WORKING PAPER

ITLS-WP-24-09

The Link between Service Frequency and Patronage: A short note

By
David A. Hensher[a], Edward Wei[b], Wen Liu[c], John D. Nelson[d]

[a,b,c,d] Institute of Transport and Logistics Studies (ITLS),
The University of Sydney, Australia

May 2024

ISSN 1832-570X

INSTITUTE of TRANSPORT and LOGISTICS STUDIES
The Australian Key Centre in
Transport and Logistics Management

The University of Sydney
Established under the Australian Research Council's Key Centre Program.

NUMBER: Working Paper ITLS-WP-24-09

TITLE: The Link between Service Frequency and Patronage: A short note

ABSTRACT: Bus service frequency is extensively studied in many papers; however, we found a lack of a single source that will enable a synthesis overview of the main elasticity evidence on the relationship between service frequency changes and patronage growth. This note provides such a synthesis, drawing on the published literature and some new scenario predictions for metropolitan Sydney.

KEY WORDS: ***bus service frequency, patronage growth, direct elasticity***

AUTHORS: **Hensher, Wei, Liu, Nelson**

ACKNOWLEDGEMENTS: N/A

CONTACT:

INSTITUTE OF TRANSPORT AND LOGISTICS STUDIES (H04)

The Australian Key Centre in Transport and Logistics Management
The University of Sydney NSW 2006 Australia
Telephone: +612 9114 1813
E-mail: business.itlsinfo@sydney.edu.au
Internet: http://sydney.edu.au/business/itls

DATE: May 2024

Background

It is often asserted that what makes a bus service attractive is its ability to deliver on frequency, connectivity, and visibility. While frequency, or more specifically service frequency, is extensively studied in many papers, we found a lack of a single source that could be used to respond to a request made at the NSW bus inquiry on the relationship between service frequency improvements and bus patronage growth. At the recent hearing into current and future public transport needs in Western Sydney, the following question was asked:

> *"Is there an impact if you increase the services? Is there a nexus between the rise in patronage versus the increase in services? Is there some kind of established nexus there? If we expand the bus services across the whole network by 15 per cent is there likely to be a consequential knock-on in terms of increased patronage?"*

In responding to this request, we address it as follows. First, if we increase bus services in Western Sydney alone, what will be the likely increase in bus patronage? Second, if we increase bus services across the whole of the Greater Sydney Metropolitan Area (GSMA) on the current bus network, what will be the likely impact?

Before providing the local evidence, we review some key past research on the impact of bus frequency on patronage growth. We then summarise the evidence from past research together with new scenario tests undertaken using MetroScan (Hensher et al. 2020 and Appendix herein) for local bus frequency increases in Western Sydney followed by scenario test results for the Greater Sydney Metropolitan Area (GSMA) bus network.

Past research on the impact of bus service frequency on bus ridership

This section covers past research on bus service frequency on bus ridership with a focus on direct elasticity evidence. *Direct elasticities* signify the percent change in ridership that results from a 1% change in bus service frequency, *ceteris paribus*. The elasticity of bus service frequency can vary depending on location and different scenarios. Other influencing factors can include the country and city where the bus network is located, existing transport usage and behaviour, and urban design. On the supply side, for areas with high bus service levels (as in the areas of Sydney closer to the Central Business District (CBD)), the patronage response to an increase in bus service frequency can be less than that for areas with a lower level of bus service. Paulley et al. (2006) suggest that the elasticity of service frequency is higher in the long run and for off-peak hours. Brechan (2017) points out that service frequency elasticity has more variation than bus fare elasticity.

In a study using bus service data in several US cities from 2012 to 2018, Berrebi et al. (2021) found that bus ridership is inelastic to service frequency changes with an elasticity range of 0.62 to 0.78 for weekday ridership. This is also the case in other studies. For example, in a small-scale survey of 100 respondents in Norway, Brechan (2017) found the direct elasticity effect for bus frequency on ridership is 0.6. Hence a 10% increase in service frequency results in a 6% increase in patronage, *ceteris paribus*. Higher direct elasticities of 1.1 to 1.2 have also been reported for bus in the past (Taylor et al. 2009), but most past studies on this topic show a sirect elasticity lower than 1 (i.e., relatively inelastic).

Accessing the ITLSW data base on elasticities[1] eighteen different studies shows that the elasticity of bus service frequency is between 0.5 and 0.7, with the lower elasticity for all times of day (0.575), and higher one for peak hours (0.66), as shown in Table 1.

Table 1 Direct Elasticity of bus service levels from past literature review by ITLS

		Sample Size	Average	Std Dev
Frequency				
Bus	All times of day	18 studies	0.575	0.491
	Bus peak	14 studies	0.660	0.523

What this says is that if we increase service frequency across all times of day by 10%, we will get a 5.75% increase in bus patronage, similar to the Norwegian evidence in Brechan (2017).

Todd Litman of the Victoria Transport Policy Institute reviewed past research and discussed transit fare and service elasticities in 2023[2]. According to Litman, "The elasticity of transit service expansion (routes into new areas) is typically 0.6 to 1.0, meaning that each 1% of additional transit vehicle-miles or vehicle-hours increases ridership 0.6-1.0%, *ceteris paribus*, although much lower and higher response rates are also found (from less than 0.3 to more than 1.0)." (p12). Litman has also noted some lower elasticities; for example, for a 100% increase of peak-period feeder buses, only 29% increase occurred in ridership (Fehr & Peers 2004).[3]

Daniels and Mulley (2012) have shown how the bus frequency, bus ridership and bus network coverage trade off in public transport service provision can be approached by loading up kms/hrs on better used trunk routes and using freed up kms/hrs to provide coverage through a more flexible system, commonly involving smaller vehicles and, sometimes, different (cheaper) drivers.

Following, Ho and Mulley (2014) examined capacity and frequency of Metrobuses in Sydney to identify the impact on Metrobus ridership changes. The statistical evidence in their study shows that the service level increase for Metrobus is more elastic, in a range of 0.6 to 1 level for growing patronage in Metropolitan fringe areas where the service level was relatively low. However, the same cannot be said for inner areas where the total boarding rate along the Metrobus corridor is already at a high level, and hence the response to service frequency increase is weaker with a resultant lower direct elasticity.

Hensher and Li (2012) studied ridership drivers of bus rapid transit (BRT) across a large number of countries and estimated a mean headway elasticity of -0.294. This headway elasticity is equivalent to a service frequency per hour (=60/headway) elasticity of 0.299. This means that a 100% increase in BRT frequency would increase BRT ridership by about 30%. Similarly, Alam et al. (2018) studied travel demand by bus using data covering the US Metropolitan Statistical Area Level and found a direct elasticity for average headway of -0.227 for bus, equivalent to a service frequency per hour elasticity of about 0.26 on ridership. Daldoul et al. (2016) argue that the elasticity for bus service quality can be summed up in the direct elasticity of service frequency, being lower at about 0.2 in the short-run and higher in the long run at about 0.4.

In summary, the direct elasticity of bus service frequency can range from 0.2 to 0.7, with many studies noting the range of 0.6 to 0.7. However, the actual elasticity response is very much dependent on the services and areas involved. Past studies have revealed a lower direct elasticity in the range of 0.2 to

---

[1] Drawn from an extensive data base that ITLS has on the many direct and cross elasticities in the transport sector.

[2] https://www.vtpi.org/tranelas.pdf

[3] Fehr & Peers (2004), Direct Ridership Forecasting: Out of the Black Box, Fehr & Peers (www.fehrandpeers.com).

0.4. The variation in elasticity reflects the differences in many factors that have impacts on bus ridership.

If the existing bus service level is already at a high level (i.e., high bus frequency), the impact of increasing service frequency will not be as great as expected (hence at the lower level in the range of the estimated elasticities). If the bus service level is not frequent, service frequency change will make bigger difference on patronage, holding all other changes fixed.

Research on the impact of changing bus frequencies in Western Sydney

Stanley et al. (2022) showed that if we doubled bus services in Middle and Outer Western Sydney (e.g., areas such as Paramatta and Penrith), this will increase bus patronage across whole GSMA bus network by 15% and 23% for 2023 and 2033, respectively (195 million trips to 224 million bus trips in 2023, and 234 million bus trips to 288 million bus trips in 2033) (see Table 2).

Table 2 The Impact on mode trips in the GSMA with a doubling of bus services in the Middle and Outer Western Sydney (in million trips) (Stanley et al., 2022)

	Year	Base Value	Project Value	Percent (%)
Bus travel (million trips)	2023	195	224	14.9
Bus travel (million trips)	2033	234	288	23.4

If there is a 15% increase, based on the Stanley et al. study, we would predict a 3.5 to 4% increase in patronage across the whole of the GSMA network if we follow a stable (linear) direct elasticity, but there is likely to be a greater increase in patronage locally because most of the increase will occur locally (suggested to be around 0.6). These results are obtained from MetroScan (see Appendix), the integrated transport and location strategic model system developed by ITLS (Hensher et al. (2020)).

To further examine the local impact on the Western Sydney bus network, if we increase bus service frequency only in local areas, as tested in MetroScan, a scenario with a 15% increase of bus service frequency in Western Sydney, mainly covering areas in both Parramatta and areas close to Parramatta, found a more substantial local bus ridership increase of 21.2% in the Parramatta area (equivalent to a direct elasticity of 1.4).

Moreover, there is an even more significant increase during off-peak hours (outside 7 am to 9am and 4 pm to 6pm), with a 21.7% increase in bus ridership (equivalent to a 1.45 direct elasticity), compared to a lower elasticity during peak hours between 7 am and 9 am and 4 pm to 6 pm at 18.5% (equivalent of an elasticity of 1.23). This finding on the differences between the peak and off-peak increase aligns with past research by Paulley et al. (2006). The larger impact in outer metropolitan areas echoes Ho and Mulley's findings (2014).

If we extend the OD areas to include Sydney Inner, Sydney South, Sydney East, Sydney West, and North Sydney, which are inner city and CBD areas where people living in Parramatta may travel for work and other activities, the impact of this 15% bus frequency change in Parramatta starts to reduce. The peak-hour bus ridership increase becomes 11.7%, less than the local increase of 21.2% in Parramatta. Similarly, the off-peak bus ridership increase becomes 13.7%, less than the local increase of 21.7%. This finding aligns with previous discussion.

Research on the impact of changing bus frequencies in the GSMA using MetroScan

For the GSMA network, we tested two scenarios:

- Increasing bus service frequency of the GSMA bus network by 15% in 2024, with no further increase in the following years; and
- Increasing bus service frequency of the GSMA bus network by 10% in 2024, with no further increase in the following years.

The current version of the MetroScan system (Appendix) used in the new scenarios, incorporates research undertaken in 2022 and 2023 on the transition to electric cars (Hensher et al. 2021) and work-from-home (WFH) (Hensher et al. 2023) penetration in different location, so it is a later version compared to the system applied when the study by Stanley et al. (2022) was undertaken.

As shown in Table 3, an increase in bus service frequency of 15% is predicted to increase bus ridership by 3.5% to 3.7% from 2024 to 2033. This is equivalent to a direct elasticity of bus demand of 0.24. A 10% increase in bus frequency is predicted to increase bus patronage by 2.43%.

Given that a large part of the bus network in the GSMA exists in the well-serviced inner-city areas, the response is less elastic than increasing service levels with a focus only on metropolitan fringes (e.g., Ho & Mulley 2014).

Table 3 The Impact on bus trips in GSMA with doubling of bus services in the Middle and Outer Western Sydney (in million trips)

		15% bus service frequency Increase of bus network in GSMA		**10% bus service frequency Increase of bus network in GSMA**	
Year	**Base Scenario Annual Bus Trips (in mil)**	**Scenario Annual Bus Trips (in mil)**	**% increase**	**Scenario Annual Bus Trips (in mil)**	**% increase**
2024	186.7	193.2	**3.482%**	191.2	**2.410%**
2025	190.0	196.7	**3.526%**	194.6	**2.421%**
2026	194.0	201.0	**3.608%**	198.7	**2.423%**
2027	198.1	205.2	**3.584%**	202.9	**2.423%**
2028	202.2	209.6	**3.660%**	207.1	**2.423%**
2029	206.4	214.0	**3.682%**	211.5	**2.471%**
2030	210.8	218.5	**3.653%**	215.9	**2.419%**
2031	215.2	223.1	**3.671%**	220.4	**2.416%**
2032	219.1	227.2	**3.697%**	224.4	**2.419%**
2033	223.1	231.4	**3.720%**	228.5	**2.420%**

Concluding Comment

These findings are a reminder of the important role of the bus in metropolitan and suburban areas. It is in the urban context that the bus most obviously fulfils its role as the “workhorse” of passenger movement (Olyslagers et al., 2021). Buses generally form a small percentage of the total volume of vehicles on a carriageway, but they have the ability to carry most of the people travelling. With good design, it is possible to exceed the carrying capacity of some rail-based alternatives. Table 4 (Zhang 2009) provides a reference of transit line capacities under design conditions with BRT based on a maximum frequency of 120-300 transit units / hour, compared to the 51-72 achieved by a standard bus and the 24-48 achieved by LRT. In reality, the capacities of these transit systems vary dramatically because of such factors as operational techniques, depot constraints, demand for public transport, and road conditions.

As Western Sydney continue to expand, the findings in this paper will be relevant when considering the public transport requirements of greenfield estates.

Table 4 Line capacity of main modes of public transport

Mode	Vehicle Dimensions (length × width m)	Transit Unit Capacity (seat + standing spaces)	Minimum Headway (s)	Maximum Frequency (transit units per hour)	Line Capacity
Standard bus	12.00 × 2.50	75	70–50	51–72	3,800–5,400
Articulated bus	18.00 × 2.5	120	80–60	45–60	5,400–7,200
High-capacity bus (BRT)	22.00 × 2.50	160	30–12	120–300	9,000–30,000
LRT (partially separated ROW)	24.00 × 2.65	3 × 170 = 510 or 2 × 280 = 560	150–75	24–48	12,200–26,900
MRT	21.00 × 3.15	10 × 240 = 2,400	150–120	24–30	67,200–72,000

References

Alam, H. Nixon and Q. Zhang (2018) Factors Affecting Travel Demand by Bus: An Empirical Analysis at U.S. Metropolitan Statistical Area Level*, Transportation Research Record,* Vol. 2672, Issue 8, pp 817-826.

Berrebi, S.J., S. Joshi and K. E. Watkins (2021), On bus ridership and frequency, *Transportation Research Part A*, 148, pp140–154.

Brechan, I. (2017), Effect of Price Reduction and Increased Service Frequency on Public Transport Travel*, Journal of Public Transportation*, Vol. 20, No. 1. (http://scholarcommons.usf.edu/jpt); at http://scholarcommons.usf.edu/jpt/vol20/iss1/8.

Daniels, R. and C. Mulley (2012) Planning Public Transport Networks—The Neglected Influence of Topography*, The University of Sydney, Journal of Public Transportation,* Vol. 15, No. 4*.*

Daldoul, M., S. Jarboui and A. Dakhlaoui (2016) Public transport demand: dynamic panel model analysis, *Transportation*, Vol. 43, pp 491-505.

Hensher, D.A. and Z. Li (2012) Ridership drivers of bus rapid transit system*, Transportation,* Vol. 39 (6), pp 1209-1221.

Hensher, D.A., Ho, C., Ellison, R., Liu, W., Wu, E., Schroeckenthaler, K., Cutler, D. and Weisbrod, G. (2020) MetroScan: A quick scan appraisal capability to identify value adding sustainable transport initiatives, invited paper for *Sustainability* special issue*,* Transport Systems for Sustainability: Policy, Planning & Exploitation, guest edited by Rosario Macario & Vasco Reis.
https://www.mdpi.com/journal/sustainability/special_issues/transport_systems

Hensher, D.A., Wei, E. and Liu, W. (2021) Battery Electric Vehicles in Cities: Measurement of some impacts on traffic and government revenue recovery, *Journal of Transport Geography,* 94, 103121.

Hensher, D.A., Wei, E, and Liu, W. (2023) Accounting for the spatial incidence of working from home in MetroScan - an integrated transport and land model system, *Transportation Research Part A (* See also and early version: https://ses.library.usyd.edu.au/handle/2123/27127), 173, 103793.

Ho,C. and C. Mulley (2014)*,* Metrobuses in Sydney: How high capacity and high frequency services are benefiting the Metropolitan fringe*, Research in Transport Economics,* Vol. 48, pp.339-348.

Olyslagers, F., Mulley, C., Nelson, J.D (2021). Bus: From workhorse to thoroughbred. In C. Mulley, J.D. Nelson and S. Ison (Eds.), *The Routledge Handbook of Public Transport* (pp. 171–185). Abingdon: Routledge.

Paulley, N.R., R. Balcombe, R. Mackett, H. Titheridge, J. Preston, M. Wardman, J. Shires, and P. White (2006). The Demand for Public Transport: The Effect of Fares, Quality of Service, Income and Car Ownership. *Transport Policy*, 13, pp 295-306.

Stanley, J., D. A. Hensher, E. Wei and W. Liu (2022) Major urban transport expenditure initiatives: where are the returns likely to be strongest and how significant is social exclusion in making the case. *Research in Transport Business and Management*, 43, 100731

Taylor, B.D., D. Miller, H. Iseki and C. Fink (2009) Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas*, Transportation Research Part A,* Vol. 43, pp 60-77.

Zhang, M. (2009) Bus versus rail meta-analysis of cost characteristics, carrying capacities, and land use impacts, *Transportation Research Record*, No. 2110, pp. 87–95.

Appendix

The MetroScan Structure

One of the most important features of comprehensive land use and transport planning is an ability to identify candidate projects and policies that are adding value to the sustainable performance of transport networks and to the economy as a whole. There is a case to be made for having a capability to undertake, in a timely manner, a scan of a large number of potentially worthy projects and policies that can offer forecasts of passenger and freight demand, benefit–costs ratios and economy-wide outcomes. Such a framework would then be meaningful in the sense of offering outputs that are similar to those that are the focus of assessments that are typically spread over many months, if not years, on very few projects, which may exclude those which have the greatest merit. We named the system MetroScan Transport Infrastructure, or MetroScan for short. MetroScan, a strategic-level transport and land use planning application system allows for mapping of passenger and freight activity, as well as an endogenous treatment of the location of households and firms. In short, MetroScan is all-in-one forecasting and scanning system enabling us to conduct quick forecasting on the demand characteristics for cars, public transport, freight activities, and many other travel demand characteristics.

Figure 1 shows how the macro generator works by taking inputs from existing transport models, such as the road and public transport network, and any OD matrices for the starting year to be used as a base, then uses the network travel times and distances by time of day. Characteristics of households, such as dwelling, household types, or car ownership, in synthetic data carry sociodemographic and behavioural elements into the system. The scheme also uses some defaults for values and distributions to fill in gaps when input data or models do not support such information (e.g., population growth rate or inflation rate). One of the central features of the macro generator is the adoption of macrozones. These macrozones can be predefined using the standard zone definition (e.g., from the Australian Bureau of Statistics), but can also be manually defined in the system. The macro generator can aggregate any OD skims to the macrozone layer. If executed outside the system, this would be a difficult task that can require months to correct. MetroScan has this process automated so changes to any OD skim matrices can be contemplated on the macrozone level when a proposed initiative is being processed. To provide further background, the macro generator applies a data manager to manage imported networks from different origins, such as TRANSCAD, VISUM, EMME, CUBE, and other systems. While preserving the accuracy for fast scanning, the macro generator largely reduces many detailed zones to a manageable number of macrozones, including the ones made by users. By doing so, initiatives under investigation can be assessed very fast in order to generate forecasting results from travel demand and economic impact. A trade-off exists between computation time and accuracy due to the detailed level of the macrozone. For example, in Sydney, there are over 3000 detailed zones in the transport network. In practice, we would apply 60 macrozones, which could satisfy both accuracies of forecasting and efficiency of the computation process. In reality, the forecasting results for major macro zones would also provide more meaningful and actionable insights for policymakers. Many strategic initiatives also start with higher levels of macrozones and request scanning results at the same level from travel demand to economic impact factors.

MetroScan was designed to apply synthetic households as units to gain numerous responses to alterations in the system driven by both broad and in-depth policy measures as presented in Figure 2. MetroScan applies a large number of choice models on both the macro and micro level, including behavioural aspects, providing more behavioural realistic market responses robust in contrast to traditional model systems. MetroScan processes and delivers forecasts for different modes, travel purposes, and time-of-day choices for medium to long-term decisions up to 20 to 30 years (i.e., currently forecasting up to 2056). It also suggests long-term decisions or choices on vehicle types, fleet size, vehicle technology, residential and work locations, job and firm growth areas, dwelling types, and many others. Besides forecasting commuting, non-commuting trips, such as personal business and social purposes, and business trips, light commercial vehicle, and freight commodity models support business activity responses by location, volumes, and trips at macrozone levels.

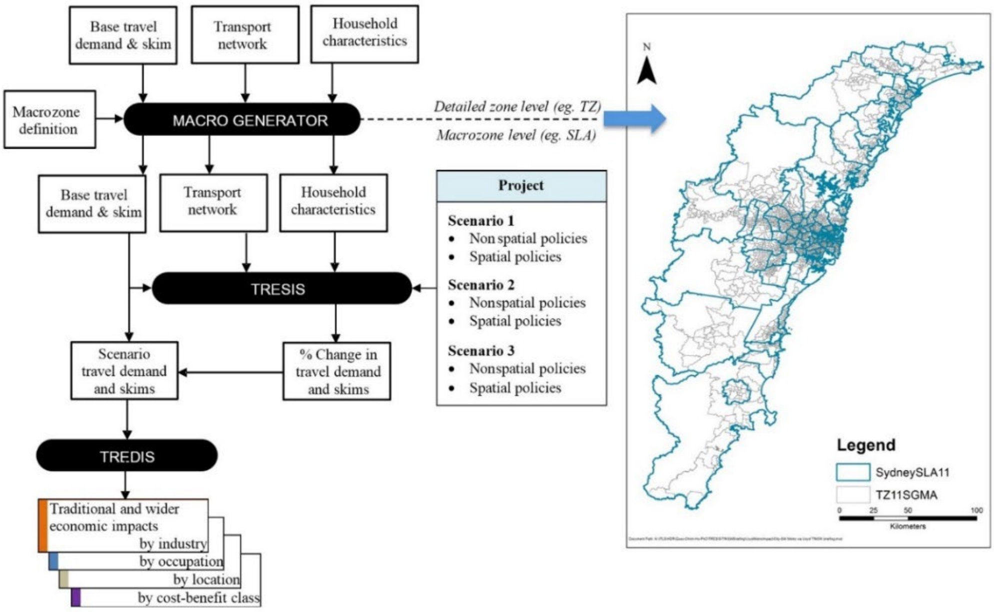

Figure 1. MetroScan framework.

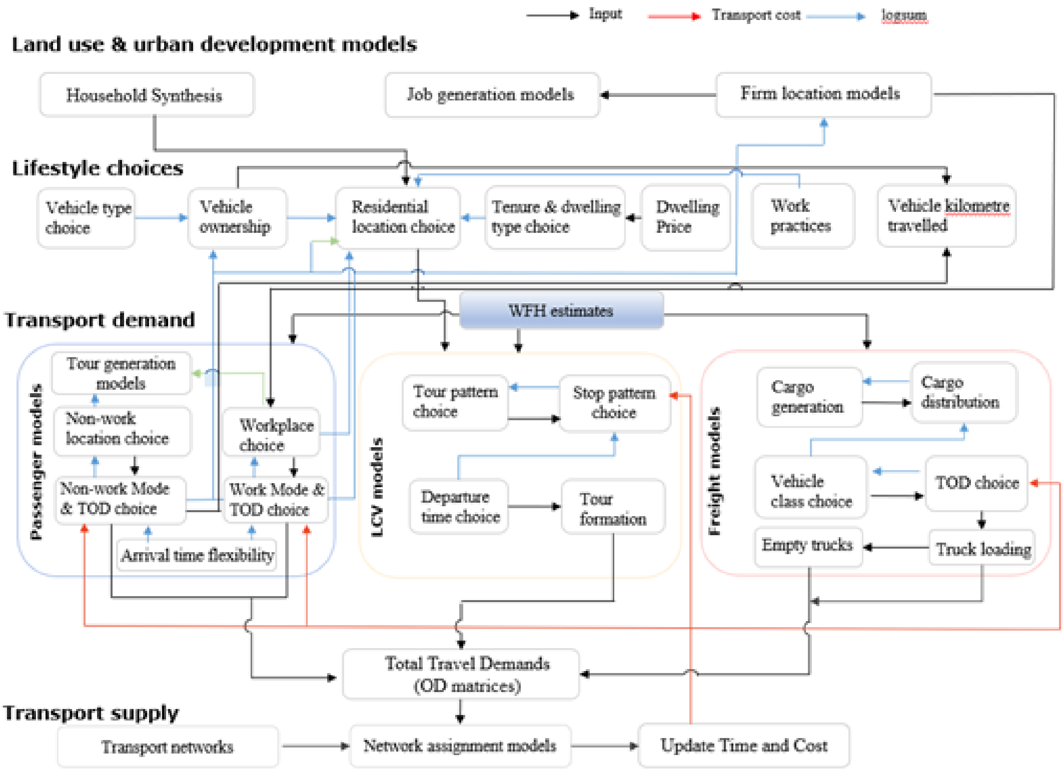

Figure 2. The demand-side behavioural model system for passenger, light commercial, and freight travel activity and the benefit-cost analysis (BCA) and economic impact modules. Source: Hensher et al. (2020).