SIMULATION OF THE OPERATION OF A METRO STATION

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ABSTRACT
This document presents a simulation study carried out in a metro station in Mexico City, which was made in order to determine whether the station has sufficient capacity to meet passengers demand in hours of maximal influx (6 to 9 am) and to evaluate some scenarios of interest. The document begins by presenting an introduction to the metro station, then defines specifically the problem and presents the methodology followed; it presents the simulation model built in SIMIO and then shows the results. Finally, we give some conclusions about the operation of the station.

Keywords: metro simulation, simio, collective transport system, metro station.

1. INTRODUCTION
The **Constitucion de 1917** station is one of the main stations of the Collective Transport System (CTS) of Mexico City, in an average weekday, it receives an influx of over 110,000 passengers and about 18% of them access the station in the morning, from 6 to 9 am. In the next table, it is shown the busiest stations on an average weekday in 2011:

Table 1: Average Weekday Influx in the Busiest Stations

No.	Station	Line	Influx
1	Cuatro Caminos	2	130,511
2	Indios verdes	3	128,417
3	Constitución de 1917	8	111,188
4	Pantitlán	9	106,643
5	Pantitlán	A	101,723

The station is located on Ermita Avenue, almost at the cross with Periferico Avenue. It is classified as a surface terminal that belongs to the Line 8 of the CTS, which does not link with any other line of the transport system. To the north of the station there are 2 bridges that serve as access and exit. To the south there is a bridge that serves only as entry and another that serves only as exit. In this direction, there is a Bus Terminal that has more than 21 routes, which connects to the south, central, north and east of the city.

The Station is a multimodal transfer center that connects the south-eastern region of Mexico City.

Figure 1: Aerial view of Constitucion de 1917 station

The Station has 2 ticket offices for selling tickets, each of them located at the longitudinal ends of the station.

It was decided to make the study because the Constitucion of 1917 station is one of the busiest terminals and the highest passenger flow occurs from 6 to 9 am on a weekday.

It is common at that time, that the lines to buy tickets exceed the capacity of the available space and invade other areas. For example the Northeast access stairs and the south corridor exit.

The station also presents saturation on the platform, to a point that it is not possible to access it, jeopardizing the safety of passengers.

Different factors has been widely studied in metro stations. There are some studies related to the behavior of passengers during boarding and alighting trains (Zhang et al., 2006), or the impact that the size of the access gates has on the flow of passengers (Hoogendoorn and Daamen, 2004).

Other studies are focus on specific factors such as pedestrian flow (Cheung and Lam, 1997), route selection (Cheung and Lam, 1998) or speed-flow relationships (Daly et al., 1991). In this case, we decided to focus on the relationships between passengers, ticket offices and the platform.

The present study aims to determine whether the station has, at this time, sufficient capacity to meet passengers demand and to evaluate some scenarios of interest such as including ticket machines, or the possible impact that the decrease of passengers will have due to the opening of a new metro line.

Figure 2: Pictures of Constitucion de 1917 station

2. PROBLEM DEFINITION

The following research questions are formulated to serve as a guide during the study:

- Is there sufficient capacity at the ticket office to deal the passengers demand?
- What is the average time that a person should expect to wait from the moment he reaches the station until he leaves on a train?
- Is there enough capacity on the facilities or are they overwhelmed by the number of passengers?

The scope of the investigation is limited to the Constitucion de 1917 station, which belongs to the Line 8 of the CTS; we study the influx of passengers on weekdays and from 6 to 9 am, which are the maximal influx hours.

We only consider the people who arrive to the station *from outside of the system*, and we do not consider the passengers that come from the previous station because they are a low number at that hour.

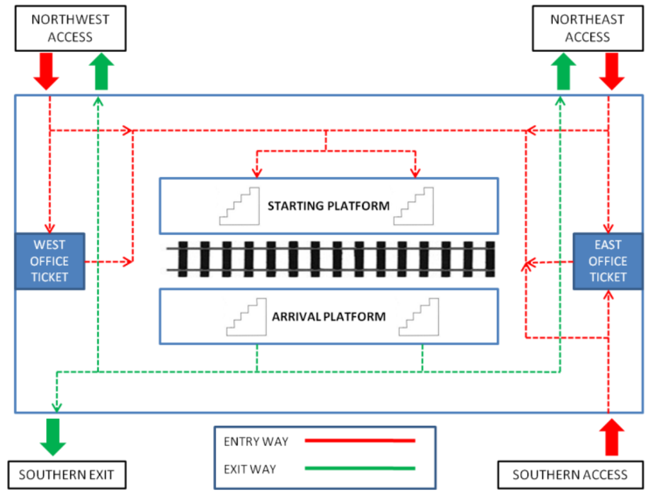

Figure 3: Diagram of the System

The objective is to obtain descriptive measures of the performance of Constitucion de 1917 station, throughout a simulation study that models waiting times at ticket offices and on the platform, determine whether it has sufficient capacity and to evaluate some scenarios of interest.

3. METHODOLOGY

The order in which the research was made followed the next methodology (Flores, 2006):

3.1. Problem definition

Here we determined the general objective and also the specifics ones of the research, the scope, and resources needed to carry it out.

3.2. System conceptualization

Once the research problem had been defined, we determined *which aspects or factors are the most relevant* and have the greatest explanatory behavior of the phenomenon, to decide whether to include them in the model and with what level of detail.

3.3. Data collecting

Once the system conceptualization was completed, we determined the information we had available, if it was reliable and what other information was needed to be collected according to the requirements of the model.

3.4. Model formulation

SIMIO software was selected to carry out the simulation due to their robustness and ease of use. We constructed a model that incorporates the relevant aspects defined above.

3.5. Verification and validation of the model
Some tests were performed to find and correct logic errors in the model and other tests were made to ensure that the model results maintain a correspondence with the real system, so the model could adequately predict actual system behavior within the defined framework.

3.6. Design of experiments
In this part we defined scenarios of interest and they were expressed in terms of the parameters that will experience change.

3.7. Data analysis
Here we compile the obtained results and some conclusions were drawn about the current operation of the system.

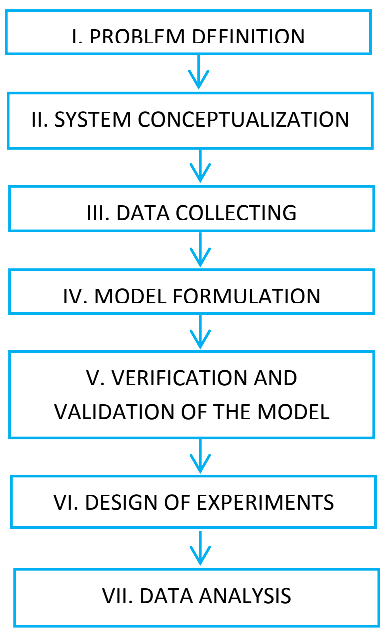

Figure 4: Methodology Followed

4. SIMULATION MODEL

4.1. System conceptualization
On the definition of the objective of this study, we determined the elements that are relevant for modeling the system. In the following diagram it can be seen that the system has three entries, corresponding to the doors: *Northwest*, *Northeast* and *Southern Access*.

There are two ticket offices which are independent one from another, so a passenger that is at any of the ticket offices can´t reach the other from there because there is a physical barrier.

Finally we have the *platform*, which is the space where passengers wait for the train to arrive.

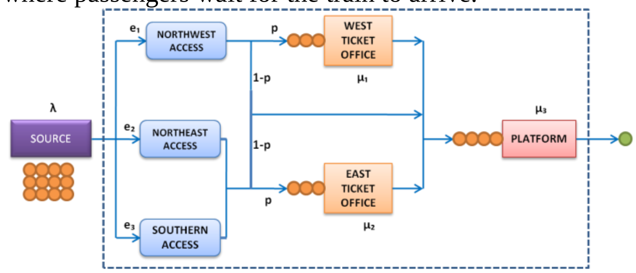

Figure 5: Diagram of the Process

4.2. Data collecting
Most of the information related to the operation of the station was obtained from the website of the CTS where they provide many useful data. However, it was necessary to take field samples to determine: the proportion of arrival of passengers associated with the access doors, the service times of the ticket offices and the departure times of the trains.

It should be mentioned that the collection of data also served to validate some of the data provided by CTS in its page. The data collection was taken on these days: Monday, Wednesday, and Friday; from 06:00 to 09:00.

4.3. Model formulation
The model was built as a system with one source that generates entities, any of them can enter to the station by one of the three accesses and follows a path that divides into two at each ticket office. There, for every entity, is a probability ***p*** to buy a ticket (therefore the entity goes into the waiting line) and a probability ***1-p*** to go straight to the platform, where the entity waits until a train arrives.

As mentioned above the software selected to carry out the simulation was SIMIO. We used the following objects:

4.3.1. Entities
We used two types of entities. The first type is the *passengers* and four types of passengers were created, each with a different movement speed to represent the passengers that walk at different speed. The other type of entities is the *trains* which are generated at the station.

4.3.2. Sources
We used two sources. The first one generates the passenger entities according to an exponential distribution. During the time considered in this investigation, the arrivals of passengers change throughout the time, so it was decided to change the parameter of arrivals in a stepwise way.

The parameter starts with a fixed value and then starts to increase until a maximum, after it reaches it, the parameter decreases. The following table shows the parameter values associated to time:

Table 2. Arrival Rate of Passengers per Hour

No	Time	λ	Classification
1	6:00-6:30	3,889.64	Minimal
2	6:30-7:00	5,834.46	Regular
3	7:00-7:30	9,724.10	Maximal
4	7:30-8:00	9,724.10	Máximal
5	8:00-8:30	5,834.46	Regular
6	8:30-9:00	3,889.64	Minimal

The second source generates the train entities that were properly adjusted to a triangular probability distribution.

4.3.3. Servers

There are two *servers*, which correspond to the ticket offices; each one on either side of the station. As mentioned before there is no path that connects them, so they are considered independent. Each ticket office can have up to two people at service and they have a single queue which follows a FIFO (First In First Out) discipline. The distribution of time between services was adjusted to a triangular probability distribution.

4.3.4. Combiner

A *combiner* was used to represent the platform where the passengers wait until a train arrives. This object was chosen because the arrival of a train can be modeled as an event where **one** train is combined with ***n*** number of passengers, where ***n*** is the minimal between the maximal train´s capacity and the number of passengers waiting in the platform at that moment:

$$n = min\{train\acute{}s\ capacity, passengers\ waiting\} \quad (1)$$

4.3.5. Sink

A *sink* is an object that destroys the entities; in this case we only used one sink to destroy both types of entities.

4.3.6. Paths and Nodes

The *paths* were used to determine the trajectory of the entities within the system and the *nodes* to represent the points where the entities select one of many paths. For example, the path that comes from the passengers source has a node which represents the decision of selecting one of the three possible entries; each one goes to a different door (northwest, northeast and south). The probability of selecting one of them is e_i such that:

$$e_1 + e_2 + e_3 = 1 \quad (2)$$

It is noteworthy that the model dimensions are scaled with the actual facility, and with the use of the *path* object (that takes some time to be traveled by an entity depending on the distance it has), the model better reflects the movement of passengers within the station.

Below there are some images of the simulation model:

Figure 6: East Ticket Office

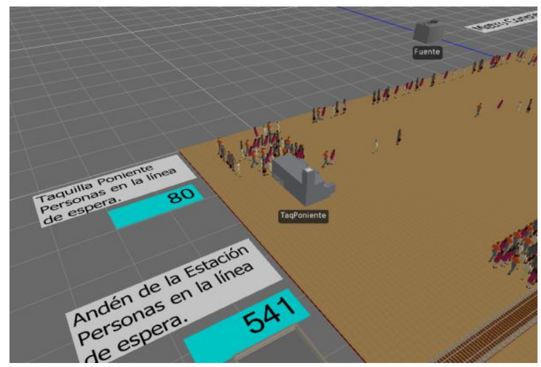

Figure 7: West Ticket Office

Figure 8: Platform

Figure 9: Simulation with SIMIO

4.4. Verification and validation of the model

To validate the model we used the following techniques:

4.4.1. Comparison with the real system

We ran a simulation using the parameter of maximal influx and we compared the number of people waiting in the queue on both ticket offices and on the platform; the results obtained were similar to the amount of passengers in the real system.

4.4.2. Behavior in extreme cases

We ran a simulation with significant delays on train departures and a large agglomeration of passengers was produced on the platform to the point of saturating it. This has happened on rare occasions in the real system, with similar results.

In another test we significantly decreased the influx of passengers to the station and we noticed that there were no queues on both servers (ticket offices) as well as on the platform. That situation is common to see in the real system at times when the influx of passengers is low.

5. DESIGN OF EXPERIMENTS

5.1. Scenario A. Current conditions

We ran a simulation of the system under the conditions in which it works currently considering that each ticket office is working with two servers, and the arrivals of the trains change with the time as shown in the table 2.

The purpose is to know the measurements of the system´s performance during normal conditions at peak traffic hours.

5.2. Scenario B. Two servers remain closed

In this scenario we simulated the event in which one of the servers on the east side and another on the west side ticket office, are disabled to operate, either because of absenteeism of the workers or not having the necessary equipment or any other case.

The purpose is to determine the impact to the system when the ticket offices have only one server during peak traffic hours.

5.3. Scenario C. Ticket vending machines

We simulated the event that there are installed two ticket vending machines, one on each side of the station next to the ticket offices. We assume that the speed of service of the machines is equal to the time of service of the server in the ticket office.

The purpose is to determine the possible reduction of waiting time at the ticket offices that these ticket vending machines can provide.

5.4. Scenario D. A decrease on the influx

We simulated the scenario that the influx of passengers to the station decreases by 10% due to implementation of Line 12 of the CTS, so the amount of people from the south-east region of the city would be reduced.

The purpose is to assess the potential impact on the station due to the expected reduction of passenger influx.

5.5. Scenario E. Constant departure time

We wanted to know the impact on waiting times and number of people on the platform when the time between arrivals of the trains is constant, taking as the constant parameter the *mode* of the triangular distribution.

The purpose is to evaluate the change in the average waiting time and average number of passengers waiting on the platform when the arrivals between trains remain constant.

In this table there is a summary of the information about the scenarios considered above:

Table 3. Summary Table of Scenarios.

Scenario	Description
A	The simulation is run with current operation conditions.
B	One of the servers at each ticket office is disabled.
C	One ticket vending machine is installed at each side of the station.
D	There is a decrease of 10% on the arrival of passengers.
E	The time between the arrivals of the trains is constant.

6. RESULTS

The experiment consisted of running the simulation over the period considered (three hours), changing the parameter of arrivals according to the above table. There were 10 replicates of each experiment. This was repeated for each scenario considered.

Scenario A represents the measure of comparison with the rest. The results are shown below:

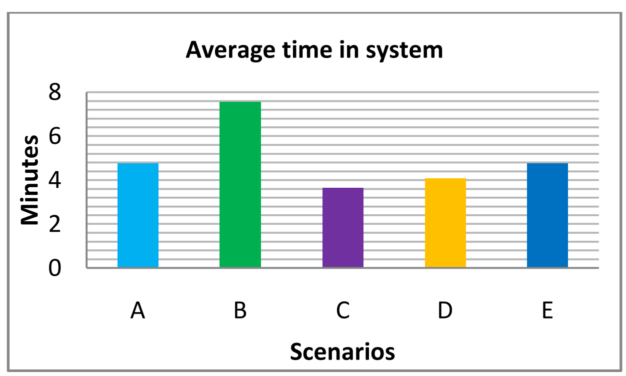

Figure 10: Average Time in System

The average time in the system is **5.2 minutes** under normal conditions. We can see that when there is only one server on each side (scenario B), the time increases by almost 60%. In addition, if ticket vending machines are set up (scenario C) the average time in the system would be reduced by 25%.

The scenario D which considers a 10% decrease in the influx of passengers, has an impact of about 15% less on average time in system, a total of **4.1 minutes**.

Finally, if the arrivals of the trains have a constant time, it would not significantly affect the average time in system (Scenario E), which is **4.75 minutes**.

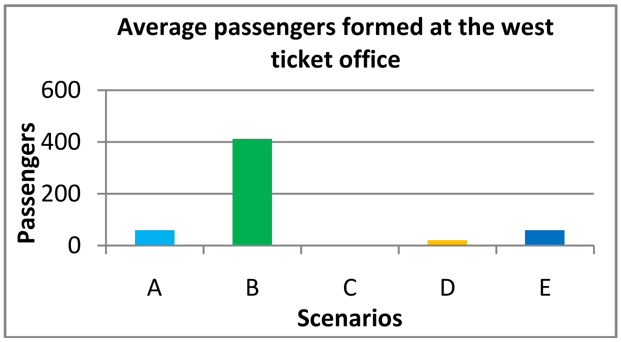

Figure 11: Average Passengers Formed at the West Ticket Office

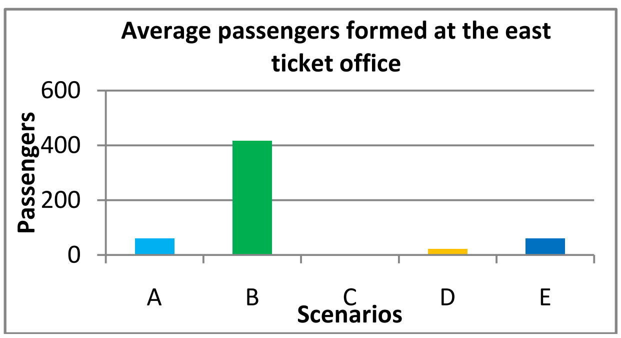

Figure 12: Average Passengers Formed at the East Ticket Office

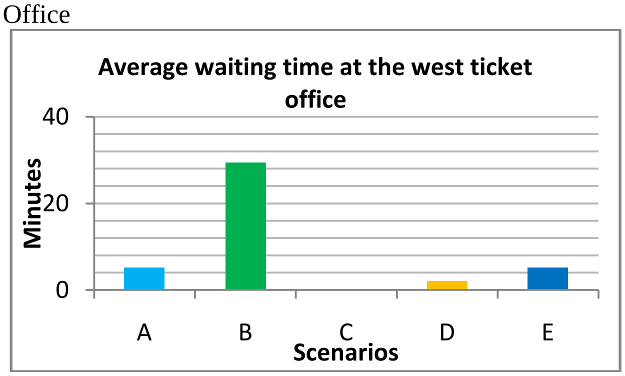

Figure 13: Average Waiting Time at the West Ticket Office

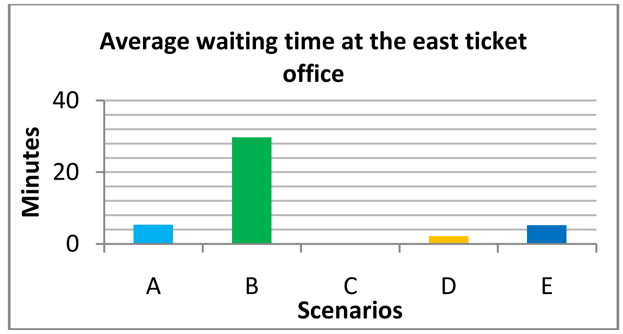

Figure 14: Average Waiting Time at the East Ticket Office

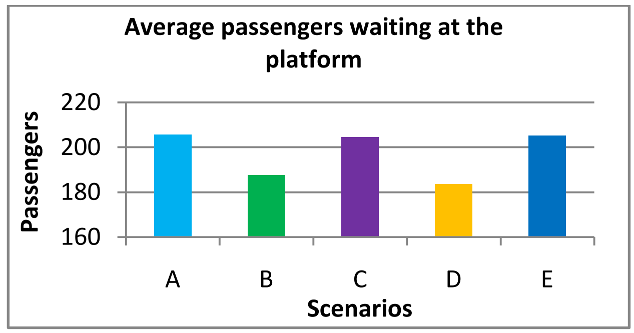

Figure 15: Average Passengers Waiting at the Platform

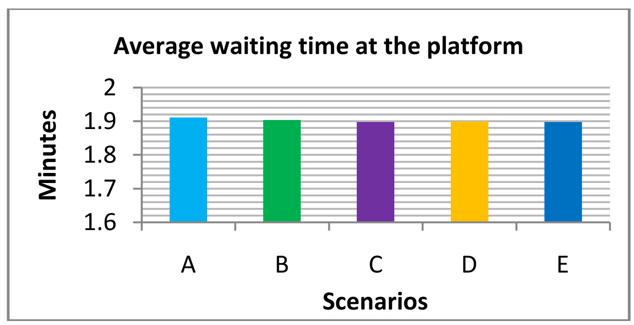

Figure 16: Average Waiting Time at the Platform

On the platform there were **205.6 passengers** and **1.91 minutes** on average waiting time for the A scenario. For B scenario, these values decreased slightly to **187.6 passengers** and **1.9 minutes**. This may be because of the lower capacity of the servers which implies that a greater amount of passengers are stopped in them. For the C scenario, there were **204.4 passengers** and **1.89 minutes** and it does not represent a significant change. In the D scenario there were **183.5 passengers** and **1.89 minutes**. For the E scenario there were **205.2 passengers** and **1.89 minutes**, a little variation compared to scenario A.

7. CONCLUSIONS

This study has been useful in understanding the impact of some operational policies on the service to passengers. It has also allowed a better understanding of the behavior of passenger arrivals.

With the results obtained it is possible to perform a cost-benefit analysis to evaluate the installation of ticket vending machines. Simulation has been a useful tool in studying stochastic systems.

There is sufficient capacity to meet the passengers demand in peak traffic hours. In the case of the ticket offices, while both work with two servers (cashiers), the number of passengers that are lined up to buy tickets is kept under control, but if any of them works with less servers then the number of people increases significantly, leading to a potentially hazardous situation. For the platform there is a similar case. The crowding of passengers that is produced there is generated because of the preference to travel sitting rather than standing, so the passengers remain in the platform until they can get a seat on a train. This situation increases the number of passengers waiting in the platform.

The servers at the ticket offices have a major impact on the total time in the system. Although approximately 80% of the passengers do not buy a ticket at the considered hours, the largest time that is spent in the system take place at the ticket offices, where the wait in the queue is more than double than the wait on the platform. If one of the servers could not be open in any of the ticket offices, it would generate an increase of seven times in passengers waiting, and five times in waiting times, which is a significant impact. On the other hand, the use of ticket vending machines greatly reduces important queue length and waiting times, in such a way that could be a viable option to improve the overall performance of the station.

If the time between arrivals of the trains is constant, this would not imply a reduction on the number of passengers that are waiting on the platform. According to the data obtained, the decrease of passengers at the platform is minimal, indicating that the current operating times are satisfactory.

A decrease in the influx flow is equivalent to the installation of ticket vending machines. We can observe a similar behavior in the system´s variables when we increase the capacity of the servers and when we decrease the influx of the passengers; except in the average number of passengers waiting on the platform, where the C scenario is higher than the D in approximately 20 people. Therefore, it would not be advisable to install ticket vending machines if a decrease of passengers influx is expected.

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