A Performability Model for the BRT System

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***Abstract*—Large cities have increasing mobility problems due to the large number of vehicles on the streets, which results in traffic jams and thus a waste of time and money. An alternative to improve traffic is to prioritize the public transportation system. Several metropolises around the world are adopting Bus Rapid Transit (BRT) systems since they present compelling results considering the cost-benefit perspective. Evaluating metrics such as performance, dependability, and performability, aids in planning, monitoring, and optimizing BRT systems. This paper presents hierarchical models, using CTMC modeling techniques, to assess metrics such as performance and performability. Results show that these models pointed to the peak intervals that are more likely to arrive at the destination in a shorter time, in addition to showing the probability of the vehicle being affected by the failure at each interval. It was also possible to establish bases for the replication of the model in different scenarios to enable new comparative studies.**

I. Introduction

Large cities have increasingly faced problems due to a large number of vehicles on the streets, which results in traffic jams and thus a waste of time, and a decrease in urban mobility. As an alternative to heavy traffic scenarios, governments have invested in improvements in public transport systems, in an attempt to create quality systems that enable citizens to migrate away from private vehicle use, thereby reducing the number of vehicles on the roads. A solution that has shown satisfactory results is Bus Rapid Transit (BRT) [1]. BRT operates on exclusive routes, with an off-board method of charging customers; this perspective allows for greater reliability and speedier transit.

In this context, analytical approaches to determine the overall performance and reliability of BRT systems have been proposed in the literature. The authors in [2], [3] and [4], propose modeling their approaches on transport systems, considering how to supply the passengers' demand in rush hour, along with travel time and reliability, including important mode-specific issues such as bus bunching.

The main contribution of this work is the development of the hierarchical models to evaluate BRT systems and the model validation using experimental data taken from the literature. Whereas the models presented do not find evidence to refute them, as the studies show, these models can be used by planners of a BRT system to obtain performance metrics, reliability, and performability when searching for viable alternatives to the system.

II. Related Works

The authors in [2] show the effects of implementing BRT in Copenhagen, including how to evaluate and model bus operations. For this purpose, a mesoscopic simulation model is developed. In the model, bus operations are modelled on a microscopic level whereas the interactions with other traffic are modelled macroscopically. This makes it possible to model high-frequency bus services such as BRT lines in more detail, without the time consumption of micro-simulation models. The developed model is capable of modeling bus operations in terms of travel time and reliability, including important mode-specific issues such as bus bunching.

In [4], the authors propose a Petri Net simulation model for a very well used public transportation system in Bogota (TransMilenio). The modeling of the system is done using a multi-agent approach in order to simulate and analyze the resources involved to supply the passengers' demand in rush hour. Real data are acquired to make the model more realistic. Furthermore, an experimental methodology is used to verify the accuracy of the proposed model and validate the simulation results.

The performability is presented in [5], which treats the utility of modeling performability for systems that can operate partially, in the specific case, fault tolerant computer systems and distributed systems. In his work [5] brings a range of tools that are useful for modeling and performability analysis, evaluating its structure, its capabilities in terms of measures that can be obtained, and the modeling formalism utilized.

The present work offers a different approach from those described above. Here, the modeling of the system is made in a hierarchical manner; with the composition of models for performability evaluation we propose CTMC models. Metrics are developed for the evaluation of the system, such as a metric for the probability of arrival at the destination at any given time, and these metrics can be considered as a gauge of system performance. This work differs from others in the literature by combining performance and dependability measures in BRT systems; it is relevant to planning these types of systems.

III. Fundamental Concepts

This section presents a summary of the concepts necessary for understanding this work, and also provides an overview of the performance model in BRT systems.

A. Performability

Performability is the study of performance combined with dependability, providing more consistent results concerning the evaluation of the system [6]. Regardless of the system, the study of performability allows the description of the effects of the occurrence of faults and repairs on the system performance degradation.

Performance and dependability modeling usually occur in separate ways, as it is considered that individual components or subsystems may not necessarily affect system performance. In fault-tolerant systems, whose aim is the continuous supply of the service, even with loss of performance, independent modeling should not be used, in order to not have an incomplete or inaccurate assessment. A performability model can be represented by a model of dependability, a performance model, and a method to combine the overall results of these models [7].

B. Methods and models for dependability evaluation

Aspects of dependability deserve great attention for the assurance of the quality of the service provided by a system. System dependability can be understood as the ability to deliver a specified functionality that can be justifiably trusted [8]. Dependability studies look for a determination of reliability, availability, security, and safety metrics for the infrastructure under analysis [9].

There are formal techniques which may be used for modeling computer systems and estimating measures related to system availability, reliability, and performance. RBDs [10], Fault Trees [10], Stochastic Petri Nets (SPNs) [11] and Markov chains [12] have been used to model many kinds of systems and to evaluate various availability and reliability measures.

C. BRT system

A BRT system can be viewed from three different perspectives. There are performance characteristics together with the individual elements which determine how a useful system is generated. The *Major Elements* of a BRT are represented here, together with their respective features and attributes: running ways (dedicated busways), stations, vehicles, fare collection system, Intelligent Transport System (ITS: fundamentally the creation of intelligent traffic lights) as well as the operation planning service and operation plan. *System Performance* refers to the following attributes: travel time savings, reliability, identity and image, safety and security, and capacity. *System Benefits* refer to the various benefits a BRT affords, including: ridership (high passenger levels), transit-supportive land use development, environmental quality, capital cost effectiveness, operating efficiency, and many other benefits. This three-perspective structure suggests the relationships between the major elements, system performance, and system benefits.

Wright (2002) describes the main features of BRT systems as: segregated busways; rapid boarding and alighting; clean, secure, and comfortable stations and terminals; efficient preboarding fare collection; effective licensing and regulatory regimes for service operators; clear and prominent signage and real-time information displays; transit prioritization at intersections; modal integration at stations and terminals; clean bus technologies; sophisticated marketing identity; and excellence in customer service [13].

IV. METHODOLOGY

One of the first tasks in a study is to determine the goals and how they may be reached. To evaluate the behavior of any system, it is necessary to understand and define the parameters to be evaluated; the considered resources should be important to the analysis and should help complete the objectives [14]. After listing the important resources, a determination can be made as to a way to obtain the needed information [14].To achieve that, modeling strategies and analytical models were defined, trying to evaluate the behavior of a BRT System from the perspective of the probability of a vehicle reaching its destination, the reliability, and the performability. Finally, scenarios were constructed to evaluate the models, considering actual systems already in place, and possibilities for the implementation of new systems. Figure 1 shows an organization chart that summarizes the strategy used in this paper.

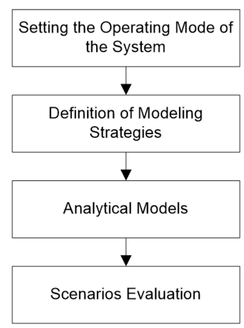

Fig. 1: Organization of the study.

V. MODELS AND PROPOSED ARCHITECTURE

This paper analyzes the performance, dependability, and performability of BRT systems. In order to evaluate and address the problem of research, a baseline scenario was built considering the description of the BRT system with the settings of the metrics for analysis. This baseline was taken from the BRT descriptions found in [1] [15], which consider all the fundamental characteristics, components, structures, performance evaluation criteria, and benefits of a BRT system. After modeling the baseline scenario using CTMC, we gathered its underlying mathematical equation that was used to evaluate BRT's performance. In order to analyze the performability, a CTMC model that is composed of the described systems above, has been created. The scenario described in the Changzhou BRT [15], which details travel times and, from these, calculates system reliability, was employed to verify the system validation.

The proposed architecture considers a compound BRT system of two central stations and six intermediate stations (see Figure 2). This architecture was designed according to real world BRT systems, where the main goal is to link suburbs to the center of the city, including, within this parameter, numerous stops which attempt to satisfy passenger demand.

The BRT system can be presented as follows: the vehicle component (Bus) and Infrastructure (IE) (Figure 3). To analyze the IE subsystem, two aspects have been considered from the perspective of this work that may interfere with the reliability of the system: the pathway (stretch) and stations. Even from that perspective, for an analysis of the station, a more restricted model was created, which considers for the operation of the station, where the entry and exit mechanism must be working. These mechanisms will be presented in details in the following subsections. The operational mode of the system obeys the following rule:

- The system are operational if the IE subsystem, and the Bus subsystem is operational. We restrained our context and assumed that those subsystems are stochastically independent.

A. Probability Model for Vehicle Arrival

To represent the BRT system and perform the probability analysis, the following crucial factors were considered: number of stations, travel time, and the number of vehicles in the system. The model can be described with a Hypoexponential distribution, which is the generalization of the Erlang distribution, but having different rates for each transition [16]. The Hypoexponential distribution is used in this model, since there are different rates for the displacement between stations, in this case, α_tt, for displacement from the central station to station 1, and α_ttw, for the displacement between the other stations. This can also be described by Equation 1 [12]:

$$PDF = \sum_{i=1}^{k} \gamma_i \alpha_i e^{-\alpha_i t}, t > 0, \tag{1}$$

with,

$$\gamma_i = \prod_{j=1, j \neq i}^{k} \frac{\alpha_j}{\alpha_j - \alpha_i}, 1 \leqslant i \leqslant k, \tag{2}$$

where, for the *Probability Density Function* (PDF), γ=(γ_1,γ_2,γ_3,γ_4,...,γ_n) with $\sum_{i=1}^{n} \gamma_i = 1$, α_i is the rate of displacement between stations and *t* is the time wanted.

It is also possible to obtain a closed-form equation for calculating the Mean Time To Reach the Destination (MTTRD), given by the average calculus in hypoexponential distribution (see Equation 3), employing the same parameters used in Equation 1.

$$MTTRD = \sum_{i=1}^{k} \frac{1}{\alpha_i} \tag{3}$$

B. Performability Model in BRT System

From the perspective of reliability and performance, and in order to analyze the impact of failure on the system's performance, a CTMC's model was built to evaluate the performability. This model represents the composition of the CTMC's models of performance and RBD's models of reliability, being represented by Figure 4.

The commuting time between stations as well as system time to failure are (considered to be) exponentially distributed. In this model, the states $Station\_Central$, Station_1, Station_2, Station_3, Station_4, Station_5, Station_6, and $Station\_Final$, represent that the system is UP, the α_{tt} rate represents the commuting time between the states $Station\_Central$ and $Station\_1$, and α_{ttw} rate, the commuting time between stations, considering the waiting time for entry and exit of passengers.

The λ_{Syst} rates represent the possibility of system failure, considering the MTTF, where, λ_{Syst} is given by 1/MTTF. The system failure leads to $Fail\_BRT$ state, which considers that, in this place, the system will be inoperative. Thus, the performability is obtained by equation 4:

$$Performability\,(t) = 1 - P\,(Fail\_BRT)\,. \tag{4}$$

This model does not consider the possibility of recovery of failures because it tries to show the impact of the failure in the system, identifying the probability of the system being completely inoperative, that is to say, to go into fault. The model presented shows the probability of the failure in the trip to the destination, considering one trip only. This model considers the same probability of failure for the entire BRT route.

To analyze the possibility of the system failing over a longer period of time, that is, in how many trips there is a probability the system is working, the performability model, Figure 5, was created.

The commuting time between stations as well as system time to failure are (considered to be) exponentially distributed. In this model, the states $Station\_Central$, Station_1, Station_2, Station_3, Station_4, Station_5, Station_6, $Station\_Final$, Station_1_R, Station_2_R, Station_3_R, Station_4_R, Station_5_R, and Station_6_R, represent that the system is UP, the α_{tt} rate represents the commuting time between the states $Station\_Central$ and $Station\_1$, and $Station\_Final$ and Station_6_R, and α_{ttw} rate, the commuting time between stations, considering the waiting time for entry and exit of passengers. For the calculation of the performability, Equation 4 can be used.

VI. RESULTS

For verification of results two studies were performed to demonstrate the suitability of the models. The first study makes a comparison between the results obtained from the CTMC model with a simple study of the system given in [15]. In algebraics, for expressions that consider the reliability of the BRT system, we used data obtained from Volvo's website [17], to find the bus failure time, as well as data obtained from manufacturers of components and road safety systems so as to assign the MTTF parameters of our models. It is important to stress the purpose of using algebraic expressions. The choice was made because algebraic expressions enable

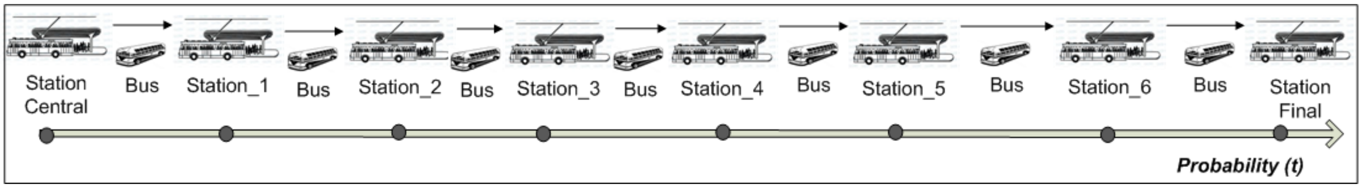

Fig. 2: Default route for BRT systems

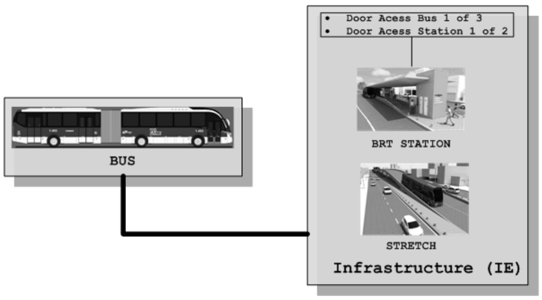

Fig. 3: Items for the reliability of the BRT System

easier evaluation of reliability and availability of systems, and because it is a less sophisticated formalism, being easier to make; however, it takes into account the parameters requested in the study with precision, which makes it more appropriate for this stage of the research.

We have also evaluated the performability of the BRT system with a CTMC model.

In the second study, a scenario is illustrated based on information obtained from a real BRT system. This scenario expands the first study, since it shows a scenario with a larger number of stations, and reveals the importance of the model for scenario planning, considering that, with the inclusion of information and the accuracy of the model, it is possible in a scenario with more data, by estimating the arrival at the destination and the impact that the failure can have on the system .

A. First Scenario Results

For the composition of the first scenario, a dataset taken from [15] as given in Table I, was used, and the probability of vehicle arrival time in the final lane in a particular time period was calculated. The particular time period is defined based in day period, considered by Zhao [15].For the calculation of the probability, i.e. the possibility of the vehicle reaching the destination in a given time interval α_{tt}, referred to the bus travel time to the next station and α_{ttw} referred to the delay time at the station and the time displacement between stations, in this case, the Station_1 to Station_6.

Table I describes the travel times for five different intervals in a particular route [15]. The travel ranges are: *Early*, *AM Peak*, *Inter-Peak*, *PM Peak* and *Evening*.The maximum journey time for each travel time interval is considered as the sum of wait time and travel time, where, the origin stop headway (Hi) is the cumulative wait time for all stations and, In-vehicle travel time (Ti) is the cumulative travel time in a route.

TABLE I: BRT system information from [15].

Trip	Origin Stop Headway (Hi) min	In-Vehicle Travel Time (Ti) min	Max. Journey Time (Hi + Ti) min
Early	7.15	22.80	29.95
AM Peak	1.87	21.52	23.39
Inter-Peak	4.07	18.88	22.95
PM Peak	5.65	17.35	23.00
Evening	5.75	21.70	27.45

The current study has seven stations along a pathway, and so the dataset in Table I can be subdivided to represent each station, at their respective peak time. Thus, Table II illustrates the dataset for each peak times. The α_{ttw} can be subdivided from 1 to 6 stations. The transition α_{tt} has no wait time, since this is the starting lane, and it is assumed that the bus leaves on time.

TABLE II: Input parameters for each peak time

Period of the day	Parameters	Average Waiting Time (min)	Average time on the vehicle (min)	Value (min)
Early Time	α_{tt}	–	3.26	3.26
	α_{ttw} 1 to 6	1.19	3.26	4.45
AM Peak Time	α_{tt}	–	3.07	3.07
	α_{ttw} 1 to 6	0.31	3.07	3.38
Inter-Peak Time	α_{tt}	–	2.70	2.70
	α_{ttw} 1 to 6	0.68	2.70	3.38
PM Peak Time	α_{tt}	–	2.48	2.48
	α_{ttw} 1 to 6	0.94	2.48	3.42
Evening Time	α_{tt}	–	3.10	3.10
	α_{ttw} 1 to 6	0.96	3.10	4.06

We have a description of a real scenario that will serve as a starting point to verify our model, presented in Section V. Equation 1 can be used to know the probability of being in any of the stations in a given time. With this model, we can offer the user the forecast of the time in which the vehicle will be at the stations of departure and arrival, providing one of the objectives that the BRT System proposes, that is, the confidence in the displacements between the destinations.

Figure 6 illustrates these probabilities. It can be seen that *Early* and *Evening* demonstrate the worst behaviors. This probably occurs as a result of the facts that fewer buses are released at these times, that there is minor demand, and that the BRT takes a route at its lowest speed, thereby taking longer to reach its destination. The *AM peak*, *Inter-peak*, and *PM peak*, demonstrate practically identical behavior, reflecting the fact that, at peak times the number of buses on the route is greater,

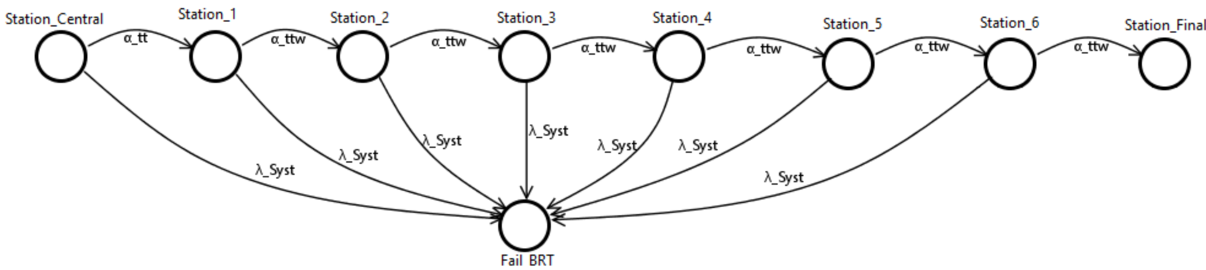

Fig. 4: CTMC model for performability evaluation of BRT system

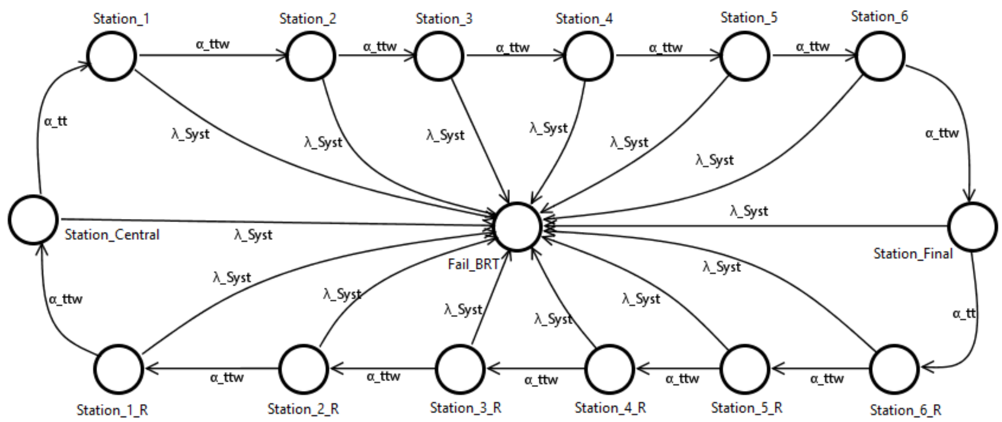

Fig. 5: CTMC model for evaluation of BRT system performance considering several trips

given the increased demand, which results in a shorter arrival time.

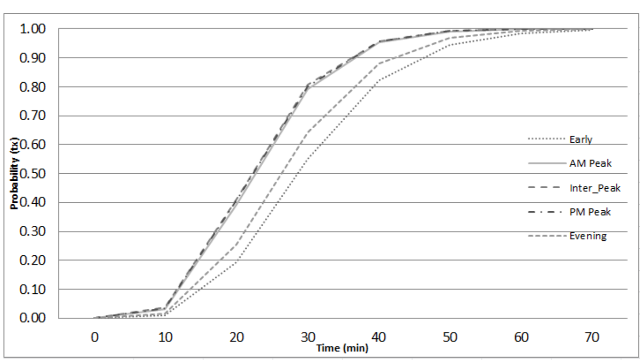

Fig. 6: Destination arrival probability.

This relationship, probability and arrival time, indicates that a transit planning process is a fundamental requirement to assist in reducing the journey time by improving the probability of arrival at the destination; in other words, it is essential in ensuring that the passenger arrives at his destination on time.

Another factor that can be considered is the probability of bus arrival within a specific time frame, a time judged to be acceptable to the waiting user. In the *Inter-Peak* period the mean maximum journey time is 22.95 min (Table I). Therefore, for a time frame of 25 to 35 min, as illustrated in Figure 7, there is an 80% probability of the BRT vehicle arriving at its destination.

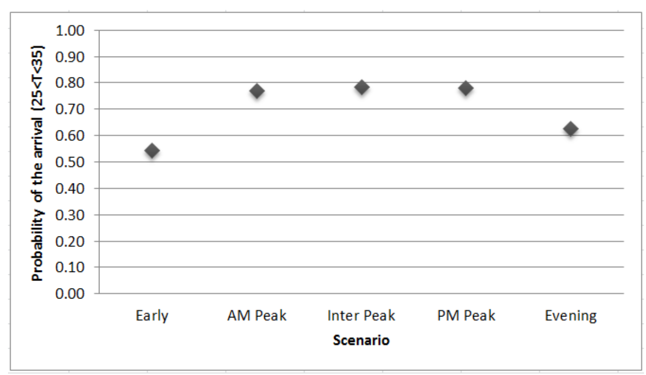

Fig. 7: Arrival probability in a range ($25 < T < 35$)

The behavior during *AM Peak* and *PM Peak* is similar to *Inter-Peak*, where the probability of arrival within the 25-35 min interval is approximately 80%. The *Early* and *Evening* intervals have probability of arrival rates of around 60%.

Table III compares the Mean Time To Absorption with that calculated in Equation 3 with the actual data extracted from [15]. The mean errors, which were calculated based on the relationship between the MTTA and the actual value of the system, suggest that the model is accurate and therefore valid.

TABLE III: Average Error for Mean Time To Absorption.

Trip	Journey Time	Mean Time To Absorption (by model)	Mean Error
Early	29.95	29.96	0.00033
AM Peak	23.39	23.39	0.00005
Inter-Peak	22.95	22.95	0.00011
PM Peak	23.00	23.05	0.00200
Evening	27.45	27.45	0.00080

TABLE IV: Input Data

Data	Value
Early Time	α_{tt} 3.26 min
	α_{ttw} 4.45 min
AM Peak Time	α_{tt} 3.07 min
	α_{ttw} 3.38 min
Inter-Peak Time	α_{tt} 2.70 min
	α_{ttw} 3.38 min
PM Peak Time	α_{tt} 2.48 min
	α_{ttw} 3.42 min
Evening Time	α_{tt} 3.10 min
	α_{ttw} 4.06 min
λ_{Syst} 1/MMTF	1/64260 min

These data are considered to reveal the system's performance, which will be considered for the performability model. For the dependability's study we considered the BRT system shown in Section V.

For the calculation of the performability, from the CTMC model presented in Figure 4, the input data shown were used in Table IV, and, the results shown in Figure 8 can be extracted.

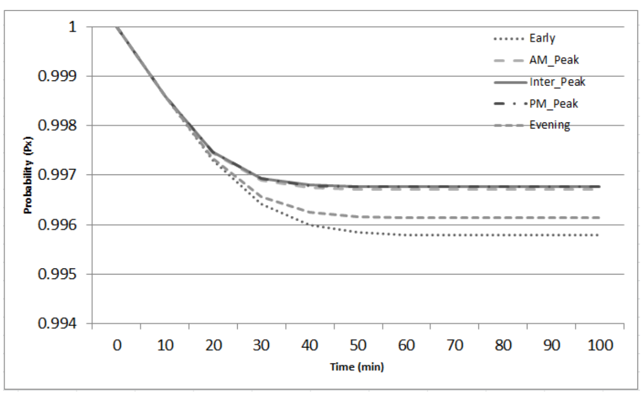

Fig. 8: Performability for BRT System.

It is possible to see in Figure 8 that the performability remains approximately 0,99 (two nines) in all evaluation intervals. The least favorable outcome that corresponds to the Early period, is also representing the worst performance, a result shared with other periods corresponding directly proportionally to this factor. The impact of system failure causes surface impacts if it analyzed the period of one trip only.

Thus, for a more thorough evaluation, the model described in Figure 5 was used, which considers the BRT System with a round trip system from Central Station to Final Station. The results presented in Figure 9 show the relation of the probability of survival of the BRT System considering that when the fault occurs the repair will not occur, that is, the system come into in Failure, in an amount range of trips, either one way or return.

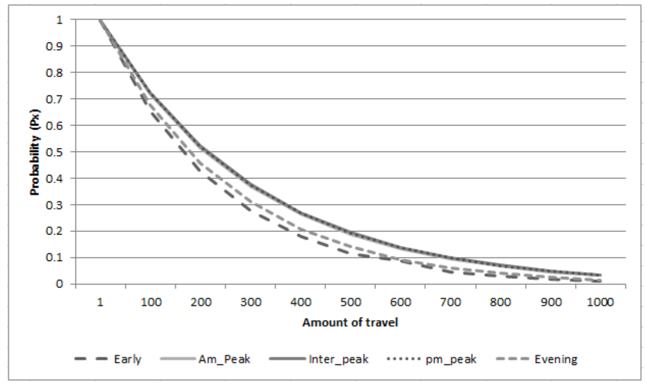

Fig. 9: System Performability considering constant travel.

Figure 9 sshows that, considering the number of trips, the studied BRT System could survive about 1000 trips, that is, considering that the maximum travel time does not exceed 30 minutes and that the daily journey time of the vehicle is 12 hours, that is, daily, the vehicle would make 24 trips. In this way, it is possible to perceive the need to maintain the system, since it would only survive for approximately 42 days if there were no investments in its maintenance.

The *Early* and *Evening* peaks would have a worse result, with the system coming into defect more quickly, since the time of travel of these peaks is greater, which directly impacts the process of operating the system.

B. Second Scenario Results

Since there were no grounds for refuting the model CTMC, Figure 8, presented in Section VI-A, a second scenario was implemented based on a system currently being implemented in the city of Recife, North-East Brazil. We considered 22 stations and a distance of 500m between them, as presented in [18].

The scenario also took into account the average speed of the vehicle according to [19], which states that efficient BRT systems have approximate average speeds between 23 and 39 km/h. Another important factor considered in the scenario was the average stop time for passenger boarding and disembarking. In this study the figure adopted was 22 seconds, which is the given stop period for an articulated four-door vehicle [19].

With this data, three scenarios were examined, relating to the minimum (23 km/h), the average (31 km/h), and the maximum speeds (39 km/h), hereafter referred to as, respectively, *scenario 1*, *scenario 2*, and *scenario 3*. Table V, gives transition times for each scenario. Note that, as in the previous study, there is no wait time (α_{tt}) at the first station since it was assumed that the bus leaves on time. The alpha ttw considers the delay time at the station and the time displacement between stations, in this case, $Station\_1$ to $Station\_21$.

TABLE V: Input parameters for each scenario.

Scenarios	Parameters	Average Waiting Time (min)	Average time on the vehicle (min)	Input Value (min)
23 Km/h	α_{tt}	–	1.30	1.30
	α_{ttw} $1to21$	0.36	1.30	1.66
31 Km/h	α_{tt}	–	0.97	0.97
	α_{ttw} $1to21$	0.36	0.97	1.33
39 Km/h	α_{tt}	–	0.77	0.77
	α_{ttw} $1to21$	0.36	0.77	1.13

With this model the mean time to absorption can be measured, representing the time that the BRT takes to get to the last station. This is a prime item of information for BRT system planning. In this study, as can be seen in Table VI, the absorption time, which has a direct influence on the probability of arrival at a given time, is inversely proportional to the speed.

In Table VI it can be noted that *scenario 1* at 23 km/h has an MTTA of 34.50min. In *scenario 2*, the speed has increased by approximately 35% (from 1.00 to 1.35), whereas the decrease in MTTA is 20% (0.80 of the MTTA in *scenario 1*). In the *third scenario* the speed increases by 70% (from 1.00 to 1.70) in relation to *scenario 1*, while the decrease in MTTA is 32% (0.68 of the MTTA in scenario 1). Thus, it can be noted that although the increase in speed is inversely proportional to the decrease in MTTA, there is no direct correlation. In other words, increasing the bus speed by a factor of 2 does not mean that the bus will arrive in half the time.

TABLE VI: Relationship between Mean Time To Absorption and Travel Speed.

TRIP	Relationship Between Trip	Mean Time to Absorption (MTTA) (min)	Relationship Between MTTA
23 Km/h	1.00	34.50	1.00
31 Km/h	1.35	27.57	0.80
39 Km/h	1.70	23.37	0.68

In Figure 10, which illustrates the probability of arrival at a given time *(t)*, it can be seen that for a time interval of 20 min the probability rises from less than 0.03 (3%) at 23 km/h to almost 0.30 (30%) at 39 km/h. This confirms the impact of bus speed on arrival probabilities. Another important point to note is that, at a time interval of 40 min, the probability of arrival at a vehicle speed of 23 km/h is 0.70 (70%), while at speeds of 31 and 39 km/h, the probability is already at 0.99 (99%).

If the natural assumption is taken that a high probability of arrival within a given time period is perceived as having a major impact on passenger confidence in the system, then it is important to establish an acceptable range. In this case, a range of between 21 and 32 min might be considered as an acceptable journey time to ensure customer satisfaction.

According to these parameters, as illustrated in Figure 11, the strong impact of speed on arrival probability is clear; at 23 km/h the probability of arrival within this frame is just 0.30 (30%), whereas at the other end of the speed scale, at 39 km/h, the probability of arrival is 0.90 (90%).

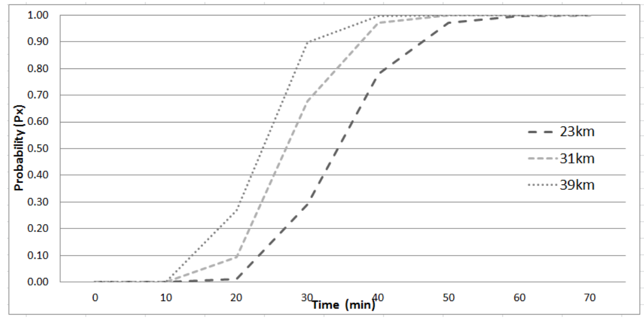

Fig. 10: Destination arrival probability.

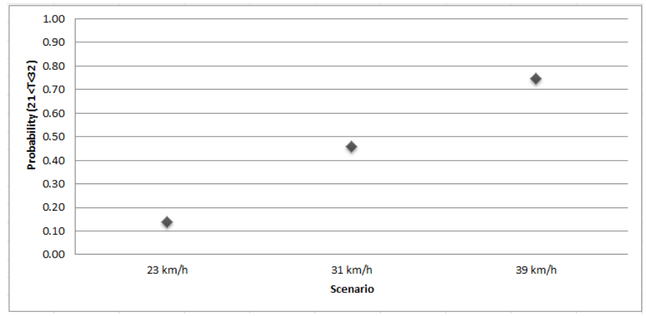

Fig. 11: Probability of arrival within the required range.

For the performability model, the twenty-two stations were considered, changing the failure rate of the BRT system and considering the travel time in each studied speed. Input dates for Scenario 2 show in Table VII. For that, it has the results displayed in Figure 12.

TABLE VII: Input data for CTMC of performability Scenario 2.

Data	Value
23 Km/h	α_{tt} 1.30 min
	α_{ttw} 1.66 min
31 Km/h	α_{tt} 0.97 min
	α_{ttw} 1.33 min
31 Km/h	α_{tt} 0.77 min
	α_{ttw} 1.13 min
λ_{Syst} 1/MMTF	1/6666.67 min

From the presented Figure 12 it was noticed that the performability is influenced by the speed of the vehicle on the track, which may provide better results for the system. In this way, the result is directly proportional to the performance of the system with low impact of the failure at the end context.

Figure 13 shows the low survival rate considering the number of trips; the studied BRT system could survive about 1000 trips. That is, considering that the maximum travel time does not exceed 35 minutes and that the daily journey time of the vehicle is 12 hours, daily, the vehicle would make 21 trips. In this way, it is possible to perceive the need to maintain the system, since it would only survive for approximately 48 days

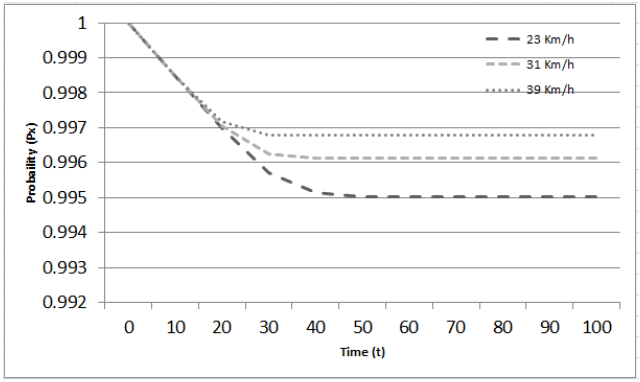

Fig. 12: Performability in Scenario II.

if there were no investments in its maintenance.

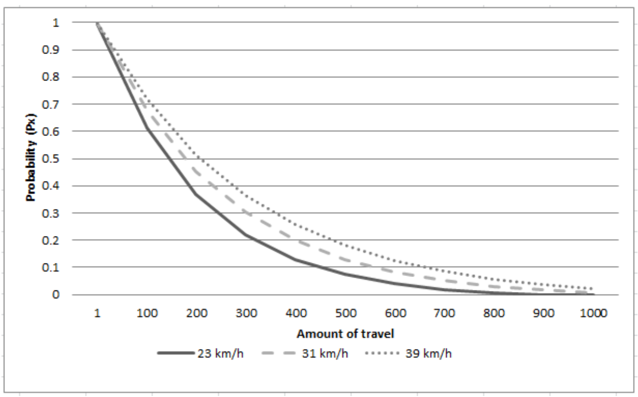

Fig. 13: System Performability considering constant travel in Scenario II.

This study emphasized speed as the relevant factor for guaranteeing destination arrival within the prescribed time frame. A very significant advantage of a BRT system is that, since it operates on an exclusive route and is therefore not influenced by traffic levels, reliable information regarding travel times can be passed on to the passenger, thereby creating a feeling of trust in the system which attracts more customers to the service. Thus, through a combination of factors such as average speed and number of vehicles on the route, the system can be productively employed to provide a mass means of transport, creating better mobility conditions in the cities by decreasing the number of vehicles on the road and ensuring that passengers can confidently predict their travel times.

VII. Conclusion

This paper addressed the fundamental factors involved in BRT systems, employing CTMC models as a means to foster system analysis and improve the planning process, particularly in regards to arrival probability, reliability, and performability. The models allow a mathematical function to calculate the probabilities of a corresponding architecture. The results show that the BRT system performance evaluation can provide the arrival time at the destination, which offers the user the assurance of being at his/her destination in a certain allotted time interval. For the reliability of the BRT system, the factor that has the most impact is the bus as it has the lowest survival time. And from the perspective of performability, although in both studies there are “two nines ”, performability is more impacted by travel time than by the occurrence of the failure. For future studies other metrics, such as capacity, availability, and stream system can be added. Another factor that should be considered is the travel accumulation, which affects the system’s reliability, reducing the failure time on each trip, which could bring deeper results for the studied systems. In a future perspective, the cost factors can be studied and harnessed to ensure better prospects for planning BRT systems.

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