SIMULATION OF BOARDING PEDESTRIAN IN MEXICAN SUBWAY: THE CASE OF PANTITLAN TERMINAL STATION

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ABSTRACT
The Collective Transportation System (STC) of Mexico City transports more than 1.6 billion passengers annually and it is considered one of the cheapest in the world. The increasing demand has caused saturations that, together with the operational problems, affect the time of transfer of the passengers and therefore the quality of the service of the transport system. There are currently no measurements of the time passengers wait to board the train. The purpose of this paper is to simulate the operation of the Pantitlan terminal station using the Simulation Model-Based Methodology for Complex Systems Analysis, MoSASCoM, and AnyLogic™ simulation software, to measure the boarding time of the passengers and to generate a tool in which it can be varied: the arrival rate of passengers, number of passengers that approach, the opening time of train doors and the frequency of arrival of trains, in order to assist the decision making of the operational management.

Keywords: hybrid modeling, boarding time, urban mobility, Mexican subway.

1. INTRODUCTION

The accelerated and uncontrolled urbanization process that takes place every day in the Metropolitan Zone of the Valley of Mexico (ZMVM) has led, over the last decades, the implementation and the use of mass transit of passengers that are efficient, Facilitate the ability to move from one place to another. However, in addition to being a necessity, it is also a right, as stated in the Federal District Transport and Road Law, in its article 101 "Users have the right to the public transport service to be provided in a continuous, uniform manner, Permanent and uninterrupted and in the best conditions of safety, comfort, hygiene and efficiency. Faced with the exponential growth of the population in the ZMVM and the need for mobility, the project for the construction of a massive underground transport, proposed in 1965, was consolidated on April 29, 1967, through the creation of a public and decentralized body: of Collective Transport (STC). This system currently has 12 lines that cover 196,383 km and has an influx of just over 1.6 billion passengers annually. Based on the Origin-Destination 2007 survey, carried out by the National Institute of Statistics and Geography (INEGI), the majority of passengers use the STC as a means of connecting with other transfer options. In that same survey, it was identified that during the morning the passengers are added, at 06:00 a.m. start with 1.2 million passengers; Between 07:30 a.m. and 07:44 a.m., reaches the maximum of 1.9 million passengers, while at 09:00 a.m. in the morning reaches 1.3 million passengers.

According to the main aspects of the quality of the service of the STC, they are: the perception of the passenger with respect to the service, the capacity, the speed, the regularity, accessibility in stations and security. However, based on the results of the survey "one year of price increase to $ 5.00 M.N. By ticket "(closed at 9:00 p.m. on January 12, 2016) by the Political Animal news portal, it was observed that 79% of the people surveyed consider that the STC service is reflected in images related to agglomerations and over demand, as shown in Figure 1.

Figure: 1 Agglomerations and over demand of passenger in the STC

Together with a team of Department of System and the team of Engineering and New Projects Department of the STC, the various reasons that affected the operation were reviewed, which directly impacts the operation. Time of transfer of the passengers and therefore to the quality of the service.

The determination of the time of permanence to board the trains in mass transport systems like the STC, at a global level, has been analyzed from the point of view of the structure and design of the platform, studies have also been made of the systems that work on scheduling of the arrival of the train to the stations, under the assumptions of output frequency and capacity of the trains constant. The objective of this research is to simulate the operation of the Pantitlan terminal station using the software AnyLogic™, measure the boarding time of the passengers and generate a tool in which it can be varied: the arrival rate of passengers, the number of passengers that board the train, the opening time of train doors and the frequency of arrival of trains, to assist the decision making of the operating management.

This paper is prepared as follows: in section 2 the conceptual model of Pantitlan terminal station is presented, in section 3 the construction model is shown, in section 4 the simulation model of Pantitlan terminal station is implemented using AnyLogic™ software. Concluding remarks are drawn in Section 5.

2. THE CONCEPTUAL MODEL OF PANTITLAN STATION

Figure 2 shows the conceptual model of the Pantitlan terminal station, which analyzes the interaction of passengers and trains. Pantitlan terminal stations is a terminal and the most important transfer station because it has correspondence among lines one, five, nine and A. We focus on terminal Pantitlan terminal station line one, which was the first line opened, nowadays this line travels from the Pantitlan terminal station to the Observatorio terminal station. On the left side, the activities of the passengers to board the train are indicated and the right side describes the activities of the train to transport the passengers.

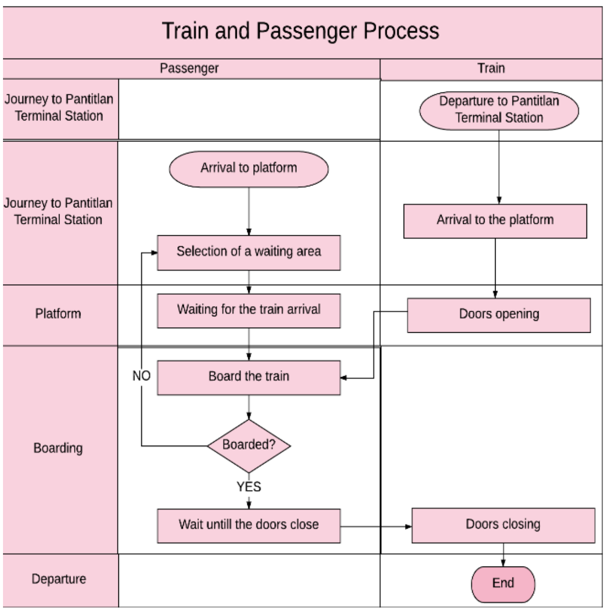

Figure: 2 Conceptual model of the Pantitlan terminal station

The entrance to the station by the passengers is done by four fixed stairs that are found throughout the station. The staircase leading to the first train cars is assigned for the exclusive use of women, children under 12 years and people with different capacities, and the rest of the train for use by the whole public, the procedure for boarding the train happens from the same way in both sections. The train, on the other hand, starts when it goes to the Pantitlan terminal station and up there, it remains in the platform of the station with the doors open so that the passengers can carry out the descent and ascent of passengers, if it comes from the Zaragoza station heading to the Pantitlan terminal station; or, only during the ascent of passengers when the train arrives from the train station to the Pantitlan terminal station.

In this station, the trains can start the race in two ways, one is by means of the trains that leave the train station and go to the Pantitlan terminal station, and the second is by means of the trains arriving from the Zaragoza station to the terminal station Pantitlan to finish and immediately start a new race, so passengers can board on both sides of the platform, as shown in Figure 3.

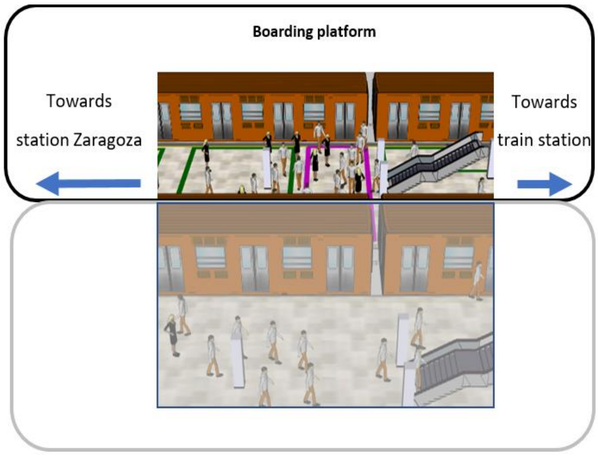

Figure: 3 Waiting area to board

The interaction between the trains and the passengers is on the platform. After the passenger arrives at the station, he goes to a waiting area and waits until the train arrives and opens the doors. Due to the capacity and demand of the system, users waiting on the platform may or may not board the train, in case they cannot climb, they repeat the process of choosing a waiting area, waiting for the train to arrive and attempting to board again to see it. It should also be noted that, as the first station, passengers choose to wait for the next train in the hope of reaching a seat. The boarding ends when the user leaves with the train to the next station. The measurement about the trains is made by cycles, composed by the time that is expected by the next train, plus, the train time on the platform. The time of arrival runs from the train on the platform closes the doors for the descent and ascent of passengers. One cycle includes both the time of arrival and the time on the platform.

3. DEVELOPMENT OF THE MODEL USING THE MOSASCOM METHODOLOGY

Passengers and trains are dynamic entities that move through the system, so they will be the agents of the system. The simulation model shows the dynamics of the door with the greatest number of passengers, located in the area where most men travel; however, women also travel, therefore the attributes used are men and women, being predominant that of men. The resource in our system is the capacity of passengers entering the section of the wagon analyzed by the door of greater influx. The decision variables are: the frequency of trains, the arrival rate of the passengers, the opening time of doors and the capacity of the train. For the characteristics described above, it was concluded in the construction of a hybrid model based on the Simulation Model-Based Methodology for Complex Systems Analysis, MoSASCoM, to guide the modeling and simulation process to analyze emerging properties to certain initial conditions. In this case, the problem is the complexity of the measurement of the time of boarding of the passengers of the STC, which cannot be determined by analytical methods, due to its process of self-organization among its elements; an important feature of the study of complex systems, Huerta (2016). The methodology is constituted by five defined stages: 1. Base question; 2. The development of the model (DEMO); 3. The simulation of the model (SIMO); 4. Analysis of the simulation model (AMSI); and 5. The documentation of the simulation model (DOMSI).

The first of five stages, is the base question, which for this study is What is the boarding time of passengers? The second stage is the development of the model, DEMO, whose objective is the design and development of the real system model through the recursive cycle of five phases: 1. Level of abstraction. 2. Perspective, 3. System operations, 4. Potential approaches to modeling and 5. Model communication (Huerta 2016). The analysis was about the door with a greater influx of both sides of the platform, which is located at the end of the first access stairs to the platform. In the software, the plane of the station was represented by placing the rails and the platform of passengers, whose length is 150 meters, along which are distributed the nine wagons of the train and four doors for each wagon. For the animation and representation of the doors we used the SketchUp 2016 animation software trial version. In order to obtain information, the area of interest separated from the rest of the animation was performed independently. For this purpose, the decomposition was carried out first and then the synthesis, as indicated by the MoSASCoM approach. The values of the parameters of the frequency between trains, the rate of arrival of passengers and the time of opening of doors raised in field, that were used for the simulation were realized through a data acquisition, during the fourth quarter of 2016, beginning, intermediate and weekend of business days, from 07:00 a.m. at 09:00 a.m. for the operations of the system, the operational flows of the arrival of trains to the platform and arrival of arrival of passengers were modeled.

The third stage is the simulation of the model, SIMO, which is the implementation of the conceptual model in a computer. For the choice of software, we reviewed and compared simulation software published with the name "Simulators Comparison V.1" of the year 2014 in Critical Manufacturing S.A. The tools that compare this publication are: Arena, FlexSim, AnyLogic, Simul8 and Internal Simulation, from which AnyLogic was selected, because it can integrate the simulation based on agents and processes, achieving the hybrid simulation through its Libraries and logical flow of processes. The implementation of the conceptual model, from the Pantitlan terminal station of Line 1 of the STC, was realized in the software AnyLogicTM by synthesis and by decomposition, using rail, process modeling analysis and pedestrian libraries. By means of the animation interface the platforms were built to scale; through the logical process, the objects were implemented, through which the simulation model was programmed; and the graphs show the result of the interest measurement with its respective mean square error (MSpE, Mean Square Pure Error), see Figure 4.

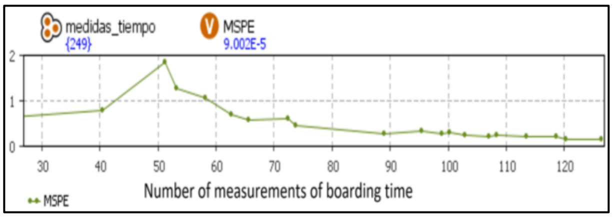

Figure: 4 MSPE Curve

4. THE SIMULATION MODEL

We implemented the simulation model of pedestrian and trains activities in the subway station using discrete-event simulation (DES) and Methodologic Based on Simulation Models the Analysis of Complex System (MoSASCoM). The first one uses the top-down perspective while the second one, uses the recursive perspective. So, in this simulation model we combine two modeling perspectives. Then we implemented the model using AnyLogic software. A tool was developed using the software Anylogic, which allows simulating the process of boarding passengers at the Pantitlan terminal station of Line 1, the measurement area is at the door of greater influx. In the right part of the window is a configuration area that allows establishing seven initial conditions of the simulation:

1. Passenger per minute measuring gate, which is the number of passengers arriving in one minute to the measuring gate. You can select a fixed rate or a Poisson distribution that generate random values with lambda equal to the value placed.
2. Duration of doors opening, in which it is possible to configure the time the train keeps the doors open waiting for boarding passengers. The values can follow the lognormal, exponential, uniform distribution; or, a fixed rate, depending on the option that is chosen.

3. Time of arrival of trains Zaragoza Pantitlan: It allows to select between four distributions: Lognormal; Exponential; Poisson and Uniform. Depending on the distribution selected, the editable tables will be displayed to capture the parameters of the distribution. The selected distribution will determine the arrival values of the trains to the platform.
4. Arrival time of trains Zaragoza Pantitlan, is the time between trains arriving by the middle route, h2, and can be enabled or disabled. The options to choose are lognormal distribution, Exponential, Poisson, Uniform; Or fixed rate, depending on the selected option, the editable tables will be displayed that allow capturing the parameters of the same.
5. Arrival time of trains Pantitlan Zaragoza, is the time between trains arriving by the upper route, h1, and can be enabled or disabled. The options to choose are lognormal distribution, Exponential, Poisson, Uniform; or fixed rate, depending on the selected option, the editable tables will be displayed that allow capturing the parameters of the same.
6. Number of passengers that climb, is the number of people who decide to board the train at the measuring gate. In this case, you can choose the Poisson distribution, Uniform; or a fixed rate.
7. Number of passengers per minute, allows the simulation of the arrival of passengers along the platform. In this case the passengers arrive by four stairs of access to the platform of boarding, and in each one of them can be configured the amount of people that arrive per minute. The selected value will be used to generate random values that follow a Poisson distribution with mean equal to this value.

The Figure 5 shows the interface screen with the fields that can be edited by the users.

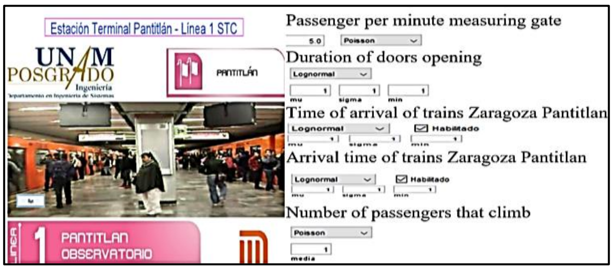

Figure: 5 Interface screen for users

The fourth stage of the MoSASCoM methodology is the analysis of the simulation model, AMSI. For verification, it is determined that the simulation model correctly reflects the conceptual model, and the context of the base question formulated, in addition to verification using the compiler included in AnyLogic. The execution time in the simulation is two hours, within which it is possible to observe in the graph of the MSpE, a square of pure error in the interface, the stabilization of the system response, see Figure 6.

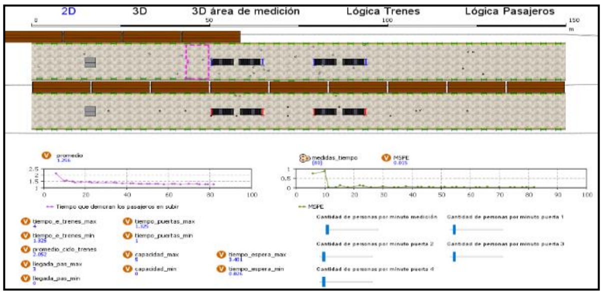

Figure: 6 Execution of the simulation model

4.1. Analysis of the simulation model

Through the design of experiments, the 2^k factor design was analyzed the impact of the variables at two levels, high and low. The factors of the simulation model are four: 1. Arrival rate of passengers, 2. Opening time of doors, 3. Time of arrival between trains and 4. Number of passengers that go up. Therefore, sixteen scenarios are required. Through the combinations of the high and low factors, the sixteen runs were executed with a simulation duration of two hours (120 minutes). The obtained results were: the time of boarding, the average time between trains and the average square of pure error. The latter increased considerably in the scenarios where the high level of passenger arrival rate was considered. In the graph of main effects for the result, it is possible to appreciate that the model presents greater sensitivity to the variable X_1, the rate of arrival of passengers, because depending on the value of this the time of boarding can be less than five minutes until greater to 30 minutes. The variable X_4, number of passengers that climb, also has a considerable impact on the response of the model, because as they board fewer passengers the time of boarding can reach the time it is reduced by approximately 20 minutes. The effect to the time of seam by X_3, time of frequency between trains, is approximately 10 minutes; And about five minutes, by the variable X_2, door opening time (see Figure 7).

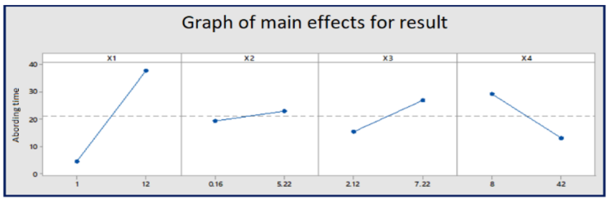

Figure: 7 Graph of main effects of boarding time

To obtain the results of the approach time of the terminal station Pantitlan, Line 1 of the STC, by principles of the *Central Limit Theorem*, it is known that while there is a considerable number of data, these will approximate a normal distribution. For this case, 50 executions were performed in the simulation model, the results were entered in Minitab software 17 and the Anderson-Darling test identified that the data follow a normal distribution. Besides the time of approach, the cycle time between trains was analyzed, in order to calculate in how many cycles the passengers manage to approach.

5. CONCLUDING REMARKS

The boarding time in the fourth quarter of 2016 was from 0.093 to 24.9893 minutes, indicating that passengers were up as soon as the first train arrived until the wait for six trains after their arrival.

The results for the month of October 2016 for the beginning of the week was on average boarding time of 1.3841 minutes, the passengers boarded in the first cycle of the arrival of trains. In the middle of the week, an average boarding time of 8.4181 minutes was obtained, so passengers waited for one cycle after having arrived and even up to five subsequent cycles. At the weekend of the month of October obtained an average time of 4.7604 minutes, reason why the passengers waited of one to two cycles at the most to be able to board.

For the month of November 2016, at the beginning of the week, an average boarding time of 3.3840 minutes was obtained, the passengers boarded in the first or maximum in the third cycle of arrival of trains. In the middle of the week an average value of boarding time of 12,014 minutes was obtained, so passengers expected an average of three cycles. At the weekend, an average boarding time of 6.0962 minutes was obtained, so the passengers waited for two train arrival cycles on average.

For the month of December 2016, for the beginning of the week, an average boarding time of 9.5636 minutes was obtained, the passengers boarded in the third cycle of arrival of trains. In the middle of the week an average boarding time value of 1.7771 minutes was obtained, reason why the passengers waited for a cycle after having arrived. For the weekend an average time of 4.4331 minutes was obtained, reason why the passengers waited of one to two cycles at most to be able to board.

With the above it is possible to say that to perform the simulation model in the Pantitlan terminal station of Line 1 of the STC by means of Methodology based on Simulation Models for the Analysis of Complex Systems, in this case, the time of boarding of the passengers, which under initial conditions, supported the development of the model with characteristics similar to the system under study; it was also possible to generate a tool that contributes to the decision-making of STC's operational management.

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