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Urban Impacts of Accessibility – Brisbane's Green Bridges Program

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Abstract

A common practice in transport economic evaluation is to include potential changes in land use arising from the implementation of transport projects. Typical practice is to use a deterministic process to ascertain the land use change and apply an assessment of the value uplift. In the economic analysis of the Green Bridges Program (GBP) in the City of Brisbane, second-round transport benefits (conventional transport benefits that have been recalculated after allowing for land use changes) have been used. It is proposed that this offers a reasonable and sound methodology for ascertaining additional economic benefits arising from a project, being based upon empirical relationships within the existing urban form and allowance for external factors such as constraints within the Brisbane CityPlan.

1. Introduction

In the last 20 years, transport project evaluation has included reference to other economic benefits beyond simple benefits arising from changes to transport networks such as reduction in travel time, operating costs, accidents and pollution. These wider economic benefits have included changes to land use and property values and formal wider economic benefits.

The land use impacts of transport changes and greater accessibility have focused on the economic impacts of converting a land use to another land use and the changes in property values that may arise from it (Litman 2022). Part 8 of the Australian Transport Assessment and Planning (ATAP) Guidelines provides guidance on the land use benefits of transport initiatives. ATAP describes land use benefits arising from transport as higher value land use, 'second-round' transport demand changes (eg. induced demand), infrastructure cost impacts, public health benefits, sustainability impacts, and WEBs (ATAP 2021).

This paper first shows land use methodologies as they have been used in medium size public transport projects. The paper then shows how a methodology to assessing second round transport benefits was applied to the economic analysis of Brisbane City Council's Green Bridges Program and the results of that assessment. and considers whether this is a more defensible approach to estimating wider benefits from transport initiatives.

2. Land Use Benefit Analysis

Brisbane's Green Bridges Program is the first instance where a walking and cycling project in Australia that has encompassed land use considerations. Three public transport projects of comparable value have been reviewed: Canberra Light Rail Stage 1 and Stage 2 and Gold Coast Light Rail Stage 3. Publicly available information on the methodologies is limited.

2.1 Canberra Light Rail Stage 1

The key land use benefits used for the Capital Metro Business Case included the urban densification benefits, land value benefits, and infrastructure efficiency savings. Urban densification included a change in housing stock formation (from greenfield low-density housing to brownfield medium density apartments) and agglomeration and productivity benefits. The largest gain is an anticipated increase in the value of the use of the land along the corridor. The project benefits are summarised as follows:

Table 1: Summary of Canberra Light Rail Economic Evaluation

Project Benefit	PV ($m) of each element	Cumulative ($m) PV	BCR*
Transport	406	406	0.5
Land Use	381	787	1.0

*Total PV of costs $823 million

The benefit of realizing higher density was calculated from the market value of new land use, less the market value of existing land use, less developer costs. Infrastructure efficiency savings were calculated by the difference in the cost of infrastructure and services in urban infill compared to a greenfield area.

2.2 Canberra Light Rail Stage 2

In the Stage 2a and 2b economic analysis, a slightly different approach was used. The project case assumes that the light rail investment will unlock accelerated growth of population and employment in the light rail corridor at the expense of growth elsewhere (ACT Government 2019). However, as the ACT Auditor General pointed out, there is no further information provided in the draft Economic Appraisal Report in relation to the development costs, the methodology for quantification and the assumptions underpinning the calculation (ACT Auditor General 2021 p4).

Table 2: Summary of Canberra Light Rail Stage 2A and 2B Economic Evaluation

Project Benefit	PV ($m) of each element	Cumulative ($m) PV	BCR*
Transport	349	349	0.3
Land Use (City Shaping Benefits)	402	751	0.6

*Total PV of costs $823 million

2.3 Gold Coast Light Rail Stage 3

A further recent example of land use being incorporated into the project justification is the Broadbeach to Burleigh Heads of the Gold Coast Light Rail Project (Stage 3). The project is presented as a catalyst for growth within the corridor. The Business Case Summary (Building Queensland 2019) presents a first and second round analysis without explaining what this is. The second round includes “urban renewal benefits” of $599 million. It is not revealed how this was calculated but includes “potential increase in property values” and “protection of regional greenspace by concentrating development in the serviced area”. This implies a projected land use change and an increase in per square metre value of that property uplift. This property uplift could be the time and operating cost savings already counted in the transport benefits capitalised into land value with a risk of falling into double counting.

Table 3: Summary of Gold Coast Stage 3 Light Rail Economic Evaluation

Project Benefit	PV ($m) of each element	Cumulative ($m) PV	BCR*
Transport	1,353	1,353	2.0
Land Use	599	1,952	2.9

*Total PV of costs $668 million

3. Green Bridges Program

3.1 The Program

Brisbane City Council’s Green Bridges Program (GBP) is the development of a linked network of strategically located cross-river walking, cycling and micro-mobility bridges across the Brisbane River to enable residents and workers to replace car-based trips with public and active trips. A key objective of the program is to improve access and connectivity between residential and economic activity areas in conjunction with existing river crossings and support long-term network development. Four green bridges are proposed:

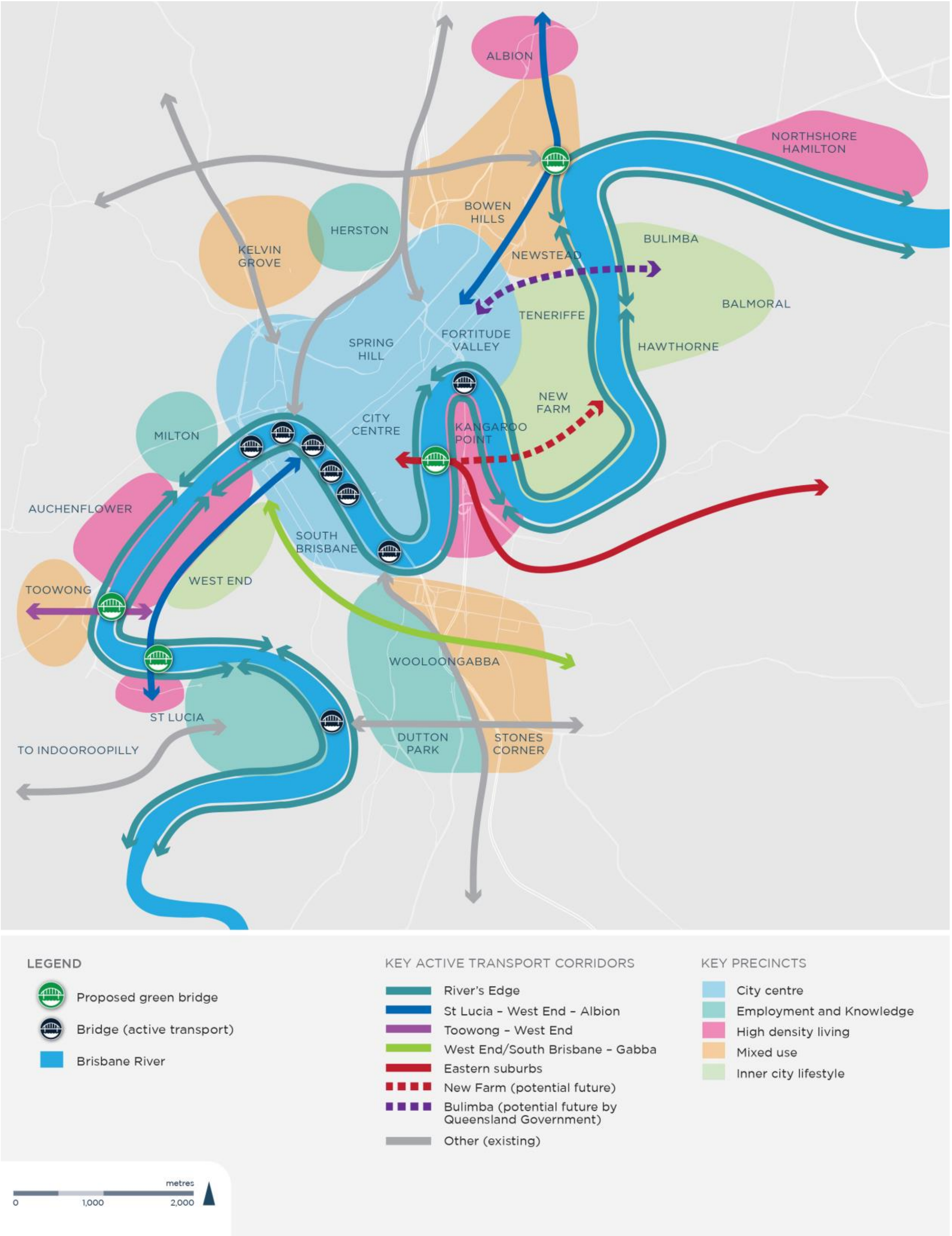
- Across Breakfast Creek in the north on the inner urban area
- Kangaroo Point to Brisbane’s CBD
- Toowong to West End; and
- St Lucia to West End.

Figure 1 shows the interrelationships between the major urban centres, the bridges and the key movement patterns. These bridges also link and expand the catchments of major public transport links and nodes. For instance, the Kangaroo Point to CBD Green Bridge provides accessibility for the very high-density Kangaroo Point peninsula to the Cross River Rail station at Albert Street, providing access for this suburb to suburban and regional rail services for the first time. In the South, West End has immediate access to rail services at Toowong, and St Lucia has access to high frequency bus services (Blue CityGlider) into the high growth employment areas in South Brisbane and the Brisbane CBD.

As part of the Business Case development, a conventional detailed economic analysis was undertaken of the preferred options (walking, cycling and e-mobility[1]) with demand modelling undertaken using the Brisbane Strategic Transport Model V2.1 (BSTM-MM). To improve on the accuracy of the modelling, the Jacob’s Brisbane Cycling Assessment Tool (BCAT) was used to supplement the cycle route choice modelling in BSTM-MM. Two further innovative enhancements to the demand model were the recognition of the recreational value of the bridges with a model developed for recreational cycling and a model developed for e-mobility based upon existing trip patterns of e-scooter hire schemes and estimations of future origins and destination based on expansion of the scheme and increase of the cap on the number of hire e-scooters in the inner city. As well as travel time saving, health benefits from additional walking and cycling were included in the economic model.

[1] As part of the options analysis ‘rapid’ economic analyses were undertaken of the two West End bridges as public transport bridges.

Figure 1: Movement Interrelationships of the Green Bridges within the Inner City



3.2 Conventional Economic Results

The results of the conventional economic analysis were as follows:

Table 4: Conventional Economic Analysis Results

Discount Rate	4%	7%	10%
Total benefits ($M)	621.1	375.4	249.8
NPV ($M)	129.7	-62.0	-146.3
BCR	1.26	0.86	0.63

The total benefits consist of direct user benefits and wider transport network benefits and wider societal benefits. Direct user benefits consist of travel time savings (walking cycling and e-mobility) and perceived health benefits. 39% of the user benefits are generated by travel time savings to new walkers and cyclists (walkers and cyclists diverting from other travel modes), 33% is generated by travel time savings to existing walkers and cyclist), 2.5% is generated by existing and new e-mobility users and 26% is generated by perceived health benefits. User benefits are 23% of the total benefits.

Wider transport network benefits consist of highway decongestion, PT travel time savings, vehicle operating cost savings, accident savings and savings in road network provision. Highway travel time (decongestion) is the single largest benefit stream included in the appraisal. It represents about 54% of the wider network benefits and 49% of total benefits.

Wider societal benefits consist of reduced emissions from reduced private vehicle kilometres and health system benefits due to a more active community. The health benefits dominate, being 78% of the wider societal benefit.

4. Economic Benefit from Land Use Changes

In the estimation of economic benefit, dynamic land use changes are not considered. Population and employment grows whether there is a project or not. However, there will be an effect on population and employment as the greater accessibility to places will draw more people and therefore development into these places. The additional population and jobs combined with a shorter travel time (ie. effective density) will in itself provide additional travel benefits that can be monetised and attributed to the project’s economic case.

The estimation of the impacts of the GBP on land use and its feedback into economic value is based upon developing a broad overall mathematical model of the city shape based upon existing relationships between population density and “centrality” (i.e. how easy it is to get to a job).

It should be noted that the change in land use does not change the overall population and employment of the modelled region ie. Brisbane becomes more competitive than other capitals and regions and therefore experiences greater growth. This would require the combined effort of a number of transport projects of regional significance combined with a number of internal and external factors. Within the constraints of the CityPlan this methodology estimates a redistribution of the future population and employment growth. Some parts of the city may grow at a slower pace than in the base case whilst others, due to the bridges, would accelerate.

For the Green Bridges Program, the approach to estimating the additional benefits of dynamic land use changes involved:

1. calculating the accessibility of each model zone using the travel time by different modes to every other model zone and the level of activity (employment and education enrolments) at the other model zones
2. calculating the centrality of each model zone from the accessibility. This is effectively the weighted average travel time to all jobs and enrolments in the Greater Brisbane modelled area
3. estimating a relationship between density and centrality; essentially a mathematical model that explains the existing city shape.
4. calculating the change in accessibility, centrality and hence equilibrium density between the base and project scenarios for each year
5. adjusting the forecast population, employment and enrolments for the area with improved accessibility in proportion to the change in density
6. estimating the additional travel cost and travel time savings and health benefits deriving from the adjusted population, employment and enrolments for the area and summing these to derive the overall additional economic benefit.

4.1 Estimation Process

In detail, the estimation process involved the following steps:

1. Using Emme, to export 2021 base AM peak period travel times from BSTM-MM 2.1 by mode (car, public transport, cycle and walk)
2. Using KNIME[2] to calculate 2021 base activity (S) for each model zone (j). This has been defined as the sum of total jobs:

$$S_j = \text{total jobs}_j = \text{retail jobs}_j + \text{service jobs}_j + \text{professonal jobs}_j + \text{industrial jobs}_j + \text{other jobs}_j$$

3. Calculating accessibility (X_j) by mode for each origin model zone (i) using a simple gravity model with the cost being the sumproduct of destination model zone (j) activity (S_j) and the Travel Time^2.

$$X_{mode\ i} = \sum_j S_j \times travel\ time_{mode}{}^2$$

4. Using Excel to calculate a combined accessibility for each origin model zone (X_i) using the fixed proportions shown in Table 5 below.

[2] KNIME (Konstanz Information Miner) Analytics Platform is an open-source software for data science workflows. It allows efficient processing of larger data sets than is possible using other software such as Excel or Access. It can be downloaded for free from www.knime.com.

Table 5: Assumed Proportion of Combined Accessibility by Mode

Mode	Proportion (P_{mode})
Car	50 %
Public Transport	30 %
Cycle	10 %
Walk	10 %

$$X_i = \sum P_{mode} \times X_{mode\ i}$$

5. Calculating the total activity (S_{total}) for the entire model area.

$$S_{total} = \sum_j S_j$$

6. Calculating the centrality (Y_i) of each model zone by dividing the accessibility (X_i) by the total model area activity (S_{total}). The centrality is effectively the average travel time to every activity (enrolment or jobs) in the entire modelled area.

$$Y_i = \sqrt[2]{\frac{X_i}{S_{total}}}$$

7. Adjusting the centrality ($Y_{adjusted\ i}$) using the adjustments shown in Table 6 below. The reason for this is that accessibility is not the only influence on density. Amenity such as proximity to the Brisbane River, bayside and cultural facilities is another influence. The adjustments provide some representation of higher amenity that can be spatially quantified. 30 minutes was selected as a proxy to reflect aspiration (ie. 30 minute city).

Table 6: Centrality Adjustment by Location

<table>
<tr><th>Location</th><th>Adjustment ($Y_{adjustment}$)</th></tr>
<tr><td>CBD</td><td rowspan="3">-30.0 minutes</td></tr>
<tr><td>River</td></tr>
<tr><td>Bayside</td></tr>
</table>

$$Y_{adjusted\ i} = Y_i + Y_{CBD\ adjustment\ i} + Y_{River\ adjustment\ i} + Y_{Bayside\ adjustment\ i}$$

8. Using GIS, calculating the developable area of each model zone by land use type using:
    - City Plan Level 2 (for model zones inside Brisbane City)
    - ABS Mesh Block Category (for model zones outside Brisbane City).
9. Calculating the developable area of each model zone ($Area_{developable\ i}$). Tables 7 and 8 below show the land use types that were considered to be developable for City Plan Level 2 Zones and ABS Mesh Blocks respectively. This split is partly subjective as some land use may in practice become developable if accessibility or centrality was significantly increased. For example, "Rural" or "Primary Production" areas on the urban fringe may well become developable as the transport network is improved. However, this is less of an issue for this project which is focussed on the inner city.

Table 7: Assumed City Plan Developable vs Non-Developable Level 2 Zones

Developable	Non-Developable
Character residential (Character), Character residential (Infill housing), Community purposes, District centre (Corridor), District centre (District), Education purposes, Emergency services, Emerging community, Extractive industry, General industry A, General industry B, General industry C, Health care purposes, High density residential (Up to 15 storeys), High density residential (Up to 8 storeys), Industry investigation, Low density residential, Low impact industry, Low-medium density residential (2 or 3 storey mix), Low-medium density residential (2 storey mix), Low-medium density residential (Up to 3 storeys), Major centre, Major health care, Medium density residential, Mixed use (Centre frame), Mixed use (Corridor), Mixed use (Inner city), Neighbourhood centre, Principal centre (City centre), Principal centre (Regional centre), Priority Development Area - Part 10 of Brisbane City Plan 2014, Rural residential, Special industry, Special purpose (Airport), Special purpose (Defence), Special purpose (Detention facility), Special purpose (Port), Special purpose (Transport infrastructure), Special purpose (Utility services), Specialised centre (Brisbane Markets), Specialised centre (Entertainment and conference centre), Specialised centre (Large format retail), Specialised centre (Major education and research facility), Specialised centre (Marina), Specialised centre (Mixed industry and business), Tourist accommodation, Township	Cemetery, Conservation, Conservation (District), Conservation (Local), Conservation (Metropolitan), Environmental management, Major sports venue, Open space, Open space (District), Open space (Local), Open space (Metropolitan), Rural, Sport and recreation, Sport and recreation (District), Sport and recreation (Local), Sport and recreation (Metropolitan)

Table 8: Assumed City Plan Developable vs Non-Developable Mesh Block Categories

Developable	Non-Developable
Commercial, Education, Hospital/Medical, Industrial, Residential, Transport	Other, Parkland, Primary Production, Water

10. Calculating the 2021 base equivalent population of each model zone ($Population_{equivalent\ i}$) using the population equivalences ($Population\ Equivalence_{Demographic}$) shown in Table 9 below.

Table 9: Population Equivalences

Demographic	Population Equivalent ($Population\ Equivalence_{Demographic}$)
Population	1
Retail Jobs (retail, service, professional, industrial, other)	0.5

The 0.5 factor applied to jobs represents how much space a job occupies compared to a resident. Simple example – an office worker may use roughly 20 m2 of space (Arup 2001). In the absence of more local data, New South Wales data has been used. The minimum floor area for a one-bedroom apartment in New South Wales is 50 m2 based on the net area (NSW Department of Planning and Environment, 2015). The average occupancy of a one-bedroom apartment in New South Wales was 1.44 persons in the 2021 census. The minimum area per person would then be 35 m2. This was rounded up to 40 m2 to approximate the gross area allowing for common areas leading to the conclusion that a job is equivalent to 0.5 people.

$$Population_{equivalent\ i} = \sum Population\ Equivalence_{Demographic} * \ Demographic_i$$

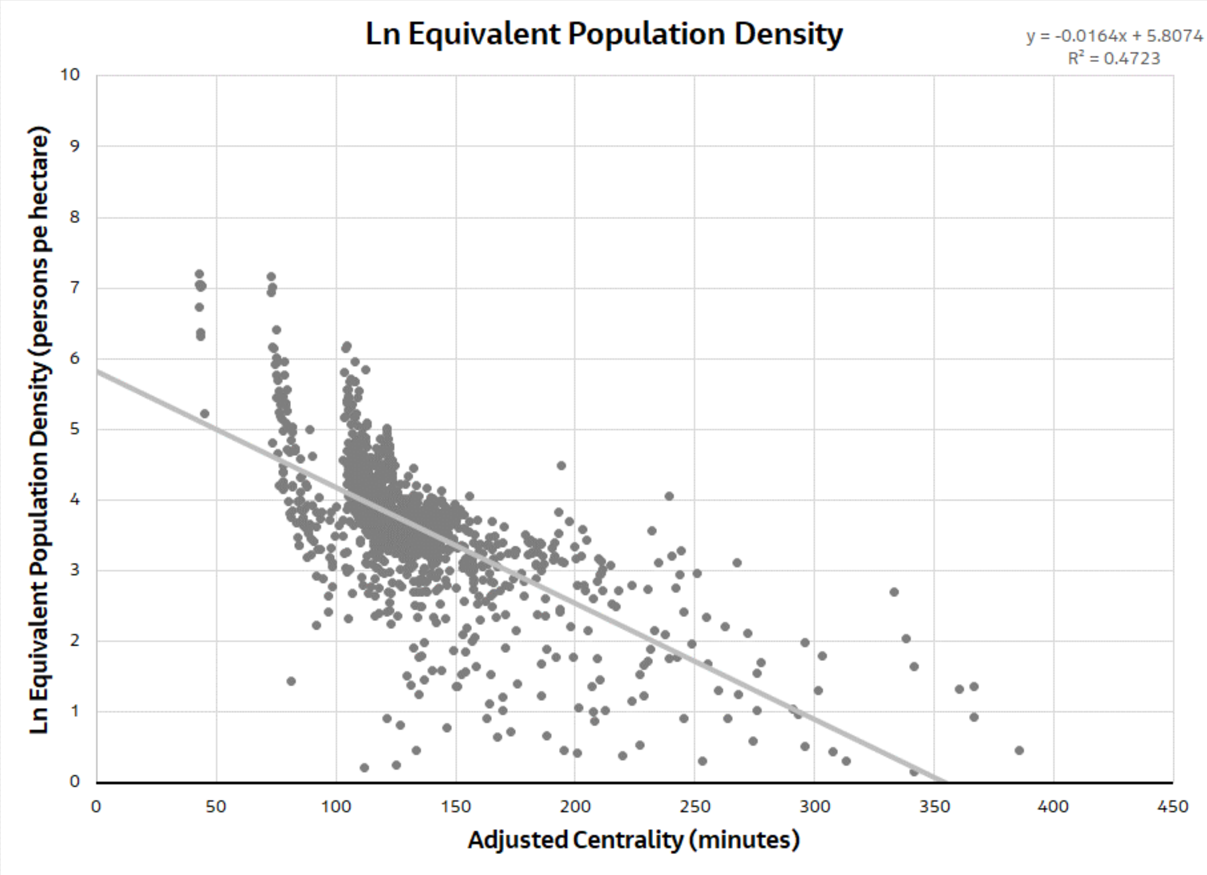
11. Calculating the 2021 base population equivalent density (D_i) of each model zone

$$D_i = \frac{Population_{equivalent\ i}}{Area_{developable\ i}}$$

12. Determining the relationship between population equivalent density and adjusted centrality. The population equivalent density (D_i) was plotted against the adjusted centrality ($Y_{adjusted\ i}$) as shown in Figure 3 below. Each point represents a model zone. Some model zones were excluded from this analysis for the following reasons:

- Model zones where the land use is expected to continue to be unaffected by accessibility considerations. This includes major cultural and sporting facilities (eg Gabba, QPAC) as well as major parks (eg Roma Street Parklands, Mt Coot-tha)
- Model zones that are currently underdeveloped and/or under development eg. the previous go print site in Woolloongabba that is being redeveloped as part of the Cross River Rail project.

Figure 3 Equivalent Population Density vs Adjusted Centrality



The line of best fit has a slope of -0.0164 and a constant (K) of 5.8. This is equivalent to:

$$\log D = -\frac{\sigma}{S^{\frac{1}{2}}} \times Y_{adjusted\ i} + K$$

where:

$$\sigma = 18.9$$
$$K = 5.8$$

Table 10 below compares these estimated parameters with those estimated in previous studies Bornhorst Ward Veitch (1990) and Davidson (1994) The estimated parameters are similar to those estimated previously, particularly the 1990 Brisbane Traffic Study line (a), even though this estimation has also considered walk and cycle times and has used newer demographic and land use data. Even though there has been significant transport investment and land use change between analysis years, the relationship between land use and transport appears relatively stable.

Table 10: Line of Best Fit Parameter Comparison

Parameter	2021 Green Bridges	2006 BSD Transport Accessibility Analysis Data Generation		1990 Brisbane Traffic Study	
		1	2	(a)	(b)
Travel cost impedance power (n)	2.0	2.0	2.0	2.5	2.5
Public transport contribution	30%	45 %	45 %	35 %	35 %
Cycle contribution	10 %	Not considered	Not considered	Not considered	Not considered
Walk contribution	10 %	Not considered	Not considered	Not considered	Not considered
Job person equivalence	2	2.1	2.1	1.667	1.667
Log of Maximum Density (K)	5.8	6.187	7.557	5.8	7.11
Slope (σ)	18.9	44.4	54.5	23.5	35
R^2	47.2 %	56.2 %	63.9 %	Not reported	Not reported

The line of best fit is effectively the equilibrium line. Zones above the line may be considered to be over-developed (i.e. their density is higher than their accessibility/centrality would suggest). Zones below the line may be considered to be under-developed.

Accessibility, centrality and adjusted centrality were calculated for the 2031 and 2041 base and project scenarios using the process described in the previous section. The following steps were then followed:

- The change in equilibrium population density was calculated between the base and project scenarios for each year
- The forecast population, employment and enrolments for the areas with improved accessibility were adjusted in proportion to the change in equilibrium density
- The forecast population, employment and enrolments in the rest of the modelled area were reduced to maintain the same global totals
- BSTM-MM was rerun with the adjusted demographic forecasts as a land use sensitivity test.

4.2 Results

The following figures demonstrate the results from applying the methodology:

- Figure 4 - Centrality 2041 Base - below shows the base centrality. Lower (greener) values are more accessible with a lower centrality value representing a weighted distance to activities (jobs). Inner city areas have lower centralities due as they are close to jobs within the CBD but also has good road, public transport and active transport access to jobs outside the CBD.

- Figure 5 – Change in Centrality 2041 Program – below shows the change in centrality between the 2041 Base and 2041 Program scenarios. The Green Bridges increase accessibility and lower the centrality in areas either side of the bridges but particularly West End, Kangaroo Point, St Lucia, Toowong, Brisbane City and, to a lesser extent, areas to the east along Wynnum Road and to the west along Moggill Road. The change is smaller to the north-east along Kingsford Smith Drive.
- Figure 6 – Change in Population 2041 Program and Figure 7 – Change in Jobs 2041 Program – shows the calculated increase in population and jobs, respectively, that may be possible from the increased density that the improved accessibility supports. The largest increases are in Brisbane CBD and West End.

Figure 4: Centrality 2041 Base

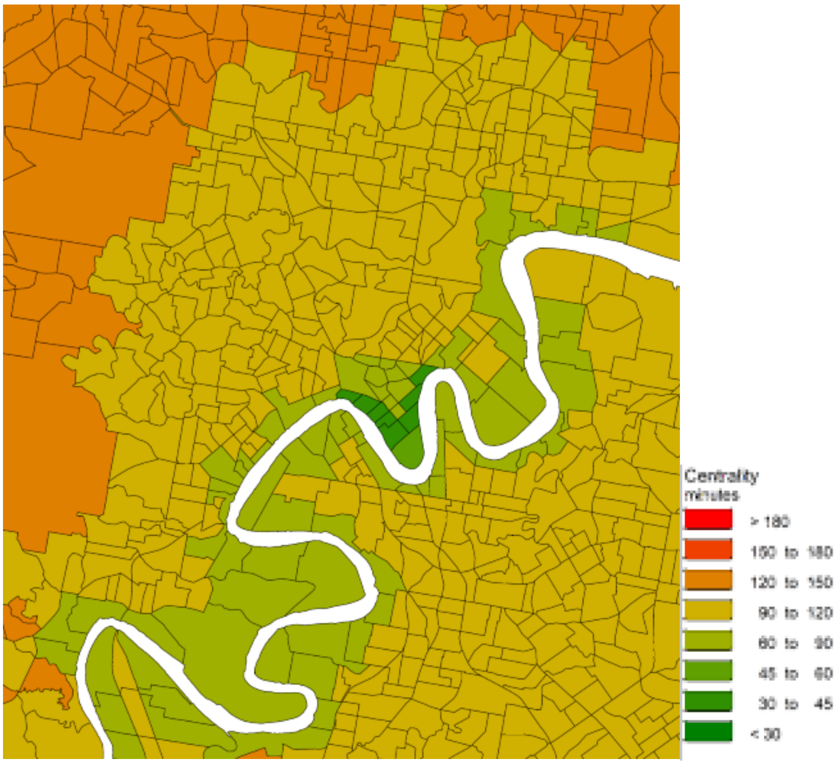


Figure 5: Change in Centrality 2041 Program

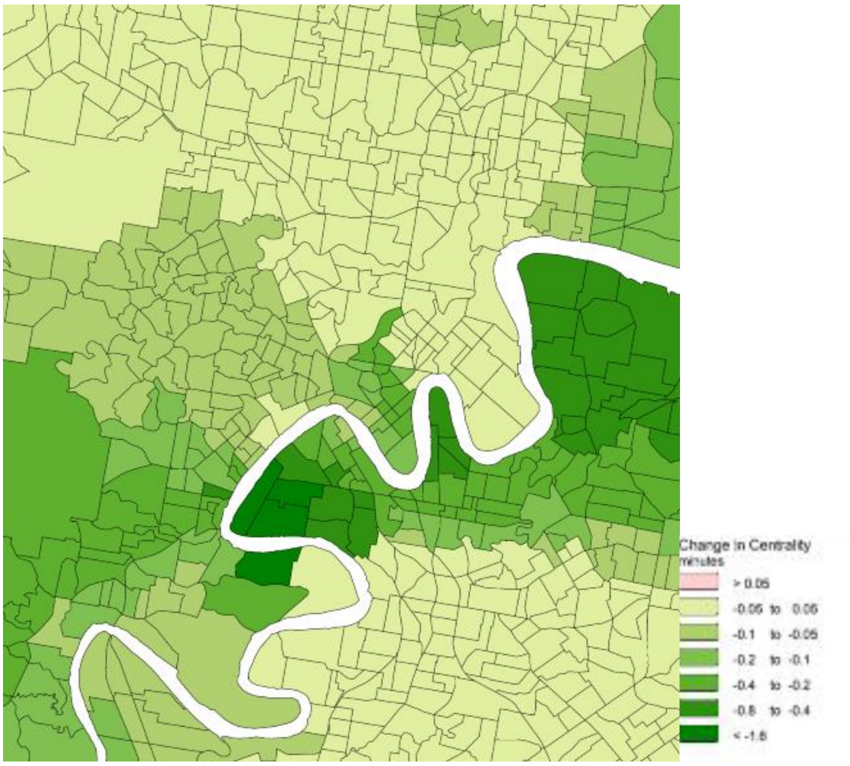


Figure 6: Change in Population 2041 Program

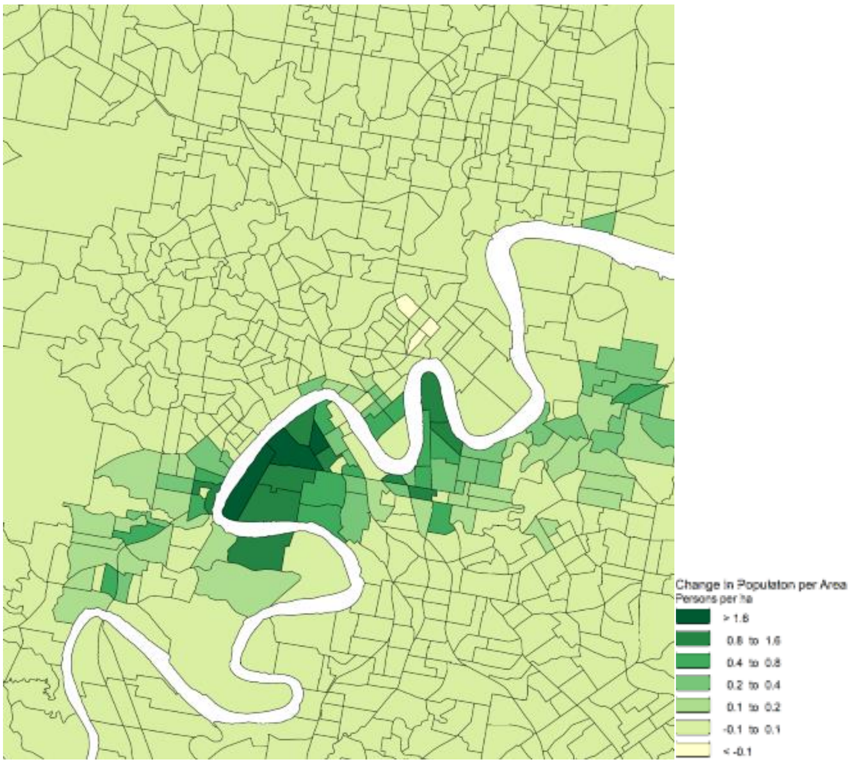


Figure 7: Change in Jobs 2041 Program

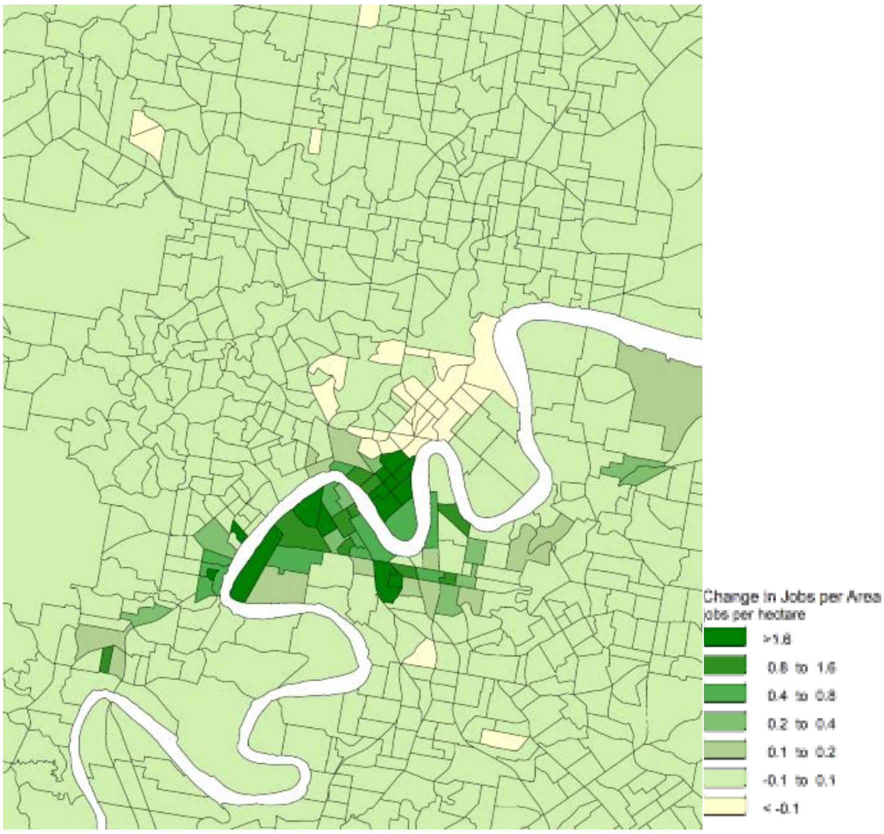


Table 11: Forecast Land Use Travel Changes

Mode	Project Case		Project Case With Land Use	
	2031	2041	2031	2041
Change in daily trips by mode				
Car driver	-4,120	-4,362	-6,337	-7,232
PT	-2,299	-2,004	-1,018	-1,534
Cycle	665	797	701	818
Walk (excluding walk access/egress to PT)	4,919	5,986	6,110	7,315
Change in daily vehicle and passenger kilometres travelled				
Car	-31,000	-30,762	-49,417	-56,364
PT	-6,363	-8,954	-1,142	-2,297
Cycle (excluding recreational trips)	3,387	4,076	3,444	4,060
Walk	8,131	9,852	9,135	11,009
Change in daily vehicle and passenger hours travelled				
Car	-1,108	-1,138	-1,736	-1,987
PT	-527	-690	-319	-422
Cycle (excluding recreational trips)	147	176	146	170
Walk	1,626	1,970	1,827	2,202
Daily bridge patronage				
Cycle	4,899	5,828	4,919	5,852
Walk	10,123	13,013	10,416	13,137
E-wheeling	926	1,218	926	1,218
TOTAL	15,948	20,059	16,261	20,208

4.4 Additional Economic Impact

The GBP increases accessibility and lowers the centrality in areas either side of the bridges but particularly West End, Kangaroo Point, St Lucia, Toowong, Brisbane City and, to a lesser extent, areas to the east along Wynnum Road and to the west along Moggill Road. The change is smaller to the north-east along Kingsford Smith Drive. Population changes relative to the central case are largest in the Brisbane CBD and West End.

The impact of including land use change within the cost benefit analysis is shown in Table 12 below. The GBP is forecast to generate shifts in settlement patterns and employment nodes that bring people closer to where they work, study or play. Overall, the monetised impact is significant, with total benefits increasing by $121.5 million, thus turning the NPV positive ($59.5M) and pushing the BCR above 1 (1.14). The contribution to the change in benefits is almost entirely driven by wider transport network benefits as the change in settlement patterns and employment locations drives a significant increase in public transport trips and mode share (including walking to public transport) and associated reduction in private vehicle kilometres travelled.

Table 12: Economic Results with Land Use Change applied ($M, 7% discount rate applied

Category	Project Case	With Land Use Change
Active travel time savings (New users)	33.3	33.8
Active travel time savings (Existing users)	28.2	28.3
E-wheeling travel time savings	2.1	2.1
Active travel health benefits	22.8	35.5
Total direct user benefits	**86.4**	**99.8**
Highway de-congestion	74.9	106.8
Public transport travel time savings	23.6	24.5
Vehicle operating costs	49.3	80.0
Accident savings	-2.7	23.3
Road network provision savings	8.0	13.0
Total wider transport network benefits	**153.1**	**247.8**
Reduced emissions	20.7	32.0
Health system savings	71.9	74.1
Total wider societal benefits	**92.6**	**106.1**
Total other benefits	43.2	43.3
Total benefits	**375.4**	**496.9**
NPV	**-62.0**	**59.5**
BCR	**0.86**	**1.14**

4.0 Conclusion

Where land use benefits have been used in economic evaluations a 'static' and deterministic approach has been used. Assumptions about a future state of land use that is consequent to the transport investment.

The methodology presented here presents a dynamic approach and recognises that transport projects have the ability to change effective density and that additional benefits accrue from changes in employment and population.

This paper offers a methodology that recognises the dynamics of land use albeit with constraints of current urban plans. Therefore it may provide a more robust way for measuring extra benefits from transport projects, but which are conservative and possibly more defensible than other methodologies.

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