INTERNATIONAL CERTIFICATION IN MANAGEMENT OF RAIL AND METRO RAIL SYSTEMS

VARIABLE TRAIN OFFERING PROGRAM USING THE WEIGHT OF THE TRAINS TO ANALYZE THE DEMAND

PROGRAMA DE OFERTA DE TRENS VARIÁVEL UTILIZANDO O PESO DO TREM PARA ANALISAR A DEMANDA

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We dedicate this work to our families members, who supported and encouraged us, and our organizations, for the opportunity of this International Certification.

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“Follow effective action with quiet reflection. From the quiet reflection will come even more effective action”.

(Peter Drucker)

ABSTRACT

In an electric trains rail operation the energy consumption is very high. Looking for the environment care (less energy consumption) and company costs reduction, given that energy is one of the major costs, it is necessary to analyze the demand of passengers and adjust the train offer considering this information. Measuring the weight of each car in each station it is possible to estimate how many passengers there are in the train, build the demand graph, calculate the number of passengers per square meter and analyze in what time of the day is necessary to put or take out trains in operation, considering the contractual occupation limits. With this it is possible to adjust the timetable frequently, optimizing the train offer totally based on the real demand, and consequently optimizing the energy consumption.

Key words: Train offering optimization; demand analysis; energy consumption; passenger per square meter; timetable.

RESUMO

Em uma operação ferroviária de trens elétricos o consumo de energia é muito alto. Buscando cuidar do meio ambiente (menos consumo de energia) e reduzir os custos da empresa, já que o custo com energia é um dos maiores, é necessário analisar a demanda de passageiros e ajustar a oferta de trens considerando essa informação. Medindo o peso de cada carro em cada estação é possível estimar quantos passageiros estão no trem, construir o gráfico de demanda, calcular o número de passageiros por metro quadrado e analisar em que hora do dia é necessário inserir ou retirar trens da operação, considerando os limites contratuais. Com isso é possível ajustar a tabela horária com frequência, otimizando a oferta de trens baseado na demanda real, e consequentemente otimizando o consumo de energia.

Palavras chave: Otimização da oferta de trens; análise de demanda; consumo de energia; passageiros por metro quadrado; tabela horária.

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ABBREVIATION LIST

APC – Automatic Passenger Counting

BNC – Bonocô Station

BCE – Brake Control Electronics

BCU – Brake Control Unit

CBTC – Communication Based Train Control

DBS – Data Bus System

EMU – Electrical Multiple Unit

IR – Infrared

LPA – Lapa station

OBCU – Onboard Control Unit

POT – Programa de Oferta de Trens

PPP – Public-Private Partnership

PRJ – Pirajá station

ToF – Time-of-Flight principle

TTS – Train Track Server

WCU – Wayside Control Unit

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1 INTRODUCTION

In rail operations the energy consumption holds an important role in the strategy of the company. With rising concerns related to environmental impact and the costs of electrical energy, it is essential to optimize the energy consumption.

In 2022, the average of passengers in rail and metro rail systems in Brazil was almost 8 millions per weekday, representing approximately 4% of the total population of the country. It is a total of 2,3 billions per year, covering an extension of 1.129,4 km of rails in passenger operations all over the country.

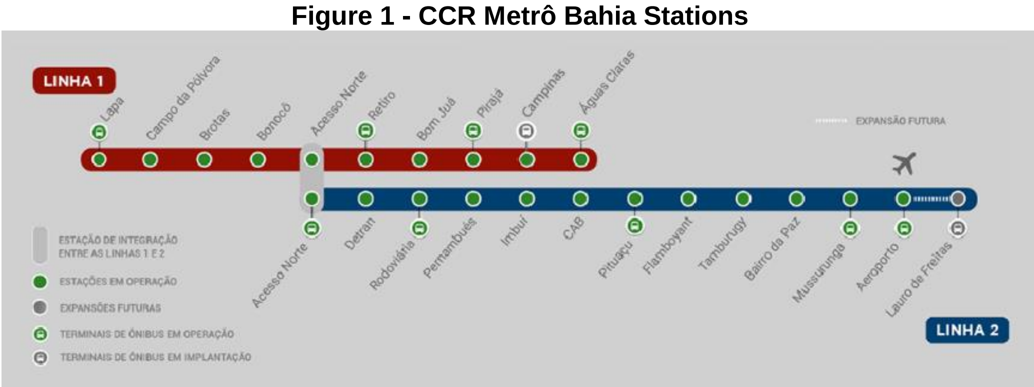
The passengers operations in Brazil normally use electric trains, therefore the energy consumption is significative.

In this paper it will be discussed an alternative to raise the efficiency of the use of energy in rail and metro rail passengers systems, applying the suggested model in CCR Metrô Bahia during the year of 2023, to verify if the results are positive.

1.1 CCR Metrô Bahia

The operation of Metrô Bahia started in June of 2014, with 6 stations and 6 km of extension. In the beginning of 2024 the system already counts with 22 stations and 38 km of extension in two lines. Furthermore the company is responsible for the operation of 8 bus terminals integrated to the metro stations. Almost 370.000 passengers use the system every weekday.

Figure 1 - CCR Metrô Bahia Stations



Source: Metro Bahia Website[1].

[1] Disponível em: <https://www.ccrmetrobahia.com.br/>. Acesso em: 06 jan. 2024.

The system has 40 trains, supplied by Hyundai-Rotem, and the signaling system implemented is the CBTC, provided by Siemens AG.

The PPP started in 2013, and the contract has 30 years of duration. The company is responsible for the maintenance and operation of the system during these years.

Figure 2 - CCR Metrô Bahia trains

Source: Metrô Bahia (2024)[2].

1.2 Goals

The goal of this project is to develop a systematic to analyze with more detail the demand of passengers per train per day in CCR Metrô Bahia, making possible the construction of timetables more adjusted to this demand, making the trains actually run as necessary, reducing the consumption of electrical energy.

1.3 Brief Presentation of the Chapters

Chapter 1 introduce the Project and show a short presentation of the company where it was developed. It brings too the goals expected.

In Chapter 2 are presented the methodologies and technologies available to count people.

Chapter 3 describes how the project was developed, considering the technologies and solutions available in the company.

Chapter 4 brings the results obtained during the year of 2023 with the appliance of the project, checking if the goals were achieved or not.

In Chapter 5 the cost-benefit of project is analyzed using the SWOT methodology.

[2] Disponível em <https://www.ccrmetrobahia.com.br/>. Acesso em: 06 jan. 2024.

Chapter 6, based on SWOT methodology of the previous chapter, shows a risk analysis of the project.

In Chapter 7 it is presented an improvement that is already being developed to make the analysis of the base data automatically.

In the last Chapter, number 8, it is presented the conclusion of the project including an idea of next step to measure other possible gains with this implementation.

2 CONCEPT BASIS

To make possible to adjust the train offering using the real daily passenger demand it is necessary to:

- Measure the number of passengers in each train in all trips during all the operational hours;
- Have the demand data available to be analyzed;
- Define the limit of passenger per square meter allowed in the trains;
- Have a method to analyze and check if the train offering is adjusted to the passenger demand;
- Have a method to build timetables that offers the possibility to change it accordingly to the needs of the company.

The beginning of the process is the measurement of the number of passengers in the trains. To make it possible there are different technologies available that can be implemented in trains and even in platforms. In the following items these technologies will be described.

2.1 Manual Passenger Counting Methodology

Historically, the data most appropriate for examining the performance of a transit system has been obtained from manually-derived passenger ridechecks (a ridecheck is a ride, usually on a transit bus or train, on which staff manually tabulates the number of passenger boardings and alightings at each stop by time of day, tracks ontime performance, and observes the operator' skills and compliance with rules and standards). Generally, these ridechecks reveal peak passenger loads by bus/train stop and run times on a specified route.

Experience has shown that many transit systems use labor-intensive manual ridechecks during specific service periods to collect ridership (number of boardings and alightings at the stop level) and operational data such as run times. Currently, this is one of the most cost-effective data collection methods for most transit systems.

This manual method of collecting ridership data and system operational information produces both limited systemwide and route specific reports due to the amount of manual ridechecking required and the manual data processing involved.

Manual people counting, whether by paper or a handheld tally counter, is not very accurate. Some estimates say it's inaccurate by as much as 15%, meaning staff will count only 85% of people accurately.

2.1.1 John Fruin's Method for Manual Passenger Counting

John Fruin's method of passenger counting is known for its simplicity and effectiveness. Fruin, an expert in pedestrian flow analysis, proposed a manual counting technique that involves sampling a specific area within a transportation facility.

The process typically includes the following steps:

i. Define Counting Zones: Identify specific areas within a transportation facility where passenger counts are needed. These zones could be entry/exit points, platforms, or other critical locations.
ii. Determine Sampling Time: Select specific time intervals during which manual counts will be conducted. The sampling should be representative of various periods to capture fluctuations in passenger traffic.
iii. Assign Counters: Train personnel to manually count passengers entering and exiting the defined zones during the chosen time intervals. Fruin often recommended using a team of observers for increased accuracy.
iv. Compile Data: Record the counts and compile the data for analysis. This information can be used to understand passenger flow patterns, peak travel times, and overall demand at different locations within the facility.

While this method is manual and might be time-consuming, it offers a cost-effective way to gather valuable data for planning and optimizing transportation facilities. Automated methods like APC systems have become more prevalent, but Fruin's approach remains relevant, especially in situations where advanced technology might not be feasible or cost-effective.

2.2 Automatic passenger counting systems

APC system is a technology used in public transportation vehicles – mostly in trains and buses – to accurately tally the number of passengers boarding and disembarking. Typically integrated with sensors, cameras, or other data collection devices, APC systems can provide real-time data that helps Operators to optimize routes, improve efficiency, and enhance overall service planning. These systems contribute to better resource allocation and informed decision-making in the management of public transportation networks.

The choice of APC technology depends on factors such as accuracy requirements, cost considerations, and the specific characteristics of the transportation environment.

2.2.1 Onboard Train Weighing Systems

In the Passenger Railway Transportation segment, some Rolling Stock can be equipped with weighing systems to proper calculate Traction and Braking effort demand based on the load of the vehicle, they can be called as LSD – Load Sensing Devices.

Mostly these systems rely on devices, such as electrical Load cells, electrical Rotary encoders, or air pressure gauges and switches on pneumatic suspension air line.

Those weighing systems depend on data obtained from electrical or mechanical devices installed on the vehicle floors, mainly converting a measured parameter to an electrical signal that can then be processed by the railway systems into a mass value. Those devices can accurately estimate the current load of the train set.

Considering the reference of 70 kg per passenger and the known mass value for an empty train, the data acquired from these devices can be used to estimate the number of passengers onboard the vehicle, since the only way of change the load of a train is with passengers boarding in and alighting.

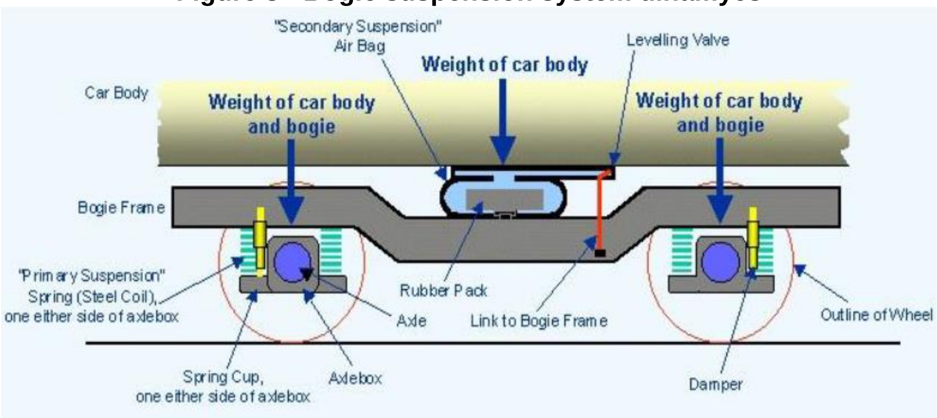
Therefore, it is possible to gather, instantaneously or not, the data from a train onboard weighing system and use it as an Automatic Passenger Counting System.

The concern with this type of solution is the variability of the dynamic load on the undercarriage, suspensions or air springs, which can be overcome by measuring the load status only at the beginning or end of stops, therefore when the vehicle is at standstill.

2.2.1.1 Suspension air pressure monitoring

Use of pressure sensor to measure the pneumatic circuit pressure and therefore obtain the weight information of the car. Normally these types of sensors are installed undercarriage, inside the BCU (Brake Control Unit), and can sense the mean pressure of the car body's weight on top of the pneumatic secondary suspension system (air bags).

Figure 3 - Bogie suspension system dinamycs



Source: Site Semantic Scholar[3].

It is common for EMU type of Rolling Stock to be equipped with a pneumatic suspension system mainly responsible for car's stability in movement, levelling the car and capable of obtaining the weight of the car for the traction and braking systems.

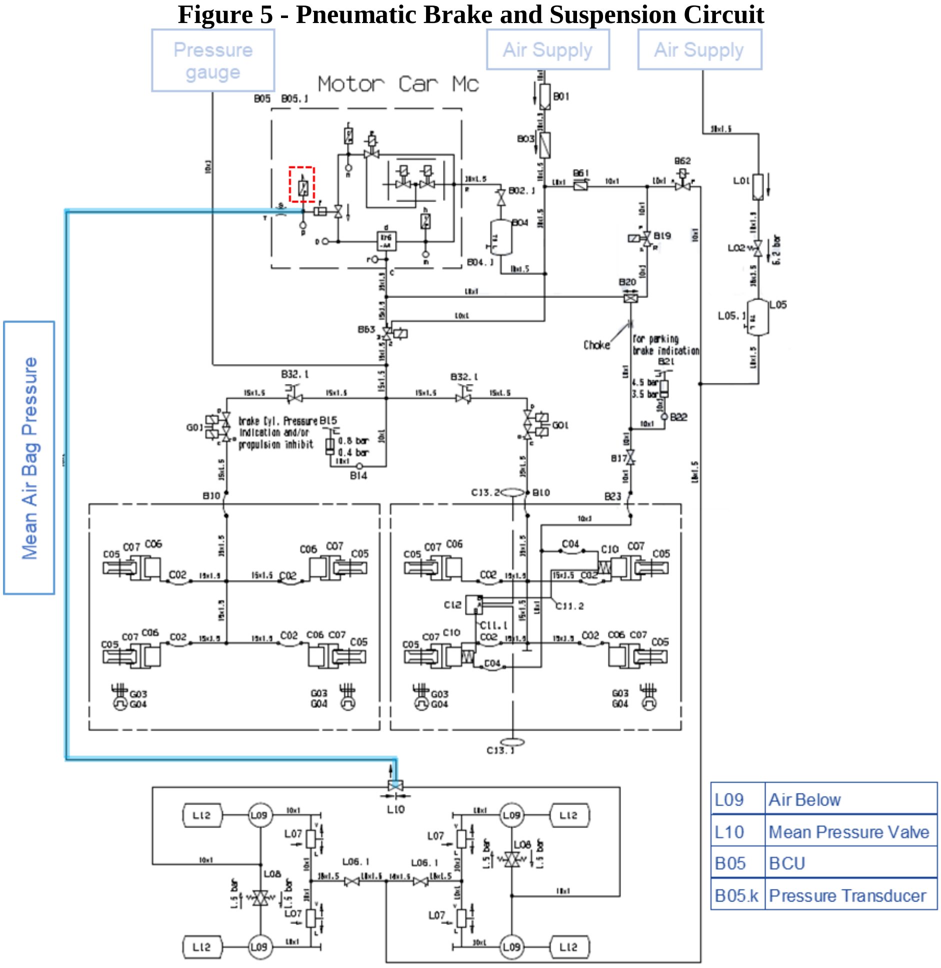
[3] Disponível em: <https://www.semanticscholar.org/paper/THEORETICAL-ANALYSIS-OF-TRAIN-BOGIE-SUSPENSION-Hasan-Kumar/96f43db22df46b5c3a17b53a693c7433f34fca5a/>. Acesso em: 13 jan. 2024.

Weight variable is obtained from certified railway pressure transducer, which converts pressure readings to electrical signals (4-20 mA, 1-5 V, etc) and sends it to BCE. The BCE can process the electrical signal and calculate the weight of the car.

Figure 4 - Example of P/I railway Transducer

Source: Site Baumer[4].

Figure 5 - Pneumatic Brake and Suspension Circuit



Source: Internal Documents

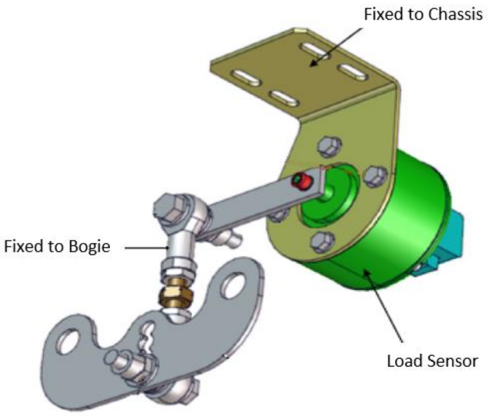
[4] Disponível em: <https://www.baumer.com/ch/en/product-overview/process-sensors/pressure-measurement/railway-certified/c/14380/>. Acesso em: 13 jan. 2024.

2.2.1.2 Onboard electro-mechanical load sensor

Typical transducers assembled undercarriage between the bogie (fixed position) and the train chassis (position depends on passenger loading) can acquire electrical or mechanical data, converting it to electrical signals and processing those signals: Rotary Encoders, Load cells, Accelerometers (experimental) etc.

For instance, Rotary Encoders installed on Tramway rolling stock can convert the angular positioning of the rotating shaft, due to the displacement of the train chassis when loaded with passengers, to an electrical signal output of 4 – 20 mA, which then can be processed into an incremental mass value.

Figure 6 - Alstom Citadis 402 Tram Load Sensor



Source: Internal Documents

Figure 7 - Alstom Citadis 402 Tram Load Sensor – Rio de Janeiro Tramway VLT Carioca

Source: Internal Documents

2.2.2 3D counting cameras

Automatic Passenger Counting trough 3D Stereoscopic Cameras provides real time insights on passenger numbers per vehicle, helping operators improve operations whilst ensuring passenger and driver safety.

Passenger numbers are collected using counting sensors in each vehicle’s door. The counting sensors normally have two stereoscopic cameras which provide a counting balance accuracy of 95% - 98% (depending on the manufacturer and selected model of the APC sensor).

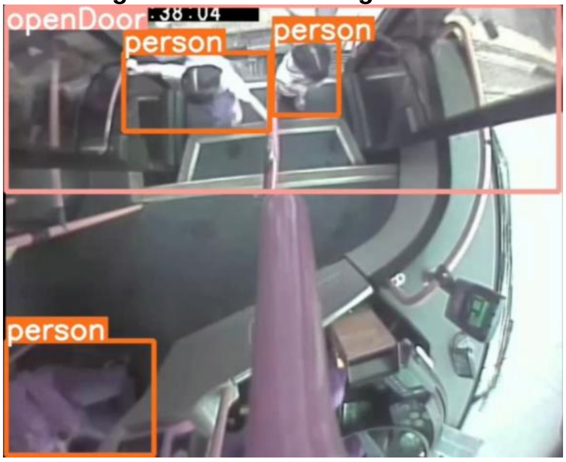
Those kinds of systems often rely on Artificial Intelligence solutions based on image recognition, capable of precisely identifying a human’s head and counting the “Ins and Outs” at every train or bus door.

Figure 8 - 3D Stereoscopic Camera

Source: Site Acorel[5].

[5] Disponível em: <https://acorel.com/en/products-and-services/sensors-equipment/>. Acesso em: 07 jan. 2024.

Figure 9 - 3D Counting Camera



Source: Site Rail Sensing[6].

2.2.3 Optical sensors

Most modern Automatic Passanger Counting systems rely on the “Time-of-Flight principle” as new technology.

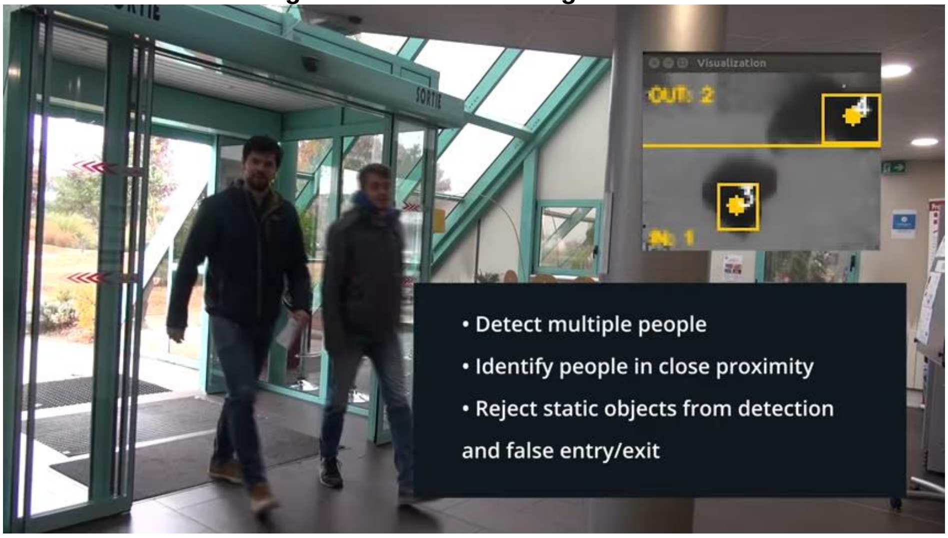
The principle is a method for measuring the distance between a sensor and an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object. Various types of signals (also called carriers) can be used with the Time-of-Flight principle, the most common being sound and light.

For range-finding and distance sensing, ToF is very powerful when emitting light rather than sound. Compared to ultrasound, it provides far greater range, faster readings, and greater accuracy whilst still maintaining small size, low weight and low power consumption characteristics.

Such sensors are not prone to environmental influences like changing lighting conditions, temperature variations and humidity in buses or trains do not affect the light propagation time and can offer an accuracy greater than 99% in people counting.

[6] Disponível em: <https://acorel.com/en/products-and-services/sensors-equipment/>. Acesso em: 07 jan. 2024.

Figure 10 - TOF counting sensors



Source: Site Terabee[7].

2.2.4 Active Infrared sensors

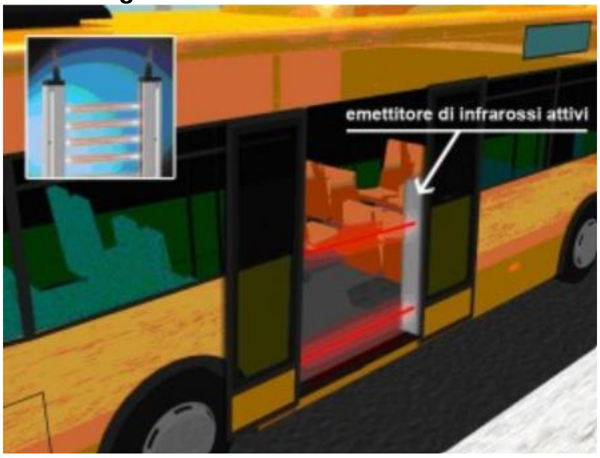
Beam counter sensors – also known as infrared beam counters, or IR people counters – consist of receiver and transmitter units installed side by side at the entrances. When the transmission signal is blocked due to an object obstruction, a count occurs.

Beam sensors have some downsides; For example, they don't provide in & out numbers separately since they have no sense of direction. Also, beam counter sensors aren't the most accurate since side-by-side objects are counted as one, and the accuracy decreases as the door width increases.

Most AIRs are bidirectional and are typically installed on one or both sides of a doorway.

[7] Disponível em: <https://www.terabee.com/shop/people-counting/terabee-people-counting-l/>. Acesso em: 07 jan. 2024.

Figure 11 - IR Beam on bus door



Source: Site Intelligent transport[8]

2.2.5 Treadle mat sensor

Placed on the steps of a bus, a tram or a train, Treadle or sensing mats, register passengers as they step on a mat. The counting system uses treadle mats located in proximity of the vehicle gates, typically on the access steps.

These Mats use field-proven ribbon switch technology. They operate as normally open switches and can be used to control relays, lights, or alarms from a low voltage source. Can also function as hidden switches when placed under carpeting or matting.

It's also used as safety sensor, for instance, blocking the door closure when actuated.

If the public transport line equipped with this kind of APC is always very crowded, the errors can be relevant and – in such cases – the use of different means, may be preferable. On the other hand, if there's a slower passenger flow, possibly in "single row", the devices can be very precise reaching over 95% accuracy in optimum conditions of use.

[8] Disponível em: < https://www.intelligenttransport.com/transport-articles/3116/automatic-passenger-counting-systems-for-public-transport/>. Acesso em: 07 jan. 2024.

Figure 12 - Sensing Mat

Source: Site Tapeswitch[9].

Figure 13 - Treadle Mat installation

Source: Site Intelligent Transport[10].

[9] Disponível em: <https://www.tapeswitch.com/mats/cvp.html/>. Acesso em: 07 jan. 2024.
[10] Disponível em: < https://www.intelligenttransport.com/transport-articles/3116/automatic-passenger-counting-systems-for-public-transport/>. Acesso em: 07 jan. 2024.

3 SOLUTION DEVELOPMENT

In many stations in Metrô Bahia the scalators are in the extremity of platforms. This causes an effect that most passengers tend to stay in the first and last cars of the train. So the middle cars normally were less crowded than the other ones.

In 2021 a project was started to be implemented in every platform with monitors showing to passengers the level of crowdedness of each car of the train. To develop this the Engineering team used the information that was available in the trains, that is the weight of the cars using the air suspension system monitoring, that could be send to the data servers through the signaling system. So they developed an application to read these real time data, interpretate and transform it into information to the passengers using the platforms monitors. Another information that is showed to the passengers is the amount of time to next train arrival. The system implemented was called “Próximo Trem”, or “Next Train” in a loose translation.

Figure 14 - "Próximo Trem" board

Source: Internal Documents.

Figure 15 - "Próximo Trem" platform monitor

Source: Internal Documents.

3.1 Technology chosen solution

3.1.1 Solution's Architecture

The load capacity (empty and loaded) of the Rolling Stock is a known variable since it's a parameter provided by the manufacturer.

Figure 16 - Trains Car weight (number of passengers)

	UNIDADE - TONELADA PASSAGEIROS (XXX)				
	MC1	**M1**	**M2**	**MC2**	**TOTAL**
AW0: Peso Tara	42.30	41.60	41.60	42.30	167.80
AW3: AW0+ 8 pass./m²	64.50 (311)	64.30 (318)	64.30 (318)	64.50 (311)	257.60 (1,258)
AW4: AW0+ 10 pass./m²	69.20 (377)	69.00 (384)	69.90 (384)	69.20 (377)	276.40 (1,522)

Source: Internal Documents

Passenger’s weight data is continuously sensed by the undercarriage pressure sensor at the BCU, which sends the electrical sign to the BCE, then processing the electrical sign and converting it to the weight of the car value. The rolling stock onboard Data Bus System collects the weight variable of each car. The onboard control unit, rolling stock embedded equipment responsible to communicate with the signalling system (CBTC), sends the weight of each car to the ground.

Siemens Wayside Control Unit, by using antennas alongside the tracks can receive all the necessary information coming from the running trains, included the weight of each car. All the data is stored in the signaling systems database servers.

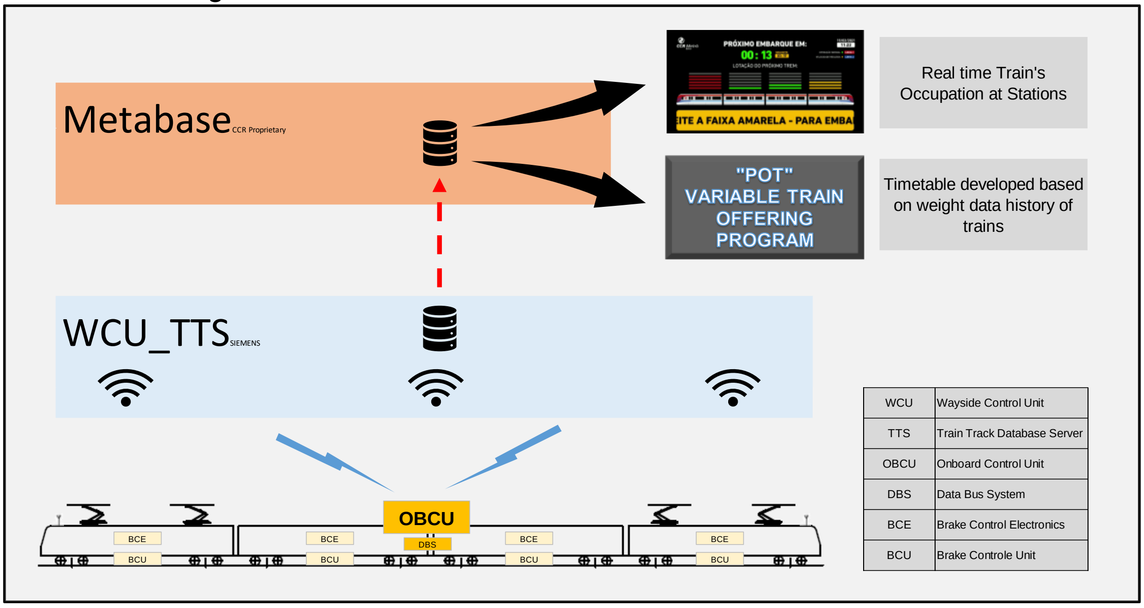
The CCR team has developed a platform application to consult all the data from the trains stored at Siemens servers. The platform is called Metabase and can display and treat the weight variable of each train car. By knowing the online weight of the car and the weight of an empty car and having the reference of 70 kg per passenger, it is possible to estimate the number of passengers for each car, in real time.

Finally, the data of Metabase treated data is the source for the implementation of two solutions:

“Próximo Trem” Project: Screens alongside the station’s platforms display the remaining time for the next train to come and also its currently occupation by car.

“POT” Project: Variable Train Offering Program using the weight of the trains to analyze the Demand.

Figure 17 - "POT" and "Próximo Trem" solutions architecture



Source: Internal Documents

3.1.2 Counting the number of passengers

As shown in "Próximo Trem" system the Engineering team had already developed a way to measure the occupation of each train's car in this project. So, the first step to the variable train offering program was already done. It wasn't necessary to develop another system to generate these data because they were already available in a server.

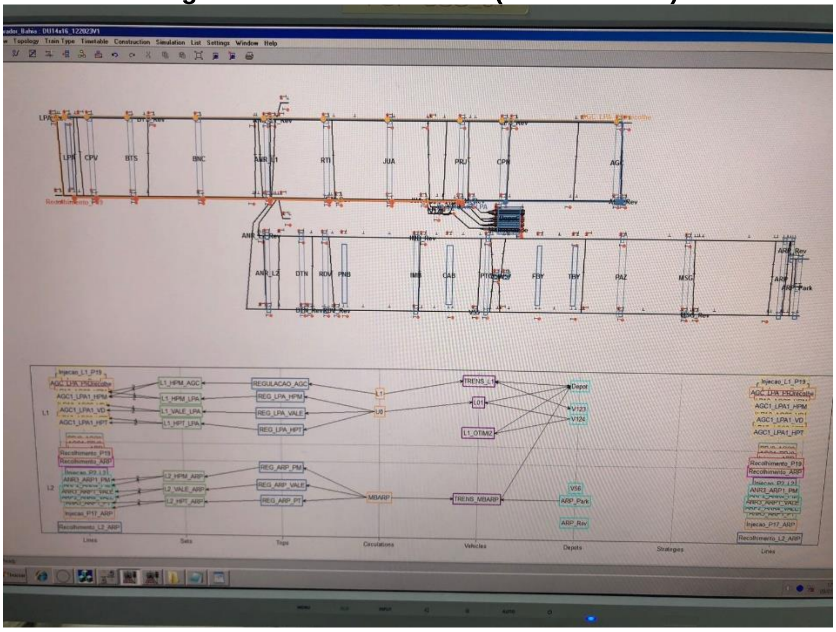
Metrô Bahia trains have 500 kg accuracy to do this measurement. To this project it was considered that each person in the train have an average weight of 70 kg. So the accuracy for this project is around 7 passengers.

Considering that the average maximum number of passengers in each car is 250, the error tolerance in the measurement is 2,8%.

3.1.3 Building the timetable

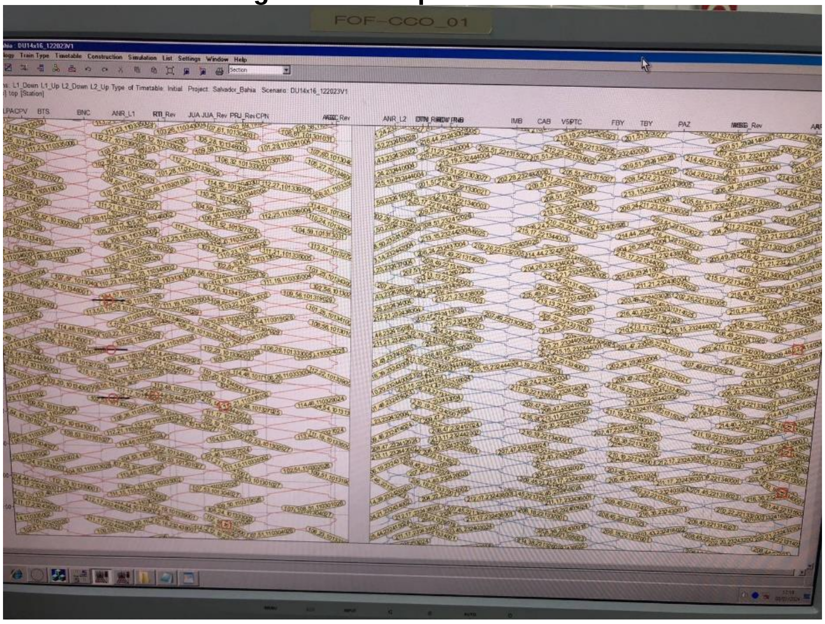
To build the timetables the signaling system implemented in Metrô Bahia has a native software to it. The Falko software allows the configuration of the operation parameters like dwell time, headways, loops, and then the timetable is automatically build.

Figure 18 - Falko software (main window)



Source: Internal Documents.

Figure 19 - Graphic timetable



Source: Internal Documents.

3.2 Definition of the maximum passenger per square meter

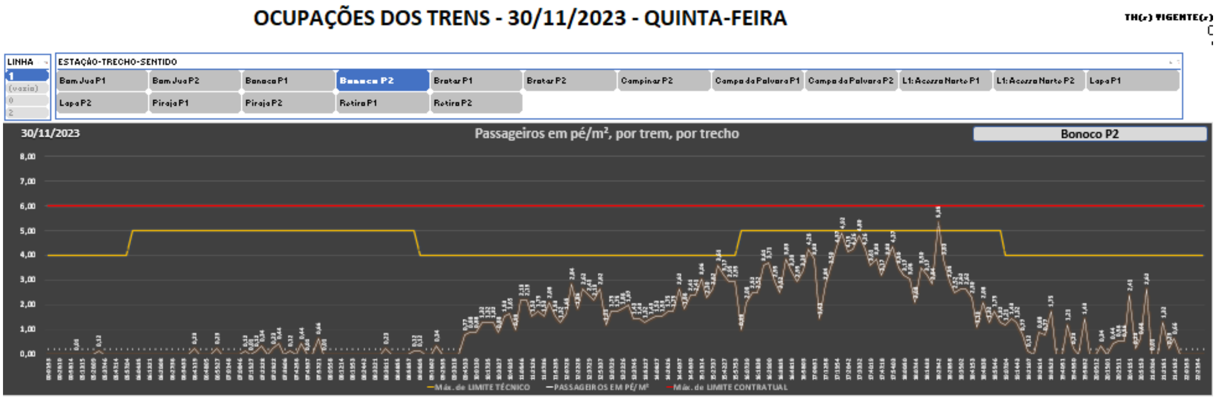
In CCR Metrô Bahia contract there is a maximum defined limit of passengers per square meter in the trains, that is 6. Considering that it is possible to have occurrences in the system that cause delays in the trains, the project needs to consider that this limit is lower than 6 passengers per square meter, because with the delays the trains will become crowder. So the maximum limits to project the timetables were defined nearly 5 passengers per square meter.

Another important definition of this project is that the contract defines de maximum headway allowed, that is 10 minutes. So, even if the demand analyzes shows that is possible to implement a headway greater than 10 minutes, this maximum headway is kept.

3.3 Method to analyze the train offering x passenger demand

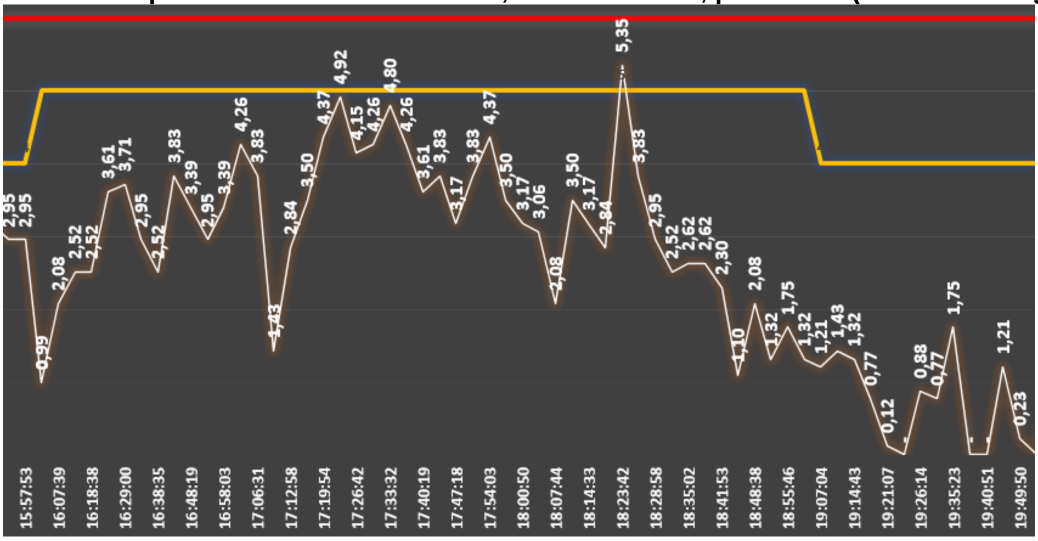
With the data generated by each train the Engineering team developed an Excel dashboard that get these and plot in a dynamic graph to make possible to analyze if the train offering program, named POT, is according with the passengers demand. It is possible to analyze the train occupation in each platform.

Figure 20 - Occupations in Line 1 in 23/11/30, in BNC station, platform 2



Source: Internal Documents.

Figure 21 - Occupations in Line 1 in 23/11/30, in BNC station, platform 2 (zoom in the figure)



Source: Internal Documents.

Another information given by this sheet is the highest occupation in peak hours, at what time that happened and in which train this occurred. With this it can be analyzed if some high occupation was caused by an specific occurrence in the line.

Table 1 - Highest occupations in Line 1 in 23/11/30, from LPA to PRJ

PRJ-LPA	Sentido Pirajá >> Lapa							
RANKING	Ocupação Pass. em pé/m²	Quantidade de Passageiros	Trecho-Sentido	Horário registrado	Trem	Intervalo realizado	Atrasado? (Intervalo+10%) "mm:ss"	Intervalo planejado
1	5,26	899	L1: Acesso Norte P1	07:32:18	Bravo 30	00:03:26		00:03:25
2	5,15	885	Bonoco P1	07:34:53	Bravo 30	00:03:23		00:03:25
3	5,15	885	Retiro P1	06:24:26	Bravo 22	00:05:40	atrasado em 01:50	00:03:50
4	4,93	856	L1: Acesso Norte P1	07:52:46	Bravo 12	00:03:21		00:03:25
5	4,93	856	Retiro P1	07:32:34	Bravo 17	00:03:25		00:03:25
6	4,82	841	L1: Acesso Norte P1	06:27:39	Bravo 22	00:05:58	atrasado em 01:08	00:04:50
7	4,82	841	L1: Acesso Norte P1	07:35:42	Bravo 17	00:03:24		00:03:25
8	4,82	841	Retiro P1	07:29:09	Bravo 30	00:03:28		00:03:25
9	4,71	827	Bonoco P1	07:55:23	Bravo 12	00:03:23		00:03:25
10	4,71	827	L1: Acesso Norte P1	07:28:52	Alfa 6	00:03:23		00:03:25
11	4,71	827	Retiro P1	07:35:57	Bravo 4	00:03:23		00:03:25
12	4,60	812	Bonoco P1	06:30:04	Bravo 22	00:06:02	atrasado em 02:12	00:03:50
13	4,60	812	Bonoco P1	07:17:50	Bravo 12	00:03:21		00:03:25
14	4,60	812	Bonoco P1	07:38:20	Bravo 17	00:03:27		00:03:25
15	4,60	812	Retiro P1	06:15:06	Bravo 30	00:05:44	atrasado em 01:54	00:03:50

Source: Internal Documents.

With all these information a multidisciplinary team make a weekly meeting to discuss the next week steps based on the previous week data. Beyond these is analyzed too if in the next week some different demand behavior is expected based in the historical data or public information received. In this meeting is decided if the timetable needs to be changed or not.

4 RESULTS ANALYSIS

The implementation of the project started in the beginning of 2023. Over the respective year a lot of lessons have been learned, like the expected behavior of the demand on each line per period of the year, and even the behavior in each weekday. In some months of the year, for example, the demand profile on Mondays and Fridays was different from the other weekdays. So the timetable during these days were different too.

The main goal of the project was defined to a reduction of R$ 4 million in the cost of energy in 2023, resulting in 18% less energy consumption. Besides, the contractual occupation limits should be respected.

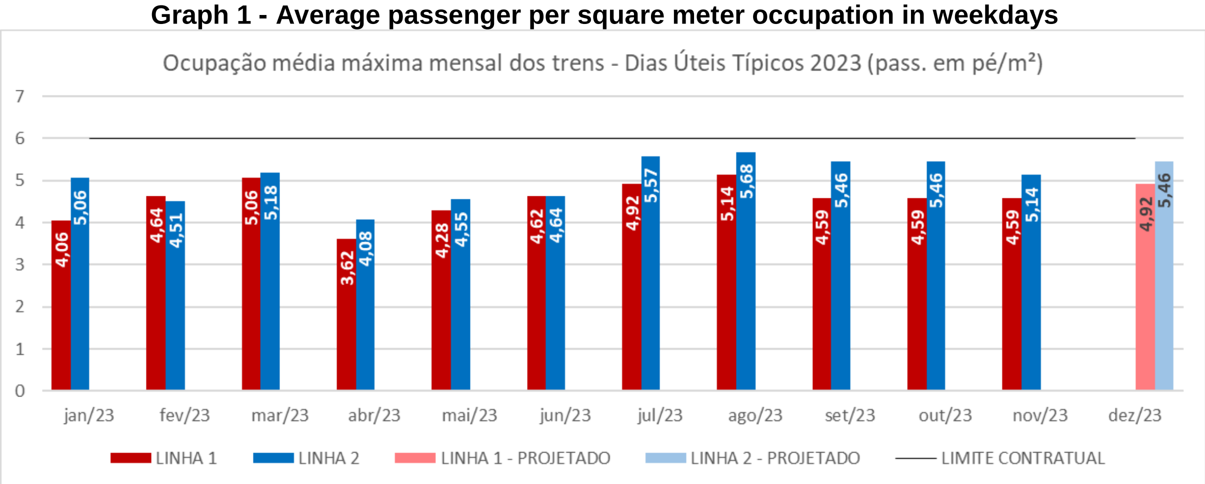
Along the year of 2023 the results of the project were being determined, and they will be showed in the following items.

4.1 Average train occupation

The average occupation of the trains should be lower than the contractual limit, that is 6 passengers per square meter. In a day that the headway in a period of time, mainly in peak hour, increased because an occurrence on the line, the occupation was over the limit in some train, but it just happens in specific cases.

Analyzing the entire year, considering the average per month in weekdays, it is possible to see that the result was positive.

Graph 1 - Average passenger per square meter occupation in weekdays



Source: Internal Documents.

From April to June the results were different from the other months due to some tests that were being done in the lines to understand and check other operation parameters. And more trains were circulating on the lines.

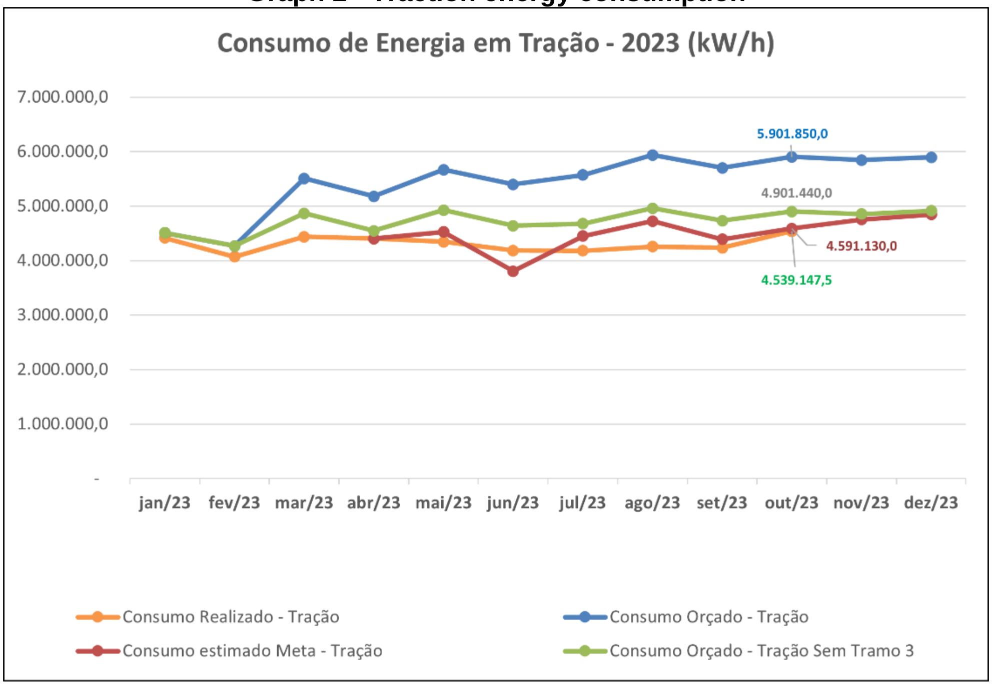
In the last months the result is much more stable. This shows that the team involved in this project is becoming more experienced with it and can be more precise in the weekly decisions.

4.2 Energy cost and consumption

The variation on energy cost and consumption were defined considering an average cost per trip in each line, based on some studies and train measurements done by the Engineering and Maintenance team, and the number of trips that were suppressed by the new timetables when compared to the number of trips that were planned in 2022 to be done in 2023.

This type of calculation was necessary because the trains don’t have individual energy consumption meter, and some parameters could change the results, like the non operational trips that were not measured to do the planning.

Graph 2 - Traction energy consumption



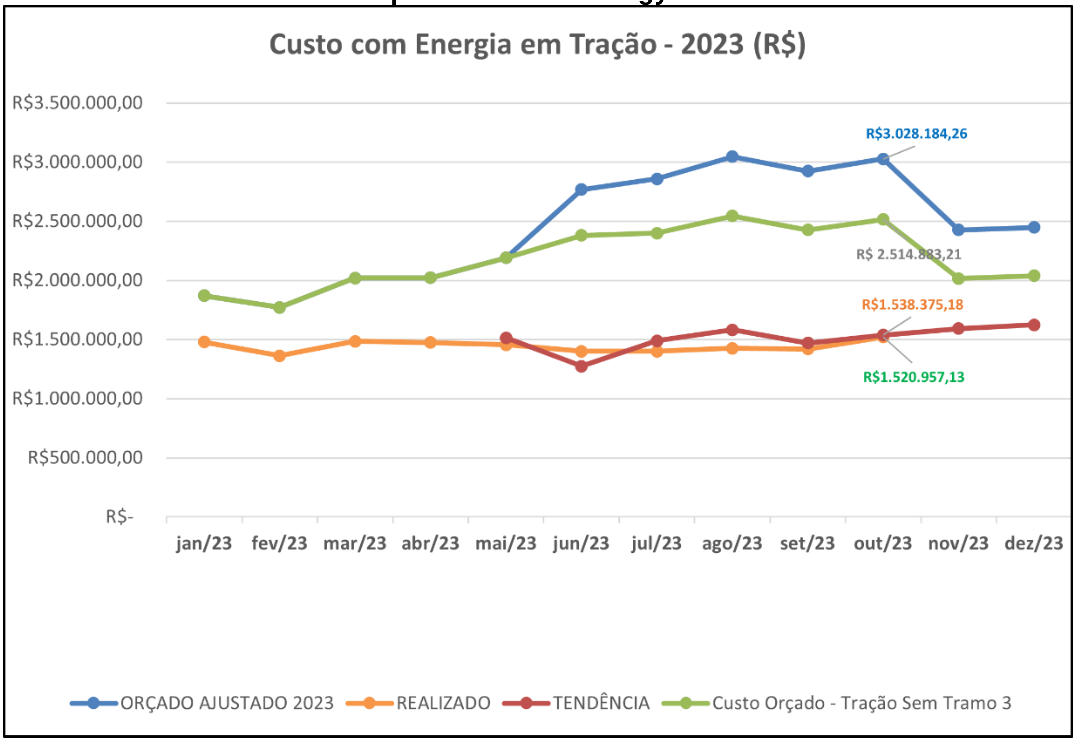
Source: Internal Documents.

The green line in the graph represents the estimated consumption per month but not considering the two new stations of line 1. The blue line in the graph represents the consumption planned when these both stations were operating. The full operation of them began in January of 2024, but some circulations were already being done since 2023, and even with this, due to this project, the real traction energy consumption, represented by the orange line was below of the planned one. At the time that this paper is being written the consumption of November and December are only estimated because there is a lag of the energy Concessionaire to issue the energy bill.

The red line represents the project energy consumption goal. The only month that it was not achieved was in June. Due to the school holidays in Bahia it was planned a great reduction of the trains in operation. But it didn't happen because of some operational tests that the company was doing until that month.

Considering that the energy consumption was lower than the planned, it can be presumed that the energy cost was lower too.

Graph 3 - Traction energy cost



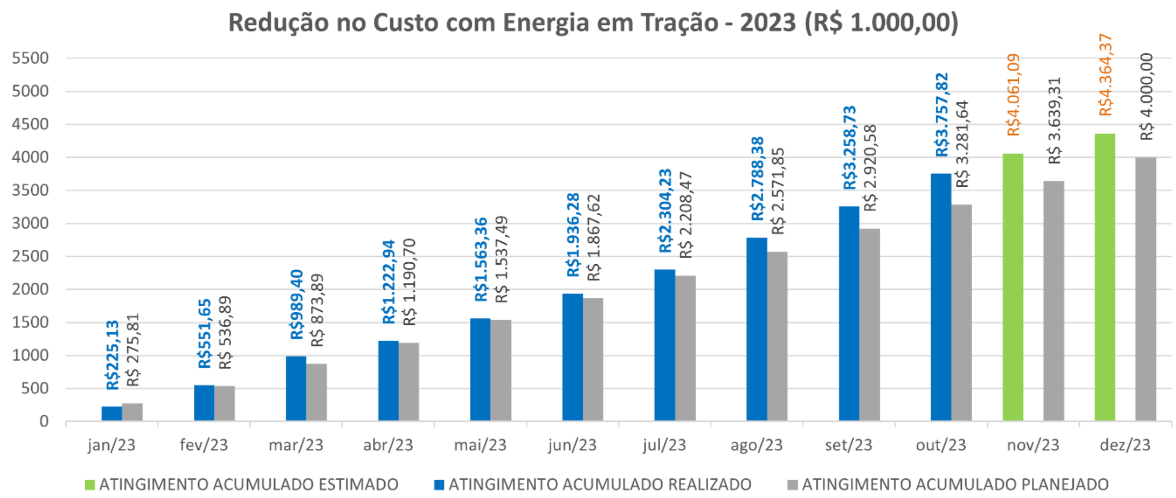
Source: Internal Documents.

The green line represents the estimated cost per month but not considering the two new stations of line 1. The blue line in the graph represents the cost planned when these both stations were operating. The orange line represent the real cost, and it can be seeing that in all months of the year the cost was below of the planned one.

A conservative estimation of savings in traction energy in 2023 is R$ 4,36 million, being 9% above the initial project goal.

The following graph shows the accumulated savings over the year, and the green bar in December represents the estimated total savings in 2023.

Graph 4 - Traction energy savings



Source: Internal Documents.

5 COST-BENEFIT ANALYSIS

A cost-benefit analysis (CBA) is the process of comparing the projected or estimated costs and benefits (or opportunities) associated with a project decision to determine whether it makes sense from a business perspective. Generally speaking, cost-benefit analysis involves tallying up all costs of a project or decision and subtracting that amount from the total projected benefits of the project or decision. Stobierski, Tim, 2019.

To carry out a CBA, an important tool to be used is the SWOT analysis. SWOT Analysis is an analysis method used to evaluate the Strengths, Weaknesses, Opportunities and Threats involved in an organization, a plan, a project, a program, a person or any kind of business activities. SWOT Analysis is the most commonly used strategic planning tool to access the Internal and External factors of any organization. This is considered as an effective framework plan and mange the organizational resource to achieve certain goals in a specific period of time To carry out a CBA, an important tool to be used is the SWOT analysis (WILDAUER, 2012).

To facilitate the implementation of this project, a SWOT analysis was carried out, thus making the gains that the project would bring to Metrô Bahia more visible. Below is the Table 04 with the developed SWOT matrix.

Table 2 – Strengths and Weaknesses

S	INTERNAL STRENGTHS
1	Cost Reduction / Saving
2	Maintenance Reduction (at trains and tracks)
3	ESG applied (Energy consumption saving)
4	The collected data already exists
5	Improvement in the platform flow. due to the organization (behavior) and preparation of the customer in knowing when the train is arriving, and which car is the emptiest.
6	Elements that contribute to a more efficient and comfortable experience of the costumer

W	INTERNAL WEAKNESSSES
1	Increase of the manually work
2	Increased time spent by engineering and programming teams
3	As it is embedded electronics, some equipment must be replaced over time due to its useful life or obsolescence
4	Availability of the information on the screen, in case of TV issues of embedded equipment.,
5	Spent time by training maintenance team if you must change any equipment or Technologies at this Project.

Source: Internal Documents.

Table 3 – External Oportunities and Threats

O	EXTERNAL **OPPORTUNITIES**
1	Development of new technologies
2	Help Rail Market to reduce the effects of ESG
3	Develop a real time APP to view all these information on the personal cellphone
4	Opportunities in carrying out this development for internal components or other systems
5	Incorporate external data, such as local events, Weather conditions and traffic events to adjust forecast and improve system responsiveness
6	Sound Messages of this systems for the hearing impaired have the same information and experience

T	EXTERNAL **THREATS**
1	Increase CAPEX to obtain new technologies
2	It can become an obligation with the Government (carbon reduction policy)

Source: Internal Documents.

6 RISK ANALYSIS

Risk analysis is the process of identifying and analyzing potential issues that could negatively impact key business initiatives or projects. This process is done to help organizations avoid or mitigate those risks.

To understand the risks that this Project are exposed, a SWOT analysis was provided, although a SWOT analysis may prove to be a launching point for further discussion, risk analysis often addresses a specific question while SWOT analysis are often broader. Some risks may be listed on both, but a risk analysis should be more specific when trying to address a specific problem, however its presented below a Risk Matrix with the study of the threats identified at SWOT analysis.

Table 4 - Main points of risk analysis

1	Increase CAPEX to obtain new technologies
2	It can become an obligation with the Government (carbon reduction policy)

Source: Internal Documents.

Table 5 – Risk Matrix

Impact	RISKS					TOTAL	
	4-Critical	0	0	0	0	0	Intolerable
	3-Severe	0	0	0	0	0	Moderate
	2-Moderate	1	1	0	0	2	Acceptable
	1-Minimum	0	0	0	0		
TOTAL = 2		Unlikely	Possible	Probable	High Probable		
		Probability					

Source: Internal Documents.

7 PROJECT PLAN

The project was implemented in the beginning of 2023 in Metrô Bahia. During the respective year the results could be measured and analyzed. The process will be continued.

However more steps can be taken to improve the process. The main development planned for the year of 2024 is a tool that provides an analyze optimization of the data.

Every day almost 9000 lines in an Excel sheet is generated by the system. This must be treated using Excel formulas. So it is necessary a lot of human work to do this.

Figure 22 - Example of the generated data

1	timestamp	estacao	li		trem	peso_	peso_	peso_	peso_	peso_(	peso_	0	DATA	HORA	FAIXA HO	LI	TREM	P	PASSAGE	ESTA	ORDE	PASS.	LIMITE CONTR
568	11/30/23 09:22:00	Retiro	1	1	TRAIN_230	45	45	47	49	186	166		30/11/2023	09:22:00	09:15	1	Bravo 30	20	290	Retiro P1	5	0,66	6,00
569	11/30/23 09:16:30	Retiro	1	1	TRAIN_231	45	46	48	50	189	167		30/11/2023	09:16:30	09:15	1	Bravo 31	22	319	Retiro P1	5	0,88	6,00
570	11/30/23 09:10:48	Retiro	1	1	TRAIN_215	46	45	48	49	188	167		30/11/2023	09:10:48	09:00	1	Bravo 15	21	305	Retiro P1	5	0,77	6,00
571	11/30/23 09:06:09	Retiro	1	1	TRAIN_213	46	46	48	50	190	166		30/11/2023	09:06:09	09:00	1	Bravo 13	24	348	Retiro P1	5	1,10	6,00
572	11/30/23 09:01:25	Retiro	1	1	TRAIN_105	51	48	45	47	191	179		30/11/2023	09:01:25	09:00	1	Alfa 5	12	174	Retiro P1	5	0,00	6,00
573	11/30/23 08:56:15	Retiro	1	1	TRAIN_222	45	45	49	50	189	166		30/11/2023	08:56:15	08:45	1	Bravo 22	23	334	Retiro P1	5	0,99	6,00
574	11/30/23 08:51:25	Retiro	1	1	TRAIN_204	49	49	50	54	202	170		30/11/2023	08:51:25	08:45	1	Bravo 4	32	464	Retiro P1	5	1,97	6,00
575	11/30/23 08:46:36	Retiro	1	1	TRAIN_106	55	48	55	58	216	193		30/11/2023	08:46:36	08:45	1	Alfa 6	23	334	Retiro P1	5	0,99	6,00
576	11/30/23 08:41:54	Retiro	1	1	TRAIN_230	50	48	52	53	203	167		30/11/2023	08:41:54	08:30	1	Bravo 30	36	522	Retiro P1	5	2,41	6,00
577	11/30/23 08:36:55	Retiro	1	1	TRAIN_231	48	48	50	52	198	166		30/11/2023	08:36:55	08:30	1	Bravo 31	32	464	Retiro P1	5	1,97	6,00
578	11/30/23 08:33:06	Retiro	1	1	TRAIN_215	49	48	49	53	199	166		30/11/2023	08:33:06	08:30	1	Bravo 15	33	479	Retiro P1	5	2,08	6,00
579	11/30/23 08:29:16	Retiro	1	1	TRAIN_212	48	48	50	50	196	166		30/11/2023	08:29:16	08:15	1	Bravo 12	30	435	Retiro P1	5	1,75	6,00
580	11/30/23 08:25:31	Retiro	1	1	TRAIN_213	48	47	49	51	195	166		30/11/2023	08:25:31	08:15	1	Bravo 13	29	421	Retiro P1	5	1,65	6,00
581	11/30/23 08:21:55	Retiro	1	1	TRAIN_105	56	53	52	52	213	179		30/11/2023	08:21:55	08:15	1	Alfa 5	34	493	Retiro P1	5	2,19	6,00
582	11/30/23 08:17:47	Retiro	1	1	TRAIN_222	50	50	53	54	207	166		30/11/2023	08:17:47	08:15	1	Bravo 22	41	595	Retiro P1	5	2,95	6,00
583	11/30/23 08:13:52	Retiro	1	1	TRAIN_204	48	48	51	52	199	169		30/11/2023	08:13:52	08:00	1	Bravo 4	30	435	Retiro P1	5	1,75	6,00
584	11/30/23 08:10:05	Retiro	1	1	TRAIN_217	47	47	50	50	194	166		30/11/2023	08:10:05	08:00	1	Bravo 17	28	406	Retiro P1	5	1,53	6,00
585	11/30/23 08:06:40	Retiro	1	1	TRAIN_230	50	49	52	51	202	167		30/11/2023	08:06:40	08:00	1	Bravo 30	35	508	Retiro P1	5	2,30	6,00
586	11/30/23 08:03:37	Retiro	1	1	TRAIN_106	55	49	56	59	219	184		30/11/2023	08:03:37	08:00	1	Alfa 6	35	508	Retiro P1	5	2,30	6,00
587	11/30/23 08:00:54	Retiro	1	1	TRAIN_103	49	49	52	56	206	178		30/11/2023	08:00:54	08:00	1	Alfa 3	28	406	Retiro P1	5	1,53	6,00
588	11/30/23 07:57:28	Retiro	1	1	TRAIN_231	50	51	55	55	211	168		30/11/2023	07:57:28	07:45	1	Bravo 31	43	624	Retiro P1	5	3,17	6,00
589	11/30/23 07:53:08	Retiro	1	1	TRAIN_215	54	51	52	55	212	167		30/11/2023	07:53:08	07:45	1	Bravo 15	45	653	Retiro P1	5	3,39	6,00
590	11/30/23 07:49:35	Retiro	1	1	TRAIN_212	55	53	55	57	220	166		30/11/2023	07:49:35	07:45	1	Bravo 12	54	783	Retiro P1	5	4,37	6,00
591	11/30/23 07:46:10	Retiro	1	1	TRAIN_213	53	52	55	55	215	166		30/11/2023	07:46:10	07:45	1	Bravo 13	49	711	Retiro P1	5	3,83	6,00
592	11/30/23 07:42:47	Retiro	1	1	TRAIN_105	56	53	53	52	214	180		30/11/2023	07:42:47	07:30	1	Alfa 5	34	493	Retiro P1	5	2,19	6,00
593	11/30/23 07:39:20	Retiro	1	1	TRAIN_222	52	52	54	55	213	166		30/11/2023	07:39:20	07:30	1	Bravo 22	47	682	Retiro P1	5	3,61	6,00
594	11/30/23 07:35:57	Retiro	1	1	TRAIN_204	54	56	57	60	227	170		30/11/2023	07:35:57	07:30	1	Bravo 4	57	827	Retiro P1	5	4,70	6,00
595	11/30/23 07:32:34	Retiro	1	1	TRAIN_217	55	56	56	58	225	166		30/11/2023	07:32:34	07:30	1	Bravo 17	59	856	Retiro P1	5	4,92	6,00
596	11/30/23 07:29:09	Retiro	1	1	TRAIN_230	55	55	58	57	225	167		30/11/2023	07:29:09	07:15	1	Bravo 30	58	841	Retiro P1	5	4,80	6,00

Source: Internal Documents.

The idea with the mentioned tool is to have some application that can do the analysis in an automatic way. The engineering team is responsible for this development and the expectation is to have the product to test in July of 2024.

8 CONCLUSION

For the Variable POT Project developed in Metrô Bahia the goal was to have a systematic to make possible to analyze the demand in each train to have more efficient timetables, reducing the consumption of electrical energy in traction. Like described on Chapter 3 the team developed a methodology and an Excel tool that is possible to analyze the demand comparing with the train supply per hour of the day, and finely adjust the number of trains in operation.

Furthermore, like shown on Chapter 4, comparing the planned amount of energy to be consumed in 2023 with the real consumption in the same year after applying the project, It is possible to see that the company had a great amount of savings on it. The goal of the project was to save R$ 4 millions with the traction energy cost, and the calculated reduction was estimated in R$ 4,3 millions. So the goal of the project was achieved.

At the first chapters some possible technologies for the occupation measurement were shown. So, for each type of trains or operations the project can be adapted. The most important data for the project is how many passengers there are in the trains, in each local. So if a company can obtain these data, the concepts shown in this paper can be directly applied to the respective company. The project is already been applied in another lines operated by CCR Group.

For the next step, beyond the idea described on Chapter 7, it can be analyzed the impact on maintenance costs that this project can produce. With less kilometers circulated, less train maintenance will be need. So the reducing in the costs of maintenance is directly related to this project. With this the total gains would be possible to be calculated with the implementation of these concepts.

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