Queuing theory models in urban passenger waterway transport terminals

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Abstract

This study aims at contributing to the development of future projects to design urban passenger waterway transport terminals, considering among other aspects, the boats used; the demand to be satisfied; and operational parameters such as the frequency or flow of boats, service intervals, and the passenger waiting time. The main critical points located in the terminal – bottlenecks – have been identified, where a large number of retained passengers can be found, contributing to the accumulation of queue. The vehicle arrival and service processes were analyzed with the use of Queuing Theory models. At the end of this research, some models of the Queuing Theory associated with methods for setting up traffic signal time were suggested as tools for optimizing time during loading and unloading of vehicles in the urban waterway transport terminals, in accordance with the model proposed by Brinati [1]. In order to validate the study, data were collected at the Silo Joaquim’s urban waterway transport terminal, located in Salvador, Bahia – Brazil.

1 Introduction

Countries with great amount of natural resources (rivers, lakes, bays), as Brazil, hold a good potential to exploiting the waterway transport. The geographic aspects such as geographic location, conformation and accessibility to the cities from riversides are factors that differentiate the form of the urban evolution, and the utilization of the transport ways for displacement of people. Among the urban equipments of importance to dislocation between cities, stick out the terminals for loading and unloading of passengers that must offer comfort and
security to the passengers, and the adjusted integration with the others models of transport.

However, in the Brazilian urban passenger waterway terminals, it has been observed that addressing some of the passengers’ needs are not satisfactory, appearing in the form of: deficiencies in operational order, in terms of insufficient time for attendance and inadequate facilitation to the need of the passengers largely in absence of control to the processes of arrival and services and, consequently in absence of adjusted models for optimizing time for loading and unloading of vehicles.

Among the existing models of analysis on arrival and services of customers identify the studies proposed by queuing theory. Beyond these, the models can also quote methods for setting up traffic signal time. This paper admits that initially such models could be used as tool in the control of arrival and services of passengers in urban waterway transport terminals and consequently optimize users’ time of loading and unloading the System of Passenger Urban Waterway Transport - SPUWT.

2 Main characteristic of the SPUWT - current situation

According to Barbosa [2], the SPUWT holds some characteristics that distinguishes it from the others systems of transport. Besides, it refers essentially to the people displacement by waterway and navigable rivers with the idea of using boats that must attend exclusively to the urban and suburban transport and for displacements in small distances. However, some deficiencies are inherent in SPUWT and they must be analyzed in order to develop a viable and efficient recourse, which would adjust to the most diverse situation.

An of the deficiencies that affect the system and, any, contributes for the operational disorganization of the waterway transport service, mentions an of the main constituent elements of the STHUP, terminal, for through it, not only activities of loading/unloading of passengers and loads are executed, but several other tasks, as the existing relation between the user of the transport service and the proper offered service, for this reason is that its performance determines the acceptability of the service (Morlok [3]).

Thinking about the several problems and other factors that can establish the inefficacy of the urban passenger waterway transport service, it was that, in 1999 the National Bank of the Development - BNDES [4], published a referring infrastructure notebook to the SPUWT, in which to be contained the main characteristics of the system.

2.1 Advantages (BNDES [4])

Low cost of operation for passenger; predictable trip time; high personal security accidents-wise; reduced index of pollution per passenger; capacity of integration and development of littoral and marginal regions; investments in infrastructure relatively low and easy to be shared with other modalities.
2.2 Critical points of the conventional systems existing in Brazil (BNDES [4])

The critical points observed in the conventional system are: long duration of trips due to low speed of service and delay in loading/unloading; physical, operational and fare integration nonexistent or precarious with the terrestrial ways; low level of comfort existing on boats; ageing fleet with imbalanced technical inputs; physically, terminals with unsatisfactory environment of comfort and aesthetically in a degraded landscape; insufficient information and communication facilitation for the users; improper ticket sale systems.

2.3 Current situation (BNDES [4])

The urban passenger waterway transport services in Brazil are set up mainly in urban clusters located in the seaboard of South-east/North-east and in Amazonian river basin. The main urban systems are Rio de Janeiro, Santos, Salvador, Aracajú and Vitória; all the lines are operated by private companies, in regimes of concession, permission or third party of the transport services. These systems had carried in 1998, 37.6 million passengers in its 10 lines. Considering the matrix of collective transport, the waterway transport model had an accentuated loss of passengers, due services deterioration and the competition with others models in the waterway areas of influence (in the eighties had carried annually, in average 61.2 million passengers); in the majority of the urban passenger waterway transport terminals existents in Brazil. The failure and loss of passenger were the result of poor physical and operational problems related with the arrival and services to the passengers, inefficient system of conducting vehicles with considerable backlog of vehicles in lines, located in the bay of access to loading gate.

3 Queuing theory and intersection with traffic lights

In accordance with the Kleins [5], the queuing theory can be understood as a mathematical process that is concerned about the measurement of the attendance stations, in the nature to minimize its costs jointly, with the costs of elements waiting which implies the waiting element to be taken care of. However, Dantas et al. [6], tells that the queuing theory is a way of studying the waiting phenomena and takes into account the necessity of sharing and utilization of resources. This way, it can be affirmed that the queuing theory was created with the intention, i.e., to try to get an adjusted balance between the service offered and the demand for same, determining an acceptable level of attendance for the lesser cost.

Somehow or other, it can be affirmed that the use of the queuing theory, hold innumerable applications, for example as it is shown in this paper, i.e., the utilization of its concepts together with the techniques of traffic flow control, and setting up traffic signal time, similar to analyzing the processes of arrival and services to passengers in urban passenger waterway transport terminals.
3.1 Queuing theory in the setting up traffic signal times

Intends to present the method for setting up traffic signal time in an intersection, using a model of queuing, developed for Brinati [1]. In that study, the author to the end proves it’s hypothesis of the determination of average time of wait for vehicles at an intersection can be made using a model of queuing with attendance in groups, at constant intervals.

In this paper the objective is to verify the possibility to use a similar method like Brinati’s method, analyzing the processes of arrival and service, and posterior optimization of the loading and unloading times of passengers in the urban passenger waterway transport terminals.

3.1.1 Calculation of wait times using a model of queuing

In the calculation of waiting time, two artifices can be used one by mathematical equations, the other using beyond mathematical equations and some computational programs. Both the cases must consider some statistical parameters referring to the model of queuing. In the study developed for Brinati [1], the author used the second artifice, i.e., he was assisted for computational tools, such as the programming language FORTRAN, either.

Applying a model of queuing, Brinati [1] got the wait times of several vehicles in one determined intersection. The used expression was the following:

\[
\bar{W}_i = \frac{\bar{Q}_i}{\phi_i} + \frac{Ve_i}{2}
\]  

(1)

Where: \( \bar{W}_i \) = average time wait in the queuing of band i (seconds); \( \bar{Q}_i \) = average queuing in band i (number of vehicles); \( \phi_i \) = flow of vehicles arrival, for band i; \( Ve_i \) = red phase effective (seconds).

Brinati [1] needed to still calculate some parameters of entrance directed toward the programming in language FORTRAN, aiming at to calculate in the end, the expected value of the queuing length and the variance of the queuing length. The parameters initially determined by Brinati are the following:

**Index of congestion (\( \rho_i \))**: considering the flow of arrivals for the two approaches as being: \( \phi_1 = 540 \) vehicles/h and \( \phi_2 = 720 \) vehicles/h; e using the equation (2), as it follows.

\[
\rho_i = \frac{\phi_i S}{\phi_i S e} + 1
\]  

(2)
Capacity for bands i \((C_i)\): initially calculating the times of green cash \(G_{e_1}\) e \(G_{e_2}\) using the equation (3).

\[
G_{e_i} = \left( \frac{\phi_i}{\sum \phi_i} \right) Se
\]  

(3) 

Parameters of the queuing model considered: the author considered the queuing model with constant intervals of attendance, from Erlang distribution of order \(K \to \infty\).

After using such parameters in the program, Brinati [1] got the result, referring values to the queuing length \((\overline{Q}_i)\) and the variance \((\text{Var}(n))\). Finally, using the equation (1), once definite an effective red phase \((V_{e_i})\), calculated the wait times for each band. The global average wait time was determined by equation (4).

\[
\overline{W} = \frac{\sum_i \overline{W}_i \phi_i}{\sum \phi_i}
\]  

(4) 

After determining the values of the global average wait time in an intersection with traffic light, Brinati applied the Webster’s equation (equation 5) for the same case, it got \(\overline{W}\) compatible values using a queuing model.

\[
\overline{W}_i = \frac{S(1-\alpha_i)^2}{2(1-\alpha_i \rho_i)} + \frac{\rho_i^2}{2\phi_i(1-\rho_i)} - 0.65 \left( \frac{S}{\phi_i^2} \right)^{1/3} \rho_i^{(2+5\alpha_i)}
\]  

(5) 

Where: \(\overline{W}_i\) = average wait time, band i; \(S\) = cycle of the traffic light (seconds); \(\rho_i\) = index of congestion for band i; \(\alpha_i\) = fraction of cycle \(S\) to the cash green time for band i \((\alpha_i = \frac{G_{e_i}}{S})\); \(\phi_i\) = flow of vehicles, band i (vehicles/second).

After having defined the values of medium wait time, using a queuing model and Webster’s formulates, Brinati [1] located the values in same graphic, and verified that the curves refersent to the two set of values were practically coincident in a variation band of cycle \(S\), which allows to affirm that the queuing model applied by Brinati in the calculation of the average wait time and the Webster’s formulates are similar.
4 Analysis of the arrival and attendance of passengers with vehicle in the urban passenger waterway terminals – case study

The operational and statistics analysis had been done through of a case study in Salvador city located in Brazil, with the propose to verify the characteristics as to the loading of passengers with vehicles in the São Joaquim’s urban waterway terminal, finally, to identify the queuing model that better describes the arrivals and attendance processes.

4.1 Arrival process

The first characteristic analyzed was the form as the arrival rhythm of the passengers develops in the bay of access to the loading gate of the terminal. However, some points of operational and statistics character in nature had been made in the analysis of this process, which will be portrayed to follow.

4.1.1 Statistical analyses

Towards the statistical analyses, the main approach’s done; mention the vehicles arrivals rhythms in the terminal. In this way, it was possible to verify by graphic representation, as the arrivals hold, thus identifying, statistical distribution that are more close to the real data. That was possible; comparing the real data curve with the curve of distributions known in the statistical science, figure 1.

![ARRIVAL PROCESS: Real data & Poisson distribution](image)

Figure 1: Arrival process: Real data & Poisson distribution.
Thus, the conclusion was, the successive vehicles arrival process that occurs in the Sao Joaquim’s urban waterway terminal obeys the Poisson distribution, which was taken to affirm that the arrivals process are markovians (D) or probabilistic.

4.2 Attendance process

Using the same reasoning made in the arrivals process, analysis, which initially had made some operational conclusions, however, the statistical analysis had been considered prior.

4.2.1 Statistical analysis

The statistical analysis developed in the vehicles attendance process, had been similar to the process of arrivals, i.e., the identified statistical distribution was more close to the real data. The figure 2 depicts the collected data, referring to the attendance time of passengers with vehicles in the São Joaquim’s urban waterway terminal.

Figure 2: Attendance process (n = 25): Relative frequency (fr) x Average time (X).
Figure 3: Erlang distribution for the real data.

Analyzing beforehand verify that the curve in the figure 2 presents a certain tendency to resemble it a normal distribution curve, however, it is necessary to carry out a further analysis. Thus, Erlang distribution was used in the attempt to describe the vehicles attendance process in the São Joaquim’s urban waterway terminal, as shows figure 3.

Examining carefully the vertical axis in the figures 2 and 3, we can observe there exists a difference in the both scales. While the curve in the figure 2 has its vertical axis represented in arithmetic scale; the curve in the figure 3 has its axis represented in logarithmic scale, therefore the two function of distribution are distinct. However, the factors are more interesting in this analysis as it refer the likeness existing between the two curves, mainly in the interval of time between 0,0245 and 0,0845 minutes which is the concentrated bigger frequency of the time attendance. However, the remark made earlier may be necessary to do a shift of variables for the likely use of the curve.

After which the conclusion that the vehicles attendance process can be represented by Erlang distribution of order $k = 5$, wherever, tending for an infinite value, attendance process represented for curve of figure 3 tends for a normal distribution, and attendance times are considered constant and equal the medium value ($\bar{x}$).

4.3 Model of queuing, existing - analysis

Analyzes of the other basic’s characteristics refer the queuing model existing in the São Joaquim’s urban waterway terminal, to know. Discipline of the queuing:
FIFO (first in, first out); capacity of the system: almost all the whole year is considered infinite; number of attendance canals: only one; and finally the attendance stages: there are two stages.

Shortly, using the Kendall’s notation have: $M/E_5/1/\infty/PEPS$; or by reduced form: $M/E_5/1$, i.e., the arrivals are markovians or probabilistic; the attendance is described for Erlang distribution of order $k = 5$ and holding 1 only canal of attendance. In that way, it can affirm that, not only the arrival and attendance vehicles processes in the waterway terminals, but, all queuing building as well as characteristics that compose it also, behave like one intersection with traffic lights, when compared the queuing model described at Brinati’s [1] study, thus, the building of queuing in the intersections with traffic light are similar the process identified in the urban waterway terminals, i.e., $M/E_5/n$ (probabilistic arrival, attendance as Erlang distribution, and with $n$ canals of attendance).

5 Conclusion

The studies developed on the waterway model still, are considered to be of small relevance due to little importance that the sector accords to the problem. However, it is observed that, increasingly there is the necessity to develop studies and project alternative that can reduce the costs in transports, mainly toward the maintenance of ways and vehicles, and displacement of loads and people that use the facilities of the terminals.

As the waterway model is accorded with low priority in relation to the other models one can only imagine, as the urban passenger in waterway transport as among the one with lesser development emphasis, considering it as economically less lucrative when compared with the other models. This is evidenced by scarce studies and research developed regarding the urban passenger waterway transport.

Noting the small number of research studies on the subject in question, and the potential of using the waterway model for the development of the Hinterland of some regions of Brazil, a research idea have been developed. In this case, considering the terminal element as being the starting point for reorganization of the waterway system, whose performance do many authors consider as determinative factor of the acceptability. This was opted in working with a small parcel of activities that intervene on the terminal internal environment, but that has power to determine its operational characteristics, i.e., the passengers with vehicles arrivals and its respective loading times.

Thus, through the analysis made this paper attempts to show that the arrival and attendance processes, and the subsequent loading and unloading of the vehicles in the waterway terminal can be studied like an intersection with traffic lights. The method of determination of the vehicles average wait time can be applied for the control of both processes (arrival and attendance of vehicles) including the optimization of the loading and unloading times as Brinati’s model [1]. Finally, in the near future, exact analysis method of the passenger’s arrivals and attendance can be used like a tool in measurement of facilities in the urban waterway transport terminal.
References


