STOCHASTIC ANALYSIS OF TRANSIT ROUTE SEGMENTS’ PASSENGER LOAD VARIATION
FOR CAPACITY AND QUALITY OF SERVICE ASSESSMENT

Jonathan M Bunker
Civil Engineering and Built Environment School, Science and Engineering Faculty
Queensland University of Technology
2 George St, Brisbane, QL 4000, Australia
Tel: +61 7 3138 5086; Fax: +61 7 3138 1170; Email: j.bunker@qut.edu.au

Word count: 4,799 words text + 10 tables/figures x 250 words (each) = 7,299 words

Resubmission Date: 10/16/2014
ABSTRACT

This paper investigates stochastic analysis of transit segment hourly passenger load factor variation for transit capacity and quality of service (QoS) analysis using Automatic Fare Collection data for a premium radial bus route in Brisbane, Australia. It compares stochastic analysis to traditional peak hour factor (PHF) analysis to gain further insight into variability of transit route segments’ passenger loading during a study hour. It demonstrates that hourly design load factor is a useful method of modeling a route segment’s capacity and QoS time history across the study weekday. This analysis method is readily adaptable to different passenger load standards by adjusting design percentile, reflecting either a more relaxed or more stringent condition. This paper also considers hourly coefficient of variation of load factor as a capacity and QoS assessment measure, in particular through its relationships with hourly average and design load factors. Smaller value reflects uniform passenger loading, which is generally indicative of well dispersed passenger boarding demands and good schedule maintenance. Conversely, higher value may be indicative of pulsed or uneven passenger boarding demands, poor schedule maintenance, and/or bus bunching. An assessment table based on hourly coefficient of variation of load factor is developed and applied to this case study. Inferences are drawn for a selection of study hours across the weekday studied.

Keywords: Transit, Quality of Service, Load Factor, Peak Hour Factor
INTRODUCTION

The Transit Capacity and Quality of Service Manual (TCQSM) (1) and Vuchic (2, 3) underpin urban transit capacity and quality of service (QoS) analysis. Measures describing productive performance are very useful to the operator in quantifying their resources’ capabilities and passenger quality of service. Bunker extended productive performance measures to quantify efficiency and operating fashion of transit services and lines, demonstrating their usefulness to the transit operator in planning, design, and operational activities (4), and applied Automatic Fare Collection weekday data on a premium bus line in Brisbane, Australia to investigate correlation between transit route passenger loading and travel distance and its implications on QoS and resource productivity (5). This paper extends this research by investigating stochasticity in route segment load factor by study hour in order to improve and enhance transit capacity and QoS assessment.

LITERATURE REVIEW

Vuchic (2) defines (transit) load factor at a particular location as the ratio of passenger transported to spaces offered at Maximum Schedule Load (MSL). This measure does not exceed 1.0 for a particular type of operating equipment, unless under crush load conditions.

Passenger demand tends to be spread out both over time and space, which prevents offered transit point capacity from being fully utilized throughout the peak period (5) and along the entire line. TCQSM 3rd Edition (1) accommodates temporal variation broadly in capacity analysis using the Peak Hour Factor (PHF), while in QoS analysis it discusses how passenger load standards can be expressed as an average during a peak 15, 30, or 60min period (1). TCQSM 2nd Edition (6) by example specifically incorporated PHF into passenger load standards for QoS analysis.

Spatial variation can manifest itself through variation in passenger loads as a consequence of boarding and alighting patterns along the line, along with loading diversity within operating equipment. Vuchic (2) overcomes the point capacity limitation by evaluating a line by segment. Maximum flow can ordinarily be achieved only on the Maximum Load Segment (MLS), while the passenger demand pattern results in reduced flow on all other segments. He reports how an entire line may be analysed in terms of utilized transit work. This provides the operator a picture of total transit performance along the line during a time period. Bunker (4, 5) similarly considers all individual services and passenger patterns at stops within the distance-time window.

Hassold and Ceder (7) offer a promising approach in consideration of passenger QoS in scheduling by focusing on the determination of daily, hourly and individual service maximum load points in timetable creation using a multi-objective optimisation network approach. Criteria include wait time, empty-seat km, and empty-seat hours. With respect to demand data for determination of maximum load points, they consider random passenger arrivals for wait time estimation, but use either actual point checks or Automatic Fair Collection (AFC) data for load profiles. Notably, this approach is not a precise methodology for QoS assessment of an existing route.

Pass-ups occur on a transit line when passengers are left behind when a service departs under Maximum Schedule Load (MSL). The effective service frequency for these passengers is reduced from that which is scheduled, as they are forced to wait for the next service or find another means of making their trip (1). This can give rise to multiple MLSs and to disparity in schedule keeping between services on segments along the route or line causing bus bunching, which is inefficient and impairs reliability. Strategies to better manage headway have been investigated in several studies in an effort to reduce adverse impacts of bunching (8, 9, 10).

Automatic Vehicle Location (AVL) data can be used to provide a detailed depiction of transit service reliability including location of reliability problems (11) and can also be used in improving transit performance and management by examining crowding (12). Automatic Fare Collection (AFC) data lends itself well to travel time reliability analysis (13).

This paper further investigates the spread of passenger demand in time across a study hour, considering stochasticity of passenger load factor in contrast to the PHF approach. AFC data was obtained
for a case study weekday from a hybrid smart-card touch-on/off and legacy on-board paper ticket sale system with a 100% sample rate.

**THEORY DEVELOPMENT**

**Transit Segment Load Factors**

In order to consider a segment hourly design load factor based upon stochastic distribution of load factors across study hour $H$, we need to consider all $m$ services (revenue trips) that traverse segment $i$ as the sample, and each service $k$ as a member.

The average load factor of the $m$ services that traverse segment $i$ during study hour $H$ is given by:

$$LF_{av,i,H} = \frac{\sum_{k=1}^{m} \left( \frac{P_{k,i}}{P_{MSL,k}} \right)}{m}$$

(1)

Where:

$P_{k,i}$ = passengers aboard $k^{th}$ service on segment $i$ (p)

$P_{MSL,k}$ = maximum schedule load (seated plus standing spaces) of operating equipment used for $k^{th}$ service (p)

The corrected standard deviation of load factor of the $m$ services that traverse segment $i$ during study hour $H$ is given by:

$$LF_{sd,i,H} = \sqrt{\frac{1}{(m-1)} \sum_{k=1}^{m} \left( \frac{P_{k,i}}{P_{MSL,k}} - LF_{av,i,H} \right)^2}$$

(2)

With respect to passenger load, the peak hour factor (PHF) on segment $i$ during study hour $H$ can be calculated by:

$$PHF_{i,H} = \begin{cases} 
\frac{\sum_{k=1}^{m} P_{k,i}}{m \max_{1 \leq k \leq m} (P_{k,i})}, & m \leq 4 \\
\sum_{k=1}^{m} P_{k,i} \left( \max_{1 \leq k \leq m} \left( \frac{1}{4} \left( P_{k,i} + \frac{(m-4)}{4} P_{k+1,i} \right) \right) \right), & 4 \leq m \leq 8 \\
4 \max_{1 \leq k \leq m-1} \left( \frac{1}{4} \left( P_{k,i} + \frac{(m-4)}{4} P_{k+1,i} \right) \right), & m \geq 8 
\end{cases}$$

(3)

Equation 3 is applicable to headways of 7.5min or greater. Where necessary this equation could be expanded for headways less than 7.5min.

The load factor of a PHF service that traverses segment $i$ during the peak 15 minutes of study hour $H$ is given by:

$$LF_{PHF,i,H} = \frac{\sum_{k=1}^{m} \left( \frac{P_{k,i}}{P_{MSL,k}} \right)}{m PHF_{i,H}}$$

(4)
If we assume load factor on segment $i$ to be distributed normally throughout study hour $H$, which is examined by case study below, the standard normal variable corresponding to the PHF service can be estimated by:

$$Z(LF_{PHF,i,H}) = \left(\frac{LF_{PHF,i,H} - LF_{av,i,H}}{LF_{sd,i,H}}\right)$$  \hfill (5)

In turn, the PHF service lies on the cumulative distribution of passenger loadings at the following percentile in fractional form:

$$F(LF_{PHF,i,H}) = \Phi(Z(LF_{PHF,i,H}))$$  \hfill (6)

Where:

$$\Phi(\cdot) = \text{the cumulative normal distribution function}$$

If we assume load factor on segment $i$ to be distributed normally throughout study hour $H$, we can estimate an hourly design load factor on segment $i$ of route $R$ during study hour $H$ by:

$$LF_{des,i,H} = LF_{av,i,H} + Z(LF_{des,i,H}) LF_{sd,i,H}$$  \hfill (7)

Where:

$$Z(LF_{des,i,H}) = \text{the standard normal variable corresponding to a desired, design percentile of the normal distribution}$$

**TRANSIT ROUTE CASE STUDY**

The case study route is the inbound direction of a premium radial bus route in Brisbane, Australia that was used by Bunker (5). AFC data was provided by Queensland Transport and Main Roads’ TransLink Division for a single, representative 24 hour weekday in April 2012 for Route 222, from which boardings and alightings for each service along the route were determined. Figure 1 illustrates the route’s location.
Route 222 contains 12 segments of total length 12.9km (8.0mi). The outermost five are on-street bus (OSB) segments on an arterial road corridor while the innermost seven segments are on a bus rapid transit (BRT) line. The outermost terminus (denoted RSC in Figure 1) is at a regional shopping center, which is a major bus interchange for numerous other radial, circumferential, and feeder routes. The OSB stops (denoted MSA through MSD in Figure 1) are located at main street shopping nodes surrounded by low to medium density suburban development. The BRT stations (denoted SCH through IMT in Figure 1) are premium stations adjacent to significant inner urban precincts; refer to [5]. The BRT segments between UNI and IMT are on transitway rather than fully segregated busway, which considerably reduces buses’ running speeds.

At the time of data acquisition, inbound services offered an off-peak 15 minute frequency between approximately 05:00 and 23:00, and a 10 minute frequency during the four consecutive hours commencing 06:00 through 09:00.

A fleet of 12.5m (41.0ft) buses with 45 seats and 65p MSL was used on all inbound services, aside from the highest demand 07:25 service, for which a 14.5m (47.5ft) bus with 55 seats and 85p MSL was used.

Route 222 shares transit line with a sister, premium radial route that has a similar stopping pattern and some limited deviation, and with similar frequencies and hours of service. It also shares transit line with two all-stops routes and a number of peak period, peak direction express Sweeper routes having limited stopping patterns and some route deviations. While these other routes do provide alternative travel choices for passengers, for clarity they are omitted from this analysis.

**Route Passenger Load Factors Profiles**

Load factors by service and segment are illustrated in Figure 2 for the inbound direction of Route 222 across the weekday studied. Figure 2 reveals a strong morning peak and softer evening peak, which is quite typical of an urban radial transport facility. The MLS was predominantly after station COM, which
is upstream of the inner urban stations that provide access to major trip attractions. The evening inbound peak was substantially softer than the morning peak, and is largely attributed to contra-peak direction demand by passengers departing the regional shopping center, as well as passengers departing major inner urban attractions who use Route 222 services to reach CBD stations for onward interchange. Maximum schedule load was exceeded by up to 10 percent, reflecting crush conditions, on the inbound 07:25 service on the four consecutive segments after MSD, SCH, COM, and INT.

![FIGURE 2 Case Study Route 222 Segments’ Inbound Load Factors across Weekday Studied.](image)

**ASSUMPTION OF NORMALITY AND SAMPLE SIZE OF SEGMENTS’ HOURLY LOAD FACTOR DISTRIBUTIONS**

Two study hours were considered to test for normality. Figure 3 (a) illustrates the Quantile-Quantile (Q-Q) plot of load factor by segment during the morning peak terminus schedule departure hour commencing 07:00, during which time six services operated, while Figure 3 (b) illustrates the Q-Q plot of load factor by segment during the evening contra-peak hour commencing 16:00, during which time four services operated. The abscissa represents the value of standard normal variable corresponding to a point from a segment’s sample, when that sample is translated onto the standard normal distribution. The ordinate represents the value of standard normal variable corresponding to a point from a segment’s sample, based purely on its percentile rank. Data closely fitting the line of equality is indicative of normality.

Larger data samples would be necessary to conduct a quantitative statistical test for normality, such as the Kolmogorov-Smirnoff Test, but this would be generally infeasible for transit routes whose hourly data samples are limited by service frequency. However, the Q-Q plot approach provides a strong visual indication of normality.

Because the segments’ data samples are limited by their service frequencies, with six data ranks and corresponding quantiles for the 07:00 peak hour and four data ranks and corresponding quantiles for the 16:00 contra-peak hour, each segment’s sample cannot be expected to lie extremely close to the line of equality. However, inspection of the data does illustrate, across all segments for both study hours, a reasonable fit to the line of equality. There is no evidence of any systematic bias, particularly for the
lowest and highest observable quantiles. It is therefore considered to be reasonable to assume normality of segments’ hourly load factor distributions. Further consideration of small sample sizes is provided later. It is noted that a doubly truncated normal distribution bounded by 0 and a crush load factor such as 1.1 would be strictly more accurate. However, the extreme tails of the normal distribution are not utilized in this methodology, so the normal distribution itself is adopted for analytical tractability.
RELATIONSHIP BETWEEN LOAD FACTOR AND PEAK HOUR FACTOR

Figure 4 illustrates for the inbound direction each segment’s PHF time history throughout the weekday studied, determined using Equation 3. It is noted that, for each segment, PHF was calculated for each clockface terminus schedule departure hour (e.g. 5:00 to 6:00). PHF is plotted mid-hour (e.g. 5:30) and the time history curve connects all of these mid-hour values throughout the day. Visual inspection suggests PHF correlates somewhat between segments, because they are located consecutively along the route.

For each segment some irregular oscillation is evident throughout the day. Low PHFs mainly occur mid-morning, early-afternoon, mid-afternoon, early-evening, and mid-evening. During these off-peak times the inbound frequency is 15min, which means that a single service with a higher passenger load than the other three during the hour can significantly skew PHF downwards. This circumstance is similar to that experienced on systems with limited frequency such as commuter rail, as has been documented in (I). Low values of PHF may also be symptomatic of unreliability.

Notwithstanding its blocky nature, the rationale behind PHF in capacity analysis is important because the operator ought to be able to ensure that a particular hour’s design load conditions, being the average load across the highest contiguous 15 minutes of the hour (expressed in p/h) in the case of TCQSM’s methodology (I), can be accommodated and/or managed.

TCQSM (I) also suggests that passenger load Quality of Service standards can be expressed as an absolute not to be exceeded, or an average during a peak 15min, 30min or 60min period. PHF is similar to the 15min peak’s average. Using one of these, or even some other, design condition is an important aspect of QoS analysis.
Figure 5 illustrates for the inbound direction, each segment’s time history of percentiles of the cumulative normal distribution corresponding to the PHF load factors, by hour throughout the weekday studied, using Equations 1 through 6. PHF load factor varies irregularly across all segments within a band between the 75th and 95th percentiles of the load factor distributions. This variability highlights a conceptual difference between PHF and an hourly design percentile. While PHF is sensitive only to the ratio between the average load factor across the (clockface) hour and the average across the highest contiguous 15 min of that hour, design percentile is sensitive both to the average load factor across the hour and the variation in load factor throughout the hour as measured by standard deviation. For this reason, in investigating this stochastic approach to load factor analysis, it will be useful to compare hourly design load factor to PHF.
Figure 6 illustrates the time history of each segment’s design hourly peak load factor profile across the weekday studied, estimated using Equation 7 with a standard normal variable of 1.175 corresponding to the 88th percentile. Under the normal distribution this corresponds to the 7th highest minute of the hour, which is similar to the average of the highest 15 of all minutes across the hour. The design profile of each segment envelops most of its load factors by service, where were shown in Figure 2, indicating that the 88th percentile is an appropriate design state.

Figure 7 presents a line of equality comparison between segment PHF load factor and segment hourly design load factor. A very strong correlation between the two approaches is evident with $R^2$ equal to 0.98.

Although the stochastic approach to analysing segment load factor is subject to small sample sizes within the study hour as a consequence of service frequency, for this case study the comparison of segment hourly design load factor profile to measured load factors, and comparison of segment PHF load factor to hourly design load factor, does not show this to be problematic. Rather, this case study demonstrates that stochastic analysis is a useful means of establishing a design condition.

To demonstrate application to capacity analysis, we can see that for hour commencing 07:00, the hourly design load factors exceed 1.0 on the four consecutive segments downstream of stop MSD, and stations SCH, COM, and INT. We can therefore conclude that capacity is exceeded under the design condition on these segments.

Aside from checking design load against maximum schedule load on the maximum load segment during the peak hour, an operator might wish to consider a broader QoS condition to be a reasonable standard of hourly design load across the entire four-hour morning peak period when service frequency is highest. For example, a standard might be the load factor corresponding to a full seated load plus half of available standing spaces taken, which for the case study equates to 0.83. This condition is exceeded only on the four consecutive segments downstream of stop MSD, and stations SCH, COM and INT during the
two hours between 06:30 and 08:30, and the adjacent segments downstream of stop MSC and downstream of station HSO only during hour commencing 07:00. We can therefore conclude under this particular standard that Route 222’s four-hour morning peak period QoS would be adequate.

This stochastic analysis approach can also be adapted to different passenger load capacity and/or QoS standards. A 75th percentile hourly design load factor, similar to the average of the highest 30 of all minutes of the study hour, could be calculated using a value of standard normal variable of 0.67, while a stringent standard such as 92nd percentile hourly design load factor, similar to the highest 5 of all minutes of the study hour, could be calculated using a value of standard normal variable of 1.41.

FIGURE 6 Case Study Route Inbound Segments’ Time History of Hourly Design Load Factors across Weekday Studied.
FIGURE 7 Case Study Route 222 Inbound Segments’ Peak Hour Factor Load Factors vs Design Hourly Load Factors across Weekday Studied ($R^2 = 0.98$).

HOURLY VARIATION OF LOAD FACTOR ACROSS WEEKDAY STUDIED

Hourly Coefficient of Variation of Load Factor as a Capacity and QoS Assessment Measure

Figure 8 illustrates for each inbound segment across the weekday studied, the observed spread of hourly coefficient of variation of load factor, calculated using Equations 1 and 2, with hourly average load factor.

Figure 8 includes isometric curves that illustrate, for each constant increment of hourly design load factor between 0.1 and 1.1, the theoretical relationship between hourly coefficient of variation of load factor and hourly average load factor, which for arbitrary segment $I$ during study hour $H$ is given by:

$$LF_{cv,I,H} = \frac{\left(\frac{LF_{des,I,H}}{LF_{av,I,H}} - 1\right)}{Z\left(LF_{des,I,H}\right)}$$

(8)

Where:

$$0 < LF_{av,I,H} \leq LF_{crush,I,H}$$

$$LF_{av,I,H} \leq LF_{des,I,H} \leq LF_{crush,I,H}$$

$$LF_{crush,I,H} = \text{crush load factor specified here to equal 1.1}$$

$$Z\left(LF_{des,I,H}\right) = 1.175 \text{ corresponding to the 88th design percentile}$$
Figure 8 also illustrates a frontier that represents the upper bound of observed segment coefficient of variation of load factor with segment hourly average load factor, according to the following empirical equation developed to brace the data of this case study for all segments $I$ during all study hours $H$.

$$LF_{cv,I,H} \leq \left( \frac{a}{LF_{av,I,H}} - 1 \right) \frac{1}{Z(LF_{des,I,H})}; \quad 0 < LF_{av,I,H} \leq LF_{lim,I,H}$$ (9)

Where:

- $LF_{lim,I,H} =$ limiting hourly average load factor specified here to equal 1.0
- $Z(LF_{des,I,H}) = 1.175$ corresponding to the 88th design percentile
- $a =$ Y axis intercept constant equal to 2.39 for case study
- $b =$ decay constant equal to 0.27 for case study

Inspection of the observed frontier against the isometric curves reveals a progressive reduction in the uppermost ratio of hourly design load factor to hourly average load factor, and consequently coefficient of variation, as hourly average load factor increases from 0 to 1.0. This reflects the greater effect that one extra passenger has to hourly coefficient of variation of load factor as hourly average load...
factor reduces on the one hand, and that less spread in coefficient of variation becomes possible as segments approach observable hourly capacity on the other.

Data corresponding to values of hourly average load factor less than 0.5 dominate the spectrum. Of the data points that correspond to values of hourly average load factor greater than or equal to 0.5, most belong to the most highly loaded segments during the inbound morning peak hour commencing 07:00. Four data points lie between the isometric curves corresponding to hourly design load factors of 1.0 and 1.1, which correspond to segments after MSD, SCH, COM, and INT during hour commencing 07:00 – as were reflected in Figure 6.

Examination of data in the lower hourly average load factor reveals that, for any segment and a given hourly average load factor, substantial spread in coefficient of variation of load factor exists between the horizontal axis and the observed frontier. With the small sample sizes used to calculate hourly coefficient of variation of load factor in mind, this shows that passenger load can be quite uniform between services during one study hour while being quite variable during another of similar hourly demand. Uniform passenger load is generally indicative of well dispersed passenger boarding demands and good schedule maintenance. Conversely, variable passenger load may be indicative of pulsed or uneven passenger boarding demands, poor schedule maintenance, and/or bus bunching. Coefficient of variation of load factor therefore has potential to be a useful additional measure of service utilization and passenger QoS. Figure 8 in the form shown also has great potential as a means of fingerprinting a route’s service utilization and passenger QoS.

Table 1 presents hourly coefficient of variation of load factor as an additional assessment measure informed by this case study, on the basis of its theoretical relationship with the ratio of hourly design load factor to hourly average load factor of Equation 8, and observed spread and frontier shown in Figure 8. The degree of shading of a cell notionally reflects a worsening of QoS. Along with its feasible range, in developing this table consideration was given to how a segment’s hourly coefficient of variation of load factor reflects the evenness of passenger demand and bus bunching effect.

<table>
<thead>
<tr>
<th>Hourly Coefficient of Variation of Load Factor</th>
<th>Hourly Design Load Factor Relative to Hourly Average Load Factor</th>
<th>Hourly Average Load Factor &lt;= 0.5</th>
<th>Hourly Average Load Factor &gt; 0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 0.1</td>
<td>Consistent across hour</td>
<td>Feasible across load range, very even passenger demand</td>
<td>Feasible across average load factor range, possible indication of pass-ups under high load</td>
</tr>
<tr>
<td>0.1 to 0.2</td>
<td>Design less than 25% greater than average</td>
<td>Feasible across load range, relatively even passenger demand</td>
<td>Only possible for average load factor less than 0.95, relatively even passenger demand</td>
</tr>
<tr>
<td>0.2 to 0.3</td>
<td>Design between 25% and 33% greater than average</td>
<td>Feasible across load range, somewhat uneven passenger demand and/or minor bus bunching</td>
<td>Only possible for average load factor less than 0.9, somewhat uneven passenger demand and/or some bus bunching</td>
</tr>
<tr>
<td>0.3 to 0.4</td>
<td>Design between 33% and 50% greater than average</td>
<td>Feasible across load range, relatively uneven passenger demand and/or some bus bunching</td>
<td>Only possible for average load factor less than 0.85, uneven passenger demand and/or considerable bus bunching</td>
</tr>
<tr>
<td>0.4 to 0.6</td>
<td>Design between 50% and 75% greater than average</td>
<td>Generally reflects low to moderate load factor, uneven passenger demand and/or considerable bus bunching</td>
<td>Only feasible for average load factor less than 0.75, uneven passenger demand and/or considerable bus bunching</td>
</tr>
<tr>
<td>Load Factor</td>
<td>Design</td>
<td>Comment</td>
<td>Feasibility</td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>0.6 to 0.8</td>
<td>Design between 75% and 100% greater than average</td>
<td>Generally reflects low load factor, very uneven passenger demand and/or bus bunching</td>
<td>Only possible for average load factor less than 0.65, but unlikely</td>
</tr>
<tr>
<td>0.8 to 1.0</td>
<td>Design between 100% and 115% greater than average</td>
<td>Generally reflects low load factor, very uneven passenger demand and/or bus bunching</td>
<td>Not possible</td>
</tr>
<tr>
<td>1.0 to 1.2</td>
<td>Design more than 115% greater than average</td>
<td>Only feasible under very low load factor, highly uneven passenger demand and/or bus bunching</td>
<td>Not possible</td>
</tr>
<tr>
<td>1.2 to 1.4</td>
<td>Design extremely concentrated</td>
<td>Only feasible under extremely low load factor, extremely uneven passenger demand and/or bus bunching</td>
<td>Not possible</td>
</tr>
</tbody>
</table>

Example of Detailed Assessment of Case Study Route Segment Load Factor Variation Across Weekday Studied

Figure 9 illustrates the time history of each segment’s hourly coefficient of variation of load factor profile across the weekday studied, calculated using Equations 1 and 2.

![Figure 9: Case Study Route 222 Inbound Segments' Time History of Hourly Coefficient of Variation of Load Factor across Weekday Studied.](image_url)

The following inferences can be drawn from Figure 9, using the commentary of Table 1, regarding variation in intensity of loading on each segment for a selection of study hours:
Four services were offered during commencing hour starting 05:00. Apart from the three outlying segments downstream of stops MSB, MSC and MSD, which all had very small load factors, there was only slight to moderate variation in passenger demand.

Six services were offered during inbound peak hour commencing 07:00. Hourly design load factors were about 50 percent higher than average on the more lightly loaded segments, and about 25 percent higher than average on the heavily loaded segments. This indicates uneven passenger demand and/or some bus bunching (including with sister routes not shown in this analysis). As discussed earlier, the 7:25 service reached MSL across a number of consecutive segments, which was likely a result of bus bunching.

Four services were offered during the midday off-peak hour. All segments’ hourly average load factors were less than 0.5. Hourly design load factors were mostly in the vicinity of 25 percent higher than hourly average load factors reflecting somewhat uneven passenger demands and/or some minor bus bunching, apart from the most lightly loaded segments at the start and end of the route where they were about 50 percent higher, reflecting relatively uneven demand.

Four services were offered during the 17:00 counter-peak hour. All segments’ hourly average load factors were less than 0.5. Hourly design load factors were all between 30 percent and 60 percent higher than hourly average load factors, reflecting uneven passenger demand and/or considerable bus bunching.

Four services were offered during final hour starting 22:00. Load factors were very low across the route throughout this study hour. Hourly design load factors were about 35 percent higher than hourly average load factors on consecutive segments downstream of stations COM, INT, HSO, UNI and CCR, indicating relatively uneven demand and/or some bus bunching. Hourly design load factors were generally 80 percent higher than hourly average load factors on the other, outlying segments. These levels are reflective of the very low passenger numbers.

This paper used a case study, premium radial bus route operating on a representative weekday in Brisbane, Australia to investigate the use of stochastic analysis of transit route segments’ passenger load variation for capacity and quality of service (QoS) assessment. It demonstrated segment hourly design load factor, which reflects a chosen design percentile of distribution of load factor, to be a feasible and distinct alternative to the Peak Hour Factor (PHF) approach widely used in transit capacity and QoS analysis.

This paper also demonstrated that a route’s overall performance can be fingerprinted by plotting hourly coefficient of variation of load factor against hourly average load factor in the form of Figure 7, and interpreted using the form of Table 1 with consideration given to evenness of passenger demand and bus bunching. Detailed assessment regarding variation in intensity of segment passenger load can also be made using a time history of segments’ hourly coefficient of variation of load factor across a study day.

Along with routine passenger load analysis, most importantly this approach, which requires only automatic fare collection (AFC) data, can be used to identify both in time and in space along a route, potential operational concerns such as bus bunching and pass-ups.

Future research will pursue application of this stochastic approach to a transit route across a number of consecutive study days in order to gain stronger insight into the influences of day-of-the-week, seasonality, weather conditions, and other unique conditions on reliability of a bus route.

ACKNOWLEDGEMENTS
The support of Mr Daniel Ng of Queensland Department of Transport and Main Roads’ TransLink Division in providing operational data, and assistance of Mr Rakkitha Pathiranage of QUT in pre-screening of data, are gratefully acknowledged.
REFERENCES


5. Bunker J.M. How Transit Route Passenger Load and Distance can Together Influence Quality of Service. *Transportation Research Record Board 93rd Annual Meeting*, Jan 12 – 16, Washington, D.C.


