Discrete Event Simulation in a BRT System
Transmilenio Case

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Abstract: Recently, the bus rapid transit (BRT) systems have been implemented around the world as an efficient and low cost mass public transportation alternative. While studying such systems, a common assumption has been that the user knows and uses the fastest route every time. Therefore, this paper has two main objectives. The first objective is to model the interactions within a BRT system station, modelling the decision making process of each user independently with a cost function in which he is able to take a decision depending on different variables such as the average utilization of a bus or the time arrival of the next scheduled bus. The second objective is incorporating the stochastic nature of input data, such as arrival rates, origin-destination matrix or service time into the model. Using this model logic a complete system can be built. Thereby, investigations that mean to improve the performance of the system can be tested considering the stochastic behavior of the users during the route plan decision making process.

1 INTRODUCTION

A BRT (Bus Rapid Transit) system is defined as a flexible massive transportation solution, with rubber tires, high passenger capacity and low costs of implementation and operation compared to alternatives as trains or subways (Danaher et al., 2007).

In transportation problems, discrete event simulation offers a valuable tool for analysis as it allows to forecast results of changes, learning of the system dynamics and educating the actors involved in the decision making process (Pursula, 1999).

From a financial perspective, South American countries have invested more on BRT systems than other countries around the world. More than 45 Latin American cities have invested in BRT systems, which represents 63.6% of the total number of passengers transported by BRT systems worldwide (Rodriguez, 2013).

Examples of BRT systems that have been operational for more than 5 years are: Bogotá (Colombia); Curitiba (Brasil); Goiânia (Brasil); Ciudad de Guatemala (Guatemala); Guayaquil (Ecuador); Quito (Ecuador); and the metropolitan area of São Paulo (Brasil), specifically the "ABD". Together, these cities represent the 16% of the total number of passengers transported by BRT systems worldwide, and the 31% of the same statistic in Latin America (Rodriguez, 2013).

Several work has been published referring to the routes design and frequencies problem in the public systems of transportation. Exact and heuristics methods have been tested, and the results promise to improve the system performance (Medaglia, Walteros, and Riaño, 2015). Other fields that have approached the transportation systems performance are the probabilistic modelling (Watling and Cantarella, 2013), fuzzy logic (Lo and Chang, 2012), simulation (Sarvi, et al, 2010), Petri Nets (Mejia, 2008) and genetic algorithms (Karlaftis and Vlahogianni, 2011), among others. In general, the stochastic nature of the decision making process of the user is not directly involved in previous work, or there are other stochastic factors that are left out of the modelling process.

Transmilenio is the BRT that operates in Bogotá since the year 2000. According to the *Asociación Latino-Americana de Sistemas Integrados y BRT*, Transmilenio is considered as the world leader transportation system for its effectiveness, reach and implementation success as one of the largest BRT systems in the world (SIBRT, 2013). Given its influence worldwide, and its impact on the transportation process of a capital city with over 8 million people, a model that allows to evaluate the

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changes in performance, is a useful and meaningful tool for public policy formulation.

In this paper, the main objective is to model a BRT station. The model is intended to be used in future research with a “Lego Approach” for building a complete BRT system and applying it to the Transmilenio case. We tend to draw a general guideline for future investigations that tend to evaluate and diagnose complete massive transportation systems towards improvement of performance measurements. The innovation factor would consist in introducing stochastic elements in two components. First, the decision making process of a user that can select a service using a cost function. The second component, is the variability of input data. In the following sections of this paper, we will discuss the assumptions and logic surrounding a single station model.

2 ASSUMPTIONS

Each person or entity will choose one of the three fastest route plans in order to get to its destination. These three route plans are called candidate route plans.

A person will assign a cost function value to each of the first services of three candidate routes based on the user’s profile standardized value of four variables:

- Number of entities standing in line
- Travel time
- Bus average utilization
- Time remaining for the bus to arrive

The weight or coefficient of each of the four variables is determined by the decision profile of the person. The choice of the route will be determined by the lowest cost function. The term “route” should be interpreted as the travel plan of an entity (including transfers between stations) and it is different from a “service”, which is the identification of a bus station sequence.

People entities are familiar with the three fastest routes. These are the candidate routes or travel plans of the user.

A station wagon is where buses stop and it is also where persons stand in line. In this manner, for example if a bus stops at wagon 3, only the persons standing in line in wagon 3 can get on the bus. Persons will get inside the bus in the same order they arrived to the queue.

There are no accidents on the bus roads ans simulation time will go from 5 a.m. to 9 a.m. and the warm up period will go from 5 a.m. to 6:30 a.m. in order to initiate the recollection period when the system is in its equilibrium state.

Bus entities start their path at a programmed hour and, after completing their sequence, they are disposed. Services identifications are assigned by the company optimization software.

Entities heading north occupy a different line from the entities heading south. This same happens when heading east/west.

Dijkstra algorithm is used iteratively for finding the shortest path between all origin-destination in the directed graph that represents the BRT system.

3 METHODOLOGY DESCRIPTION

The logic of a single station was built, and the flow chart of the users and buses flow through the system is shown in the next figure. Section 3.1 explains the important facts of the users flow logic, and section 3.2 explains the important facts of the buses flow logic.

3.1 Users Flow Logic

3.1.1 Users Entrance

The user entrance is read from an outer file that contains the number of arrivals to a specific station in intervals of 15 minutes. The time between arrivals in this time frame is assumed to be uniformly distributed.

3.1.2 Destination and Profile Assignments

The destination attribute is assigned to each user based on an origin-destination probability matrix. The dimension of this matrix is NxN where N is the total number of stations in the system. The equation (1) shows the calculation of the origin-destination probability matrix.

$$OD_{i,j} = \frac{Trips\ between_{i,j}}{\sum_{i=1}^{N} Trips\ between_{i,j}} \quad \forall \quad i \in N \tag{1}$$

The profile assignment is based on the information recollected through 660 surveys in which users define the percentage of time they are in a hurry. After defining the portion of users that are time pushed while using the system, the respondents determine the weight of each of the four variables explained in assumption 2.

Finally, a set of profiles are created and each one of them is assigned with an occurrence probability based on the frequency of “representative” decision

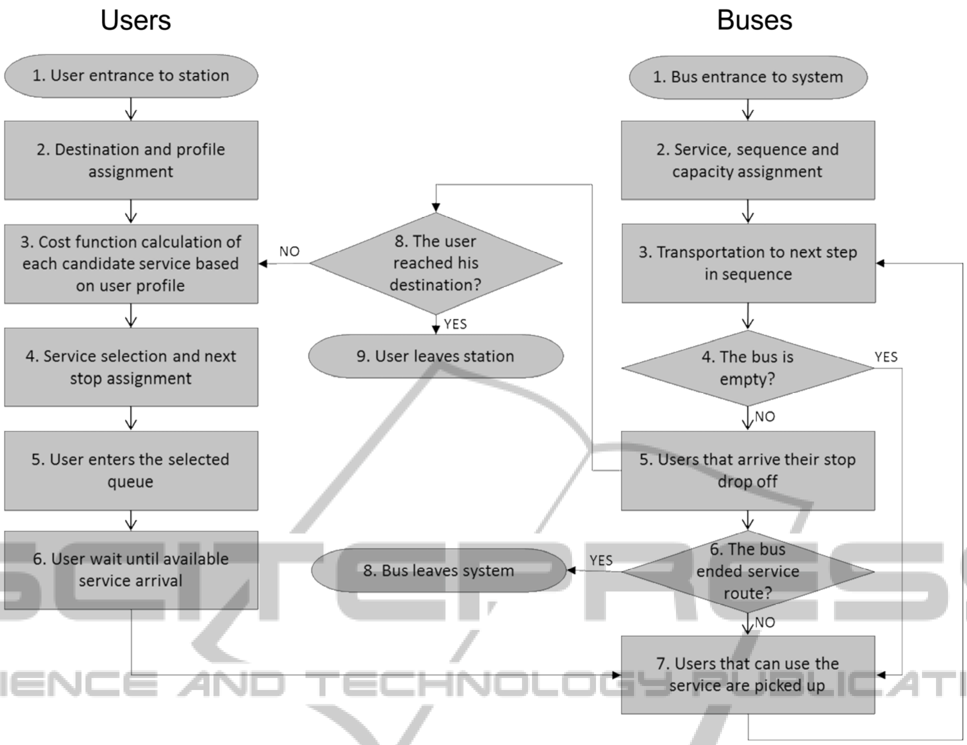

Figure 1: Flowchart of entities.

making profiles. A representative profile is build up from a clustering process that returns the variables coefficients as an average of its internal singular profiles values.

3.1.3 Cost Function Calculation

Each time a user arrival event takes place, a cost function is calculated for each of the first services from each of the three candidate route plans a user may pick from. The cost function is calculated as a ponderation of the variables values and the coefficients provided by the user's profile. The values of the variables are first standardized so their domain ranges from 0 to 100. Finally, a user will pick the route plan if its first service has the lowest cost function.

3.1.4 Service Selection and next Stop Assignment

Once the user is assigned to a service, he/she is headed to the corresponding waiting queue in which he/she will remain until the arrival of the bus entity. Simultaneously, a next station stop attribute is assigned to the user based on the chosen route sequence.

3.2 Buses Flow Logic

3.2.1 Buses Entrance

The buses entrance is read from an outer file that contains the exact time in which a bus starts its sequence.

3.2.2 Bus Attributes

The service, the sequence and the capacity are some of the main attributes of a bus entity. The service ID attribute is assigned based on an outer file provided by the transportation company. This file can be modified by the user in order to test the behavior of the system under different input conditions. After assigning the service attribute and depending on its value, sequence and capacity attributes are determined. The sequence attribute refers to the set of stations a certain service must visit whether the capacity attribute refers to the number of users that fit inside the bus entity.

3.2.3 Transportation to next Step in Sequence

Once the sequence is assigned, the bus entity is transported to its initial station with a delay time of 0.

Afterwards, in each station, the bus will be routed to its next station incurring in a time that depends on the distance between its actual station and its next stop and average transportation speed of the bus.

3.2.4 Is the Bus Empty?

Once a bus entity arrives to a station it stops at the assigned station wagon. If the bus is not empty, the first event that takes place is the unload process of the passengers that are inside the bus, if the bus is empty, it goes right to the boarding process. Finally, the bus entity continues its sequence or leaves the system in case it’s in the final station of its sequence.

4 VERIFICATION

The station model built was verified in order to assure that the decision making process of the users is working properly. To do so, Transmilenio S.A. shared data of arrivals, services, origin-destination matrix among others, in order to verify the model logic and to build the final model of the system. A model of five stations of the real system was built considering one unique station origin and four possible destinations. The 3 fastest services for each possible destination are shown in Table 1 and the travel time in seconds is shown in Table 2.

Table 1: Candidate services for each possible destination.

	Service		
Destination	1	2	3
Calle 100	H74	G12	F14
Heroes	F14	G5	F1
P Norte	B72	B53	B14
Virrey	L18	G5	F1

Table 2: Travel time between origin and destination in seconds.

	Service		
Destination	1	2	3
Calle 100	720	840	840
Heroes	600	780	780
P Norte	240	300	360
Virrey	480	600	600

The average utilization of each service was set so the fastest service (service 1) would have the highest utilization, the second fastest service (service 2) would have the second highest utilization and the slowest service (service 3) would have the lowest utilization as shown in Table 3.

Table 3: Average utilization per service.

Service	Average utilization
L18	0.7
F1	0.45
G5	0.6
G12	0.45
B14	0.45
F14	0.7
B72	0.7
B53	0.6
H74	0.7

In order to verify the logic of the decision making process, 5 scenarios were tested changing the coefficients of the cost function of the users. Table 4 shows a description of each scenario.

Table 4: Scenarios.

Scenario	Description
1	The cost function has the original coefficients found in the clustering process
2	The coefficient of the travel time is set to 1 and the others to 0 (Travel time is all that matters)
3	The coefficient of the bus average utilization is set to 1 and the others to 0 (Bus average utilization is all that matters)
4	The coefficient of the time remaining for the bus to arrive is set to 1 and the others to 0 (Time remaining for the bus to arrive is all that matters)
5	The coefficient of the number of entities standing in line is set to 1 and the others to 0 (Number of entities standing in line is all that matters)

The objective of this experiment is to identify the change in the average number of times each service (1, 2 or 3) is selected by the users to get to their destination in each scenario. Results of the experiment are shown in Figure 2. The results show consistency with the expected behavior for each

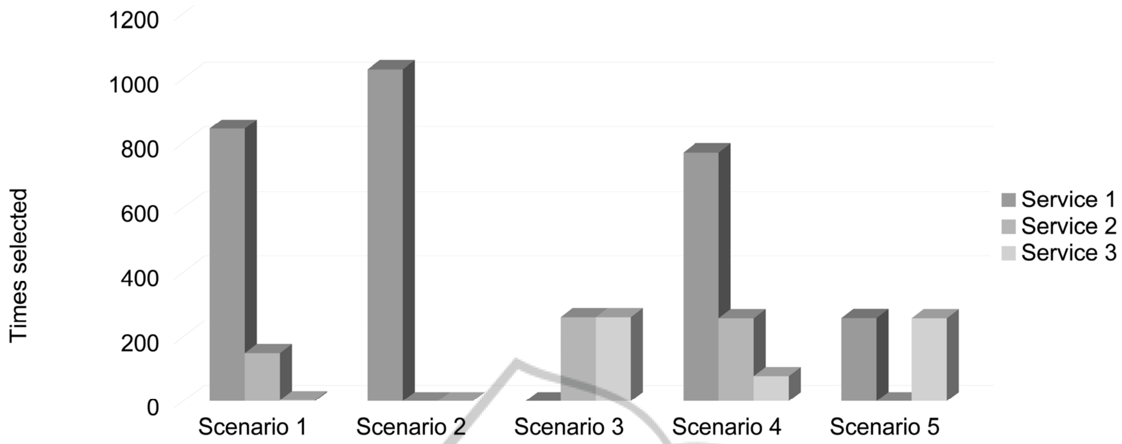

Figure 2: Number of times a service is selected per scenario.

scenario. For example, in scenario 2 all the users selected the fastest service, as the only important criteria is the travel time and in scenario 4, the proportion is similar to the scenario 1, as the time remaining for the bus to arrive is independent from the attributes of the service.

5 CONCLUSIONS

The methodology applied to the construction of the simulation model allows to represent the behavior inside one station of a BRT system. The model is flexible enough to include new services, new stations, new decision variables or behaviors of the decision makers, different times of travel and different frequencies of both arrivals and buses services.

Each user is modeled as an independent decision maker that has a unique cost function. This allows the model to represent different decision behaviors incorporating four concrete decision variables: total travel time, the bus average utilization, the time remaining for the next service arrival and the number of people in queue.

The main innovation of this work is including the decision making process of each user in the model results and stochastic elements as the variability of the arrivals, the origin-destination matrix and the transportation times. The methodology presented is meant to be a tool for testing alternatives and proposing changes that improve the system performance measures of BRT systems.

6 FUTURE WORK

For the second phase of this project, the main objective is to create a Template with a station module presented on this paper that will allow the construction of the complete Transmilenio system and to validate the model. With the validated model the objective is to test diverse proposals made by other researchers and propose original alternatives, in order to evaluate better ways to operate the system for improving efficiency.

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