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Minimizing operating failure attention times in the STC Metro: case of study of the optimal location of workshops

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Abstract

The main issue that generates dissatisfaction among users of the subway of Mexico City (STC Metro) service is related to the delay in the circulation of trains. Based on the 2018-2030 metro master plan delays are caused by a lack of rolling stock, breakdowns in trains as well as infacilities fixed. To address this situation STC Metro network has 7 maintenance workshops. The aim of this article is to analyze the geographical location of maintenance workshops, to evaluate if it is optimal to provide the best service to the user in case of failure. Subway lines 1, 3, 5 and 9 were considered for the study due to the high number failures that are attended at the maintenance workshops. Anylogistix™ software was used to run optimization models. First, a discrete model was developed in which all maintenance workshops are included, and failure attention is considered depending on the proximity to the location of each subway line. Subsequently, a continuous model was developed with the purpose of providing new locations to maintenance workshops for better attention to failures in terms of distance. From the analyzes carried out, it is expected to find solutions that allow minimize operating failures attention.

Keywords: Optimal location; resource allocation; subway; Mexico City; operational failures.

1. Introduction

The subway of Mexico City (STC Metro), is a decentralized public organization that started working on September 4th, 1969, offering service 365 days a year with different schedules between workdays and weekends.

The update subway network works with 12 lines that are integrated for 226 kilometers of railways and 195 stations, 44 correspondence stations, and 127 passing stations. If we classify the stations by type, there are 115 underground stations, 55 surface stations, and 25 elevated stations. In 2017, the STC Metro reported that 1615.6 million users were transported, to provide the service, the rolling stock made 1.2 million turns in that year and traveled 44.2 million kilometers. The network's vehicle park has 394 trains, of which 331 are pneumatic and 63 are railway.

1.1. Causes of the operating failures

Maintenance, conservation, and modernization of STC Metro are lagging due to the continuous use of the equipment and the lack of material, which doubles their useful life. Some of the failures in the operation are mentioned below:

- Accumulation of the backlog in maintenance of rolling stock, fixed installations, and civil works.
- Term of the useful life of systems, equipment of fixed installations, and rolling stock.
- Evolution in technology in market systems and equipment make technological innovation necessary.

The main problem that causes dissatisfaction in service users is related to the delay in the circulation of trains, which according to the 2018-2030 metro master plan (STC Metro, 2017), is caused by the lack of rolling stock, breakdowns in trains and in fixed installations. The maintenance of rolling stock is particularly sensitive since the deficiencies that they have are perceived directly by the user. The lack of equipment and spare parts can be observed by counting the trains that are in the maintenance workshops: 32 trains have been out of service for more than 3 years, 7 trains will be withdrawn due to the state in which they are found, but it should be noted that due to the same lack of availability of resources, it has been necessary to choose to take the parts that still serve from those trains in order to repair and return to use the trains that have faults or breakdowns. These same actions cause that by not having the complete vehicle fleet, the mileage of rolling stock in "good condition" will increase and that will cause the maintenance that must be carried out according to the manufacturer's specifications to be extended due to the same issue of not being able to further reduce the vehicle fleet, which increases the incidence of breakdowns and results in reduced reliability and availability of trains.

As shown in Figure 1, the STC Metro from the Subway General Manager is divided into three large areas, which are important for the problems raised in this work. The areas of operation, maintenance, administration, and finance are at the same level of responsibility. In the area of operation, we can see the *Engineering and Technological Development Department*, in this, all the incidents that occurred in each station per day are recorded, they are also divided by hours, with the aim of being more specific about the situations that affect the operation. To carry out this research , we were provided with the data of the incidents that occurred on the STC Metro lines in 2022.

On the other hand, the *Administration and Finance Department*, within the division of *Material Resources and General Services* there is the management of "warehouses and supplies" as well as "acquisitions and contracting of services", which, as described in the STC Metro 2018-2030 master plan, have identified problems such as: the lack of spare parts, as well as the late acquisition process. In addition, the lack of training for operators and employees. Likewise, there is a very narrow policy in the scope of contracting services, either by the type of provider required or by geographic location. In the same way, the maintenance process is affected by the long waiting times for spare parts of the train models that are operating on the lines of the STC Metro network.

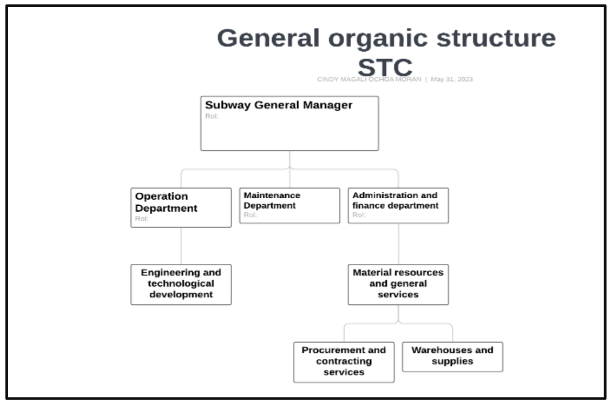

Figure 1. General organic structure of the STC Metro.

1.2. Preventive maintenance and corrective maintenance

In the Master Plan 2018-2030 is established within the institutional objectives of the organization: *Guarantee the operation of rolling stock in the best conditions of reliability, safety and comfort, through the organization, direction, coordination and execution of the programs maintenance, and in accordance with the established standards, technical and quality specifications.* The conservation and maintenance programs are described in the catalog of Systematic and Cyclic Maintenance activities, within which the periodicity and mileage are specified for each of the train models that circulate in the network.

Among the main activities that are carried out in systematic subway maintenance are cleaning, lubrication, adjustment, change of wearing parts, diagnosis, and supervision of operation. This maintenance is carried out between 6,000 and 8,000 kilometers of travel in trains with Traction technology. -Electromechanical Braking. For trains with Traction-Electronic Brake (Chopper) technology it is between 10,000 and 12,000 kilometers and for trains with Traction-Brake with asynchronous technology it is between 14,000 and 16,000 kilometers.in trains with Electronic Traction-Brake technology (Chopper) it is between 10,000 and 12,000 kilometers and in trains with Traction-Brake with asynchronous technology it is between 14,000 and 16,000 kilometers.

Subway cyclic maintenance consists of providing conservation service to train components in periods ranging from 3 to 24 months. And within the cyclical maintenance is the major cyclical maintenance, which aims to restore the operating conditions of the wagons and trains, this type of service is provided only in major maintenance workshops. To do this, the STC Metro has different major mechanical maintenance workshops. The list of workshops, major mechanical maintenance workshop, their location and train models serviced in them is shown below.

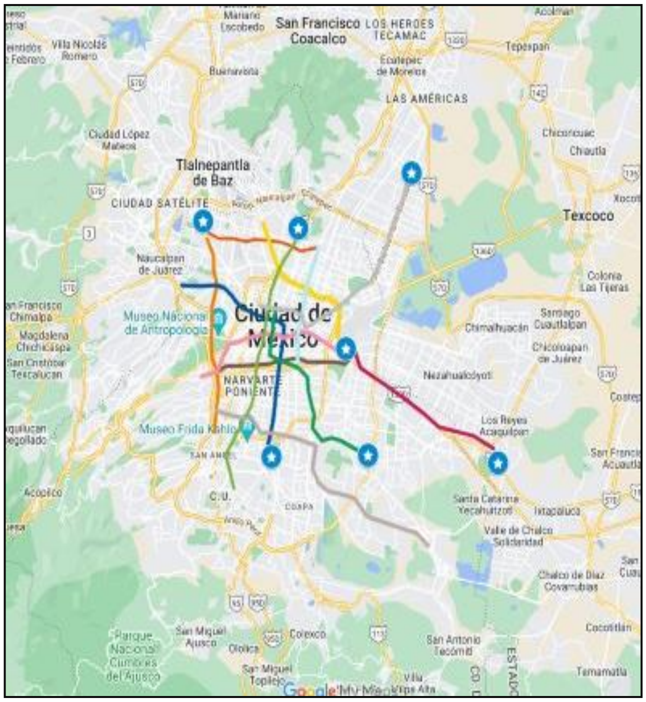

Figure 2. Major mechanical maintenance workshops location in the line map of the STC Metro.

Table 1. Systematic mechanical maintenance workshops of the STC Metro.

Workshop	Operational staff	Service to lines.
Zaragoza	189	1 and 9
Tasqueña	191	2
Ticomán	190	3 and 5
El Rosario	170	4,6 and 7
Constitución de 1917	105	8
Ciudad Azteca	135	"B"
La Paz	123	"A"

Table 2. Major mechanical maintenance workshops of the STC Metro.

Workshop	Operational staff	Model train
Zaragoza	260	MP-68R93,MP-68R96,NM-73A,NM-73B,MP-82,NC-82 and NE-92
Rehabilitation (Zaragoza)	84	NM-73A,NM-73B,NM-79 and NC-82
Ticomán	189	NM-79,NM-83A,NM-83B and NM02

As previously described, the Mexico City subway transports millions of people per day and is therefore exposed to failures during service hours, often due to a lack of timely maintenance. This study aims to capture in a more visual way if the current location of the workshops it is the correct one to give attention in the event of a failure in any of the stations close to it. With the simulation model, the current location of the workshops will be considered for a correct attention and a proposal of locations to improve the attention of failures in this system.

This paper is organized into five sections. In the following section the systematic literature review about localization theory, maintenance and subway failures are presented. The methodological approach based in discreet and continuous models and location-allocation algorithm technique to know how does an optimal geographical location impacts on the attention of the service in Section 3. The main results of the analysis and the discussion about the current and optimal location of the workshops to give attention in the event of a failure its prompt attention to it is presented in Section 4. The final observations and recommendations for future research work on a proposal of optimal locations to improve the attention of failures in STC Metro are described in Section 5.

2. Systematic Literature Review

In this section, a systematic review of the literature on location theory was presented. The literature review process proposed by Machi and McEvoy (2009) was used. Figure 3 describes the steps for conducting a literature review.

2.1. Select a topic

The maintenance workshops and spare parts warehouses have the best location for attention to service failures given the demand on subway lines 1, 3, 5 and 9 of the STC Metro was the question raised for the investigation.

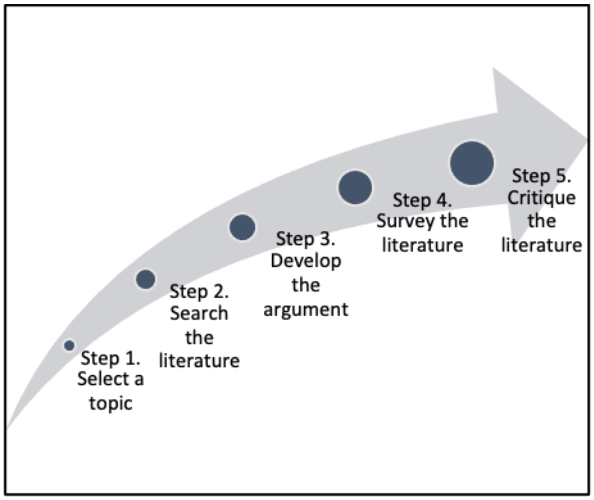

Figure 3. The literature review model, Machi and McEvoy (2009).

And if it were wrong, what would be the most optimal location or how many would provide the best service to the system? Currently, STC Metro has seven maintenance workshops. Therefore, the locations of these workshops will be analyzed, given that with the current conditions and the growth in demand in the STC Metro, they may no longer be suitable for operation. The VOSviewer™ tool was used to obtain the keyword relationship maps with respect to the topic under study. Each search was performed as described below:

From the searches carried out in the software and the maps with the co-occurrences that each set of keywords presents, it was possible to know the direction that this research will take. The first search showed the study opportunity areas in the case of maintenance. In this first iteration we chose the maintenance area for a subsequent search for information. The allocation of and activities related to maintenance efficiently were chosen for a subsequent search. key areas such as: resource management, maintenance, reliability, etc. were found in it. Finally, the current location of the workshops and their resources to cover the demand for line failures were the words used for the third information search. These searches can be seen in Figures 4 and 5.

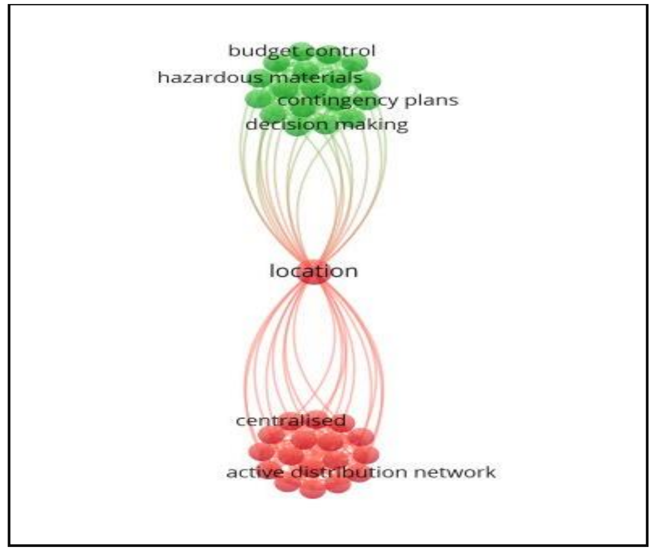

Figure 4. Clustering the keywords: *location AND allocation AND model AND fault AND attention*, based on the co-occurrences using VOSviewer™ software for search based on Scopus™ database.

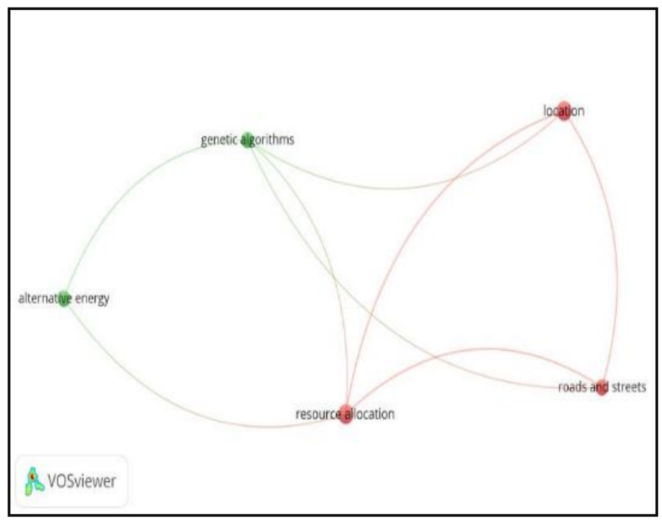

Figure 5. Clustering the keywords: *location AND resource AND allocation*, based on the co-occurrences using VOSviewer™ software for search based on Scopus™ database.

2.2. Develop the argument

Based on the previous literature review, the objective was to determine what other authors (Park J, Bosques S.) (Mendoza R, 2022) (Qi Gong, 2022) had researched or done regarding the optimal location of a maintenance workshop in each region, through the evaluation of selected potential locations. In this sense, the authors have defined that resource allocations and genetic algorithms have been used to conduct investigations that allow finding the most optimal location for incident attention.

2.3. Write the review

While we were looking for information about the location of maintenance workshops related to STC Metro, we were able to realize that, in other countries trains cannot fail while they are running, because they are given a preventive maintenance to the units and this procedure is punctual to keep the units in optimal conditions and to be able to provide a quality service. However, we found that in Mexico City, at STC Metro, there are maintenance workshops that provide service to the trains, but due to the high demand for the service and the overcrowding in the units, they present failures during their operation and consequently the service stops, creating delays that affect the entire system. Therefore, attention to failures in a matter of time efficiency is a critical point for the system. It was sought to know if the current location of the workshops has the appropriate configuration to be able to provide service to each of the lines of the system.

Within the bibliographic review, different models based on the theory of location were identified, in which they seek to find the most optimal location. The maximum coverage model is used for public services, since it seeks to serve the largest number of users, with a limited number of locations, to provide a broader range of services.

In the same way, several articles of location theory were found that explained the criteria to be able to locate unwanted facilities, since a service workshop generates noise at unwanted hours, waste and some other things that fall within the categories of unwanted facilities. Thanks to this, we were able to verify whether the current facilities comply with the required distances and the relevant safety measures.

3. Materials and Methods

3.1. Failures data

The database of failures related to subway maintenance workshops provided by the STC Metro for the period January to September 2022, was used to classify the failures and identify which are the most representative for study. Once the most representative faults were identified, subway lines 1, 3, 5 and 9 were selected for the study because they present those that require attention in a maintenance workshop. It is important to mention that for the evaluation of these subway lines, the objective was to cover the largest number of failures that occurred in the system, as well as the optimization of service times. In addition, it was considered not to affect the surrounding communities due to noise or the operation in the workshops.

3.2. Software

The free access software, in a student version, Anylogistix™ was chosen for the research as it allows us to test different analytical optimization approaches, showing the results, visually, for each proposed workshop and the subway lines under study. In that sense we developed two models that allowed us to know if the current location of the STC Metro workshops is ideal.

3.3. Methodology

A methodology for the optimal location of facilities has been used, in which a discrete model and a continuous one have been developed, the first allows analyzing the current location of the workshops and the second the optimal location of the maintenance workshops to provide attention to failures to subway lines 1, 3, 5 and 9. The subway lines were chosen because they are the ones that have presented failures that affect the service and these are particularly attended in the maintenance workshops.

As a first step, a conceptual model of the workshops and the lines under study was made. Indicating the failure for each one of the stations and indicating their geographical location by means of the coordinates of each one of these. Later this conceptual model and data was implemented in the Anylogistix™ software. Figure 6 shows the current location of the maintenance workshops in the Anylogistix™ software. On the other hand, Figure 7 shows the location of the STC Metro maintenance workshops, as well as the location of each of the stations of the lines under study in the Anylogistix™ software.

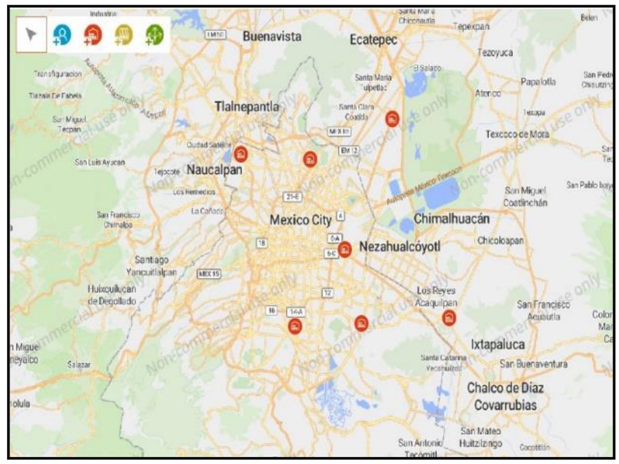

Figure 6. Map of the distribution of mechanical workshops with their current location. Self-elaboration with Anylogistix™ software. 25/05/2023

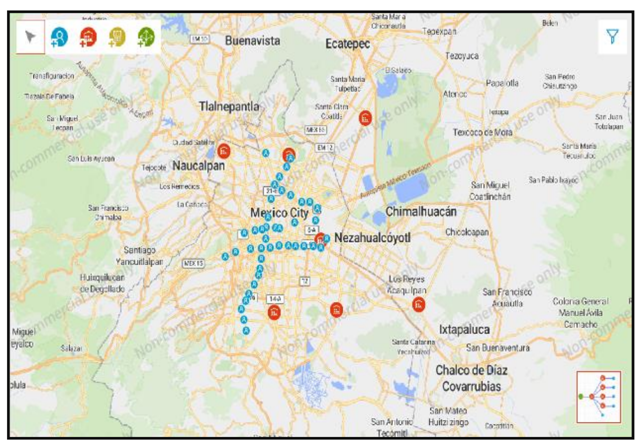

Figure 7. Map of lines 1, 3, 5 and 9 to which maintenance services are provided by the Zaragoza and Ticomán mechanical workshops. Self-elaboration with Anylogistix™ software.

Once the locations were integrated into the software the experiment was executed considering: 7 subway maintenance workshops and 60 subway stations to provide service. Additionally, a distance between subway station and subway maintenance workshop of 12 kilometers was considered.

It was observed in the discrete model that the software took only four workshops to attend to failures out of 7 existing ones. The subway workshops selected were: Rosario Workshop, Ticomán Workshop, Zaragoza Workshop and Taxqueña Workshop. The maintenance workshop that helps the most in line failures is Taxqueña maintenance workshop, since it takes stations located to the south of the city.

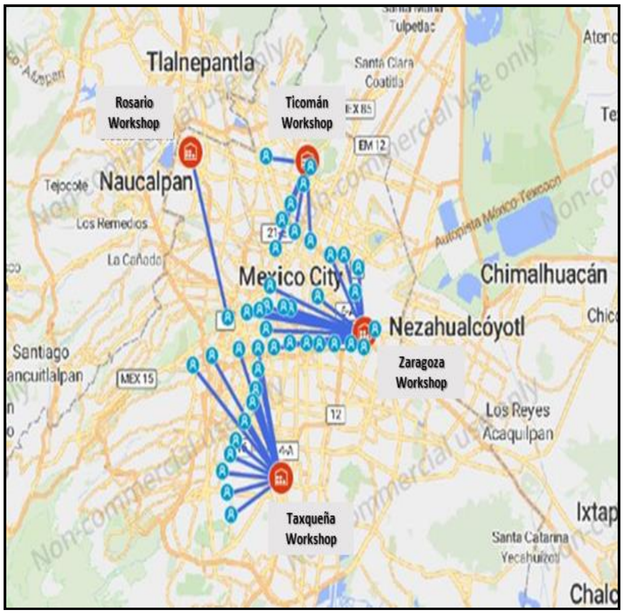

Figure 8. Discreet model. Self-elaboration with Anylogistix™ software.

Figure 8 indicates the set of stations with their respective maintenance workshop for optimal service. with. Based on the results, it was found that almost all of the stations under study are served by only two of the four workshops chosen in this model, given their proximity. An improvement proposal based on this model would be to add two locations at a shorter distance from the stations with failures, which would allow supporting the two most saturated workshops, achieving greater service efficiency. Once the discrete model was executed, the continuous model was developed, in this model the current location of the subway workshops was not considered, only the subway stations with occurred failures are located, in this case, the software defined the number of maintenance workshops, as well as , its location, based on the data uploaded, in order to provide better care regarding failures that occur by station, in each of the lines.

The results returned by the software were: 9 subway maintenance workshops were created, many of them are located in the same stations of the failures. We can observe that the distribution of the demand is a little more adequate for failure care, since on average each maintenance workshop serves four stations allowing faster attention considering a shorter distance and as a consequence there will be a decrease in transportation costs. Figure 9 shows the location of the proposed subway maintenance workshops as well as the subway stations that are serviced considering a shorter distance between them.

Based on the results obtained from the software, the current location of the subway workshops is not optimal, the service conditions could be improved by having maintenance workshops inside the subway

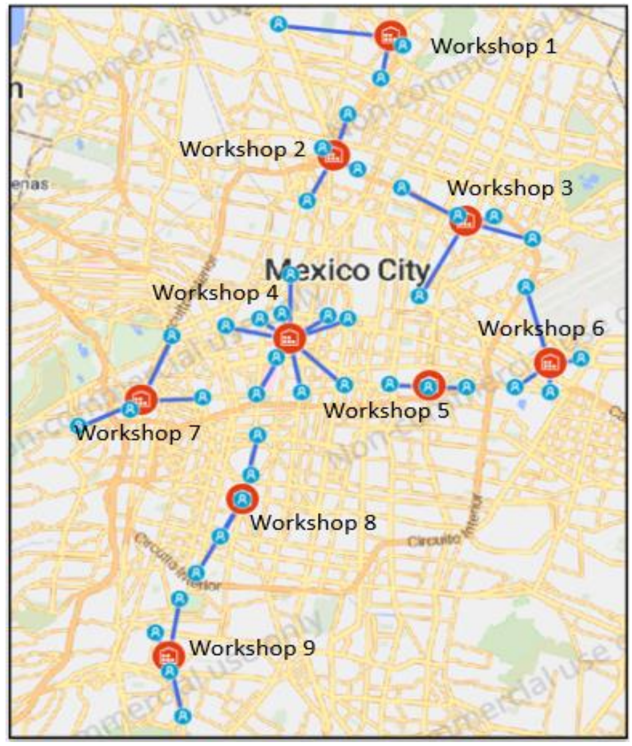

Figure 9. Continuos model. Self-elaboration with Anylogistix™ software.

stations of the lines under study or very close to them to improve attention to failures and achieve a decrease in waiting times for user service. It is important to highlight that, considering the continuous model, none of the current locations of the STC Metro maintenance workshops was chosen, this would mean that, given the current conditions of the STC Metro and the growth of the urban sprawl in Mexico City over the years, it requires a proposal for new locations for subway maintenance workshops for efficient attention to failures.

4. Results and Discussion

Currently, the subway lines under study are serviced, for the most part, by only 2 subway maintenance workshops, as could be observed in the discrete model developed, which considers the current locations of the maintenance workshops, show that 4 subway maintenance workshops must be assigned to attend to the failures presented. on lines 1,3,5 and 9.

The most saturated locations to serve the subway lines under study were the Rosario and Taxqueña workshops, it is logical to consider the latter since it can serve the stations that are closest to the south of the city and thus reduce the kilometers traveled for service to failures, however, as mentioned, it would be good to include two additional locations that would allow us a better distribution of the stations and, as a consequence, better attention to failures.

Based on the continuous model, the location of the subway workshops was not considered, only the subway stations with failures were located and the software proposed the optimal location of the subway maintenance workshops that meet the demand for failure care. The model proposed 9 subway workshops to provide the service, on average from three to four stations for each of them, for a more efficient service. It is noteworthy that none of the current maintenance workshop locations in the STC Metro were considered by the software, which makes us reflect on the timing of a change in the current maintenance workshop location. Once the results of the continuous model have been analyzed. Through the free version, student license, of the Anyologic™ software, a model was designed with the optimal locations proposed in the continuous model, of the subway maintenance workshops, considering the demand for attention to failures in each of its subway stations simulating the transfer of the trains to subway maintenance workshops, with the aim of making decisions regarding the distances traveled between stations and workshops, as well as improving service efficiency.

This model and its development helped us to conclude that the attention to failures with the new subway workshop locations has a better distribution in the subway stations to which they will provide attention, generating efficiency in the attention to faults and, therefore, an improvement in the perceived service. the user. Figure 10 shows the location of the subway workshops as well as the execution of the model with the trains moving using Anylogic™ software.

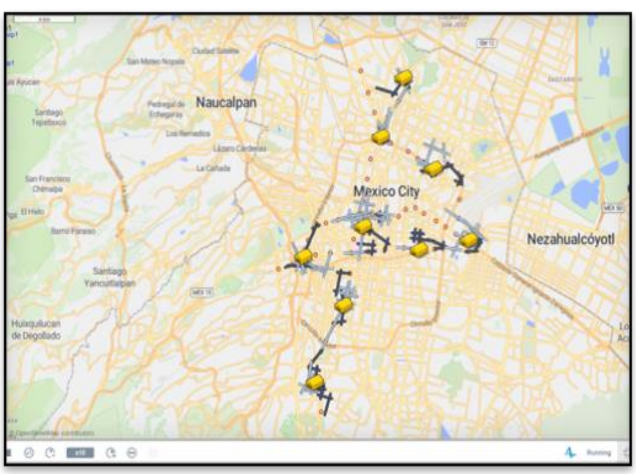

Figure 10. Simulation model of transport optimization. Self-elaboration with Anylogic™ software.

5. Conclusions

Even though only four subway lines of the STC Metro were studied, with the results obtained it was concluded that to provide more efficient attention to failures, at least two more maintenance workshops should be implemented. In order not to disable the current workshops, they will continue to operate, however, they would seek to improve their location or, as already mentioned, propose new locations within the stations for timely attention. Based on the results obtained in the models presented, a model will be sought that includes all the lines of the STC Metro network to be able to make some proposals to improve the maintenance workshop service of the STC Metro.

One of these being to designate the maintenance service to the nearest workshop or, where appropriate, that the team that oversees failure care is the closest to the failure, so that the distance traveled is less and the attention is timely and efficient for service improvement. Another proposal would be to invest in the location of new workshops as presented in the continuous model, so that faults are attended to, and current workshops are not saturated.

Finally, with this investigation, it was concluded that the current subway maintenance workshops are not enough to attend to the great demand for failures that occur in the system and that to improve the attention to failures, mechanisms that support the current workshops should be sought, such as: on-site service brigades or the location of new maintenance workshops.

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References

Bosques Sendra, J. G. (2006). Un nuevo modelo para localizar instalaciones no deseables ventajas derivadas de la integración de modelos de localización-asignación y sig. *El acceso a la información espacial y las nuevas tecnologías geográficas.*(39), 1399-1413.

Man Li and Yanhui Wang, C. S. (2011). Research on the Location Allocation Model for Subway Emergency Service. *2011 Third Pacific-Asia Conference on circuits, communications and systems (PACCS)*.

Mendoza R, R. R. (2022). Location of primary health care centers for demand coverage of complementary services. *ELSEVIER*.

Park, J., & Moon, I. (2023). A facility location problem in a mixed duopoly on networks. *Transportation search*.

Qi Gong, L. Y. (2022). Dynamic Preventive Maintenance Optimization of Subway Vehicle Traction System Considering Stages. *Applied Sciences*.

STC Metro. (2017). *Diagnóstico sobre el servico y las instalaciones del sistema de transporte colectivo. 2013-2018.* Ciudad de México.

The Anylogic company. (5 de Mayo de 2023). *anyLogistix.com*. Obtenido de https://www.anylogistix.com/

Turan Erman Erkan, W. M. (2019). Overview of Airport Location Selection Methods. *international Journal Of Applied Engineering Research*, 1613-1618.