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Understanding the influence of availability measures on bus ridership: Brisbane case study

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Abstract

Human travel behaviour pertaining to public transit uses relies on various external and internal factors. This study focus on one of the internal factors, which is Transit Quality of Service (TQoS). This analysis primarily concentrated on service availability measures of TQoS, which is the prerequisite for transit service usage. This paper aims to identify the most influential availability measure that govern ridership variation between areas. It examined a number of possible variables through regression models in order to establish the best estimator variable regarding service availability. Apart from the existing service availability measures prescribed by the Transit Quality of Service Manual (TQSM), this study developed a new approach of analysis by synthesising typical availability measures into several single variables. Amongst them, the service intensity (SI) (bus-km/km^2), which is a systematic combination of service frequency (SF), service span (SS) and route density (RD), had the best capability of explaining spatial variability in ridership rate between areas. The study concludes that bus service intensity is a key driver of service availability indicator. Hence, before investing valuable resources, transit agencies can utilise this measure to understand how it will influence the overall bus transit availability of an area and verify the plausible benefit from the investment.

1.0 Introduction

City of Brisbane comprises sprawling land use patterns and served by three integrated transit modes; bus, heavy rail, and linear ferry. Among three major public transport system, the city is highly reliant on its bus service. According to Australia Bureau of Statistics (2011), in 2011, approximately 43,707 inhabitants of the City of Brisbane used bus for their main daily travel to work and 26,840 people use heavy rail. In order to meet the transport demand of this fast rising and geographically dispersed population, in recent years the Queensland Government and Brisbane City Council have focused on developing its extensive busway (Bus Rapid Transit, or BRT) network. Since bus is the dominant transit mode used within the City of Brisbane, dynamics that affects its ridership carries utmost importance. Many factors influence mode choice of potential bus riders. These considerations have steered the primary focus of this study towards bus ridership.

Factors affecting bus ridership can be broadly categorised into two divisions; external factors and internal factors (Taylor and Fink, 2003). The external factors such as weather, demography and so on are beyond the control of transit systems. Factors that are controllable within the transit systems are known as internal factors. They include transit service attributes such as service quality, transit fare and so on. Previous study found that areas serviced with a higher quality of transit services experienced high transit ridership rate (boardings per 100 population) and lower quality of transit services experienced the opposite (Kashfi et al., 2015a). This implies that the quality of transit service of an area should influence its ridership. According to Transit Capacity and Quality of Service Manual (TCQSM) transit quality of services (TQoS) are measured by two important aspects, Availability, and Comfort and Convenience (TRB, 2013) and they have direct influence on ridership.

A prerequisite for transit service usage is service availability. It is commonly viewed by transit planners that measures of service availability govern transit ridership. Typically, data relating to calculation of various availability measure are readily available from the transit agencies. Conversely, analysis considering Comfort and Convenience measures are generally more on the imperial side (mostly related to passenger's point-of-view). Consequently, their measurements are very data intensive and require significant resources, which are beyond the scope of this study. Hence, the analysis will focus on the dominating availability measures relating to service frequency, service span and route length of the service. It will also attempt to establish their influences on variation in ridership rate between areas.

The research is set forth to answer the research question concerning what are the variables that govern ridership variation between areas. In order to answer the question, this paper aims to identify the most influential availability measure upon ridership variation between areas. Using simple linear regression method, it endeavours to develop several ridership estimation models and select the most robust model, which can deliberate ridership estimation throughout the year.

The paper is organized as follows. Section 2.0 will provide an overview of TQoS measures in terms of the principal aspect, Availability. Section 3.0 will provide details of the case study area selected in this study. Section 4.0 will describe data collection and analysis process of two datasets namely daily bus ridership data, and transit quality of service data. This section will also provide some clarifications regarding treatment of variables for this study analysis. Section 5.0 will detail measurement and calculation of various service availability measures. It will also demonstrate the linear model development process, and interpret estimation results. Section 6.0 will compare the ability of the various service availability measures and select the most suitable measure to estimate ridership variation between areas. Section 7.0 will summarise study findings and future direction.

2.0 Transit quality of service (TQoS) Indicators

A vast number of studies have analysed that high-density and mixed-use developments with good pedestrian environment are reason for higher transit (Frank & Pivo, 1994; Cervero & Kockelman, 1997; Ewing & Cervero, 2001; Cervero et al., 2004; Hendricks, 2005). Likewise, physical activity and public health related studies analysed the influence of built environment variables in a number of studies (Dannenburg et al., 2003; Frank et al., 2005; Lavizzo-Mourey & McGinnis, 2003). However, compared to these studies, few have focused on how transit quality of service affects ridership.

TCQSM (TRB, 2013) has been used in this study as the central reference to scrutinize the spectrum of attributes allied to its availability measures, in order to determine the transit system's performance within a particular area. Usually, Availability is measured by service frequency (SeF), service span (SS), and Access (TRB, 2013). This paper will deal with availability indicators only; hence, it is important to understand availability measures, according to TQoS manual. This section will review literature based on the relation between service availability measures and ridership.

2.1 Availability

Availability of transit services refers to the frequency of transit service (i.e. how often service is provided); length of transit services (i.e. how long service is provided) and ease of access to transit services.

Service frequency

Transit service frequency is evaluated as the amount of transit services available in an area within an hour towards a particular destination. High service frequency reduces the wait time of travellers; however, there is significant amount of associated cost with that. Hence, in comparison with personal vehicle as well as active transport, transit service is always face the drawback of not being available at users' disposal at any time. Fixed route transit service can only be used in accordance with a previously formulated rigid schedule. TCQSM quantifies this measure based on the time gap between buses servicing that same bus stop.

Previous research identified significant impact of service frequency (SeF) on transit ridership. They confirm the influence of transit service quality on ridership is relatively greater than transit fares (Kain & Liu, 1996; Gomez-Ibanez, 1996). Tang and Thakuriah (2012) observed that bus service frequency has a significant and positive effect on bus ridership. Litman (2008) argued that if service frequency is increased, demand for transit must increase, providing that all other relevant factors remain constant. Moreover, it is argued that when transit service is not adequate, land use qualities never provide sufficient impact to shift mode share to transit, even if land use position is optimal (Hendricks, 2005). In order to attract sufficient ridership, sufficient services need be available both in peak hours and in off-peak hours throughout the week.

Service span

The service span or actual hours of service (h), is another availability measure within the TQoS framework. According to TCQSM, service span (SS) represents the number of hours transit service is provided between two areas or along a route within a day. Extended SS serves a greater variety of trip purposes and gives travel flexibility to transit users. Khon, (2000) revealed a positive correlation between service span and ridership. This study used multiple regression to test different data elements and attempted to identify the significant variable that can explain ridership variation. Moreover, Tang & Thakuriah (2012) observed higher average weekday bus ridership for routes with late night service (24-hour service) than those with limited services.

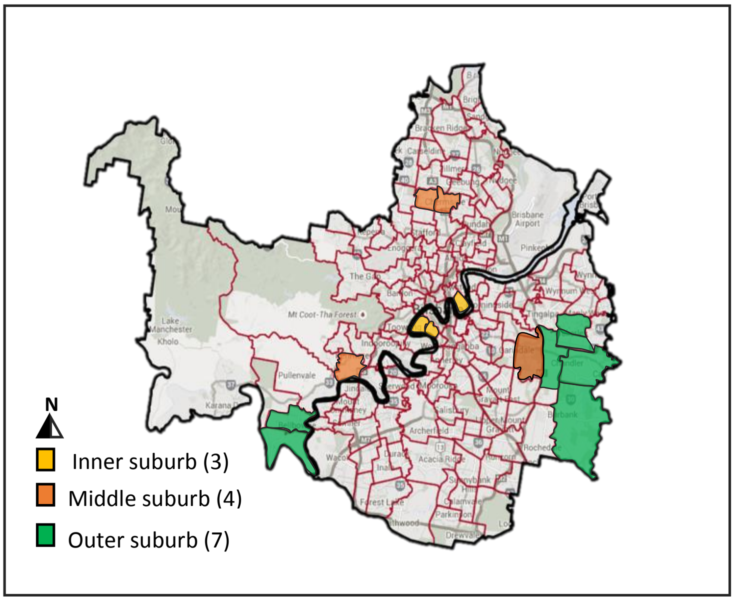
Access

Access defines the ease of access to transit service. Systematic distribution of bus routes across a given area based on their potential productivity ensures meaningful access to transit. According to TCQSM, service coverage, which is the percentage of transit supportive area served, defines access to transit via walking or other modes. Route density (route-km/km2) is a measure of service coverage that indicates the quantity of bus route length present per unit area. Studies have confirmed a significant positive association between route density (route km/km2) and transit ridership (Gomez-Ibanez, 1996; Kain & Liu, 1996).

3.0 Study area

The City of Brisbane divides its land areas into 189 suburbs. This study selected 14 out of 189 suburbs to form nine localised investigation areas (LIAs), which may be between one and a few suburbs in size. Figure 1 illustrates geographical locations of the selected suburbs.

Figure 1: Suburbs selected within the City of Brisbane to form Localised Investigation Areas (map not in scale) ***Source: TransLink Department of Transport and Main Roads (2015).***



Due to very low population densities in outer Brisbane suburbs, average daily bus ridership was also very low. In order to obtain a sufficiently large sample, some contiguous outer suburbs were amalgamated in the formation of LIAs. Among them Chandler, Burbank and Wakerley were combined and considered as one LIA. Similarly, Gumdale and Belmont were considered as one LIA as were Moggill and Bellbowrie. Table 1 provides detail demographic information of selected LIAs according to their corresponding suburb categories. To calculate the population density of the LIAs, total population was divided by total land area.

Table 1: Demography of Localised Investigation Areas Established for Study and Ridership rate calculation for individual LIAs

	LIA	Yearly average ridership rate (boarding / 100 population)	Population density (per km^2)	Distance from CBD by road (km)	Job Density (per km^2)	Net Area (km^2)	Total bus route length (km)
Inner	West End	26.51	4176.7	1.9	3533.7	1.93	14.6
	New Farm	22.49	5521.2	3.1	1607.4	2.03	12.5
	Highgate Hill	10.70	4853.3	2.7	436.7	1.2	4.26
Middle	Carindale	25.25	1449.5	10.1	442.2	9.4	66.6
	Kenmore	15.57	1631.2	10.8	322.7	5.2	38.1
	Chermside & Chermside West	20.52	2101.6	12.3	1901.9	6.8	63.9
Outer	Chandler, Burbank & Wakerley	3.00	214.5	17.4	45.1	48.4	96.6
	Gumdale & Belmont	3.05	396.0	15.6	73.6	14	24.5
	Moggill & Bellbowrie	6.37	535.6	20.2	51.7	17.6	14.5

Queensland Department of Transport and Main Roads' TransLink Division is responsible for providing mass transit including bus, train, ferry, and tram across SEQ, including the City of Brisbane. The division splits its SEQ network into 23 travel zones and the City of Brisbane encompasses the innermost five of TransLink's fare zones. TransLink provides 394 routes that originate from within the City of Brisbane region.

4.0 Data collection and treatment of variables

Two data sets were collated for this analysis, including daily bus ridership data and Transit Quality of Service (TQoS) data. Daily bus ridership data for each LIA was collated from TransLink for year 2012 (Briohny Rootman &Tristan Miles, February 2013, March 2014). To compute the availability measures, bus schedules were downloaded from TransLink for all routes servicing each LIA (TransLink, 2013). Information regarding bus routes placements and route length with an area was collated using Google transit map (Google transit map, Brisbane, 2014). Moreover, the relevant demographic information regarding variable calculation was obtained from Australian Bureau of Statistics (ABS, 2011)

This analysis only focused on the calendar year 1 January 2012 to 31 December 2012. Weekends and public holidays were excluded from analysis due to their very low ridership compared to weekdays. The dominant type of trips during weekends and public holidays are non-commuting such as recreational and shopping, where ridership is influenced heavily by sporadic events. This study considered weekdays because passenger groups tend to be predominantly commuters, whose ridership pattern are less flexible.

4.1 Treatment of daily bus ridership

The bus ridership data consists of all passenger boardings for each given 24h period considering each LIA. Two fare media are used by TransLink; electronic smartcard known as go-card and legacy paper tickets. This study was concerned on ridership data that originated from the LIAs using both tickets type. In other words, how many persons used bus from individual LIAs (i.e. origin ridership of LIA) on daily basis.

From initial observations, inconsistency in ridership amount between LIAs was observed. Among the selected LIAs, the average annual daily ridership by bus for 2012 ranges between 200 to 5,500 boardings. This vast range can be attributed mainly to difference in population (Table 1 provides detail demographic information of selected LIAs). To facilitate unbiased comparison, it was necessary to convert each LIA's daily ridership into its daily ridership rate (boardings / 100 population).

One problem yet to be resolved that LIAs including West End and Carindale have high job densities due to their key metropolitan centre status, attracting a significant numbers of workers each day who are not residents. When they leave the area on their homeward commute, they are counted as boarding trips originating from that LIA. This produces higher ridership for that particular LIA and does not reveal the real picture of its residents' ridership. In order to overcome this inflation, ridership rate was scale down adopting the ridership scaling method used in previous study (Kashfi et. al, 2015b). The process involved adding a LIA's job density to its population density when calculating its ridership rate. Job density of each LIA was obtained from Australian Bureau Statistic (ABS), (2011). In this way, overstated ridership of LIA was scale down for unbiased comparison.

4.2 Treatment of Transit Quality of Service variables

Timeframe for Variable calculation

Calculation of all of the TQoS related variables were restricted between 07:00 and 24:00 (except for service span), even though some of bus services start well before 07:00. This is because TransLink prescribes the start of morning peak period services from 07:00.

Timeframe for Service Span

It will defeat the purpose of calculating service span variable within a restricted time frame as this variable will try to distinguish the influence of difference service hours on ridership. Constraining the calculation within a certain period would limit the difference and sequentially, reduce the influence of SS. Therefore, SS will be calculated for the total length of hour bus service is provided in a particular route in a particular LIA. This original length of service hour has been labelled as 'actual hours of service' and the time frame of 07:00 and 24:00 has been labelled as 'service period of interest'. An example will clarify the difference between service hours of interest and actual hours of service. For instance, in West End (inner category suburb), route 192 runs for 11 hours within the service hours of interest period; whereas, it's actual SS is 12 hours.

Service Frequency Determination

Typically, service frequency is calculated at the route level. It involves converting the total number of buses, servicing an area within service hour of interest for a particular route, into number of buses per hour for that route. Multiple bus routes may exist in a LIA and this analysis does not contain a single, fixed destination. Thus, while calculating the overall service frequency of an LIA, service frequency for each individual bus route was weighted according to the total length of its route (km) within the LIA. The same method was used to calculate overall service span of each LIA.

Bus Route Length within LIA

For each bus route, its portion (route km) contained within a subject LIA's boundary was identified using the embedded Google Maps for bus route paths in TransLink's website (TransLink, 2014) and then customised in 'Google Maps' following the exact route path through the LIA (see Figure 2).

Figure 2: bus route path drawn for route km calculation using Google Maps for West End (*map is not in scale*)

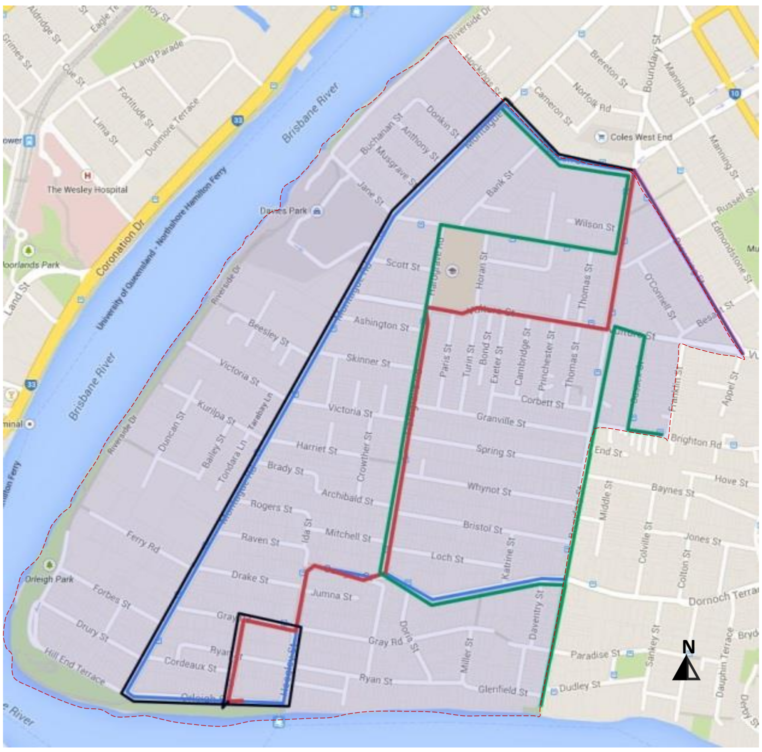


Table 1 represents net area and total bus route km calculated for each LIA. It is noteworthy that within an LIA, land where dwellings are uncommon (such as park, picnic ground, and recreational reserve) were excluded from the measurement of area for that LIA.

5.0 Calculation of service availability measures

This section examines a number of possible variables through linear regression models in order to establish the best estimator variable regarding service availability. The next section will compare the predicted capability of calculated availability measures by the means of regressing each availability measure with average ridership rates for selected LIAs. Finally, the most suitable availability measure will be selected, which can explain yearly ridership variation between LIAs.

5.1 Investigation of Most Influential Availability Measures

Service frequency (SeF) (bus/h) quantifies the availability of service to its riders without considerable waiting time. Services that are more frequent provide more opportunities for immediate travel, and allow transit to be competitive with the personal vehicles in terms of departure time convenience. Equation 1 in Table 2 defines service frequency for an LIA. It is important to note that Equation 1 weights SeF by the service hours of each individual route (within service period of interest).

Route density (RD) (km/km2) of an LIA is defined by Equation 2 in Table 2 as the available bus route length per unit of net area. Service span (SS) is calculated by the number of hours, when transit service is available along a route or at a given location or between origin-destination places. SS for a particular route was defined as the time difference between the first service entering and the last service leaving the LIA. The direction of travel was outward from the LIA. The actual hours of service for a bus route was weighed by the number of bus service and corresponding route km to calculate the overall SS for a LIA. Equation 3 in Table 2 defines SS for an LIA.

The service provision (SP) (bus-km/h) is measured by combining an area's apparent bus frequency with its total route km. Equation 4 in Table 2 defines service provision for a LIA. It is important to note that unlike service frequency calculation, Equation 4 does not weight the bus frequency by the hours of service of each individual route. Rather, it combines the bus frequency with route km for each route.

SP variable was modified to involve population factor into the calculation. The new variable service provision rate (SPR) (bus-km/hr per 100 people) was calculated by dividing SP of an area with its population and then converting it to the area's population percentage. It represents the amount of bus-km provided in an hour for 100 population. Equation 5 in Table 2 defines service provision rate for an LIA.

The measurement of service intensity (SI) (bus-km/km2) is a combination of three TQoS availability measures SeF , SS and RD. The definition adopted in this research for SI , embeds service coverage area with the frequency and then with the overall service span of an LIA. This approach provides a holistic representation of the amount of transit service provision in an LIA. Equation 6 in Table 2 defines service intensity for a LIA. It is important to note that Equation 6 weights SI by the hours of service as well as route segment length of each individual route.

Table 2: Equations for calculations of service availability measures

Service Offering Measurements	Units	Equation	Equation number
Service frequency (SeF)	(bus/h)	$SeF_s = \frac{\sum_{i=1}^{n_s}[(N_{i,s}/H_{i,s})\, R_{i,s}]}{\sum_{i=1}^{n_s}(R_{i,s})}$	1
Route density (RD)	(km/km^2)	$RD_s = \frac{\sum_{i=1}^{n_s} R_{i,s}}{A_s}$	2
Service Span (SS)	(h)	$HA_s = \frac{\sum_{i=1}^{n_s} HA_{i,s}\, N_{i,s}\, R_{i,s}}{\sum_{i=1}^{n_s} N_{i,s}\, R_{i,s}}$	3
Service provision (SP)	(bus-km/h)	$SP_s = \sum_{i=1}^{n_s}[(N_{i,s}/H_{i,s})\, R_{i,s}]$	4
Service provision Rate (SPR)	(bus-km/hr per 100 people)	$SPR_s = \frac{100SP_s}{P_s}$	5
Service Intensity (SI)	(bus-km/km^2)	$SI_s = HA_s\, \frac{\sum_{i=1}^{n_s}[(N_{i,s}/H_{i,s})\, R_{i,s}]}{A_s}$	6

Where,

SeF_s = overall service frequency of an LIA s, within service period of interest
n_s = number of bus routes operating within LIA s, within service period of interest
$N_{i,s}$ = number of bus services (revenue trips) on route i, within LIA s, within service period of interest
$H_{i,s}$ = service hour for bus route i, within LIA s, within service period of interest
$R_{i,s}$ = component length of bus route, for route i, within LIA s, within service period of interest
s = index of LIA form the nine selected LIAs
i = index of bus routes operating within LIA s, within service period of interest
RD_s = overall route density of LIA s, within service period of interest
A_s = net area of LIA s
SS_s = overall service span of an LIA s, within actual hour of service
$NA_{i,s}$ = number of bus services (revenue trips) on route i, within LIA s, within actual hours of service
$HA_{i,s}$ = actual hours of service for bus route i, within LIA
SP_s = overall service provision of an LIA s, within service hour of interest
SPR_s = service provision rate of an LIA s, within service hour of interest
P_s = population of an LIA s
SI_s = weekday service intensity of LIA s
A_s = area of an LIA s

Table 3 illustrates the calculated value range for various service availability measures for all LIAs.

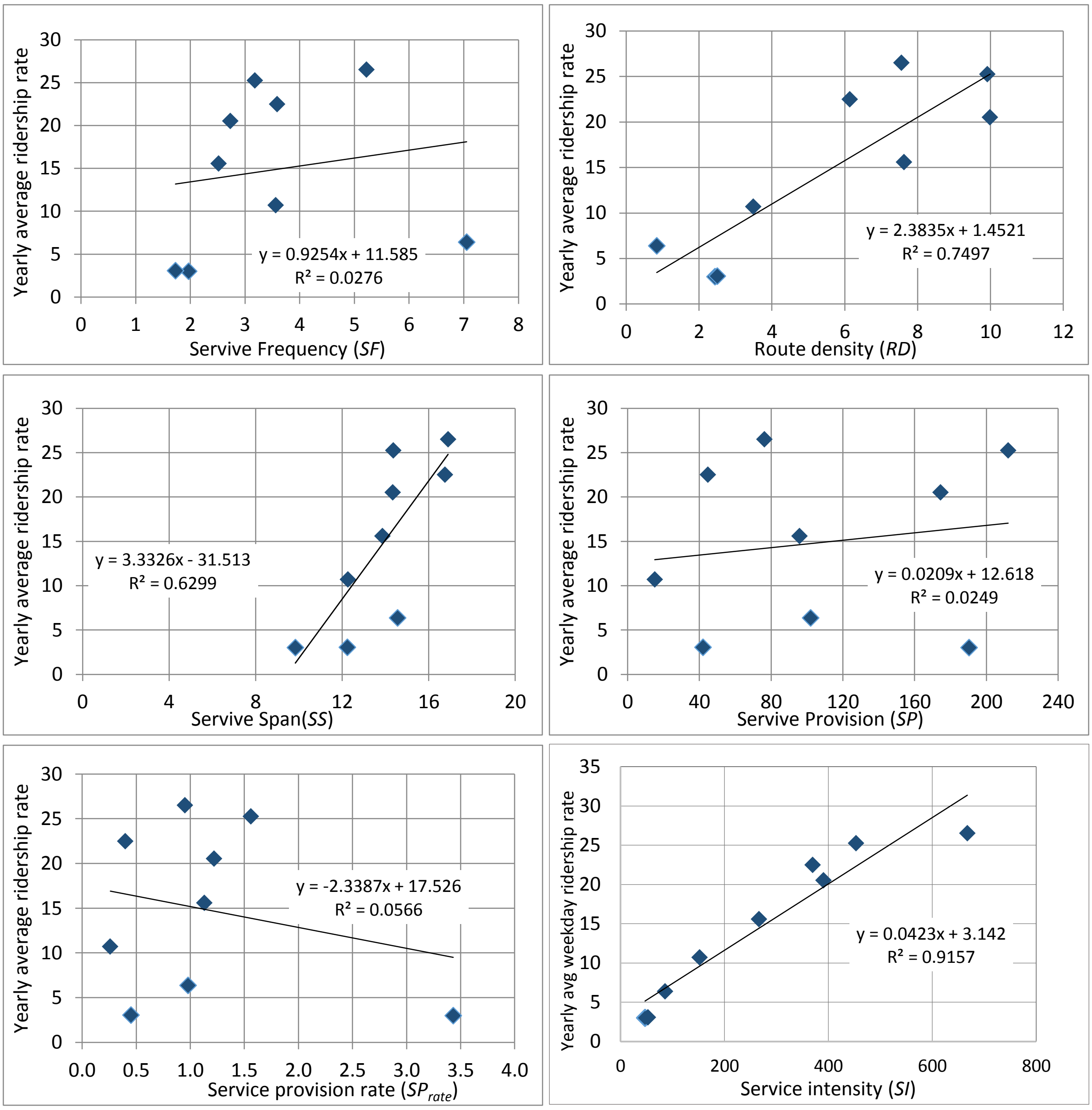
Table 3: Calculated values of various service availability measures for all LIAs

Localised Investigation Areas	Service frequency (SeF) (bus/h)	Route density (RD) (km/km^2)	Service Span (SS) (h)	Service Provision (SP) (bus-km/h)	Service Provision rate (SPR)	Service Intensity(SI) (bus-km/km^2)
West End	5.22	7.56	16.90	76.25	0.95	667.72
New Farm	3.59	6.14	16.76	44.82	0.40	370.06
Highgate Hill	3.56	3.49	12.27	15.17	0.26	152.52
Carindale	3.18	9.92	14.37	212.2	1.56	453.80
Kenmore	2.52	7.63	13.87	95.89	1.13	266.58
Chermside, Chermside West	2.73	9.99	14.34	174.5	1.22	391.05
Chandler, Burbank , Wakerley	1.97	2.44	9.84	190.3	3.43	47.43
Gumdale, Belmont	1.73	2.50	12.24	41.95	0.45	52.88
Moggill, Bellbowrie	7.05	0.84	14.56	102.0	0.98	85.90

Likewise, Figure 3 illustrates the regression results for all availability measures against the yearly average ridership rate of a LIA in terms of boardings per 100 population.

For SeF , the coefficient R^2 equals 0.03, F-value 0.19 (insignificant) and standard error is very large at 9.89 boardings per 100 population. All of test statistics indicate negligible correlation and a very poor explanatory model. In case of RD , the value of R^2 equals 0.75 and F-value equals 20.96 (significant). Although the test statistics indicates a very strong correlation between apparent route density and yearly average ridership rate, the standard error on the estimate is high at 5.02 boardings per 100 population. Hence, despite moderately satisfactory performance of route density in the linear regression, the variable selection process sought an even stronger indicator variable.

Figure 3: Linear regression between service frequency (bus/h); route density (km/km2); service span (h); service provision (bus-km/h); service provision rate (bus-km/hr per 100 people); service intensity (bus-km/km2) and yearly average weekday ridership rate.



The coefficient of determination R^2, for SS equals 0.63 and F-value equals 11.91 (significant). The standard error on the estimate is high at 6.10 boardings per 100 population despite the moderately strong correlation between SS and ridership rate. The values of R^2 for SP equals 0.03, F-value equals 0.18 (insignificant) and standard error is very large at 9.90 boardings per 100 population. This indicates negligible correlation and a very poor explanatory model.

In case of SPR , the coefficient of determination, R^2 equals 0.06, F-value equals 0.42 (insignificant) and standard error is very large at 9.74 boardings per 100 population. Similar to SP , the results for SPR is observed to have negligible correlation. Finally, the coefficient of determination R^2 for SI equals 0.92, and F-value equals 76.0 (significant). The standard error on the estimate is considered reasonably moderate at 2.91 boardings per 100 population.

Table 4 summarises the statistics of the regression for each linear regression model tested. This analysis offered valuable perspective of the performance of a number of potential estimating variables on the dependent variable of average ridership rate across the nine LIAs studied.

An efficient indicator should be able to predict the effect of increase in service facility in terms of ridership variation in an area, with minimal error. In that sense, only SI produced expected outcome in case of with highest R^2 and F-value and minimal standard error. Its closest contestant RD had R^2 value of 0.75 and SS had moderate R^2 value of 0.63 but had high standard error on the estimate. The regression of SeF, SP and SP_{rate} resulted in very low R^2, indicating the ineffectiveness of these variables, when analysing ridership in a multi-route and multi-directional condition.

Table 4: Regression statistics of all availability measures against ridership rate across all studied LIAs.

	Service frequency (SeF) (bus/h)	Route density (RD) (km/km^2)	Service Span (SS) (h)	Service Provision (SP) (bus-km/h)	Service Provision rate (SPR)	Service Intensity(SI) (bus-km/km^2)
R^2 value	0.03	0.75	0.63	0.02	0.06	0.92
standard error	9.89	5.02	6.10	9.90	9.74	2.91
F-value	0.19	**20.96**	**11.91**	0.18	0.42	**76.0**
t-statistics	0.45	4.58	3.45	0.42	-0.65	8.72
p-value	0.67	**0.00**	**0.00**	0.68	0.54	**0.00**
Sample power	0.07	0.99	0.92	0.07	0.10	1.00

The next step is to analyse the predictive capability of significant availability measures (RD and SI) and compare with the average ridership rate across LIAs studied.

6.0 Comparison of predictive capability between availability measures

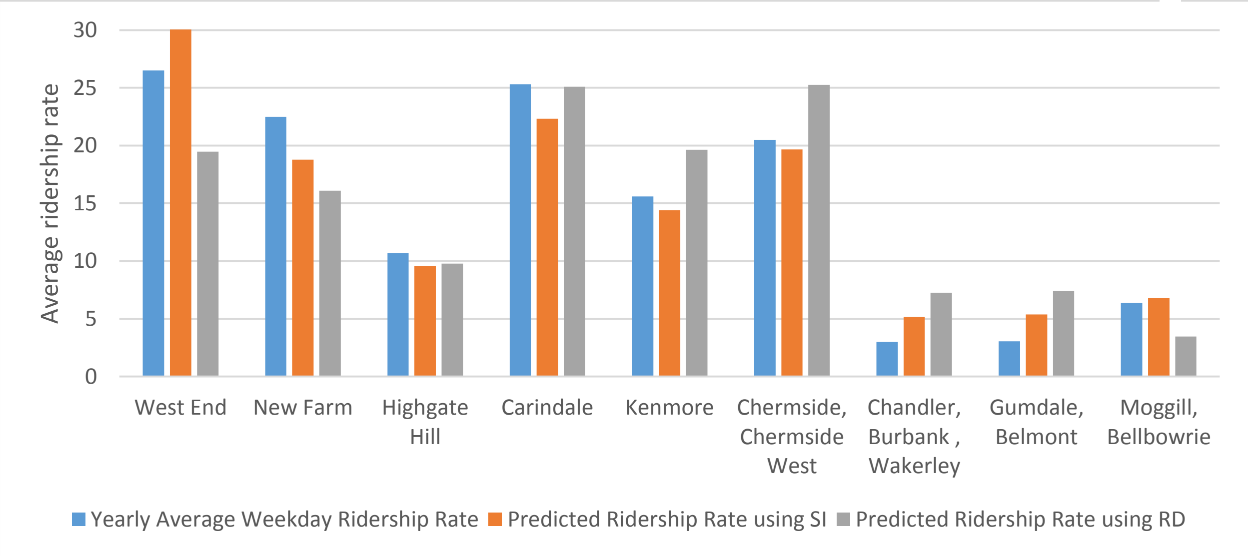
Excluding RD, all calculated availability measures showed weak performance compared to SI. Hence, predictive capability of only service intensity and route density were analysed in details.

Comparison between service intensity and route density

In order to identify the underlying reasons behind the difference in performance between two availability measure (service intensity and route density), average yearly ridership rate was predicted using RD and SI. The predicted ridership rate for both variables were plotted in comparison with the original average weekday ridership rate for all LIAs (Figure 4). Overall, the performance of service intensity was satisfactory with vary minimal discrepancy in predicting ridership rate, compared to the original ridership rate. Only for inner LIAs, West End and New Farm noticeable difference were observed between two ridership rates. The predictive capability of route density was relatively poor compared to that of service intensity. Noticeable differences were observed between original average weekday ridership rate and predicted ridership rate using RD in inner LIAs of West End and New Farm as well as middle LIAs containing Kenmore and Chermside and Chermside West. The predictive capability of route density was comparable to service intensity, but to a limited extent. In comparison with SI, the predictive capability of RD mostly performed poorly in both middle and outer LIAs (except Carindale).

In order to identify the underlying reason behind this, it is necessary to look at discrepancy in calculated value of RD across LIAs. The RD for all middle LIAs were higher than West End; whereas, their ridership rate were lower than West End. Similarly, in New Farm LIA, the RD was lower than Kenmore and Chermside & Chermside West LIAs. Whereas, its ridership rate was higher than both of the LIAs. The reasoning behind this discrepancy is related to the calculation method of route density, which only focuses on the amount of route km presented in per unit area (km^2) of an LIA.

Figure 4: Comparison between original ridership rate, and predicted ridership rates using service intensity and route density



Two of the middle LIAs, Carindale, and Chermside & Chermside West serve as a transit interchange for outer Brisbane's LIAs for going in different direction. Therefore, a significant number of bus routes (Carindale has 22 and Chermside & Chermside West 24 bus routes) pass through these LIAs and thus increase their route km and in turn their route density. Even though Kenmore does not serve as interchange, there are nine bus routes present in that LIA; whereas West End and New farm both have only five routes present in them. This in turn increases the route km of Kenmore as well as its route density.

Evidently, RD provided an inflated indication of service availability for all middle LIAs. Since SeF is not covered in the route density calculation, the actual availability of bus cannot be detected by this variable. Similar scenario occurred for the LIA containing Moggill & Bellbowrie, which has only two bus routes in it. Rest of the two outer LIAs Chandler, Burbank & Wakerley and Gumdale & Belmont have 19 and 9 bus routes in them, inflating their route density higher than Moggill & Bellbowrie. However, the ridership rate of Moggill & Bellbowrie is twice than that of other outer LIAs. The above discussion clearly indicated inefficiency of route density as an indicator of service availability measure and the biased result it may produce. This also dictated the superiority of SI over RD. Identification of the most suitable availability measure, which is service intensity, enabled this study analysis to fulfil its purpose.

7.0 Conclusion and future direction

Primarily this study focused on identifying the most influential service availability measure that governs yearly ridership of an area. People's general assumption, allied with some research findings initially dictates the notion that alteration in SeF is the key factor that sways ridership from its usual disposition. More frequent service provides more opportunities for immediate travel, and allows transit to stay competitive with the personal vehicles in terms of departure time convenience. Nevertheless, aliening with the finding of a previous research of Daskalakis & Statopoulos, (2008), this paper identified that it is not necessarily feasible to mitigate commuters' wait time by just increasing service frequency or service span, as it will increase operating cost and could contribute to road system congestion. Moreover, it poses a huge strain on state's transport budget and threatens the profitability of the transport agencies. In addition, increasing SeF during odd hours (very early morning and late night) does not offer much help for transit services, in terms of increase in ridership number. Similar for the areas with low population density.

Moreover, a closer look at the functionality of the variable revealed that, while service frequency (bus/h) describes how frequently bus service is provided in an area, it does not describe how many km of bus route services are present in an area. This information is necessary to understand the ease or difficulty of accessing transit services. If bus routes are concentrated only on certain high-density commercial points, residents in the other parts of that area cannot fully utilise the bus service. LIAs with very frequent bus service but confined to a very small portion of land area will have limited transit access for the majority of their population. Hence, increasing bus frequency alone does not always help to achieve the desired goal. However, if the service is well spread throughout the LIA, it will attract more riders, providing that the underlying assumption of LIA's population being spread out is met.

On the other hand, increasing route density by making the routes lengthier inside the LIA increases the in-vehicle travel time and in turn, the total travel time. Similar cost benefit relationship exist in the case of service span. Therefore, a harmony needs to be achieved between maximisation of availability measures and their alleged benefits. A systematic combination of SeF , SS and RD can ensure both the availability and access to the transit for the majority of residents in an area. Analysing these variables independently provided only the half picture.

The method adopted in this research for calculating SI has its own merits as it embedded all the availability measure under on variable. This approach provided a holistic view of the condition of transit service in a particular area. It describes bus service frequency, span as well as its spread in an area. Overall, this study analysed and confirmed that service intensity (SI) to be the superior form of service availability indicator, explaining ridership variation from LIA to LIA.

Findings of this paper provides a solid basis for further investigation of transit ridership. However, there are some limitations. Firstly, the study could not include the comfort and convenience measures into the analysis. It will be interesting to explore how these measures affect ridership in this city, along with the overall effect of travel time reliability on commuter's mode choice. Moreover, it can be benefitting to identify how the variable function in a multiple regression model along other variable relevant to physical characteristics of an area. Finally, analysis could include more suburbs to increase the sample size and better representation of Brisbane as a whole.

Considering analysis results, this paper provides some valuable insights to transit authorities to diagnose how the overall bus system is performing in different locations and how the existing ridership can be increased considering short-term and long-term approach in some areas. The study concludes that integrated form of availability measure, bus service intensity is a key driver of ridership. Hence, before investing valuable resources transit agencies can utilize this method to understand how it will influence the overall availability measure of an area and verify the plausible benefit from the investment.

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