3: System 02 costs for storage and visualization.

11 Cost benefit analysis

At ViaQuarto six critical point machines were selected to be monitored, for this application system 01 would cost R$ 141.450,00 and system 02 would cost R$ 824.804,50, a difference of R$ 683.354,50. This huge difference can be analyzed in two perspective:

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- Hardware: System 02 uses a hardware that has been on the market for several years and developed specifically for the railway market, it also includes a broader range of connections (fixed network and GPRS) and an SD Card Slot. On the other hand, the National hardware of systems 01 has also been on the market for a long period and is developed for industrial application, however its connection capabilities are weaken in comparison to system 02, but fulfill the connection requirements for the project. It is worth to notice that the hardware of system 01 is promptly available on the market, meanwhile the hardware of system 02 must be imported.

- Software: System 02 software has the ability to generate alarms and analyses historical data, tools that are a very powerful for the maintenance. System 01 software was developed by the employees using free solutions offered by National.

Due to the high development cost of the system 02 database, ViaQuatro director board chose to deploy the system 01.

This application would not reduce the energy consumption or increase the system efficient (reduce the headway for instance), The benefits of the system are: the efficiency increase of the maintenance (optimization of the preventive scope, reduction of the preventive intervention time, increase of the knowhow) and reduction of the corrective maintenance. Although that the system is not yet implemented, it is possible to forecast the savings based on the experience of ViaQuatro.

On ViaQuatro some critical point machines are already monitored, as seen on chapter 10. As the project is on the initial phase and few machines are monitor it was not possible to review the preventive maintenance scope or optimize the maintenance schedule. So far the maintenance knowledge about the machine has increase substantially and the visualization tool helped a lot the maintenance gang on the failure identification process. Considering the system 01 and just the preventive maintenance routine, if the preventive

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maintenance could be reduced in 20% the system would payoff in eight years, if the preventive maintenance could be reduced in 40% the system would payoff in four years.

It is also worth to notice that the system could avoid a line stop, however the cost of it are complicated to determine as beyond the payment of a penalty, which can cost from 10 thousand to 10 million reais, there is also the scratch on the public perception of the company reliability and availability.

12 Risk analysis

Regarding the installation of the system there is a risk of:

- Electric shock for humans that can be minimized by the use of personal protective equipment;
- Rupture of electric wires that can cause failure on the system and operational restrictions.

Regarding the operation of the system:

- Current oscillations caused by external sources might generate false alarms;
- Sensor failure might not measure current deviations and not generate alarms.

It is worth to notice that the system is measurement are passive, with no interference, and does not imply in further security risks for other systems.

POINT MACHINE MONITORING						
HAZOP				HAZOP II		
1	2	3	4	5	6	7
Process	Guide term	Apply guide term	Estimate consequences	Safetyguards	Actions requered	Actions assigned to
Peak current identification	Not done	No predictive maintenance	Point machine failure	Preventive maitenance	Documentation	Maitenance team
			Operational restriction			
			Delays			
	Wrong done	Umnecessary action	Unnecessary human resources expenditure	Test Procedures to confirm and validate the indication	Documentation	Maitenance team
Acident during sensor instalation	Done	Signaling system failure	Operational restriction	Execute the installation during a non-operative period	Documentation	Implementation team

Table 4: HAZOP

12.1 Event tree analysis (ETA) and Fault tree analysis (FTA)

Two event tree analysis were elaborated for the purpose of the investigation of possible system failures.

The first ETA analysis a no measurement situation, Fig 25, on which the system does not function. On a first analysis it became clear that the power supply for the whole system is a critical issue, as all the power supply receives power from an UPS this issue became less critical. The logical network is also an issue, as the metro system logical network, for safety and high availability reasons, has multiple routes, a network unavailability is not considered critical. The chassis disconnected situation could not be fully analyzed as there is few experience with it, it is recommended to monitor with attention this issue during the project initial phase. Regarding the sensor cable rupture it is recommended to protect it on the same manner as similar cables are protected on the relay room. The sensor not working issue should be evaluated during the project initial phase and with the sensor datasheet information.

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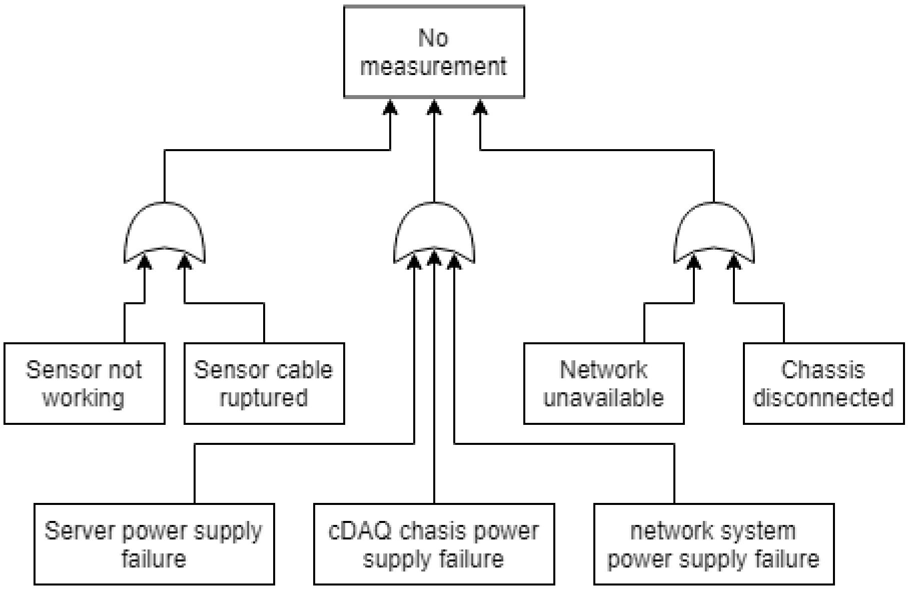

Fig 25: FTA for no measurement.

The second ETA analysis a wrong measurement situation, Fig 26, on this situation the system measurements are wrong. This situation can occur if the sensor is changed and the software parameters are not updated, thus the importance to keep a manual of the system and also to place comments on the software, in order to facilitate the software maintenance. This situation can also occur if there are problems on the sensor cable shielding and the environment produces electromagnetic interferences, thus the importance to protect the cable and to select suitable cables for the project. And finally there could be an issue on the sensor or some cable malfunction that could lead to wrong readings, the sensor must be assessed during the initial phase of the project and by the sensor datasheet documentation and the cable must be correctly mechanically protected.

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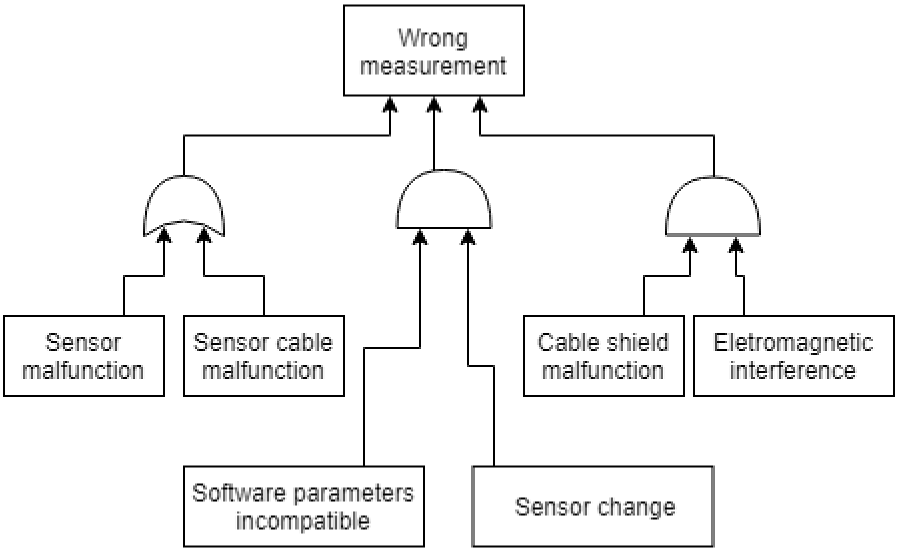

Fig 26: FTA for wrong measurement.

This event is further analyzed on an event tree analysis, Fig 27, there are 75% of chances, or three from four chances, that the event would lead to safe situations. But in one of them unnecessary human resources would happen as a false alarm would be triggered. In one of the four possible situations an alarm is not triggered and the point machine might failure, causing operational restriction.

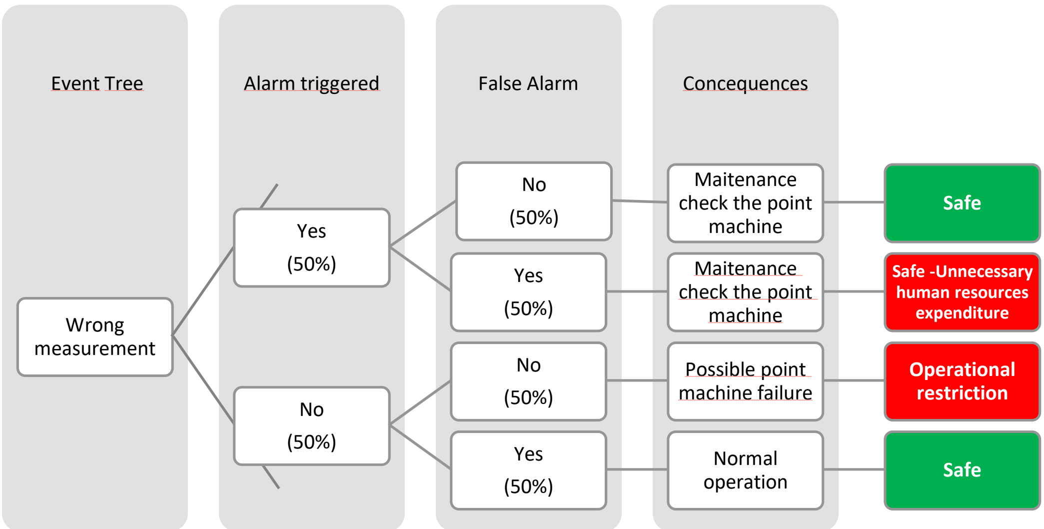

Fig 27: ETA for wrong measurement

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13 Project plan, Implementation Plan

13.1.1 Project Plan

How described above, this project deals with the improvement of preventive activities and the possibility of predictive activities through the implementation of remote monitoring tool of the machines

As seen in Cap 1.3 because it is a driverless line any faulty equipment on the track causes large impacts even to stop the line. With the possibility of equipment remote monitoring the maintenance teams can act in a assertivess way avoiding the destruction of the equipment due to serious failures, as well major operational impacts.

The goals of this project are:

- Implementation of the monitoring system in all point machines allocated in the commercial line in 6 months;
- Development of the analysis software with R$50.000,00 eight months after all point machines monitored;
- Reduction of the preventive maintenance number by 20% six months after the software analysis development;
- 40% number reduction of preventive maintenance after 1,5 years of the software analysis operation and zero corrective intervention;
- Training and qualification of the entire maintenance team after 6 months of software operation

The benefits of this project after implementation are:

- Real time monitoring of point machines, even in the field

- Current curve behavior analysis

- Recording the working data of the point machine

- Predictive performance in equipment

‘

- Use during and after preventive maintenance
- Comparative chart of stored data for comparison of failure events
- History of movements

13.1.2 Implementation Plan

For the implementation, this project can be divided in 5 phases with different objectives for each phase, Table 5.

PHASE	DESCRIPTION
Initiation	-Technical specification -Market research (cost x time) -Equipment acquisition (hardware, software) -Evaluation of point machine failure history for the test project -Point machine performance Analysis (fail x actuation)
Planning	**-Schedule (hh x Time)** **-Progress Report**
Execution	-Field equipment installation -Data collection for monitoring software development -Inserting data into software -Training -Use of the tool for real-time monitoring
Project Performance and Control	**-Occurrences Analysis by open notes in SAP** **-Network space for data storage** **-Weekly comparison of engineering data** **-Use of the tool by the maintenance team and data insertion in the SAP of the preventive activities**
Project Close	-Test project closing and definitive project implementation -Installation on all point machines -Implantation of improvements (alarms, integrated monitoring of key machines, track circuits and leakage current)

Table 5: Phases of project

To achieve the project's implementation plan it is necessary to create a macro schedule for the fulfillment of all the steps of the project, Fig 28. Through this, it is possible to monitor and control the delivery times and possible delays in the project.

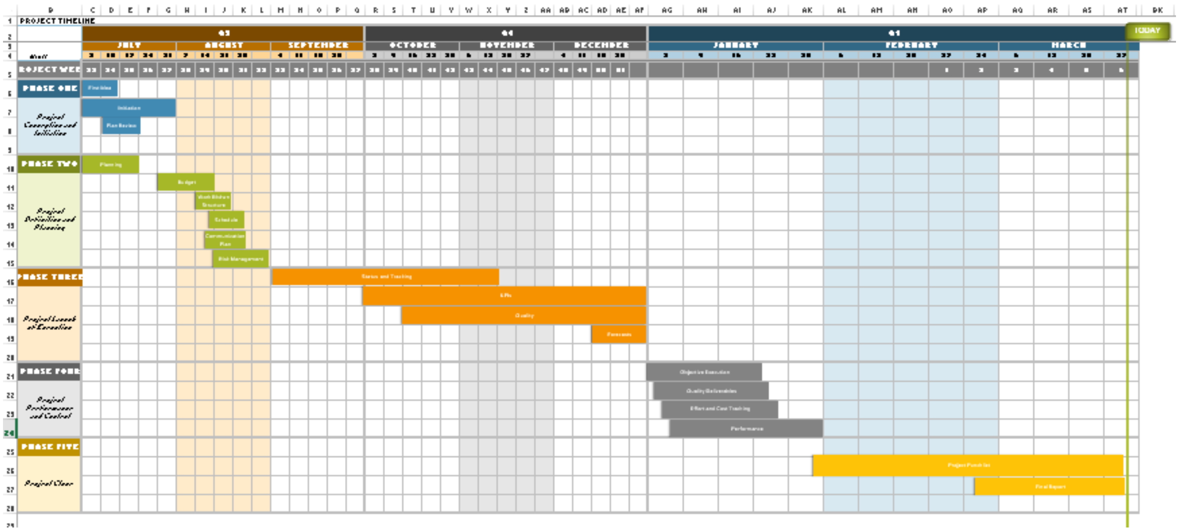

Fig 28: Project Schedule

As the project is in the test phase and has not been implemented on all point machines a WBS (Work Breakdown Project), Fig 29, was created to evidence the deliveries of the project. This structure encompasses the entire scope of work needed to complete the project and meet the business need.

The process of subdivision of deliveries and project work was done in smaller components to facilitate management.

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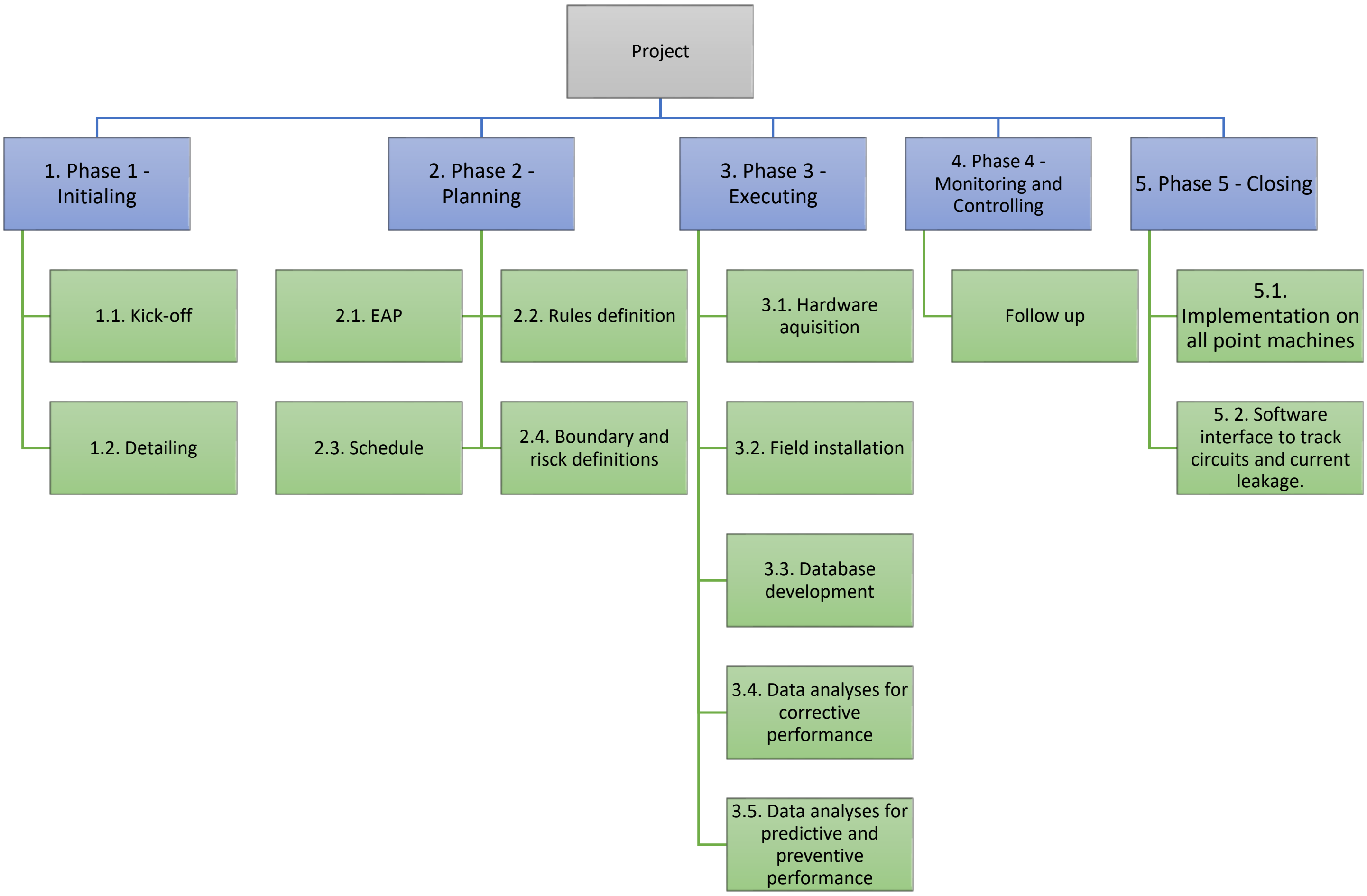

Fig 29: WBS- Project Analytical Framework

For the attendance of all the activities, it is necessary to carry out an organizational division of the activities with responsible and scope of each integral part of the project. Because it is a project developed almost entirely internally and the acquisition of hardware of national scope makes it reduce the involvement of the sectors within the company, limiting itself in engineering, maintenance and purchases, Fig 30.

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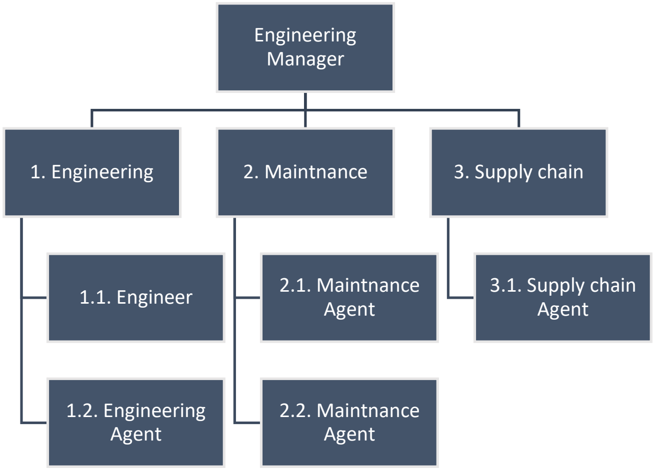

Fig 30: Project Organization Chart

When the whole scope of the project is completely divided, it is necessary to implement the process of identifying and analyzing potential issues that could negatively impact key business initiatives or critical projects in order to help organizations avoid or mitigate those risks, Table 6.

The risks will be listed in a risk sheet, using brainstorm and checklist as method. Qualitatively analyses will be performed through data collection and field verification. All mitigation and contingency actions will be described in the risk worksheet and the control will occur weekly, and analysis intervals may be reduced as necessary.

Since the project does not cause any type of operational impact due to its passive installation, the identified risks are only over the collected information reliability or lack of data collection and recording. With this, the information is saved weekly and evaluated daily, Table 7.

The identified risks in the matrix as high are checked daily by the maintenance and engineering teams. In software failure event or an emergency service locked order in SAP, an maintenance order is opened to be performed up to 24 hours for system verification and correction.

‘

Probability/ Impact	No Impact	Light	Medium	Serious	Extremely Serious
Almost right					
High			x	x	
Medium					
Low		x			
Rare		x			

Table 6: Risk Analysis

RISK	Loss of Information	Software Locking	Hardware Failure	Incorrect Data
PROBABILITY	Médium	Serious	Light	Light
IMPACT	High	High	Low	Rare

Table 7: Point machine monitoring risks

13.2 Training

The system client is the maintenance team (technical and engineers) responsible for the point machines maintenance. The training objectives for this team should be:

- Overall system introduction: concept, components, limitations and functions; this training could be an online training.
- Use the visualization software: open the software, loading and interpretation of the data. On this training should be used examples of point machines malfunctions and how it could be detected on the graphs; this training could be an online training.
- Perform basic system checks for instance: check the connection of the chassis on the network; this training could be an online training.
- After the online training program the team should have a hands-on training on the field to consolidate the knowledge.

‘

A manual of the system operation and interfaces with other assets should be made by the system developers, the client for it are:

- The information technology (IT) department regarding the network infrastructure, server and software;
- The signaling maintenance team regarding the point machine current acquisition devices;

This manual must contains information necessary for the system maintenance: definition of all components in use, description of the network interfaces, power supply information, storage information and so on. For this manual it is not necessary a training.

14 Remarks and Further Development

The proposal system is extremely simple, further sensors such as temperature sensor, load cells, sensors on the rails, gap sensor, engine temperature sensor… could lead to advanced analysis of the point machine operation condition and also the analysis of the forces acting on turnout. Load sensor on the rail could detect possible ballast or misalignment before it becomes critical, a load sensor could detect the minimum deviation of the lubrication before it becomes critical, temperature sensor could correct the normal variations of the due to thermal stress… As long as the first platform to acquire data is install and the maintenance team developed the necessary knowhow to use it is possible to further improve.

Currently, with the simplest monitoring it was possible to detect problems that occurred in the key machines causing failures and assisting the maintenance teams in asserting the true root cause of the problem. Above some examples of this failures, Fig 32.

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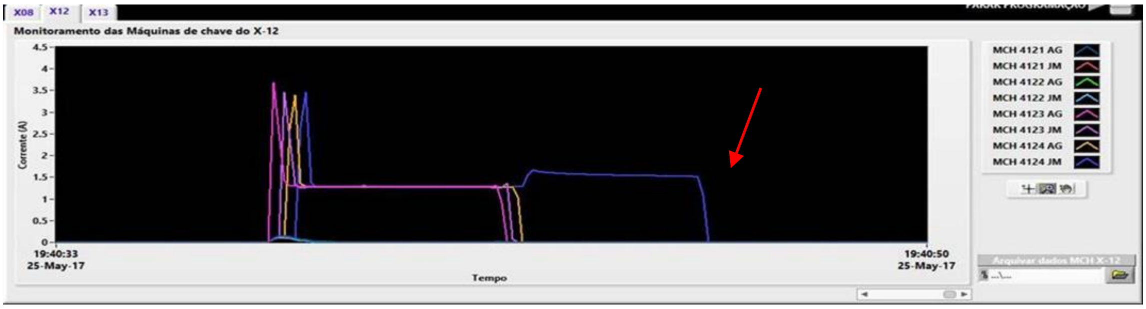

Fig 31: Current Curve Monitoring

In this case, the point machine 4124 presents the deviations in the current curve. During the maintenance, team was possible to detect the real cause of this failure. The problem was the detection bar displacement, Fig 32.

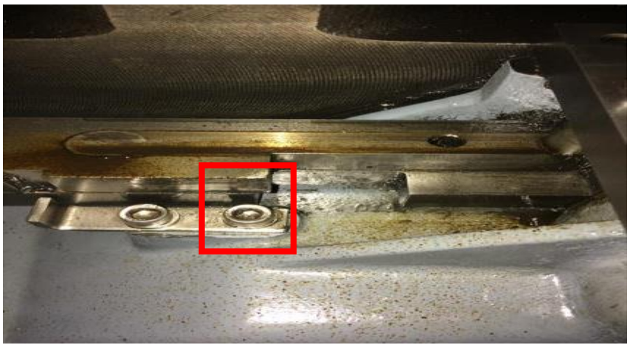

Fig 32: Current Curve Monitoring

As in the previous event the current of the machine of key did not present curves of currents outside the standards and had its route completed and mechanically locked, Fig 33. Identified by the maintenance team during the performance, the same behavior of the previous machine, with the return of the spindle, triggering the change of the status of the microswitch. In addition, components with excessive wear (pin, eccentric bushing and rollers) have also been identified, Fig 34.

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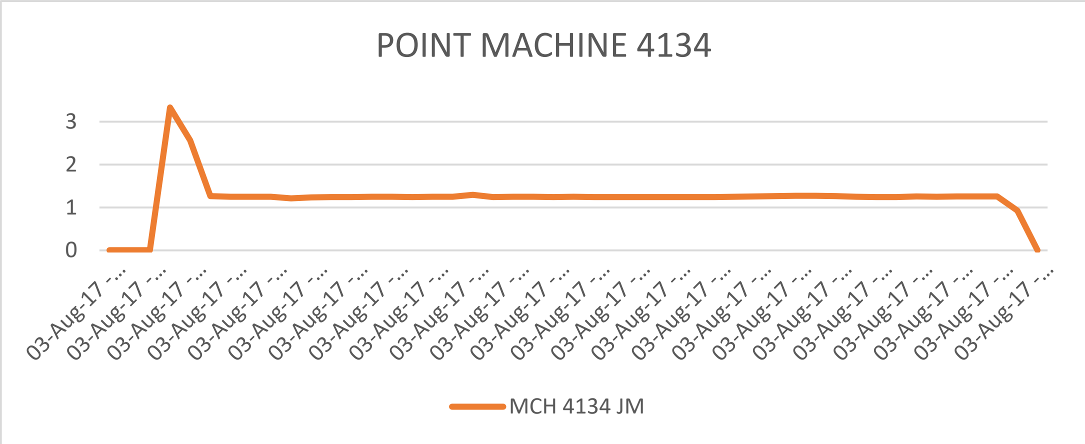

Fig 33: Point Machine 4134 Monitoring

Fig 34: Point Machine Components Replaced

This monitoring is bringing benefits to the company and maintenance team, however, for futher improvements, the integration of this monitoring software with other monitoring software and alarms generate are being studied. Today, there are two other monitoring softwares in operation being: track circuits, Fig 36, and leakage current, Fig 35.. Just as, these softwares generate alarms, send sms, e-mails and are softwares that help in the monitoring of the systems. The proposal is to insert alarms that assist the teams in the identification of failures as well as sending messages presenting deviations in the operational behavior of the point machine making possible the predictive performance in the equipment. The integration of the 3 monitoring systems would make the analysis software complete in the field of action on the track, bringing benefits to the performance team, such as ease of fault management as well as performance.

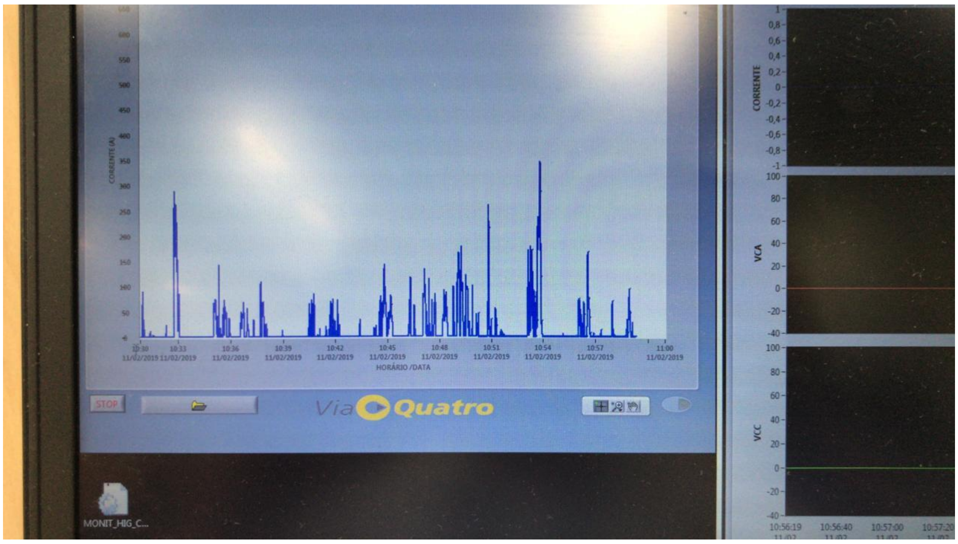

Fig 35: Leakage Current Monitoring

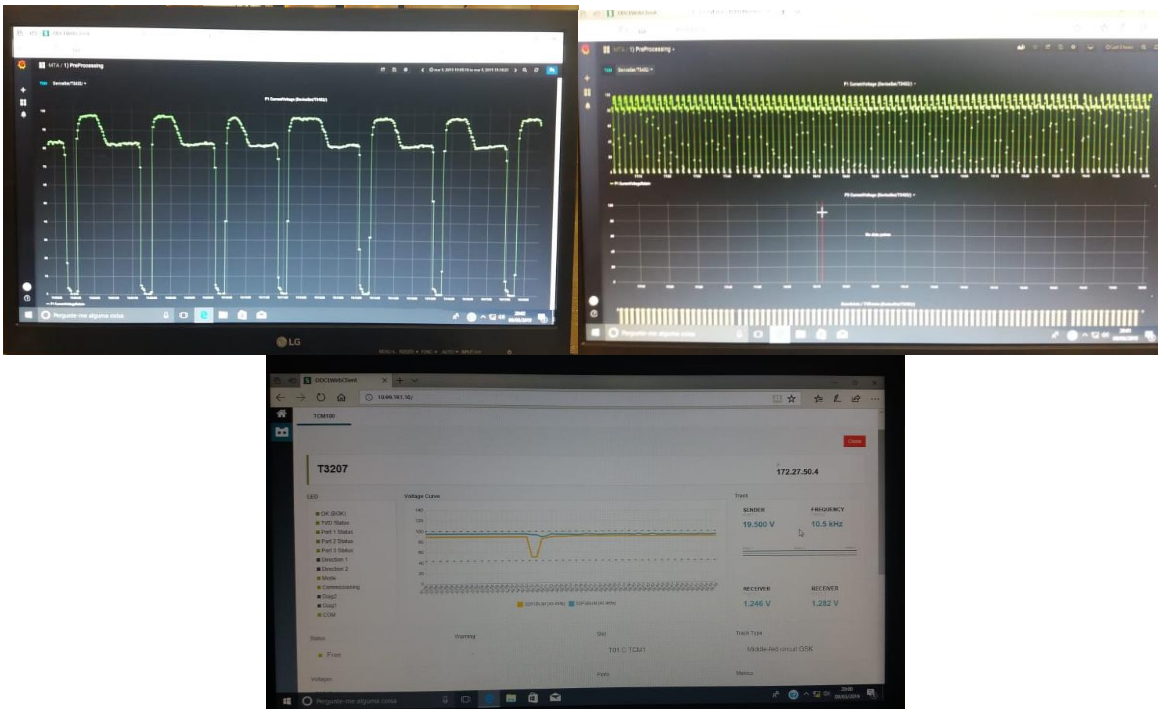

Fig 36: Track Circuit Monitoring

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