An international comparison of urban rail boarding and alighting rates

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\textbf{Abstract:} Although there is considerable engineering and demand planning analysis in the development of urban railways around the world, less attention is paid to the understanding of key operating conditions such as station stop times. The current paper takes forward research by London Underground, and shows that it is applicable to situations around the world without substantial changes in parameter values or the resulting passenger flowrates. Where passenger flow is substantially different, this can generally be explained by particular differences in the physical characteristics of the site, rolling stock, or passenger demand.

\textbf{Keywords:} capacity, dispatching, performance, station operation, benchmarking

1 INTRODUCTION AND BACKGROUND

1.1 Previous work

Around the world, there is considerable interest in the continuing development of urban rail and metro systems to solve the problems of mass transit. Town and transport planners look for the best alignments, while engineers concentrate on maximizing the technical specification of rolling stock and infrastructure. However, relatively little work is carried out in extending the understanding of operational conditions, for instance in the time required for passenger boarding and alighting at stations, even though this is a critical element of overall train service performance.

The published material in these areas comes from London \cite{1} and Hong Kong \cite{2}, but it is not clear whether the relationships derived by those authors have international applicability or not. This research used as its basis Weston’s formula, which is more sophisticated, and takes into account a greater number of variables, thus

\begin{equation}
SS = 15 + \left[ 1.4 \ast \left( 1 + \left( \frac{F}{35} \right) \ast \left( \frac{(T - S)}{D} \right) \right) \ast \left( \frac{F \ast B}{D} \right)^{0.7} + \left( \frac{F \ast A}{D} \right)^{0.7} + \left( 0.027 \ast \left( \frac{F \ast B}{D} \right) \ast \left( \frac{F \ast A}{D} \right) \right) \right]
\end{equation}

where $SS =$ station stop time (s), $A =$ number of alighting passengers, $B =$ number of boarding passengers, $D =$ number of doors, $F =$ peak door/average door factor, $S =$ number of seats, $T =$ number of through passengers, (all expressed in terms of the entire train).

Weston used a standard intercept value of 15s to allow for the time taken for doors to open and close fully, and for electrical circuitry to confirm that all doors have been closed, before power may be applied for acceleration. While this is certainly a good average estimate, the value should ideally vary by rolling stock type, and by door type – plug doors usually taking slightly longer than sliding doors. Differences in
procedures governing the use and duration of closing alarms prior to door closure also impact directly on these times.

The inclusion of terms covering, respectively, vestibule use, boarding, alighting, and the interaction between boarding and alighting should also be noted. The number of through passengers is relevant in identifying a key factor which can reduce boarding and alighting rates, by impeding movement (especially if standing in vestibules and doorways). The factor $F$ attempts to correct for the uneven distribution of passengers along a train.

Wiggenraad’s data from Holland [3] had also identified issues such as door width, and height differences between the platform and train, as impacting upon passenger flowrates. His results are comparable with the London Underground data, without enabling him to suggest a formulaic relationship.

It is, therefore, clear that a number of variables have some impact on passenger boarding and alighting rates, not least the physical characteristics of both rolling stock and platform. Wider doors, for instance, create a larger effective door width, enabling more simultaneous passenger movements. However, passenger behaviour is also a potential influencing factor – does culture impact on boarding and alighting rates and, if so, by how much?

1.2 Metros analysed

In order to understand these issues, one ideally needs a dataset consistently measured across a wide range of metros. As can be imagined, this is organisationally difficult to achieve. However, it has been possible to build up such a dataset over the years through the auspices of the CoMET and Nova metro benchmarking groups. The groups are managed and facilitated by the Railway Technology Strategy Centre at Imperial College London. The current membership of these groups is as set out in Appendix, with CoMET including the largest metros (with demand >500 million passengers per annum) and Nova smaller ones.

These benchmarking groups, set up in 1994 and 1998, respectively, share data and analysis with each other in an attempt to spread best practice between metros, which effectively do not compete with each other [4]. Train service issues have been a matter of particular concern, and were the subject of one of the earliest case studies that was carried out. However, ongoing interest in this area has provided the opportunity for data collection across the groups, which now numbers 22 metros. In addition, other Railway Consultancy work has enabled the use of the same methodology on other metros and suburban railways, further enhancing the dataset.

2 DATA COLLECTION AND KEY RESULTS

2.1 Survey methodology

Data have been collected for peak periods at the busiest stations in each of the metro systems visited. Data include considerable detail about both the train service itself, and passenger movements. Train service measurements include wheel stop and start times, door open and close times, and so on; passenger measurements include the numbers of passengers boarding and alighting, and the times they take to do so. In each case, surveys have included the results from at least 30 trains stopping, in order to ensure a reasonable statistical base. In addition, some physical measurements of the relevant rolling stock (e.g. door width) have also been carried out. To protect the commercial interests of the metros involved, however, all data in the current paper merely refer to metros A–AC.

2.2 Metro actions and resulting passenger flowrates

All the metros face similar issues in terms of managing station stop times. Greater passenger movements lead to longer station stops, which eventually reduces line capacity as station stops become the bottleneck.

Approaches to solving this conundrum on any one metro line potentially include rolling stock-based solutions and platform-based solutions. The former include trains with wider doors (e.g. Mexico City), more doors per carriage (e.g. Hong Kong MTRC), and with fewer seats per carriage (e.g. Hong Kong KCRC). The latter include wider platforms and/or platforms with space behind (Moscow), and even separate platforms for boarding and alighting (Sao Paulo), while New York has recently trialled bright orange floor panels containing the words ‘Step Aside’, the aim being to segregate boarding and alighting passenger flows. Behavioural devices such as bleepers indicating that doors are closing are commonplace, while in previous work one of the authors recommended the playing of military-style music to aid passenger flow during a period of restricted access at Norreport (Copenhagen) [5].

The relative busyness of the different systems clearly affects the time spent on different activities. The busiest metros, with very short signalled headways, have to minimize all aspects of time, including passenger movement time. One interesting way of achieving this (for instance, as in Moscow) is to run a very high level of service, thereby minimizing the potential numbers of passenger movements per door. A number of metros, including Moscow and Santiago de Chile, run services as frequently as 40 trains per hour (tph). The ‘function’ time (i.e. that time taken up by functions such as doors opening and closing, and the inevitable delay
between last door closure and wheel start) is, however, largely invariant with passenger flow, and therefore forms a higher proportion of time in the busier metros. Function time does, however, vary considerably between different train types; Weston and McKenna [6] estimated a minimum time of 10–12 s for London Underground, while Lam et al. [2] quote 6–8 s for light rail in Hong Kong. Nevertheless, the fixed nature of the minimum possible means that a high proportion of the total time can be taken up by function time in high-frequency environment, as highlighted in Fig. 1(a). On the other hand, in a less busy suburban system such as railway X (Fig. 1(c)), poorly-managed operations can lead to substantial driver delays and signal checks even despite lower train frequencies and considerable slack.

Even in some less busy situations, however, the number of passenger movements per door can be very high. With passenger movement rates typically being of the order of 1 pass/door/s, having 50 passengers attempting to use the same door is clearly going to prejudice train services of 30 tph and above, since minimum run-out/run-in, or platform reoccupation (RORI) times significantly under 1 min are extremely difficult to achieve. The key to successful high-frequency metro operation is to keep both passenger movement and function times down to around 20 s each. The addition of 60 s minimum RORI time leaves only 20 s remaining as a contingency, when operating a service at 2-minute headways. The amount of slack (the excess RORI time) would be expected to impact on reliability, although modern technologies (such as automatic train operation) can mitigate this impact; Fig. 2 shows excellent service regulation in such circumstances.

On the less busy systems, station stop management may not be a matter of particular concern in normal day-to-day operation, without the pressure of hordes of passengers. Services can deteriorate, however, particularly in such aspects as the delay caused by the driver after the last passenger has boarded. This can cause problems when, in fact, signalled headways are quite long (e.g. 120 s) and the amount of slack time may be less than imagined.

Examination of some of these issues in more detail demonstrates how critical station stop management is within the operation of a railway. A delay to the service caused by a suicide, further, along the line led to significant signal delays at high-frequency metro station F in Fig. 3, while a similar effect after service disruption can be seen in passenger movement time at suburban station AB, when 84 passenger movements were recorded through one door. However, poor platform management at suburban station W demonstrates driver delay time exceeding all other subtimes combined.

### 2.3 Impact of particular features

The wide range of metros studied has enabled the identification of the impact of various features found on some railways but not others. For instance, many modern metros incorporate Platform Screen Doors (PSDs), the benefits of which include enhanced safety (passengers cannot fall onto the track because the
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Fig. 3 Detailed analysis of station stop time in: (a) high-frequency metros; (b) lower-frequency metros; and (c) suburban railways

Doors are only open when a train is at the platform and reduced air-conditioning requirements (because only the stations, not the tunnels, need to be treated). However, a specific problem highlighted by the analysis is that PSDs add 1–2 s to the door opening time of every train stop movement. As many metro lines with PSDs have passenger loads of 20 000 passengers per hour, this is a considerable economic disbenefit which has perhaps not been sufficiently taken into account.

Double-deck stock used on some suburban railways is another feature with potentially-negative impacts on station stop times. Early results suggest an increase in alighting times of up to 0.3 s per passenger, although ensuring that doors in such stock are as wide as possible mitigates these effects. Similarly, minimizing the gap between the platform and train has also been found [7] to reduce station stop times (by up to 0.1 s per passenger for each 10 cm reduction in gap).

3 CONFIRMATION OF WESTON’S FORMULA

An early analytical task was to see if the LUL approach for station stop time estimation as set out in equation (1) was applicable in other cities. The standard procedure for this calibration has been to calculate the actual time taken for passenger movements against the time estimated by Weston's formula, in both cases adjusting for any differences in rolling stock dimensions. However, the parameters for boarding and alighting time (found to be 0.7 in London) are situation-specific, and there seemed to be no reason to assume that they would be identical in different metro situations. These parameters were, therefore, adjusted to ensure that the total times calibrate, but in fact relatively small adjustments have been necessary (see below). This has generally led to achieving significant $R^2$ values from regressing predicted times against actual times; a sample calibration is given in Fig. 4.

Fig. 4 Calibration of Weston’s formula for metro Q

In order to achieve calibration, the parameters have had to be adjusted slightly. In general, the alighting power 0.9 has had to be reduced to a value nearer 0.8, while the boarding power (estimated by LUL as 0.7) seems to vary more widely, across a range 0.45–0.9. Inspection of the station stop data underlying the overall estimate for each station sometimes gives clues for the lower values e.g. if there were more than an average number of ‘slow’ passengers (e.g. those with luggage or pushchairs).

Nevertheless, there have also been studies where adjustments have had to be made to the formula itself. As noted above, one of the authors quantified the impact of the gap between train and station platform [7] while more recent research [8] has demonstrated that the interaction part of the formula does not work at the highest levels of passenger flow. Overall, though, Weston’s formula does hold good in a wide range of urban railway environments.

The passenger flowrates observed enabled the understanding of the relative importance of culture and physical environment in determining station stop time performance. As can be seen from Fig. 5, observed passenger alighting rates have ranged between 0.18 pass/m/s (in extremely crowded situations, metros B and F) to 1.77 pass/m/s (where
Fig. 5 Passenger movement rates at metros around the world

all passengers alight, metro Y). In fact, all the slow rates observed are easily explained e.g. in terms of rolling stock with poor characteristics (e.g. badly-designed vestibules (AC), or intermediate steps between vestibule and platform (AB)) while the higher rates observed only occur when one flow is dominant (e.g. metro R) and/or there is plenty of space available. The platform at metro G, for instance, was designed with very easy access from the platform to a very large concourse immediately behind.

Observed passenger boarding rates have similarly varied between 0.37 and 1.58 pass/m/s, but again the differences can be explained in terms of unidirectional passenger flow (encouraging higher flows, e.g. metro L) and very full trains (discouraging them); greater discussion of the former of these is set out in Harris [8]. It has also been suggested that flowrates are not linear with door width, but that there are quantum gains in capacity when widths increase to permit another passenger movement to take place simultaneously; while logical, the current study has not been able to prove that. On the other hand, contrary to views sometimes expressed, this analysis has demonstrated that there is no systematic difference between the passenger performance of Asian metros and of Western metros, which cannot largely be explained by the differences in platform design, train design or the ‘busyness’ of the trains.

5 CONCLUSIONS

Station stops are critical in the operation of metro and other high-frequency passenger rail services. Although signalling parameters are important in determining line capacity, and the boarding and alighting rates of passengers at key stations are also significant, analysis of data from metros around the world also shows the importance of ‘function’ (e.g. door opening and closing) time. Indeed, function time exceeds passenger movement time in a number of metros. Where there is little slack in the timetable, train service automation may be needed in order to ensure service reliability.

Although parameters have to be varied slightly, Weston’s formula for estimating station stop time appears to have validity around the world, and the overall structure of the approach appears sound. Passenger behaviour (measured in terms of boarding and alighting rates) at the wide range of metros studied can largely be explained in terms of differences in platform design, train design and the ‘busyness’ of the trains.

Urban railways are therefore recommended to use such an approach to estimate likely station stop times within a wider consideration of line operability. This might occur in two different scenarios:

(a) for existing systems, where the authors suspect that some metros currently suffer from poor performance by not allocating sufficient time in the timetable for station stops;
(b) for new systems or lines, where the approach should be used to check the design of stations, especially the busier ones.

Further work is ongoing to produce more detailed recommendations of best practice across the range of parameters which affect urban rail station stop times.

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REFERENCES


APPENDIX

Current membership of the CoMET and Nova Metro benchmarking Groups

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