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MODELLING METRO STATION BOARDING AND ALIGHTING TIMES[1]

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Abstract

The stochastic nature of the train standing times at metro stations directly influence the minimum operational headway that can be sustained over longer period of time as well as the possible delays on the line. Therefore, any analysis of the performance of a metro line by a simulation of its operation is closely related to the problem of modelling the station dwell times. The model presented here has been based on the data collected from the Bloor metro station in Toronto, Canada. Metro trains were videotaped during two-hour study period and data were obtained on the time needed for boarding/alighting of different number of passengers per train door. The results of the statistical analysis have shown that a family of Gamma distributions with parameters that are function on the number of passengers per door appear to be a good model to represent the passenger boarding and alighting times.

Keywords - Modelling; station dwell time; simulation of boarding and alighting times; metro

INTRODUCTION

The capacity of metro line has been defined as the maximum number of vehicles that can pass a point during one hour of operation. The common approach (see [1], [2], [3]) is the one that says that it is directly determined by the minimum headway that can be operated at the station with the longest

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[1] Professional paper

dwell time. However, this approach would be correct only if the operation were deterministic: that is dwell times at all stations are constant and the movement of trains between stations is pre-programmed and same for all trains. Though the second premise can be achieved with the automated metro systems, dwell times at stations are still random variables. The consequences of this are very important: though all trains may depart from the starting station on time, at scheduled (constant) headways, due to the random dwell times at stations along the line, the headways between trains will be also random. Therefore, some trains will find themselves behind, others ahead of the scheduled times. When trains operate at short headways (near capacity), trains that follow a train that has fallen behind the schedule, will experience delay due to the need to keep safety distance between trains.

Therefore, any attempt to catch the stochastic nature of a metro line operation that operate near capacity, must begin with developing a model that can catch the stochastic nature of the station dwell times.

DEFINITION OF THE PROBLEM AND RESEARCH OBJECTIVES

In order to analyse the station dwell time more closely, an introduction of the following definitions are proposed:

Definition 1:The summation of the alighting and boarding times at each particular door is **the door utilization time**. The utilization time at door *d* of the train, denoted as $\mathbf{t_{u,d}}$ is therefore equal to

$$t_{u,d} = t_{a,d} + t_{b,d}, \tag{1}$$

Where $t_{a,d}$ and $t_{b,d}$ are the alighting and boarding times, respectively, and

Definition 2: The door with the maximum number of boarding plus alighting passengers is the **maximum door - $\mathbf{d_{max}}$**.

Definition 3: The door that has maximum utilization time is the **critical door - $\mathbf{d_{cr}}$**.

Definition 4: Time interval from the moment when a train enters the station and comes to a full stop to the moment when it closes the doors and is ready to leave the station will be referred to as **station dwelltime - $\mathbf{t_d}$**. It comprises the time for door opening and closing $\mathbf{t_{oc}}$ and the maximum utilization time (the utilization time at the critical door)

$$t_{d,k} = t_{oc} + \underset{d}{\mathrm{Max}}(t_{u,d}) = t_{oc} + t_{u,d_{cr}} = t_{oc} + t_{a,d_{cr}} + t_{b,d_{cr}}. \tag{2}$$

With these definitions in mind, it is important that the reader notice several important points:

1. The maximum door is not necessarily the critical door;
2. The time for door opening and closing $\mathbf{t_{oc}}$ can be treated as a constant, so the variability of dwell time depends on the stochastic nature of the boarding and alighting times. In addition, since the dwell time is determined by the maximum utilization time, which usually happens at the door where great number of passengers board and alight, it seems reasonable to assume that boarding passengers will first let the alighting passengers to exit and then start to board. At least this assumption was quite true for the survey data from Toronto;
3. The dwell time definition does not include any time loss that might happen if the train is forced to stay at the station for some additional time after the alighting/boarding process has been completed due to the safety distance requirement or other operational reasons.

Given the above consideration, the focus of the research presented here is on the development of model for the passengers alighting and boarding times.

REVIEW OF THE PREVIOUS RESEARCH

Among the early attempts to include the randomness into the analysis of a RT line capacity, the work done by Welding and Day [2] is the most frequently cited. Their article described a simple simulation model that took into account the randomness of the interstation travel times as well as the standing time at stations. Both variables were simulated using simple formulas that consist of two parts: the deterministic part which defined their middle value, and the stochastic part which was represented by a random variable with normal distribution, expectation value 0, and known variance. The simulation results were tested on the existing London Central Line and then were used to determine the practical minimum headway for the Victoria Line which was about to open.

Another significant study of station dwell time was done at the University of Toronto by Mori[3]. The study was based on high-quality data, collected by videotaping the alighting and boarding process during afternoon peak hour at the Bloor Station on Yonge subway line in Toronto, Canada. The data included the number of boarding and alighting passengers per door and per train, boarding and alighting times for given number of passengers at a door, and headways between trains arriving at the station. An important finding of this research was the fact the expected values of the boarding and alighting times for a given number of passengers at a door and their variances were found to show high degree of “regularity” that could be described by regression equations. As the number of passengers per door increased, the mean and variance of the boarding and alighting times increased too. As a result, when higher number of passengers at a station are handled, not only longer dwell time is to be expected, but also a higher variance of the dwell times.

Recent studies on alighting and boarding focus on two aspects: observation & data statistic and modelling.Since the process of alighting and boarding is somewhat chaotic, models and simulations of alighting andboarding movement may be full of factors beyond the knowledge or control of the researchers. The factorsof focus are also quite different. For observation and statistical study, measurements of boarding and alightingtimes for different train types were researched by Heinz [4]. Research on alighting and boarding times atDutch railway stations [5] was done focusing on the dwell time of trains. Factors assessedincluded passengers' distribution on the platform, alighting and boarding times, station type, type of train service,vehicle characteristics and period of day. Alighting and boarding in clusters and individual alighting andboarding were regarded as different phases during the alighting and boarding process.

Puong [6]presenteda dwell time model based on observations made at seven stations. The study showed dwell time is a function ofpassenger alighting and boarding volumes (linear), and of the on-vehicle crowding level (nonlinear). The effectof on-board congestion on boarding times for some stations was emphasized.

Xu and Wu [7] developed velocity–density mathematical models for Shanghai metro stations using a one-dimensional model for the people near the train door in the waiting room and a two-dimensional model for people boarding. In Xu's models, the ratio of alighting time to boarding time is supposed to be a coefficient.

Blue and Adler [8] presented a cellular automata (CA) model for multi-directional pedestrian walking simulation. CA models were also applied to the simulation of pedestrian friction effects.

RESEARCH METHODOLOGY

The data used in this research were taken over from a survey that was part of the study done by Bruce Mori at the University of Toronto [Mori, 1988]. Within this study, 44 metro trains were videotaped during two-hour study period. Data were obtained for over 12,500 alighting and 6,700 boarding passengers at Bloor Station in Toronto.

This type of data collection as well as the size of the sample, allowed reliable statistical analysis in terms of alighting and boarding times' distributions for given number of passengers at train door.

ANALYSIS OF THE SURVEY DATA

The survey data collected from the Bloor metro station in Toronto have allowed performing a detailed statistical analysis of the passenger alighting and boarding times per train door. The mean values of the times as well as their standard deviations have been computed for given number of alighting and boarding passengers per door.

Figures 1 and 2 show the sample average boarding and alighting time plus/minus two sample standard deviations. These graphs clearly show that as the number of passengers per door increases, the mean and standard deviation (or the variance) also increase. Moreover, it seems that the variance in service time increased linearly with the number of passengers per door. That implied that the variance in boarding/alighting time for n boarders/alighters is equal to n times the variance for one boarder/alighter. This condition suggested that successive boarding and alighting events were independent. It was consistent with the findings of Kraft [Kraft, 1975] who found the individual passenger service time for transit buses to be independent, following Erlang distribution.

The level of regularity of the sample averages and variances as well as the suggested independence of the alighting/boarding events that was found in the Bloor Station data, led to the idea that alighting and boarding times can be modelled by means of a single probability distribution with parameters that are function of the number of passengers per door.

The attempt to describe the alighting and boarding times as the sum of independent Erlang distributed boarding and alighting events failed to give a satisfactory fit. However, as the subsequent analysis showed, it was found that the Gamma distribution (which is a general case of the Erlang distribution) seemed to be appropriate model for the alighting and boarding times.

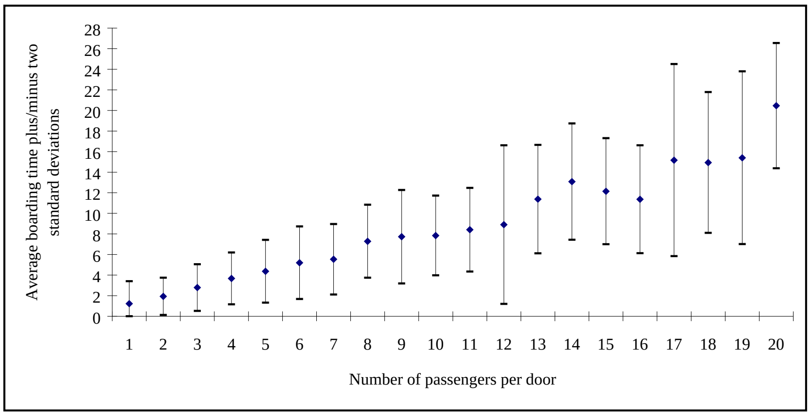

Fig. 1 boarding time for given number of passengers at a door

The form of Gamma distribution density function and its mean and variance used in this analysis are

$$\Gamma(\text{Mean}, \text{Var}) = \text{f(t)} = \frac{\beta^{-\alpha}\, \text{t}^{\alpha-1}\, e^{-\frac{t}{\beta}}}{\Gamma(\alpha)} \qquad \text{for t} \geq 0 \tag{3}$$

$$\text{Mean} = \alpha B \tag{4}$$

$$\text{Var} = \alpha\, \beta^2 \tag{5}$$

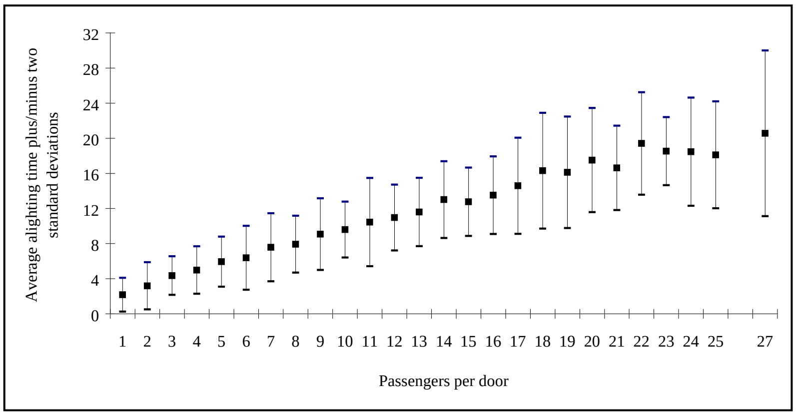

Fig. 2 Alighting time for given number of passengers at a door

The idea that parameters α and β can be expressed as functions of the number of passengers per door was pursued in the following manner:

1. Maximum likelihood estimates (MLE) of parameters α and β were determined for each group of data (number of passengers per door). MLE were determined by means of a numerical technique proposed by Choi and Wette [Choi and Wette, 1969].
2. A regression analysis on the MLE of parameters α and β was performed and checked whether there was a reasonable correlation between the Gamma parameters and the number of passengers per door.

The results of the analysis are summarized in Eqs. (6) And (7) and Figures 3 and 6.

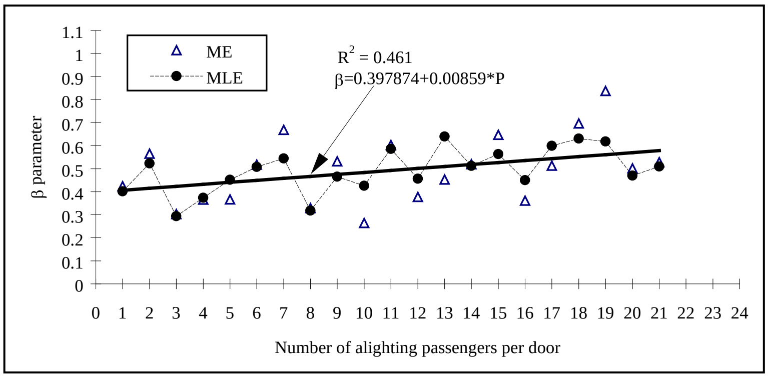

Fig. 3 Alighting time as a Gamma process: Estimation of β parameter

The regression analysis of MLE of Gamma distribution parameters α and β gave the following results:

Alighting:	$\alpha = 5.36068 * a^{0.580521}$	$R^2 = 0.8813$	
	$\beta = 0.397874 + 0.0085966 * a$	$R^2 = 0.461$	(6)
Boarding:	$\alpha = 2.54142 * b^{0.800859}$	$R^2 = 0.9725$	
	$\beta = 0.433013 + 0.0081164 * b$	$R^2 = 0.478$	(7)

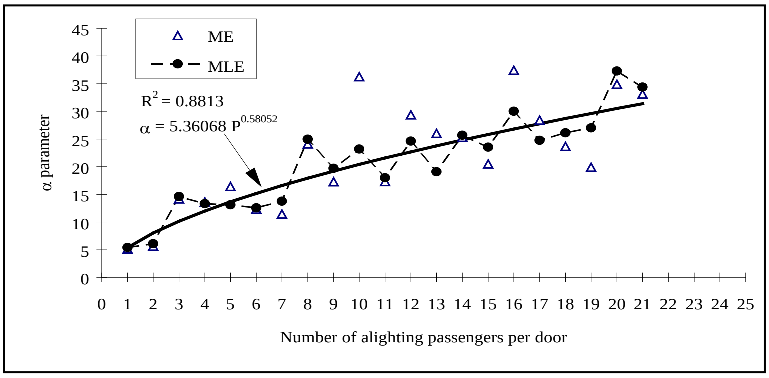

Fig. 4 Alighting time as a Gamma process: Estimation of α parameter

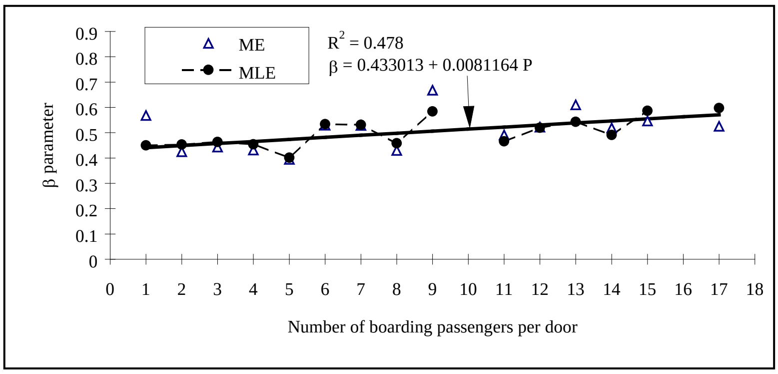

Fig. 5. Boarding time as a Gamma process: Estimation of β parameter

The hypothesis that the boarding and alighting times for given number of passengers at a door can be described by the distribution in Eq. (3) with parameters determined by Eqs (6) and (7) was further tested by means of χ^2 - Goodness-of-fit test. The test was performed on all samples of size greater than 25. The results of the analysis are shown in the table 1.

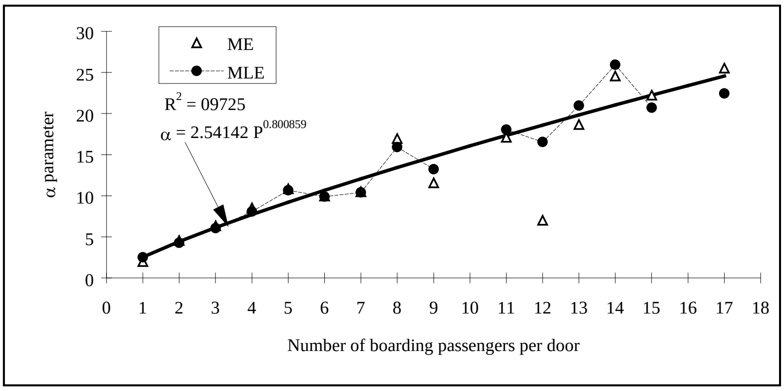

Fig. 6. Alighting time as a Gamma process: Estimation of α parameter

As can be seen from the table, the tests showed that there was no reason to reject the hypothesis of Gamma distribution with parameters determined from Eqs. (23) And (6), for level of significance of the test of 1%, 5% and 10%, in all but two cases. Both cases were for the boarding time at level of significance of 10%.

Therefore, based on the Bloor Station data, it appears that the assumption that the boarding and alighting times can be modelled as a Gamma process seems to be reasonable. The resulting Gamma distribution density functions of the boarding and alighting times for selected number of passengers at a door are given in Figures 7 and 8.

Table 1. Boarding and alighting times as Gamma process: results of the χ^2 - Goodness-of-fit test

Pass. per door	Boarding time			Alighting time		
		Level of test significance			Level of test significance	
	Sample size	α =0.1	α =0.05	Sample size	α =0.1	α =0.05
1	133	Yes	yes	36	yes	yes
2	153	Yes	yes	25	yes	yes
3	128	Yes	yes	33	yes	yes
4	97	Yes	yes	35	yes	yes
5	80	Yes	yes	35	yes	yes
6	57	Yes	yes	39	yes	yes
7	43	No	yes	53	yes	yes
8	35	Yes	yes	51	yes	yes
9	28	Yes	yes	63	yes	yes

10				70	yes	yes
11				60	yes	yes
12	26	no	yes	62	yes	yes
13				52	yes	yes
14				48	yes	yes
15				45	yes	yes
16				35	yes	yes
17				37	yes	yes
18				29	yes	yes
19				29	yes	yes

Yes - the Gamma distribution hypothesis accepted
No- Gamma distribution hypothesis rejected

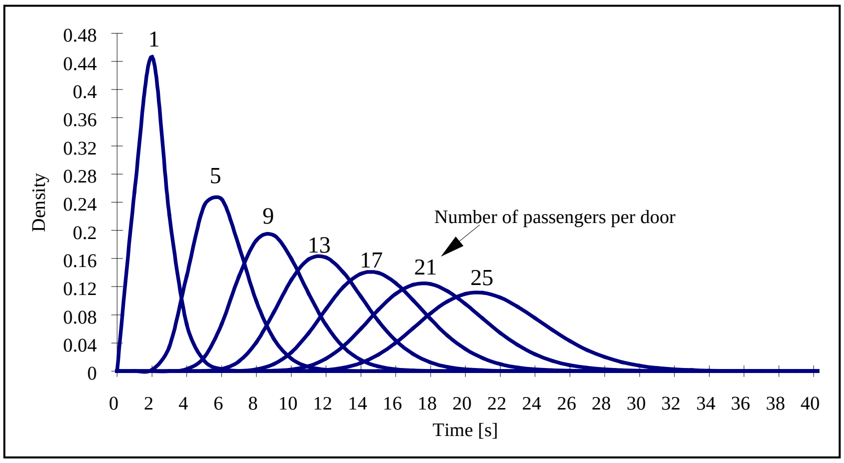

Fig. 7 alighting time distributions as a Gamma process

CONCLUSION

The analysis of the boarding and alighting times at Bloor station in Toronto, has shown that this process can be successfully described as a Gamma process or a family of Gamma distributions for different number of passengers per door. This results can be very useful in rapid transit line simulation models as well as in any analysis of the station and rapid transit line performances.

Since this analysis has been based on a data gathered at one rapid transit station, similar analysis is needed for other RT stations and lines worldwide, in order to verify or question this model as a reliable model for modelling RT alighting and boarding times at stations.

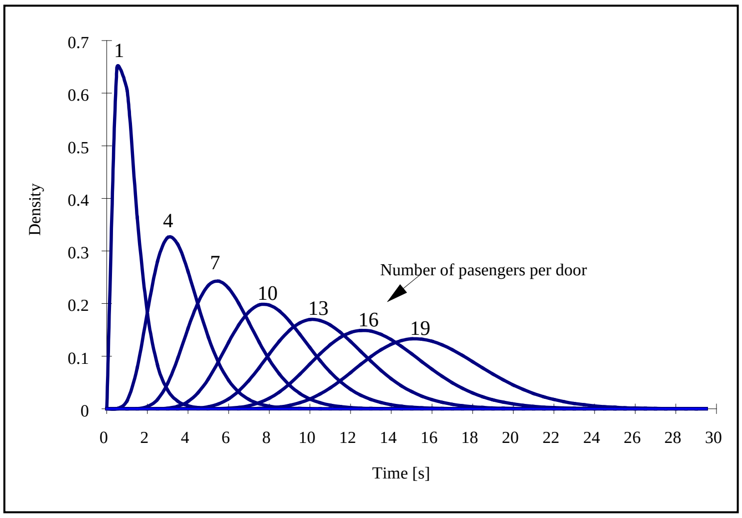

Fig. 8. Boarding time distributions as a Gamma

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