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A DISCRETE-EVENT SIMULATION MODEL TO ESTIMATE THE NUMBER OF PARTICIPANTS IN THE CICLOVIA PROGRAM OF BOGOTA

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ABSTRACT

Open-Street Programs, also known as Ciclovia, are free multi-sectorial programs for people from different socio-economic backgrounds where public spaces and streets are closed to motorized traffic and open for leisure activities. Over the past three years the expansion rate of such programs worldwide has dramatically increased due to their general benefits to public health and their resource-efficient implementation. Performance indicators of Ciclovia programs allow analyzing the programs' impact on public health. The number of participants is one of the key performance indicators, and thus its reliable estimation is crucial to measuring the cost-effectiveness of the programs for the cities and municipalities. Furthermore, a unified and flexible estimation methodology allows comparisons between programs. In this paper, we propose a discrete-event simulation model to estimate the number of participants in such programs. We apply our approach to a case study in the city of Bogota (Colombia), with the largest program in the world, where we estimate an average of 675,000 participants per day. We also perform a sensitivity analysis on the arrival rate and study its impact on the estimation.

1 INTRODUCTION

Ciclovia is defined as the temporary closure of streets to motorized traffic, creating a safe and pleasant space for walking, jogging, skating, running and cycling, among other activities (Sarmiento et al. 2011). This program was first created in Bogota on December 15th, 1974 and since then it has become popular in different countries, especially in the American continent. This is due to two main reasons: the citizens recognize it as a space designed for their health and social benefits, so they welcome and support the opportunity, and that the flexibility and resource-efficiency of the program make it relatively easy to adapt to every city (Montes et al. 2011). This way, citizens are given the opportunity of doing physical activity with no distinction of social class and the city infrastructure and resources are used efficiently, generating ample and secure spaces for the participants (Montes et al. 2011).

Most of the existing programs offer various types of physical activity including dance and aerobics stations, and promote educational and cultural activities as well as the local businesses (Diaz et al. 2013). Promotion of physical activity has become particularly important since in modern days, public health is a major concern due to physical inactivity pandemic and obesity epidemic. Furthermore, having a sedentary lifestyle is associated with chronic diseases (Díaz et al. 2013).Thus, Ciclovia programs could offer a significant impact on preventing chronic diseases and help encourage healthier and more active lifestyles among the citizens (Hoehner et al. 2008).

Therefore, local governments in cities such as Bogota and San Francisco have strengthened the development of Ciclovia programs. Their objective is to promote physical activity as a community strategy to improve public health. Due to the potentially high impact of Ciclovia programs on public health, it is necessary to have accurate estimators of the number of participants in order to evaluate the programs' effectiveness and to analyze their cost-benefit relation. In addition, in some of the Ciclovia programs the number of participants is a crucial factor to determine the budget that is going to be assigned to the programs.

Furthermore, due to the expansion of Ciclovia programs in the last few years, such estimators enable the Pan-American Health Organization to compare the performance of different programs in terms of the number of participants in the Americas. Having a common methodology which can be adapted to any Ciclovia program in consideration is a key factor for evaluation and comparison. Therefore, the objective of this paper is to establish a flexible methodology that allows the accurate estimation of the number of participants according to their type of activity in Ciclovia, applicable to different programs.

Since we envision this methodology to be used in a wide variety of areas and by several types of decision-makers, such as the medical community and the city officials, it needs to be easy to understand and manipulate. This allows the authorities of different Ciclovia programs to use the same tool to estimate and compare the number of participants in their programs, and also to study the impact of new promotional policies on the turn-out. In order to develop the methodology, we studied how manual and automated counts, surveying users and documentation techniques are used to count bikers and pedestrians. Sometimes a mixture of these methods is used since they complement each other. In the rest of this section we briefly present the existing methodologies for counting.

Manual counts consist of counting sample groups of people by hand. This might be performed by pencil and paper or by using individual or multiple counters. Manual counts are labor intensive, therefore expensive and prone to errors, especially if people flux is high and counting periods are long (Active Living Research, 2013). Automated counts rely on technology to perform the counting. These technologies are expensive to acquire and lack further information which could be easily gathered by human observation such as the age range or gender. Some examples are infrared counters (Honorato et al. 2008, Linzmeier et al. 2005) which use a general purpose technology, or Piezometric counters, which work by conducting loops and pneumatic tubes to count vehicles. For counting bicycles the pneumatic tube is shown to be the best alternative (Fiestberaad 2009).

Surveying users is mainly done in the area of interest (in this case Ciclovia) by trained surveyors, seeking to collect information on the behavior of the participants in the system. For example, the time when they usually arrive, their duration of stay and the frequency with which they participate in the program are among the questions asked in a typical Ciclovia survey. As we can see, key information that can be collected from surveys cannot be collected by other means.

Documentation techniques rely on filming or photographing the area of interest. Afterwards, videos are used for face recognition through certain algorithms (Belongie and Rabaud 2006) or pictures are manually counted (Hipp et al. 2013). One advantage of this technique is that videotapes and pictures can be accessed at any later time for recounting. But documentation techniques are generally done using public cameras for which permission is required, and the counting can be labor-intensive or requiring costly use of technology.

For bike and pedestrian counting, manual counts are the trend and currently used as an estimate in Ciclovia programs (Organización Panamericana de la Salud et al. 2009). Nonetheless, programs are seeking automated counts as a secondary estimation to manual counts and to involve the behavior of the users and hence to improve the counting. In addition, the historical counting information available for Ciclovia programs tends to be limited. However, surveys and fieldwork can be done in order to collect accurate estimators of the needed input data. We conclude that, given the current conditions of the Ciclovia, a discrete-events simulation model can serve as an alternative approach to this counting problem. Furthermore, using a discrete-event simulation model, can allow the development of Ciclovia project, seeking to better imitate the behavior of people in Ciclovia. For instance, it can be used to find the routing of people based on the recording of flows on different spots across the city to find the average number of participants in a Ciclovia street or to build energy consumption statistics for the programs and evaluate their public health impact more directly. Also, it allows studying the impact of including new streets in the Ciclovia without having to experiment in the real system.

Hence, we propose a counting model based on a discrete-event simulation, fed with the appropriate input data that allow us to obtain a reliable estimation of the number of participants by activity. This estimation permits the calculation of some other measures related to public health as well. For example, taking into account the type of physical activities and the number of participants, we can calculate metabolic equivalents, or METs, to assess physical activity levels. A weighted MET score will be given to each activity category (sedentary = 1 MET, moderate = 3 METs, vigorous activity = 6 METs) according to Organizaciónc Panamericana de la Salud et al. (2009). These weighted MET scores will be multiplied by the observed number of participants in each type of physical activity category at the moment of the observation. Then, this score will be divided by the total number of participants in the Ciclovia program. This calculation will produce a mean physical activity intensity score.

Our proposed methodology includes two fundamental aspects of counting: 1) gathering and estimation of the input information and 2) the development of the counting model. For the first step, we identify the relevant data to be used as input parameters and the way to obtain or estimate them. For the second aspect, we propose to create a discrete-event simulation model to approximate the number of people that take part in the Ciclovia. We show the performance of our proposed methodology on a case study for the City of Bogota and compare the results with other available approximations for this city.

The rest of this document is organized as follows. In Section 2 we explain the case study and the proposed methodology, including the details of the discrete-event simulation model. In Section 3 we compare the results with previous approximations for this city. Finally, Section 4 concludes the paper and points out future work.

2 CASE STUDY: CICLOVIA OFBOGOTA

The Ciclovia of Bogota is open on Sundays and Holidays from 7:00a.m. to 2:00p.m. It is currently the largest Ciclovia program in the world with an extension of 113.6 km and a geographical distribution across the city which enables the participation of people from different socio-economic backgrounds.

In order to evaluate the benefits of this extensive program, some cost-benefit studies have been developed. One of such studies suggests that the benefits to public health are higher than the costs of implementing and maintaining the program (Montes et al. 2012).An important highlight of this study is that the average number of people who take part in the Ciclovia every Sunday is declared as one of the key inputs to estimate this cost-benefit ratio.

Besides the cost-benefit studies, some other projects have been developed in the recent years regarding the Ciclovia programs, all of which require, as a key input, the estimated number of participants. For example, *The Ciclovia and Cicloruta Programs: Promising Interventions to Promote Physical Activity and Social Capital in Bogota, Colombia* (Torres et al. 2012) considers the impact of Ciclovia of Bogota on public health which is calculated according to the number of people who exercise as a result of the facilities that are offered by Ciclovia. This also applies tithe study by Gomez et al. (2012), which offers a ranking and comparison methodology for such programs, where they state that an important input to rank the Ciclovia programs is the number of participants.

In the rest of this section we explain our proposed methodology on building a discrete-event simulation model for counting the number of users of the Ciclovia of Bogota. First we explore the input data collection and then the implementation of the model.

2.1 Input Data Collection and Sources of Information

The simulation model requires the following input data: the distribution and velocities of activity categories (i.e., jogging, walking, biking or others), the distribution of sojourn time of participants and the arrival rate throughout the operating hours of Ciclovia and along its 113 km length. For the case of Bogota, we have three distinguished sources of information: previous work carried out by Universidad

Nacional (Universidad Nacional 2005), a survey conducted in 2011(Sarmiento et al. 2011), and our own fieldwork in 2013.

2.1.1 Estimation by Universidad Nacional (2005)

This study was done by Universidad Nacional in 2005 (Universidad Nacional 2005) in which the same counting problem in Ciclovia is directly approached. The methodology consists of manually counting over 5 minutes during each hour only in one direction and in a defined distance. Then expansion factors, such as the velocity and the geographic coverage of a point, are applied to obtain a forecast of 1'400,274 participants per month. They also estimate an average participation of twice a month per participant and hence it can be concluded that an average of 700,000 participants are estimated to participate on a given day of Ciclovia.

This study provides the estimated number of participants that is currently used as reference. Nonetheless, besides being outdated and perhaps not representative of the current conditions, the study does not provide any information on how the parameters of this model are calculated, making it impossible to apply their proposed expansion formula to other cities or to update Bogota's estimation. However, for lack of any better estimate, we will use this estimation to validate our model results.

2.1.2 Survey by Sarmiento et al. (2011)

In 2011 an extensive survey was conducted in Bogota's Ciclovia. The survey was done during three weekends in 16 points of Ciclovia, using a sample size of 1000 people in total. The key questions of this survey used in our model as input data are:
1) How much time do you spend in Ciclovia?
2) At what time do you join Ciclovia?
3) Where is your departure point in Ciclovia?
4) What activity do you perform in Ciclovia (Biking, Walking, Jogging, Others)?
The findings of this survey include:
1) For the sojourn time in Ciclovia, the results are shown in Figure 1. We can see that the maximum time is seven hours, which coincides with the duration of the program. Also, it is important to mention that most of the people interviewed answered this question as "rounded-up" numbers (e.g. 30 minutes, 60 minutes, etc.), which explains the peaks at the hour (e.g. 7:00, 8:00, etc.).

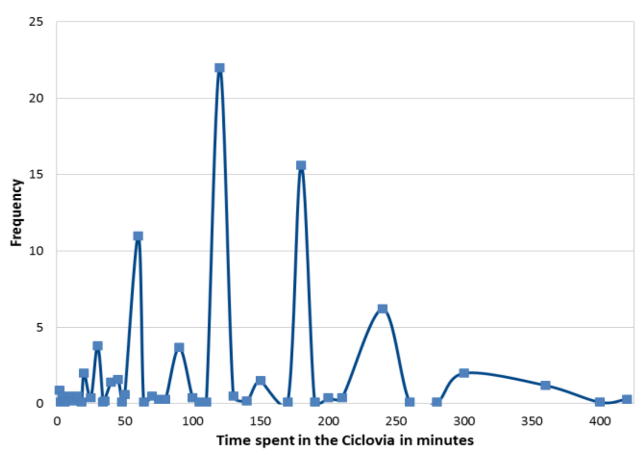

Figure1: Sojourn time at Ciclovia (Sarmiento et al. 2011).

2) The results for the arrival time to Ciclovia are presented in Figure 2. From the observations, we can state that more people tend to arrive to Ciclovia in the early morning with the peak at around 8 a.m.

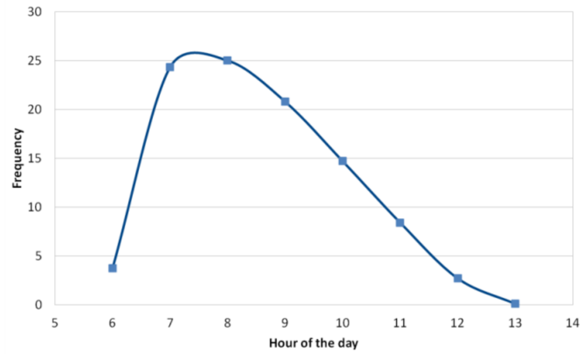

Figure 2: Time at which people join the Ciclovia (Sarmiento et al. 2011).

3) The departure point in Ciclovia was mapped using the software ArcMap, such that every surveyed participant was assigned to the closest track from his or her stated point of entry. It is important to notice that out of the 1000 survey responses, only 683 entry points could be determined, as shown in Figure 3.

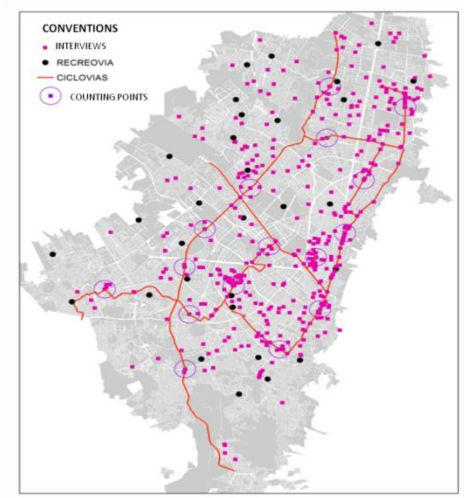

Figure 3: Entry points to the Ciclovia according to (Sarmiento et al. 2011).

4) The distribution of participant per activity categories is shown in Table 1. In order to determine the velocity, we used the values presented by Universidad Nacional (2005).

Table 1: Velocity and percentage of each activity category.

Category	Velocity(km/h)	Percentage
Cyclists	10.00	67.90%
Joggers	2.50	6.10%
Walkers	2.25	21.90%
Others	2.70	4.10%

2.1.3 Fieldwork

Since participants can join the Ciclovia at any point of a particular street, we estimated the arrival rate of participants to the Ciclovia per meter through fieldwork. This fieldwork was performed between 11:00 a.m. and 11:15 a.m. in one point of the system: (Carrera 15 between 88thand Street and 90th Street), during a Sunday, over a distance of 50 meters where we counted the participants joining the system. There were two observers who counted the number of people entered through that point to the Ciclovia and they also recorded a video in order to verify their data.

The choice of time to do this field work was due to the fact that 11:00 a.m. is the peak hour according to Instituto Distrital de Recreación y Deporte (IDRD). On the other hand, we would like to have the longest possible time in order to have more information on the arrivals of people. However, since we rely on people, the longer the time they do this task, the more they will get tired, leading us to lose accuracy on the data. Thus, counting intervals should be short enough so that the observers are sharp during the observation period, but that they can still gather sufficient information to reduce the variance. Therefore, a fairly good time to use is 15 minutes, taking into account our experience from the fieldwork. Another important characteristic when choosing the location for the experiment was the visibility (e.g. not a park or a location with many trees), a constant flow (e.g. not at traffic lights or bottlenecks) and not standing by a place which could attract people and thus bias their behavior (e.g. a church or a shopping mall). This way, we attempted to avoid the under or overestimation of the incoming people. Finally, the chosen counting distance of 50 meters, was experimentally determined in a pilot fieldwork session prior to this even, in order to cover the largest distance possible that would still give accurate observations, taking into account that this rate varies according to the time of the day. By having two observers counting simultaneously and crosschecking data for validation during the pilot session, we ensured the appropriateness of this distance.

The arrival rate we obtained was 0.113 arrivals per meter in fifteen minutes; we will be referring to this as the *reference arrival rate*. The arrival rate is considered deterministic for this study. This is because we do not have enough data from the fieldwork do fit an arrival rate distribution.

2.2 Implementation of The Simulation Model

In this subsection we define the structure of our proposed discrete-event simulation model in order to represent the Ciclovia of Bogota. We identify three required components: entities, tracks and intersections. Each entity belongs to an activity category i and when created, is assigned a sojourn time in Ciclovia. The tracks are the set of streets that make up the Ciclovia. They are connected by a set of intersections, and for modeling purposes we assume that each entity only arrives through an intersection j, taking into account that this has no impact on the number of entities who join the system. Then, entities go through a routing process, taking into account how much time they have left at Ciclovia. According to that process, they leave the system or they move through the tracks. In what follows we will explain each component of this model.

2.2.1 Entities

In our model the entities are the participants divided into four different categories according to their type of activity. To approximate the proportion of participants in each category we assumed homogeneity in all tracks. Entities arrive to the Ciclovia following an inter-arrival time distribution associated with their entry point. Each entity spends a specific time in the system following its assigned sojourn time sampled from the corresponding empirical distribution shown in Figure 1. Also, each entity is assigned a constant velocity given its category according to Table 1.

2.2.2 Tracks and Intersections

In order to build the model, we define a track as a street or a segment of a street that begins in an intersection and ends in another intersection, where at least two streets of the Ciclovia cross each other or the extreme points that are only connected to one track (located in one of the extremities of the Ciclovia). Each track has an associated length and is bidirectional. We assume infinite capacity for the tracks, as the participants do not have to wait until another person leaves the street in order to enter the system. With this definition for tracks, Ciclovia of Bogota is divided into nineteen bidirectional tracks and sixteen intersections, as shown in Figure 4.

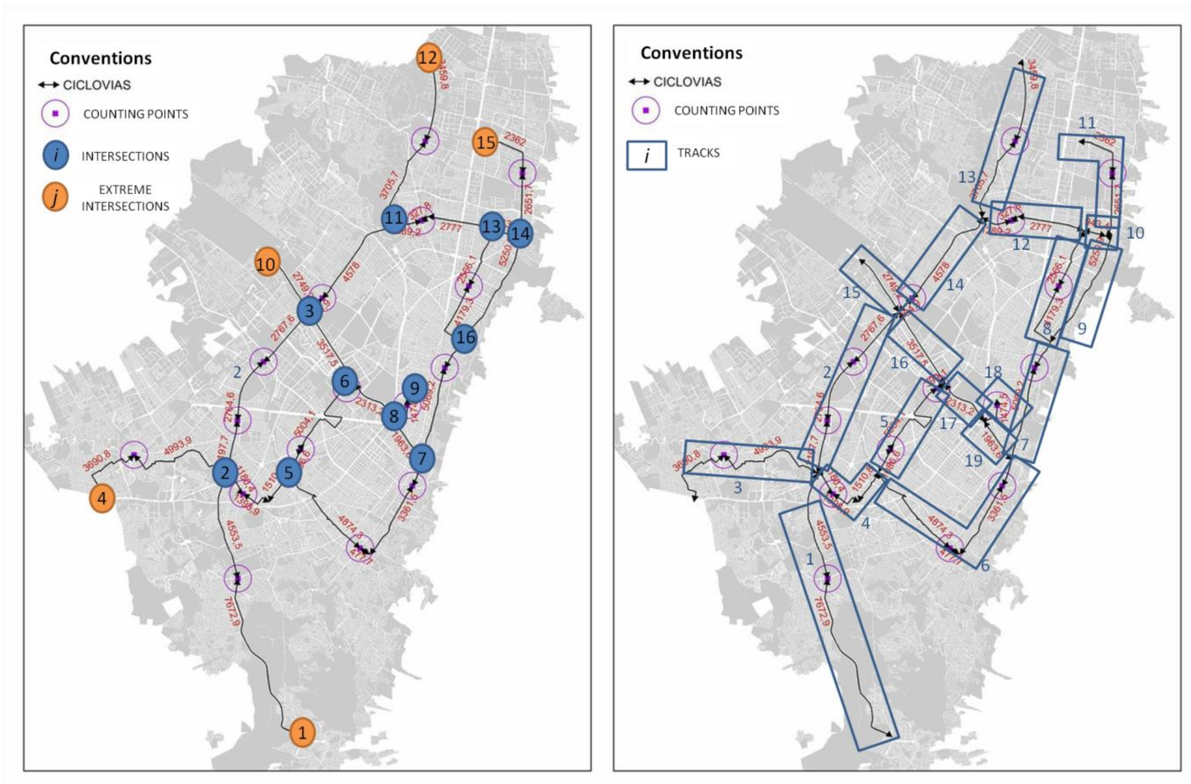

Figure 4: Defined intersections and tracks in the simulation model**.**

We assume that the arrivals to each track only take place at the associated intersections. Hence each intersection needs a separate source of generating entities, using a specific arrival rate. Additionally, in each intersection a decision is made every time an entity arrives. The objective of this process is to evaluate if an entity has enough time to arrive to one of its neighboring intersections or not. In the case of Bogota, given that it is not easy to estimate the proportion of people that choose one route or the other at an intersection, we assume that all the connecting tracks have the same probability of being chosen. This way, when a participant leaves a track, the model verifies whether with her remaining time, she is able to cover the whole distance of the largest connecting path or not. If the time is not enough, entities are delayed in their current track until their time is over and then are disposed. Otherwise, they go randomly to one of the tracks connected to the current intersection. Thus, intersections are also responsible for disposing the entities or routing them through the system, once their time in the track is over. This decision process is used every time an entity arrives to an intersection.

The flow diagram of the routing process of a track is shown in Figure 5. As we can see in this figure, the process ends with the entity leaving the system or entering a new track, in which the same process is repeated.

As we mentioned before, the rate at which entities are created in the source of the intersection is the key input to this model. However, from results of the survey and observations in the fieldwork, we know this arrival rate is not constant in the different Ciclovia tracks throughout the day. Thus, we need to adjust our *reference arrival rate* presented in Section 2.1.3 at every hour of the Ciclovia as well as in every track.

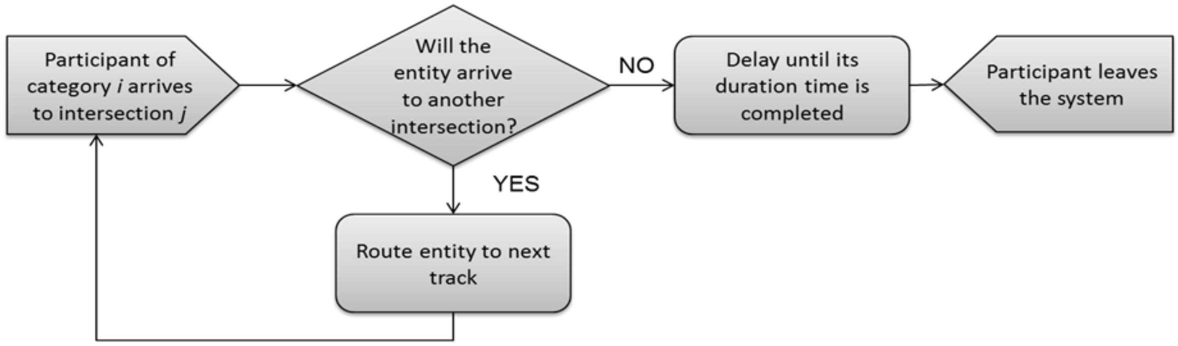

Figure 5: Flow diagram of the routing process of a track in the discrete-event simulation model.

Thus, we used the arrival time information from Section 2.1.2 to obtain the relative weights of arrivals at every hour compared to the number of arrivals at 11 a.m., expressed as a percentage. The rate at the different hours of the day is to be found by adjusting the *reference arrival rate* and its relative weight. For example, if the arrival rate at 11:00 a.m. is 50 participants per fifteen minutes and we want to estimate the arrival rate at 8:00 a.m., we multiply 50 by the relative frequency of arrivals at 8:00 am, which from Figure 2 we can see is almost three times the rate at 11:00 a.m., then we would get approximately 150 participants per fifteen minutes at 8 a.m. Now, we multiply that arrival rate by four, assuming that arrivals are homogenous during the hour (i.e., between 8:00 and 9:00 am) to estimate the hourly rate.

With regards to the weighting of arrival rates per intersection, we use data presented in Section 2.1.2 on the point of entry. As we did in weighing the arrival rates, hereto we calculate relative weights of the other tracks compared to our reference track (Track 8). This way, we obtain a frequency of participants that join the Ciclovia at a given track. Once we have the weight of each track, as well as the reference arrival rate, we multiply these two, getting the rate per track. For each track, we transform the rate per meter to the rate for the whole track by multiplying the arrival rate per meter by the total length of the given track, assuming that the track has a homogeneous arrival rate all over its length.

Now this information must be translated from tracks to intersection points. To be able to find an estimation of the arrival rate in each intersection, 50% of the arrival of the track was assigned to each of the two adjacent intersections.

3 MODEL VERIFICATION, RESULTS AND SENSITIVITY ANALYSIS

This section explains how the proposed model is verified. Then, results are presented, including the expected number of participants that arrive to the Ciclovia in a day. Finally, a sensitivity analysis on the number of people is done based on the mean and measures of dispersion of the arrival rate.

3.1 Verification

Following the recommendations for verification techniques in (Law and Kelton 2000), we built a sub-model which includes a reduced number of intersections (7, 16, 13, 14 and 15). This smaller model was built to check if the logic used works properly. We particularly focused on the arrivals to the system; this model was analyzed using three scenarios in which the distribution of the reference arrival rate was changed. In the first scenario this rate was assumed deterministic, but changing in every hour according to the weighting for that hour (Section 2.2.2), the second scenario assumed that arrivals follow a non-homogeneous Poisson process with the arrival rate changing every hour again according to the hourly weights, and the third scenario was created supposing that the inter-arrival time follows an Erlang distribution with two phases and with the mean equal to the one used in the previous scenarios. The objective of the last two scenarios is to observe how the system changes its behavior adding a stochastic component to the arrivals, to check the inner logic of the model. We also determined the number of replications by measuring the different in the mean value of the number of participants between various replications and as this average was observed to be at most 0.88% among ten replications, we used 10 replications in all of our experiments and production runs.

After defining the number of replications, the simulation was run for the three scenarios. The results are presented in Table 2, including the expected number of entities in the system, the expected sojourn time and the total number of people that enter the Ciclovia in a day. The results obtained using the Exponential and the Erlang distributions are compared with the results of the deterministic arrivals scenario, calculating the percentage difference. We observe that, when we introduce the stochastic arrival processes, the total number of participants changes. Taking into account that the three scenarios are statistically different, we conclude that, fitting the arrival distribution will be determinant to estimate the number of participants.

Additionally, we verify the expected sojourn time. For this output we verified that the average value of that time was similar to the expected time calculated using the empirical distribution shown in Figure 2. Also, we confirmed that the maximum and minimum values of the sojourn time in the Ciclovia coincided with the extreme values of that distribution.

Table 2: Comparison of the performance measures in the three scenarios.

Performance Measure	Deterministic Arrivals		Exponential Arrivals		Erlang, K=2Arrivals	
	Value	Half Width	Value	Difference	Value	Difference
Expected number of people in system	34,757.39	304.92	55,368.13	37.22%	27,675.03	25.59%
Expected time in system (hours)	1.92	0.01	1.99	3.53%	1.99	3.48%
Expectednumber of arrivals	240,883.67	1,866.80	404,446.00	40.44%	202,613.00	18.89%

In conclusion, we observed that the model assumptions were correctly translated into the simulation model.

3.2 Results

We built our simulation model using the input data explained in Section 2.1. Specifically, we used the sojourn time presented in Figure 1 and for the time in system we used the distribution presented in Figure 2. Also, as our *reference arrival rate* we used the rate found in the fieldwork, which is 0.113 arrivals per meter in fifteen minutes and assumed deterministic arrivals, due to the lack of an adequate fit to any conventional distribution. Since the run conditions do not involve stochastic arrivals, we perform ten replications to estimate the number of participants.

The simulation model was built using Simio Simulation Software, Academic Edition Version 5.83 and it estimates 675,500 participants who join Ciclovia in a day. As observed, we do not have a half-width due to the deterministic nature of the input data. For the purpose of validation, the only available data is the study from Universidad Nacional carried out in 2005 (Universidad Nacional 2005) which estimates 700,000 participants, as mentioned in Section 2.1.1. Although this value is very close to our estimation, we are conscious of the limitations of this comparison due to the time lag between the two studies.

3.3 Sensitivity Analysis

For the sensitivity analysis, the model was run simulating an average day in Ciclovia, from 7:00 am to 2:00 pm and we designed two experiments which added an element of randomness to the model. This stochastic component was included by defining a distribution for the inter-arrival times. In the first experiment, we proceeded to change the estimated arrival rate, increasing it and decreasing it by 10%, while keeping its coefficient of variation constant. Results of Experiment 1 are presented in Table 4.

Table 4: Results from Experiment 1, changing the arrival rate.

Scenario	Expected number of participants (arrivals)	Half Width	Difference (%)
Base	675,576.0	2,171.8	0%
-10%	608,280.3	2,247.3	-9.96%
10%	743,280.0	1,842.6	10.02%

As we can see in Table 4, when the expected number of participants increases while the coefficient of variation remains constant, the estimated number of participants in Ciclovia becomes statistically different than the base case, since the confidence intervals do not overlap but the length of the half width is similar in the three cases. In other words, the model behaves as expected because the total number of participants in Ciclovia is affected by the mean of the inter-arrival times but the change in the half width is not significant, since the variability is kept constant.

For the second experiment we assumed that the inter-arrival times are distributed lognormal. In each of the scenarios, the mean was kept constant and equal to the base case while changing the variance to evaluate its impact on the number of participants. In this experiment the objective was to examine how changes in the coefficient of variation impact the total number of participants in the Ciclovia program and how the confidence interval is affected, keeping the mean constant. The results of Experiment 2 are presented in Table 5.

Table 5: Results of Experiment 2, changing the coefficient of variation.

Scenario	Lognormal Distribution			Expected number of participants	Half Width
	μ	σ^2	Coefficient of variation		
1	1.0	0.000	0.000	675,203	0
2	1.0	0.251	0.251	675,218	598.268
3	1.0	0.506	0.506	675,330	862.421
4	1.0	0.755	0.755	675,450	1,086.514
5	1.0	0.992	0.992	675,565	1,300.021

The results in Table 5 show that, as the variance increases and thus the coefficient of variation, the length of the half width increases. Nonetheless, intervals overlap, which means that this difference is not statistically significant. From this experiment, we can also conclude that the model behaves as expected because the average total number of participants in Ciclovia is not affected by the variance of the inter-arrival times but the length of the half-width increases according to the coefficient of variation.

Based on the verification phase (Section 3.1) and the sensitivity analyses presented in this section, we conclude that our model is consistent and behaves appropriately within a reasonable range of error. To recall, we estimated that the total number of participants at Ciclovia at a regular Sunday is 675,500. This final output is sensitive to the entry rate to the system, taking into account that its summation over the operating hours of Ciclovia gives the total number of participants.

4. CONCLUSIONS AND FUTURE WORK

The methodology that is developed in this work contributes to the improvement of the estimators of the total number of participants in the Ciclovia and the average number in the system by activity, through the construction of a discrete-event simulation model. Additionally, the model allows finding the estimators of some other relevant variables such as the number of people expected to be in the system at a given time and the average sojourn time in the Ciclovia; all these performance measures are distinguished by activity. Even though these performance measures are not analyzed in the current project, they should be studied in future work due to their relevance for the medical community, who can use them to measure the contribution of the program to the improvement of public health.

For the case of Bogota, the implementation of the discrete-event simulation model allows validating the results of previous works, giving a tool that can be used to update the estimators for that system every time new input data is acquired. The design of our model can be improved by implementing it in open-source software so that it can be used by the different Ciclovia programs independently.

Future work also includes improving the quality of the input data in hope of improving the results. For instance, developing a mathematical model to estimate the arrival rate based on observations of the flow of people in Ciclovia makes it rely less on the selected points of observation. Additionally, further research should be done on the important factors that influence the arrival rate of participants. Some examples are the presence of Ciclovia near parks or the density of the Ciclovia network in various neighborhoods.

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