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GENERIC BUS ROUTE SIMULATION MODEL AND ITS APPLICATION TO A NEW BUS NETWORK DEVELOPMENT FOR CAIEIRAS CITY, BRAZIL

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ABSTRACT

The issue of adequate urban bus routes is very important to general population life quality. It is shown that in Brazil, 25% of the citizens from urban areas uses buses as the main transportation method. In general, bus routes are created and modified without proper methodology or analysis. Discrete Event Simulation is a paradigm that can take into consideration the variability and dynamic nature of bus routes and, therefore, provide valuable insights especially when one is trying to propose a change in an existing bus network. On the other hand, a simulation model for general bus routes is not easy to develop. The present work proposes a generic simulation model for radial networks in order to take into account data which is normally available at buses networks and, then, apply this model to the case of Caieiras city bus network redesign.

1 INTRODUCTION

One in four Brazilians uses buses in their daily activities and about 76% of bus users spend more than one hour in traffic per day. One of the main complaints of Brazilian population is the time spent on public transportation, especially due to delays (EBC Agência Brasil 2015). In Brazilian cities above 100 K inhabitants, public transportation is regarded as “bad” or “very bad” by 41% of the interviewed people (IPEA 2012). From 2011 to 2014, the percentage of Brazilian population evaluating public transportation as “good” or “very good” dropped from 39% to 24%. In the same period, the percentage that evaluates public transport as “bad” or “very bad” raised from 28% to 36%. (CNI 2015).

This generalized dissatisfaction with urban bus transportation also occurs in the city of Caieiras, a small city located in São Paulo state, Brazil, target of this work. In this city, the company Viação Cidade de Caieiras (VCC) operates eight bus transportation routes which, however, were not created based on analytical methods or with computational tools aid, having been adapted continuously over time. According to an annual customer satisfaction survey conducted in 2017, 55% of the passengers classified the interval between bus trips in the city of Caieiras as “bad” or “very bad”, representing an increase in dissatisfaction with previous years, in which the same indicator was 38% in 2016 and 15% in 2015.

The routes operated by the company follow a radial transport model, in which there is a large morning flow towards the center of the city and a great opposite flow towards the peripheries in the afternoon. The company believes that there is a possibility of routes rearrangement so that the average waiting time for buses can be reduced, but it does not have a tool for evaluating possible alternative scenarios of operation.

Thus, this paper proposes steps for the creation of a generic simulation model suitable for simulating and analyzing each bus line operated by VCC, including an alternative scenario analysis. Besides, this generic model could also model bus routes that don't belong to VCC network, as long as they follow a radial configuration, given the flexible characteristics of input data modeling that will be discussed throughout the work. This paper is organized in 4 sections: Section 2 provides a brief literature review about generic simulation models and public transportation. Section 3 describes steps towards a generic simulation model for bus routes, according to the radial transportation model. Section 4 shows the application of this generic model to VCC case. Section 5 provides conclusions for this work and proposes items for future work.

2 LITERATURE REVIEW

2.1 Public Transportation by Bus

According to Souza and Orrico Filho (2015), in most Latin-American cities, public transportation network grew intuitively with cities development, not being accompanied by proper planning and study. According to the authors, urban public transport routing should be done in such a way that the lines pass through the main poles of attraction of trips, besides providing a satisfactory coverage of the inhabited areas, in order to guarantee good accessibility to the public transport system.

Teodorović and Janić (2017) state that public transportation systems based on buses have the lowest investment cost per line length, but also, the lowest performance among road-based urban transit systems (which includes trolleybuses, semi-rapid buses and variants). This work is focused on *regular buses*, defined by the authors as buses that operate along fixed routes and according to a fixed schedule.

According to Ferraz and Torres (2004), collective transport routes can be classified according to their route or function. According to layout, a line can be classified into five categories:

- Radial, for routes connecting some city region to central area;
- Diametral, for routes connecting two city regions, passing through the central area;
- Circular, for routes connecting several city regions, forming a closed circuit;
- Interdistrict, for routes connecting two or more city regions, without passing through central area;
- Local, for routes integrally within a defined region.

These classifications are exemplified in Figure 1.

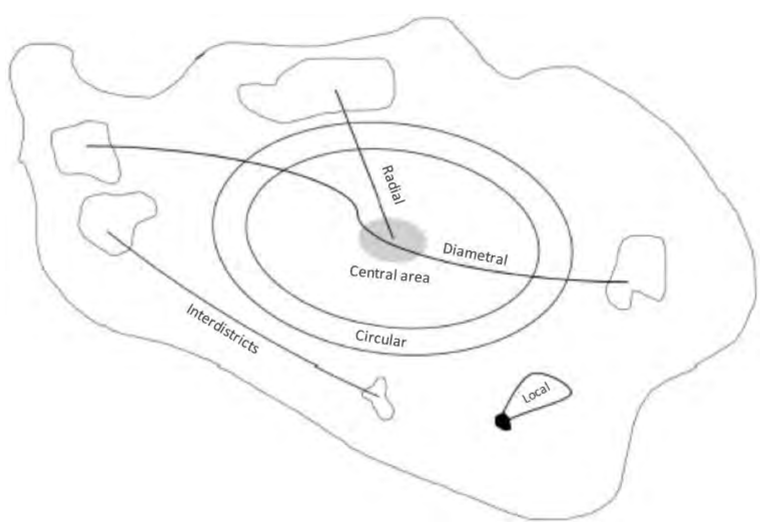

Figure 1: Route types according to the layout.

In Caieiras city, the eight routes operated by VCC forms a radial transit network, linking several suburban areas to the city central area (Figure 2).

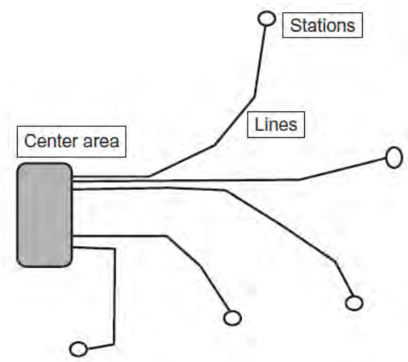

Figure 2: Radial transportation model.

As described by Teodorović and Janić (2017), in this kind of network, any passenger trip (between any two nodes) can be done without transfer, or with at most one transfer.

2.2 Approaches For Transportation Problems

As stated by Teodorović and Janić (2017), the overall public transit planning process is comprised by five steps: 1) transit network design; 2) service frequency setting; 3) timetable development; 4) vehicle scheduling; and 5) crew scheduling. This paper intends to provide a tool to aid in steps 1 and 2. Ceder (2001) classified approaches for public transport route problems into simulation models, ideal network methods and mathematical programming models. Simulation models require a considerable amount of data and can't always produce optimal solutions. Russo (1998) states that mathematical programming models can guarantee optimal transit network design but sacrifice the level of detail in passenger representation and other design parameters, which can be addressed by simulation models.

Kepaptsoglou and Karlaftis (2009) conducted an extensive review on the transit route network design problem, designing a generic framework for developing methodologies for the problem, from analytical models to metaheuristics. Ibarra-Rojas et al. (2015) also presented a literature review on optimization approaches used for planning, operation, and control of bus transport systems, pointing out that there are still open research questions, for instance, robust transit planning due to uncertainty. In both reviews, however, it can be noticed that the majority of techniques used is not related to discrete-event simulation. Our research found papers about bus routes and passengers interaction at stops (Fonseca i Casas et al. 2014; Curzel et al. 2016), bus travel times (Yu et al. 2017), allocation of vehicles to bus routes (Sánchez-Martínez et al. 2016), optimization of bus stops layout (Arhin et al. 2016; Liu et al. 2017) and even a simulation-based framework for evaluation and optimization of transportation systems (Song et al. 2013), but almost no papers regarding discrete-event simulation in urban bus transportation problem. A few exceptions arise for the Bus Rapid Transit (BRT) system (Gunawan 2014; Gunawan and Gunawan 2014). BRT is a bus-based system that mimics the high-capacity and high-performance characteristics of urban rail systems at a much lower price, occupying the middle ground between urban rail and traditional bus systems (Deng and Nelson 2011; Cervero 2013).

Despite the lack of references regarding discrete-event simulation methods for network transportation, especially public bus transportation, discrete-event simulation is a paradigm that can take into consideration the variability and dynamic nature of bus routes, characteristics that are rarely handled by classical mathematical optimization methods. Therefore, discrete-event simulation provides valuable insights especially when one is trying to propose a change in an existing bus network.

2.3 Generic Simulation Models

According to Chwif and Medina (2015), simulation projects usually involves three major steps: conception, implementation and analysis. At conception stage, the project focuses on the definition of the system objectives and the creation of a conceptual model. The next phase, implementation, is dedicated to build a computational model corresponding to the conceptual model. When the computational model is verified ("error-free") and validated, it becomes an operational model, ready to produce results for the analysis phase. The authors emphasize that the most important phase is the conception phase since it is directly related to the goals of the study and to the system in analysis. Thus, typically, a simulation project (and its simulation models) is specific to each situation. Generic models, on the other hand, are those that can be applied to a large set of similar systems, but at the same time, are able to provide accurate results for the system-specific output parameters (Mackulack et al. 1998).

Fletcher and Worthington (2009) propose a model categorization in terms of abstraction and code transportability level. A generic model would be, for example, a model capable of representing any department of emergency care in a country, so that patient flow could be studied only by changing model input parameters. On the opposite side, the "specific" model would be the one that answers the same questions but only for a specific emergency department.

The main obstacle for generic models construction is associated to its large elaboration time, which results in high costs. Mackulak et al. (1998) exemplify the situation: the greater the complexity of the model, the greater the need for development time; on the other hand, the more complex the model, the faster it is to obtain the desired response (within the project in which it is applied). The issue about how to computationally implement a generic simulation model was addressed by Gyimesi (2008), who proposed a framework for web-based discrete event simulation models. Generic simulation modeling was used in a wide range of areas such as hybrid flow-shop (Grangeon et al. 1999), maritime logistics (Medina et al. 2103), ambulance service (Pinto et al. 2015) or water resource systems (Sulis and Sechi 2013).

3 GENERIC SIMULATION MODEL PROPOSAL

3.1 Conceptual Model

In a radial transportation bus network, each route is comprised by a number of vehicles (buses) who serves groups of passengers, moving along fixed routes. Main elements of the network are vehicles, paths, stops (including terminals), garages, power supply systems and control systems. The latter is responsible, among other activities, for vehicle departs schedule. Our conceptual representation of these elements has to be able to represent the operation of any of VCC bus routes. Some hypotheses were taken into consideration so the model can be flexible enough to do this:

- It will be not considered buses breaks since, in practice, their occurrence are negligible;
- It will be not considered bus fueling: it's reasonable to assume that fueling process occurs out of operation time;
- Route deviations will be not taken into consideration;
- Two different average bus speeds will be considered for rush and non-rush hours. Street declivities or acclivities will not be considered;
- Operation of one bus doesn't affect the operation of other buses. This is an important hypothesis because implies in bus routes independence, that is, every route can be simulated independently.
- Passengers arrival process at buses stops will be represented as a Poisson process. Although this is not 100% realistic, since passengers tend to arrive at a given bus stop near the arrival time of the bus, it will give a super estimated measure of waiting times at each stop. Therefore, it will be a worst-case scenario. Disembark process will be represented in a similar manner (this will be discussed in Section 3.3);
- Boarding and disembarking time will be proportional to the number of passengers entering or leaving the bus. Figure 3 depicts a schematic representation of our proposed model.

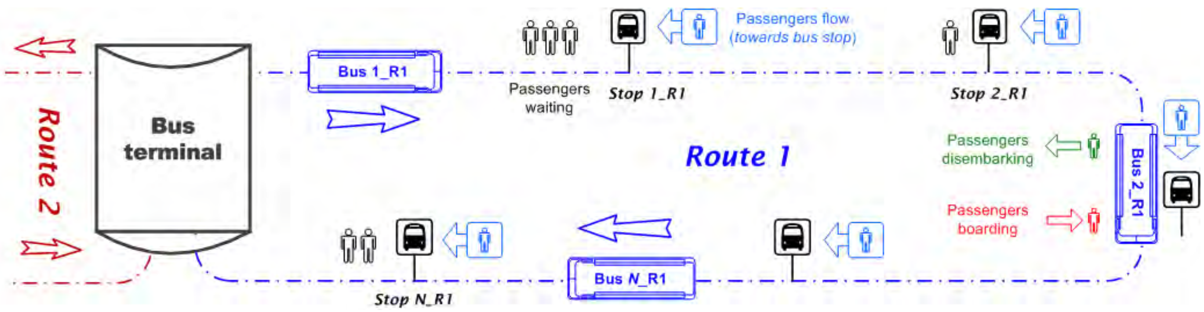

Figure 3: Schematic conceptual model.

All trips start at VCC terminal and, once a bus reaches the last stop, it restarts its cycle. According to the time of the day, additional buses are put into or removed from circulation by the bus terminal management.

3.2 Input Data Collection

For our proposed generic model, each bus route (regardless of any overlapping) is characterized by:

- Total vehicle availability, along working periods;
- Vehicle capacity;
- Total number of stops;
- Distance between stops;
- Bus speed in and off rush hours (average values);
- Total number of passengers boarding and disembarking at each stop;
- Time of boarding and disembarking process at each stop;
- Bus depart schedule (at terminals).

With exception of boarding and disembarking processes, all these data can be obtained from the bus operation management company. For the boarding and disembarking modeling, we propose that one data collector do the entire bus trip, as many times as possible, and collects the number of passengers boarding and disembarking at the terminal and at every stop, just as the corresponding time of the day. Table 1 shows an example of data collection (values of "In the vehicle" column are, actually, calculated).

Table 1: Example of data collection.

Stop	Time	Total number of passengers		
		Boarding	Disembarking	In the vehicle
Terminal A	07:00	18	0	18
1	07:06	8	0	26
2	07:15	16	2	40
3	07:20	5	4	41
4	07:20	5	1	44
5	07:28	1	2	43
Terminal B	07:33	0	43	0

After collection, these counts must be aggregated in predefined time windows, depending on total trip duration, to enable final data treatment. The final data will be the average of all measures available (rounded to nearest integer). Obviously, this data gathering process can be very time consuming but is mandatory that all work period is covered. We recommend that this process be conducted along, at least, one entire week. Table 2 shows an example of aggregated data for a 30-minute time window.

Table 2: Example of aggregated data.

Time	Total number of passengers	
	Boarding	Disembarking
07:00	15	0
07:30	7	1
08:00	5	3
08:30	5	3
09:00	9	16
09:30	2	3
10:00	2	2
10:30	0	32

With all these data in hand is possible to create our proposed simulation model, described below.

3.3 Simulation Model

Figure 4 shows our generic model (in effect, a partial view of one of the models to be discussed in Section 4) created in SIMUL8 software.

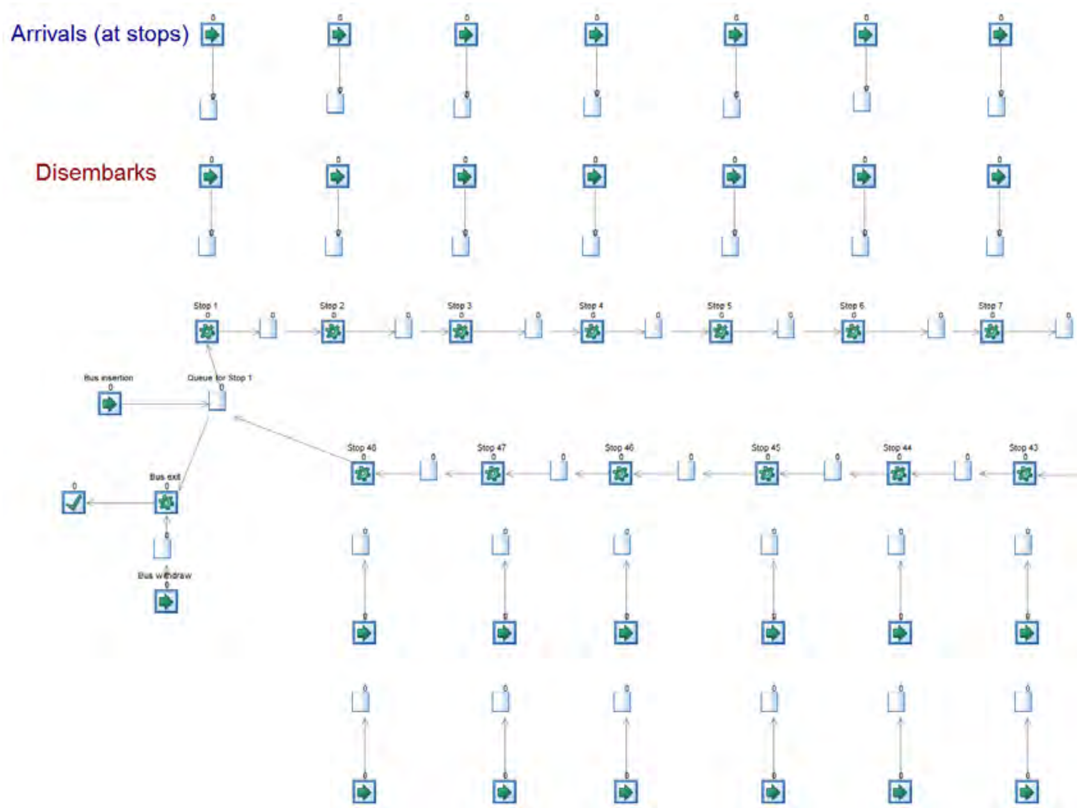

Figure 4: Simulation model.

The bus transit process is represented by a sequence of activities that represents the time spent at each bus stop and traveling to the next. Loading/unloading time is calculated as the maximum between boarding and disembarking time, since all VCC buses have two independent access doors. Displacement times are calculated according to the period of the day (rush hour affects bus speed) and the distance between stops. These activities also update, via internal programming, the number of passengers at "in and out" queues.

An initial number of available buses is fed into a queue before the first displacement activity (represented by "Queue for Stop 1" in Figure 4). According to the time of the day (rush hours and non-rush hours), additional buses are inserted into or removed from the model by "Bus Insertion" and "Bus Withdraw" objects. Figure 5 shows an example of the schedule for the bus number availability control. The schedule employs a "time absolute functionality", when an entity is scheduled to arrive at a pre-defined hour in the day, plus a delay distribution, that can even provide negative values to represent early arrivals.

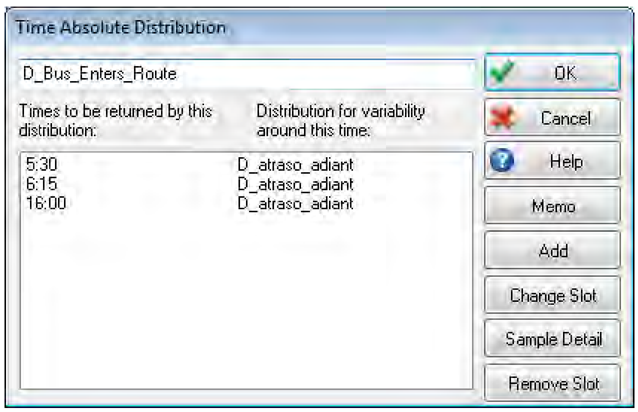

Figure 5: Schedule for bus availability.

The arrival passenger process at buses stops was represented by entry points connected to queues. Along with every programmed time-window, a certain number of passengers, at every bus stop, is inserted into the model, according to previously collected data. Within every time-window, an exponential inter-arrival time distribution is considered, as explained in Section 3.1. Figure 6 illustrates an example of this scheduling process in SIMUL8's "Day Planner" tool. In this tool, it is defined the quantity of arriving entities in each time slot of the day (a time slot can be every 15 minutes, 30 minutes etc), just as its arrival (that can be fixed, Poisson distributed or modeled by any predefined distribution).

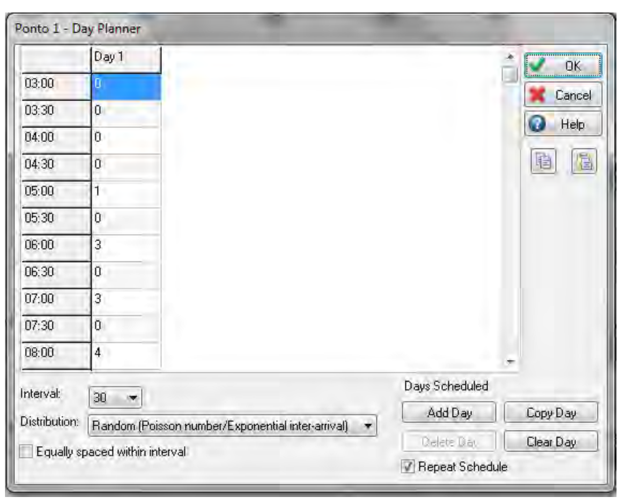

Figure 6: Example of passenger's arrival schedule.

An identical scheduling scheme was used to simulate the number of passengers who want to disembark at any stop: they "accumulate" in a queue, associated to the stop, waiting to disembark. It can be noted that this process is not synchronized with the bus travel simulation. However, if the number of passengers to disembark is higher than the actual number of passengers, due to randomness, the model will correct this discrepancy by setting the number of passengers to disembark to the current number of passengers inside the bus. Also, if the number of passengers trying to enter will provide an excess of capacity, it will be also corrected: passengers that not entered will stay at the bus stop to get the next bus.

In order to carry out the model computational verification, three of the techniques proposed by Chwif e Medina (2015) were used: modular building, step-by-step run and group review. To operational validation, the average number of passengers that entered and left the buses of each route was compared with the average value from data collected. Results showed that the entry and exit processes are adequately represented - an example is shown in Figure 7; also, we confirmed that the passengers Poisson arrival process is consistent with actual data.

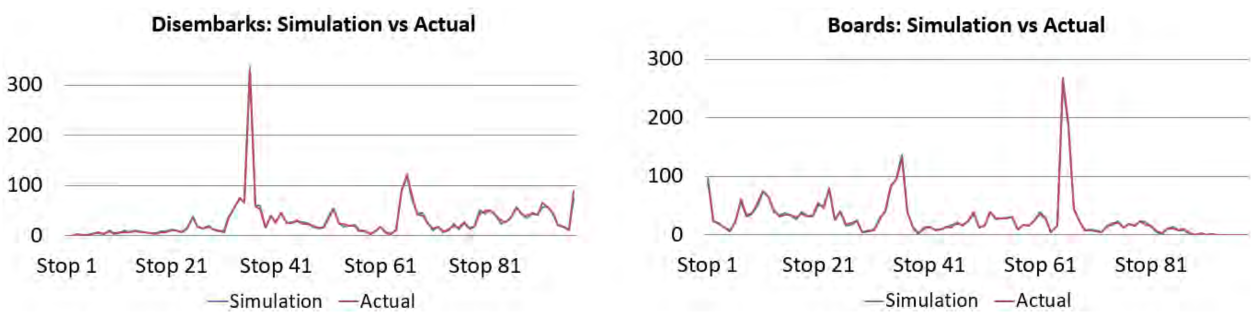

Figure 7: Graphs for real vs simulation: route 010.

Additionally, max average waiting times and average bus utilization were qualitatively analyzed (see more in Section 4.1). Once again, we confirmed that the results are consistent with what the bus drivers observe in practice. With this, we concluded that our model is valid enough to simulate all eight routes operated by VCC, either in its current configuration or in alternative scenarios. Results are discussed below.

4 APPLICATION: VIAÇÃO CIDADE DE CAIEIRAS CASE

4.1 Current Routes Simulation

Currently, VCC operates eight bus routes, as shown in Table 3. The operation runs from 3:00 AM to 23:00 PM; rush hours occur from 7:00 AM to 10:00 AM and from 17:00 PM to 20:00 PM.

Table 3: Current routes specifications.

Route ID	Total buses in circulation		Number of stops
	Rush hours	Off rush hours	
010	5	4	98
020	4	4	61
030	4	4	60
040	4	4	46
055	4	3	59
070	6	4	95
075	2	2	77
080	2	1	48
Overall	31	26	544

All input data mentioned in Section 3.1, with except passenger flow, were obtained along with VCC management. Over the course of five days, bus drivers and ticket collectors collected the number of people boarding and disembarking at each stop. As a form of validation, interviews carried out with employees involved in company daily operations confirmed the data coherence. For each route, these data were aggregated in 30-minutes time windows, as discussed in Section 3.2.

With all data in hand, eight simulation models were built, all with the same structure represented in Figures 3 and 4. Main results of interest are passengers waiting time at bus stops (average and maximum) and average buses utilization. Results obtained after five replications are shown in Table 4.

Table 4: Output results.

Route	Max average waiting time (minutes)	Bus stop ID	Average utilization
010	62,14	45	28,9%
020	64,86	20	52,4%
030	57,81	20	44,6%
040	66,28	9	25,6%
055	81,07	47	49,1%
070	74,75	44	20,9%
075	73,16	19	29,3%
080	30,99	16	19,9%
Overall	63,88	-	33,84%

As discussed in Section 3.1, we are aware that simulation results for waiting times are higher than the actual ones, due to the hypothesis of exponential inter-arrival times. Yet, these results are coherent with what happens In practice and, moreover, can be compared to the corresponding values in alternative configurations, to show if any improvement occurs.

4.2 Alternative Network

VCC is currently devising a new configuration for their bus routes, targeting less overlapping routes and fewer buses in circulation: company's plan is to cover all current stops with only four routes. Table 5 depicts the basic information for the proposed configuration.

Table 5: New routes characteristics.

New route ID	Buses in circulation		Stops
	Rush hour	Off	
01	6	6	60
02	4	4	91
03	7	7	56
04	5	5	50
Overall	22	22	257

Simulation models for this new condition have the same structure discussed in Section 3, with due changes in buses availability, travel times and stopping points. Estimates for passenger flows at stops were provided by the VCC company (unfortunately, we didn't have access to their method due to confidentiality issues; the only information we were told was that coverage overlap will decrease significantly). Simulation results are presented in Table 6. Once again, we stress that results for max average waiting times are overestimated value in comparison to the real-life situation. Table 7 compares overall outputs from the current and alternative condition.

Table 6: Alternative routes system results.

New route ID	Max average waiting time (minutes)	Average occupation
01	23,03	76,53%
02	63,04	32,43%
03	34,96	52,86%
04	24,15	42,47%
Overall	36,30	51,07%

Table 7: Current vs alternative network results.

	Max average waiting time (minutes)	Average occupation	Total buses in circulation	
			Rush hours	Off rush hours
Current	63,88	33,84%	31	26
Proposed	36,30	51,07%	22	22
Variation	-43,17%	17,23%	-29%	-15%

It can be noticed that the new routes configuration allows a reduction in maximum waiting time even with less bus in circulation. Moreover, the increase in average overall utilization indicates a reduction in bus idleness.

5 CONCLUSIONS

This paper presented a proposal for a generic simulation model for bus routes in a radial network structure, including a discussion about its conceptual modeling. The proposed generic model was applied in a real-life condition and in an alternative scenario. Simulation results showed that the generic model was able to adequately represent both scenarios and that is possible to reduce the total number of buses in circulation, reducing operation idleness and improving service quality of service by reducing the maximum average waiting time for buses.

As suggestions for future work, we intend to expand the generic model capabilities. One of the major issues is that current modeling paradigm can represent practically any bus line of a radial structure; however, in other structures, we have to consider, for instance, passenger transshipments. We also intend to make another study in Brazil's biggest city (São Paulo) to analyze the impact of bus lines remodeling by means of discrete event simulation (in parallel with a similar process currently being carried on by São Paulo City Hall). Therefore, this research is still preliminary and a lot of work have to be done in order to contribute to "Simulation for a Noble Cause" field.

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