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Rivers as barriers to mobility in Australian cities

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Abstract

Rivers are a major barrier to mobility in many Australian cities. A lack of river crossings can result in reduced accessibility, higher travel times for cross river journeys, and added congestion on routes to and from widely spaced bridges and tunnels.

Brisbane, the case study of our paper, is a case in point. While Brisbane has a total of 46 car lanes crossing the river, 28 of these are in and around the CBD. To the east of the CBD there are 22 kilometres of river, with only one crossing location (12 lanes at the Gateway Bridge). West of the CBD, there are two bridges (a total of 6 lanes), covering 45 kilometres of river.

As a result, many drivers crossing the river are forced to detour into the inner city, which results in extremely inefficient use of the road network.

In recent years, the total capacity of Brisbane River crossings has been increased by 14 car lanes, through the construction of the Gateway Bridge duplication, Clem7 and the Go Between Bridge. All of these projects bolster capacity at existing crossing locations, rather than breaching the river with new connections.

In this paper, we use travel modelling to assess the benefits of these recently implemented projects in comparison with a range of other potential crossing locations. We show that the creation of new crossing locations would be more effective than bolstering capacity at existing locations. These findings relate not only to Brisbane but to all cities which are separated by a physical mobility barrier and provide general insight into efficient and strategic placement of infrastructure.

1. Introduction

Brisbane has a total of 46 car lanes crossing the Brisbane River. However, 28 of these are in and around the CBD.

This means that more than half of the river crossing road lanes in Brisbane passes through an area within 1.40 km of City Hall, and within 2.54 km of each other (direct distance, as per Figure 1 below). The most distant of Brisbane's bridges are 29.4 km apart, leaving a vast length of river to be serviced by the remaining road lanes. This also means that 52% of river crossings place drivers on roads in or near to the CBD, which are already stressed by car and PT trips with origins or destinations in the CBD. The separation between the bridges causes multiple economic impacts, as it increases the distance that vehicles must travel to get to and from a river crossing.

Figure 1: Proximity of River Crossings in the CBD Area

Image background source: Google Maps 2013

To the east of the Story Bridge (and the CBD) there is only one crossing location (the Sir Leo Hielscher Bridges), which is 6.8 km away (as the crow flies). This forces all traffic crossing the river between these locations to travel either through crossings in the CBD area (Captain Cook Bridge, Story Bridge or Clem7 Tunnel) or to the Gateway Motorway.

Alternatively, to the south-west of the Go Between Bridge (and the CBD), the closest crossing is the Walter Taylor Bridge which is 5.5 km away and provides only two lanes. The Centenary Bridge, which provides four lanes, is 3.65 km from the Walter Taylor Bridge, or 9.15 km from the Go Between Bridge. This leaves almost 10 km with only 6 lanes of river crossing, meaning that the traffic from densely populated areas along the river south-west of the CBD, the southern suburbs and Ipswich are left with few options to cross the river.

This issue has been compounded by the trend of building crossings in close proximity to others, such as the Go Between Bridge, which is only approximately 380 m from the William Jolly Bridge, Clem 7 which goes under the Story Bridge, or the Sir Leo Hielscher Bridge, which was duplicated. The results of this are that Brisbane has five crossings within 2.54 km of each other, and only another five to cover the rest of the almost 30 km between the two most distant crossings, one of which is the Moggill Road Ferry. This trend increased the capacity crossing the river, but failed to reduce the distance that must be travelled to reach a river crossing.

This paper quantifies, through the use of strategic transport modelling, the benefits that could be made through building small bridges at strategic locations long the Brisbane River. It will cover the trip length and travel time savings that the new bridges provide. It will also cover the resultant economic benefits from reducing the following indicators:

- Travel times costs;
- Vehicle operating costs (fuel consumption, tires, oil, etc.);
- Traffic accident costs;
- Vehicle emissions (greenhouse gasses and pollutants).

There is considerable literature and numerous government publications available on methodology for, and providing data for, economic evaluation and cost-benefit analysis.

This analysis was performed using an Economic Assessment Model which is implemented within the Zenith transport model. This model is consistent with the Austroads' "Guide to Project Evaluation" (2009) and the Australian Transport Council's "National Guidelines for Transport System Management in Australia" (2006).

2. Literature Review

The premise that achieving a reasonable spread of barrier crossings improves the efficiency of a transport network is not new, however literature on this topic is sparse. The benefits of providing well-spaced river crossings are obvious due to the inherent improvement to the directness of travel. Yet, these benefits are difficult to quantify without the use of models due to the scale of transport networks, and the complex nature of transport costs.

In "The Optimal Locations of Multiple Bridges, Connecting Facilities, or Product Varieties", Braid, R. (1989) examines the problem of the optimal locations and number of bridges from a theoretical and mathematical point of view. This analysis uses a one dimensional model of travel from one side of a river to the other to optimise the number and location of bridges by minimising the total travel distance of road users.

Braid, R. found that optimally bridges should have even spacing, which is certainly not the case in Brisbane or many other cities. However this finding is not directly applicable to cities as the simplifications (used in the model) do not reflect the actual cost of travel, the non-homogenous population and employment density, and actual road networks. The model used assumes that travel distance represents cost, while actual travel costs involve operating costs, travel times, fares, and other things. Furthermore, these factors are dependent on transport network which has different modes, road standards, and congestion. Finally, the model assumed that population and employment was evenly distributed, while densities usually increase with proximity to the CBD. Many of these factors tend to give advantage to bridges which are situated closer to the CBD, where more people are working, and the public and road transport network tends to be of higher quality.

However, even with these factors considered, Braid's research still provides an important guide as to the efficiency that is offered by numerous and well-spaced bridges.

This paper aims to further Braid's research using a strategic transport model to test the efficiency gains offered by providing additional well-spaced bridges in a city with CBD-centric river crossings. The use of a strategic transport model is important as it inherently includes and accounts for the factors mentioned above.

The importance of spaced bridges is also supported by Zhu, S., et al (2010) in their analysis of the traffic disruption caused by the collapse of the I-35W Mississippi River Bridge. The authors found that the loss of the bridge caused an average increase in commute time of 3.2 minutes per month (compared to 3.21 weeks after the collapse, suggesting convergence). There was also a 14.29% rate of trip cancellation in trips affected by the collapse, a 61% rate of destination avoidance, and a 75% rate of change in time of travel. This shows the scale of the disruption and particularly suppressed travel caused by the loss of the connection.

The I-35W provided for 19.3% of river crossing traffic (Zhu, S., et al, 2010), and hence its collapse would have impacted on network congestion in the area. However, one month after the collapse the average commute time had only increased by 8% (including the time lost due to the loss of directness in travel) suggesting that congestion was not significantly worse.

3. Current Situation

3.1. Existing Bridges

As discussed in the Section 1, Brisbane currently has ten river crossings, spread over a direct distance of 29.5 km, five of these bridges and the majority of the lanes are clustered around the CBD. This excludes the Eleanor Schonell Bridge as it allows no private vehicle traffic. The location of the current bridges is shown in green on the Figure 2 below.

Figure 2: Existing Bridges

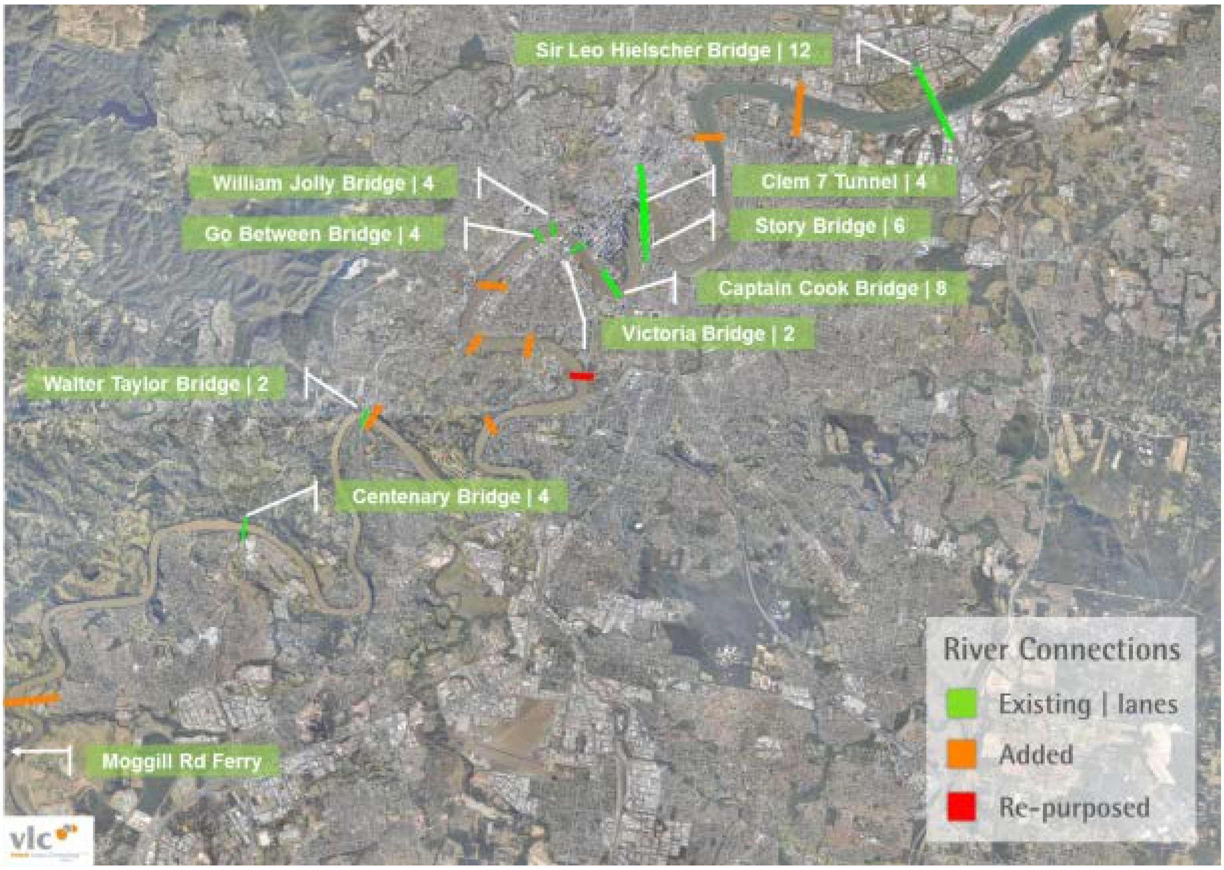


Image background source: Nearmap 2011

As Table 1 indicates, since the Centenary Bridge opened in 1964, only the Sir Leo Hielscher Bridge (built in 1986) has provided an additional private vehicle river crossing in a significantly new location (the bridge was originally 6 lanes and widened to 12 lanes in 2010). As already mentioned, the remaining new crossings opened in 2010 (Go Between Bridge and Clem7 Tunnel) and both are in very close proximity to existing bridges. It should be noted that all the crossings built since 1986, including the Sir Leo Hielscher Bridges, are tolled.

Table 1: Brisbane River Crossings

Bridge	Year Opened	Private vehicle traffic
Sir Leo Hielscher (widening)	2010	Yes
Go Between	2010	Yes
Clem 7 Tunnel	2010	Yes
Kurilpa	2009	No
Eleanor Schonell	2006	No
Goodwill	2001	No
Jack Pesch	1998	No
Sir Leo Hielscher	1986	Yes
Merivale	1978	No
Captain Cook	1972	Yes
Victoria	1969	Yes
Centenary	1964	Yes
Indooroopilly Railway	1957	No
Story	1940	Yes
Walter Taylor	1936	Yes
William Jolly	1932	Yes
Albert	1895	No

Source: Wikipedia (2013)

3.2. Traffic Crossing the River

Table 2 shows average weekday daily traffic (AWDT, defined here as AWDT during school and university term time) counts for 2012 for Brisbane's existing river crossings, split by those that are close to the CBD and those that are external to the CBD. The table shows that 54% of vehicles crossing the river do so at the crossings in the CBD area. This proportion is very similar to the distribution of river crossing lanes, as highlighted in the chapter 1.

Table 2: 2012 Daily River Crossing Counts

	River crossing	Vehicle trips
CBD area	Story Bridge	96,800
	Captain Cook Bridge	141,700
	Victoria Bridge	16,300
	William Jolly Bridge	36,100
	Go Between Bridge	13,500
External	Sir Leo Hielscher Bridge	111,800
	Centenary Bridge	86,400
	Clem7 Tunnel	24,800
	Walter Taylor Bridge	31,800
	Moggill Road Ferry	1,100
Totals	CBD	304,300
	External	255,900
	Total	560,200

Source: AWDT 2012 DTMR counts | 08/05/2012 - 14/05/2012

4. Hypothetical Situation

4.1. Proposed Bridges

For this study, nine hypothetical crossings and two potential upgrades (ferry to bridge, and Eleanor Schonell Bridge to private vehicle use) are proposed and tested. The proposed bridges can be seen in orange in Figure 3.

The locations of these bridges are intended to provide a spatial spread of river crossings. Hence they were usually located where current crossings do not exist.

As the new bridges are designed to provide additional crossing locations rather than increase the crossing capacity, they are all assumed as low standard two or four lane roads with capacities ranging from 600 to 800 vehicles per lane per hour depending on their location and the surrounding infrastructure. The proposed four lane bridges are the Hamilton and St Lucia Bridges, an assumption based on preliminary research of the demand for those crossings.

The lower standard of the bridges as well as minimal change to existing infrastructure was adopted to ensure a minimal impact on the surrounding local networks. This was important as many of the tested bridges are located in residential areas where excess additional traffic could have negative impacts.

The only bridge with extensive change to current infrastructure is the Eleanor Schonell Bridge which is currently only bus, walk and cycle access. Bearing in mind the sensitivity of a new road connection to the University of Queensland, the bridge was not connected to Sir William Macgregor Drive (the university ring road) so as not to interfere with the university's road network. Instead, the bridge access road was connected to the Sir Fred Schonell Drive university access roundabout to enable both access to the University from the east as well as bypass the university. This connection could be achieved through a "cut and cover" access tunnel that skirted around the university buildings.

Figure 3: New Crossings

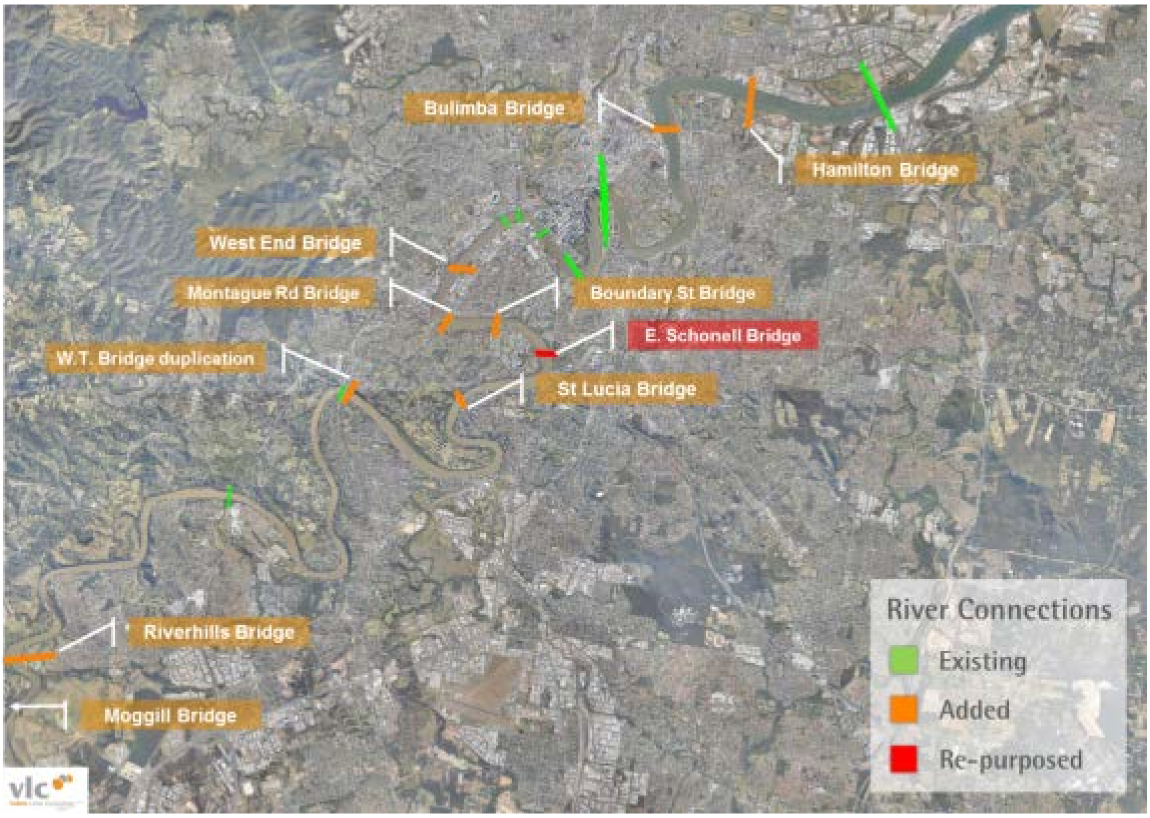


Image background source: Nearmap 2011

5. Past Studies

Many of the bridges included in this research are based on crossings proposed in previous studies. Some of these are outlined here.

5.1. Toowong and West End Area Studies

Past studies have suggested a new bridge linking Toowong to West End. The South Bank Redevelopment studies (starting after the World Expo in 1988) looked at a new bridge that linked Toowong to West End, to increase accessibility to South Bank (Transfield Cameron McNamara, Westpac & Beard & Holland, 1987).

The Proposal for the Toowong – South Brisbane Arterial (Bornhorst Ward Veitch, 1989) also recommended a Toowong to West End Bridge in the same location. This bridge would have linked to Vulture Street providing an alternate route to going through the CBD.

This bridge was included in this research.

5.2. Brisbane Transportation Study

The Brisbane Transportation study (Wilbur Smith and Associates, 1965), as commissioned under Clem Jones, proposed 5 new bridges, including:

- Centenary Bridge | built
- St. Lucia Bridge
- Merivale Bridge | built and named Go Between Bridge
- Point Bridge | built and named Captain Cook Bridge
- New Farm Bridge

Of these bridges three have been built, however two, that would provide crossings in substantially new locations, have not. The St. Lucia Bridge has been included in this research in the same location as in the Wilber Smith Study, but the New Farm Bridge has not. This is because the Bulimba Bridge, which is included in this study, serves a similar purpose.

6. Modelling Analysis

6.1. The Zenith Model

To study the impact of the new bridges, the Zenith Travel Model, which covers the entire South-East Queensland (SEQ) and Northern New South Wales with 3973 travel zones, was used. Zenith is a multimodal large-scale 4-step strategic transport model that integrates all forms of travel. The model has been implemented in the OmniTRANS software package and currently operates in 8 Australian cities and regions. The model uses enhanced modelling techniques for public transport and toll choice simulation with accurate forecasts proven on major infrastructure projects in Australia.

6.2. Methodology

For this study 19 model runs were performed. This included tests of individual bridges as well as scenarios which combined multiple bridges.

All scenarios were performed for the year 2016, including forecast demographic, road and public transport networks.

Two demand (i.e. trip matrix) scenarios were tested. The demand scenarios are discussed in more detail in the following chapters.

6.2.1. Demand Scenario 1: Based on 2016 Network

The purpose of this scenario was to analyse the impact of the bridges on traffic route choice while keeping overall travel patterns unchanged. The travel patterns (OD trip matrices by mode and time) were based on accessibility levels in the 2016 network with current bridges only. The resulting trip matrices were assigned into the following options:

- Base – 2016 network with no added bridges;
- Option I – All new bridges;
- Options II – Individual bridges.

The first option (Base) provides the base to which the tests with the bridges are compared to. Although the Option I is unlikely to happen, it provides important information about the maximum benefit to Brisbane road network gained from implementing all the new river crossings at once. The tests of individual bridges enabled evaluation of benefits the proposed bridges would deliver; assuming only one of the bridges was built.

6.2.2. Demand Scenario 2: Based on 2016 Network with the New Crossings

In comparison to the Scenario 1, this scenario was designed to test the impact of changes in trip patterns as result of all the bridges being built. This includes, for example, people switching destinations, i.e. changing jobs or shopping in different shopping centres to take advantage of the new accessibility options. To limit the number of model runs, only the impact of all the assumed bridges was tested (further referred to as Option III) and compared to the corresponding model runs in Scenario 1 (Base and Option I).

This scenario represented Brisbane travel once drivers had adapted to the new bridges and the effects that they had on the utilisation of the entire network. This resulted in additional and different trips on the network as users adapted their travel to the additional network capacity and increased connectivity.

6.3. Existing bridges (Base)

The performance of the existing bridges was assessed using the trip matrices with no change in overall travel patterns (Demand Scenario 1) and network with only existing river crossings for 2016.

6.3.1. Performance of existing river crossings

Table 3 below shows the performance of the modelled traffic crossing the river in 2016 over an average week day. This includes the following:

- Average time in minutes per trip;
- Additional kilometres travelled as result of the limited number of river crossings (compared to the direct distance between the origin and destination;
- The average network distance travelled per trip (km);
- The average direct (or "as the crow flies") distance per trip (km).

The table highlights – as expected – that the longest trips use the Sir Leo Hielscher Bridges and Centenary Bridge. The Victoria Bridge – based on the location and the demand it serves, has the smallest difference between the average network distance and direct distance, while the difference for other bridges ranges between 3.2 to 10.9. Not surprisingly, the Walter Taylor Bridge has the biggest percentage difference (47%) between the average network distance and direct distance, excluding the Moggill Rd Ferry from this analysis due to low volumes.

As a result, that traffic crossing the river must travel an extra 6.9 km over a direct route on average. This figure is considerably greater that the value for traffic that does not cross the river, which is only 2.6 km.

Table 3: Average Daily Performance of Existing River Crossings (Base)

River crossing	Average Minutes per trip	Extra Kms per trip	Average Kms per trip	
			Model	Direct
Sir L. Hielscher Bridges	48	10.8	47.8	37.0
Clem7	38	5.8	29.8	23.9
Story Bridge	23	4.0	15.4	11.3
Captain Cook Bridge	30	4.7	22.7	17.9
Victoria Bridge	10	1.3	5.0	3.8
William Jolly Bridge	21	3.2	12.4	9.2
Go Between	22	3.7	13.3	9.6
Walter Taylor Bridge	25	4.5	13.9	9.5
Centenary Bridge	45	10.1	37.5	27.4
Moggill Rd Ferry	42	10.9	25.7	14.8
Non-croissing	13	2.6	9.5	6.8
All river crossings	35	6.9	29.0	22.1
Total	14	2.9	10.7	7.8

6.3.2. Impact of Existing Crossings on the Network

The Captain Cook Bridge serves as an excellent example of the inefficient road use that is caused by the grouping of Brisbane's river crossings. Figure 4 below is an image of traffic using the Captain Cook Bridge only. This image shows that a significant amount of traffic which crosses the river using that bridge, comes from, or goes to, areas that are a considerable distance from the bridge its self, but still along the river.

Figure 4: Daily Traffic Using Captain Cook Bridge Only

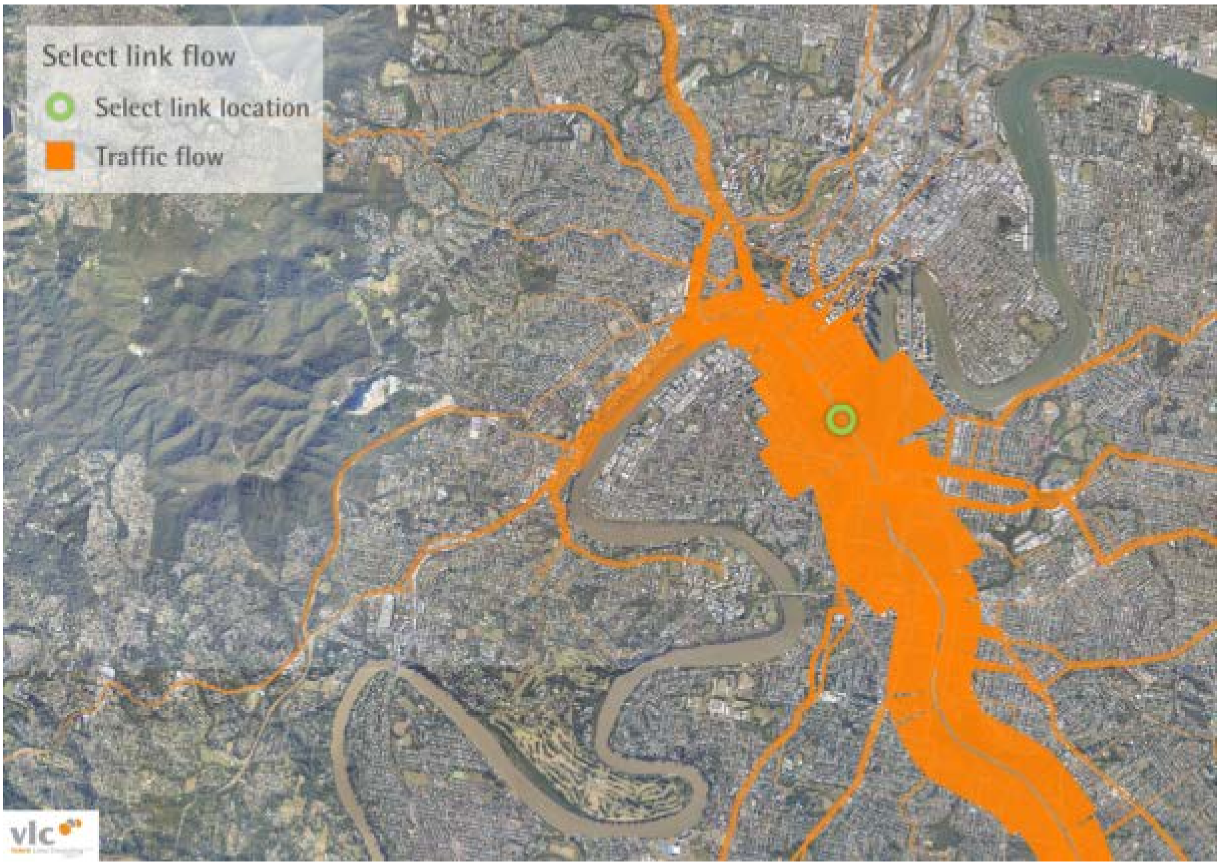
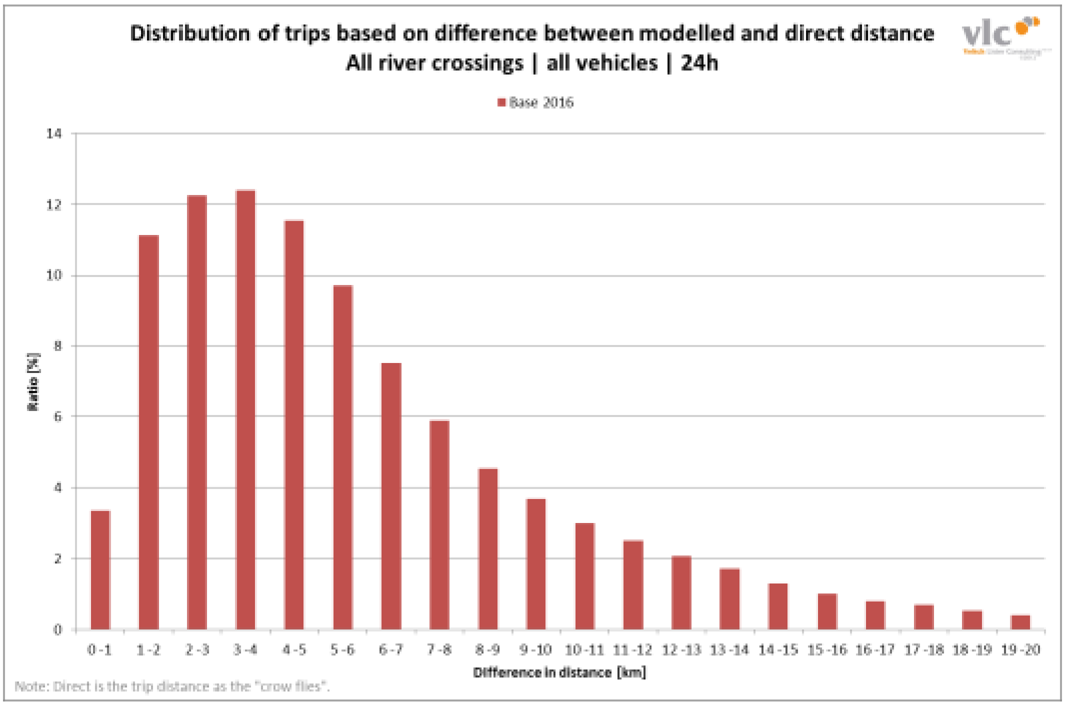


Image background source: Nearmap 2011

6.3.3. Distribution of extra trip length

By comparing the actual distance travelled as predicted by the model to “as the crow flies” distances for each trip it is possible to analyse the additional distance that drivers must travel to reach their destination using the given road network. Figure 5 shows this extra distance distributed by the additional distance travelled for trips crossing the river. The majority of trips influenced by the additional distance resulting from limited river crossing points travels 2 to 5 kilometres more on average.

Figure 5: Distribution of Extra Trip Length (Base)



6.4. Impact of All Proposed Bridges (Option I)

This chapter describes the performance of the network assuming all the bridges are built, and fixed demand matrices are used as discussed in chapter 5.2.1.

6.4.1. Performance of New River Crossings

With all the new bridges added to the network the usage of the road network changes considerably, with 142,100 vehicles using the new bridges per weekday. This has also had a significant and positive impact on the current river crossings (see Table 4), where traffic on the key existing river crossings (Sir Leo Hielscher, Story Bridge and Captain Cook Bridge) reduces between 9 to 19 per cent. Although the biggest impact is on the Walter Taylor Bridge, this is due to the new bridge being assumed to be built next to the existing one, to serve Oxley Rd traffic (see Figure 3).

The significant increase in average travel time and distance seen on the Sir Leo Hielscher Bridge is caused by an increase in longer trips using the crossing as a result of additional capacity provided by re-routing of the shorter trips onto the proposed new crossings, such as Hamilton and Bulimba Bridges.

Furthermore, the new bridges result in a saving of 23,200 vehicle hours and a reduction of 324,200 vehicle kilometres across the entire SEQ region (the modelled network). The new bridges also reduce the average river crossing trip time by 1.55 mins (4.4%) and the average extra trip length (compared to “as the crow flies”) by 0.5 km (7%).

Table 4: Comparison of Daily Trips and Performance of Existing Bridges (Option I to Base)

River crossing	Vehicle trips	Average Minutes per trip	Extra Kms per trip
Sir L. Hielscher Bridges	-12%	5%	4%
Clem7	-14%	1%	-2%
Story Bridge	-19%	-6%	-14%
Captain Cook Bridge	-9%	-6%	-14%
Victoria Bridge	0%	-3%	-5%
William Jolly Bridge	-14%	1%	-8%
Go Between	-34%	2%	-12%
Walter Taylor Bridge	-53%	-14%	-18%
Centenary Bridge	-3%	-2%	-3%

The Table 5 summarises the daily trips and performance of the new bridges. The Hamilton Bridge carries the highest number of vehicles (about 26,300 vehicles a day in both directions) followed by West End Bridge (about 19,100 vehicles a day). It has to be noted that the volume on Hamilton and St Lucia Bridges is impacted by the assumed specification of those crossings, which is four lanes (see Chapter 3.1 for more information). The relatively high difference between average travelled and direct distance for the new bridges is caused by using the trip patterns, which are based on a network with current crossings only (as discussed in Chapter 5.2.1). The impact of using the revised travel pattern (Scenario 2) is shown in Table 7.

Table 5: Daily Trips and Performance of New Bridges

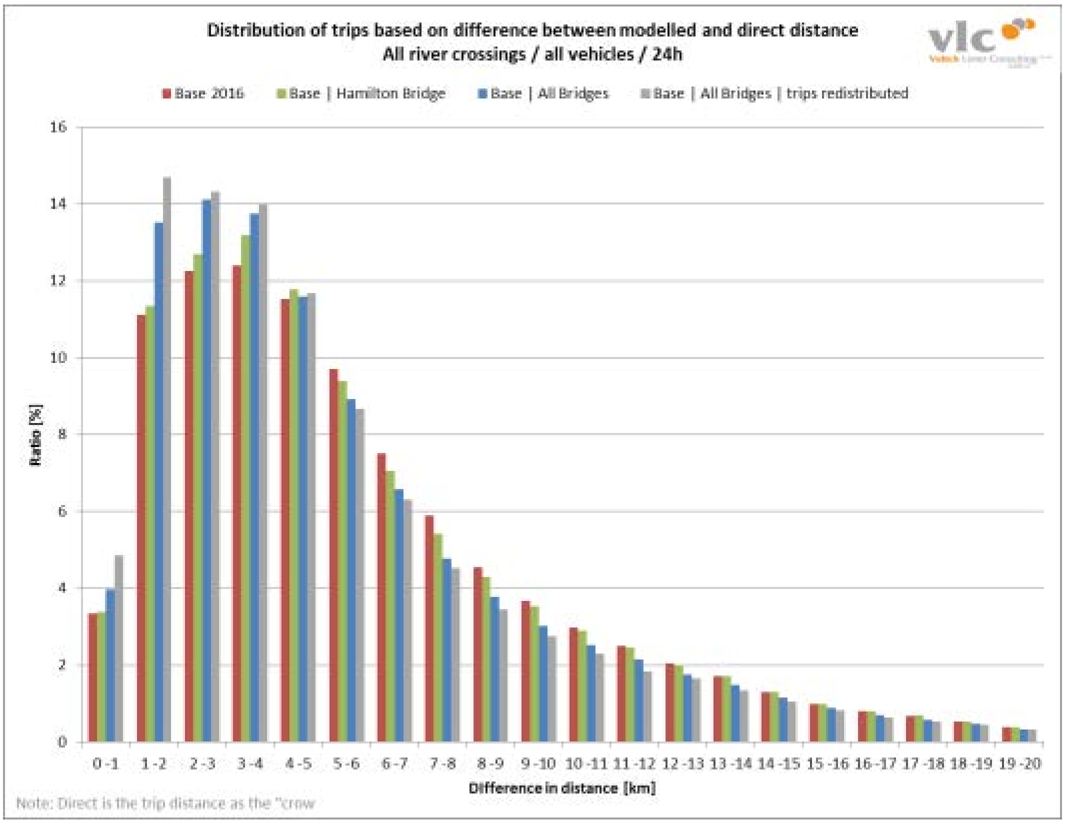
New bridges	Vehicle trips	Average Minutes per trip	Extra Kms per trip	Average Kms per trip	
				Model	Direct
Hamilton Bridge	26,300	29	6.2	22.9	16.7
Bulimba Bridge	14,600	19	3.1	11.5	8.4
West End Bridge	19,100	22	3.8	14.9	11.1
Montague Rd Bridge	7,700	21	3.5	13.2	9.7
Boundary St Bridge	9,800	22	3.2	13.6	10.3
E. Schonell Bridge	16,900	30	4.5	21.4	17.0
St Lucia Bridge	15,900	28	5.0	18.6	13.6
W.T. Bridge duplication	16,800	21	3.7	13.1	9.4
Riverhills Bridge	8,400	32	6.7	22.0	15.3
Moggill Bridge	6,600	34	9.2	29.1	19.9
Non-croissing	9,653,500	13	2.6	9.4	6.8
All river crossings	667,200	33	6.4	28.2	21.8
Total	10,320,700	14	2.9	10.6	7.8

Note: Direct is the trip distance as the "crow flies".

6.4.2. Distribution of extra trip length

For easier comparison, the chart on Figure 6 shows not only the distribution of the unnecessary or extra travel in the Option I, but also the Base, the Option II with Hamilton Bridge only and Option III (i.e. network with all bridges with the revised trip pattern). This chart indicates that the additional bridges increase the portion of trips with lesser extra distance, and hence decrease the portion of trips with greater extra distances. This means that the proposed bridges serve their purpose, and reduce the unnecessary extra distance that trips crossing the river are forced to travel.

Figure 6: Distribution of extra trip length in different scenarios



6.4.3. Impact of New Crossings on the Network

The above distribution graph show that the new bridges have the intended effect of reducing the unnecessary detours that drivers must take to when crossing the Brisbane River. However, the new crossings also benefit those who do not use the new bridges by allowing the road network to be used more efficiently.

Figure 7 highlights - similar to Figure 4 - volumes on the Captain Cook Bridge with all the new bridges in place. It shows considerable volume reductions over much of the select link. Significantly, the southern half of Coronation Drive, the Western Freeway, Sir Fred Schonell Drive, and Moggill Road now see almost no traffic from the Captain Cook Bridge. This suggests that traffic is re-routing to more efficient new bridges (especially West End, Montague Rd and Eleanor Schonell Bridges), and reducing unnecessary travel through the CBD area.

Figure 7: Comparison of Daily Traffic Using Captain Cook Bridge Only (Option I to Base)

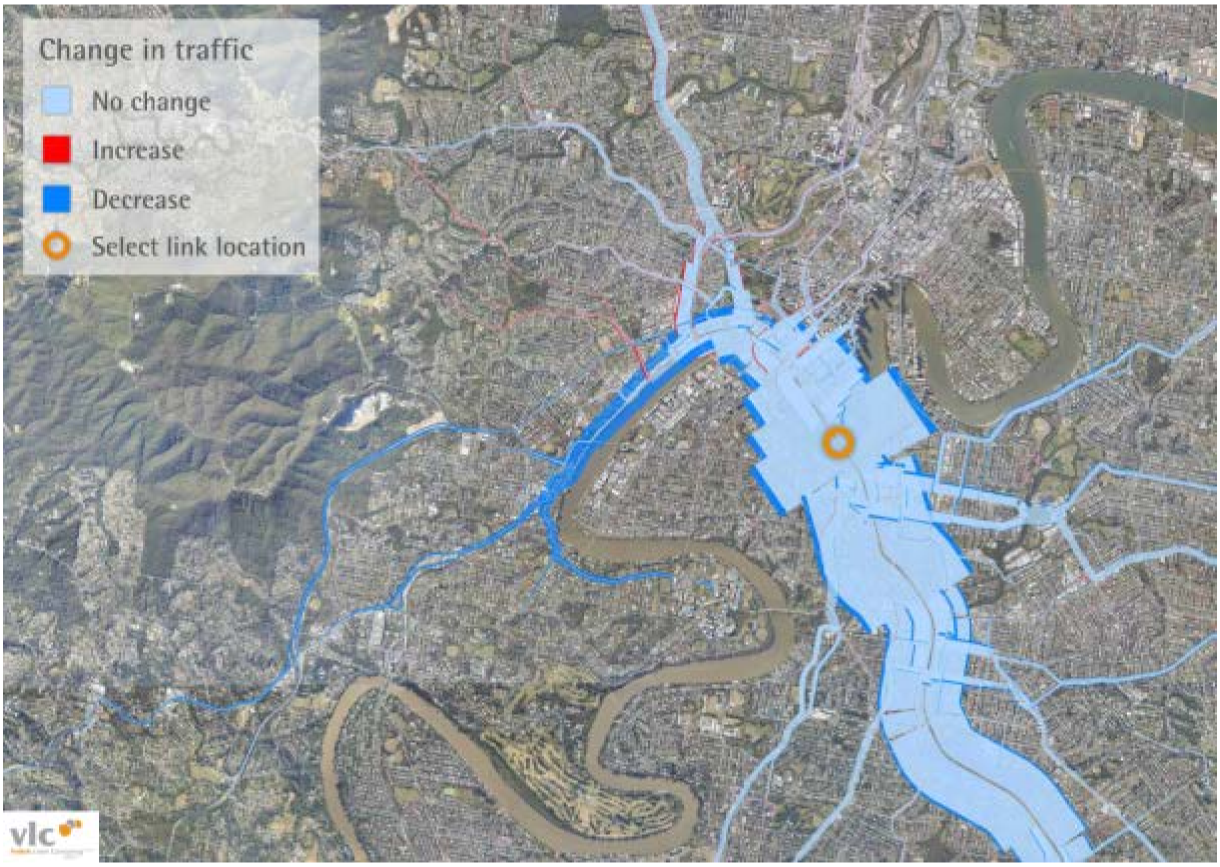


Image background source: Nearmap 2011

Figure 8 shows the impact of all new bridges on the Brisbane network. It highlights the expected reduction on existing bridges, and corresponding traffic on the new crossings. The image also shows a decrease in the usage of the much of the infrastructure in and around the CBD, and to the west of the CBD.

Of particular note is the reduction on Coronation Drive, Sir Fred Schonell Drive, and Moggill Road, each of which currently experience considerable congestion. This matches with the select link plot of the Captain Cook Bridge which showed that traffic was no longer using the bridge to reach these roads. This also shows that this traffic would not need to use these roads if alternative crossings were available.

Another important change is the reduction in traffic on Grey Street, Merivale Street, and Cordelia Street in South Brisbane. This change illustrates another area where traffic is forced to travel through an inner city area to cross the river due to the conglomeration of bridges.

Figure 8: Comparison of Daily Traffic (Option I to Base)

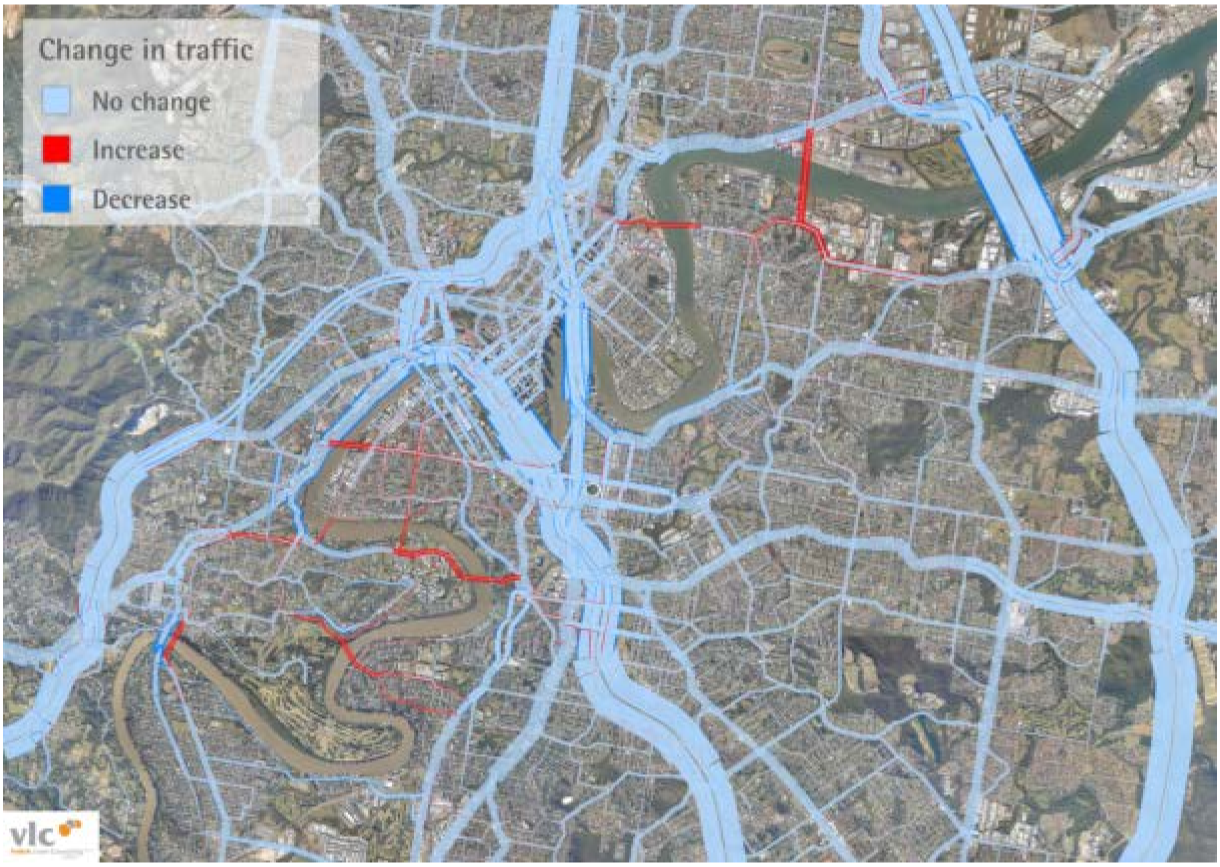


Image background source: Nearmap 2011

6.5. Impact of Individual Proposed Bridges (Options II)

Table 6 below presents a summary of key performance indicators as a result of implementing each bridge individually. The bridge volumes are higher in this summary, than was reported earlier in Table 5 which assumed all bridges co-existing. This suggests that some of the bridges may cater to overlapping traffic (such as West End Bridge, Montague Rd Bridge and Boundary St Bridge).

The Hamilton Bridge carries the most traffic, at over 31,000 vehicles per day followed by the West End and St Lucia Bridges.

Each bridge results in a significant reduction in the total 24 hour vehicle kilometres and vehicle hours across the network in comparison to the Base. The biggest distance change was caused by the Boundary Street Bridge, with a reduction of almost 100,000 vehicle kms, while the addition of the St. Lucia Bridge resulted in a saving of over 6,500 vehicle hours.

Table 6: Daily Trips and Difference in Performance (Options II to Base)

River crossing	Vehicle trips	Change against Base	
		Vehicle Kms	Vehicle Hrs
Base | Hamilton Bridge	31,200	-56,600	-2,600.0
Base | Bulimba Bridge	17,400	-55,400	-3,200.0
Base | West End Bridge	27,000	-70,100	-3,000.0
Base | Montague Rd Bridge	21,200	-85,800	-3,300.0
Base | Boundary St Bridge	20,300	-98,900	-4,000.0
Base | E. Schonell Bridge	24,500	-91,400	-5,300.0
Base | St Lucia Bridge	26,600	-92,000	-6,500.0
Base | W.T. Bridge duplication	20,100	-8,800	-1,900.0
Base | Riverhills Bridge	9,600	-29,400	-3,700.0
Base | Moggill Bridge	8,500	-5,900	-3,000.0

All of the above scenarios assume fixed demand matrices, and the effect of destination / mode switching is not taken account of. The impact of the revised trip pattern as the result of the new bridges is discussed in the next section.

6.6. Impact of All Proposed Bridges with Revised Trip Pattern (Option III)

Table 7 shows the impact of the new bridges when trips are redistributed as discussed in the Chapter 5.2.2. This represents the situation after people have been able to adjust their travel patterns to suit the network with the new bridges. This shows a further reduction in the extra kilometres for river crossing trips per trip by 4% (6.1 km compared to 6.6 km in the Base, or 6.4 km in the Option I). This is likely due to people adjusting their destinations and travel to take advantage of the new crossings. It also shows an increase in the usage of the new bridges and a 12% increase in the number of trips crossing the river.

It should be noted that although the traffic growths on the existing crossings, it does not exceed the volume as predicted in the Base network. The growth in comparison to the Option I is likely caused by the increased capacity on the existing crossings as result of the new bridges in comparison to the Base, which makes the existing crossings more attractive again.

The Montague Rd, Riverhills and St Lucia Bridges attract the highest growth in trips and reduction of extra time and distance travelled as result of the change in trip pattern. On contrary, the Hamilton Bridge remains the most well used new bridge with almost 34,000 vehicles per day in both directions.

Table 7: Comparison of Daily Trips and Performance of New Bridges (Option III to Option I)

River crossing	Vehicle trips	Average Minutes per trip	Extra Kms per trip
Sir L. Hielscher Bridges	4%	-1%	1%
Clem7	5%	0%	2%
Story Bridge	6%	3%	3%
Captain Cook Bridge	3%	2%	2%
Victoria Bridge	1%	5%	2%
William Jolly Bridge	3%	2%	1%
Go Between	8%	5%	3%
Walter Taylor Bridge	18%	4%	0%
Centenary Bridge	2%	1%	0%
New bridges			
Hamilton Bridge	28%	-16%	-19%
Bulimba Bridge	27%	-14%	-23%
West End Bridge	23%	-6%	-10%
Montague Rd Bridge	95%	-19%	-23%
Boundary St Bridge	45%	-9%	-15%
E. Schonell Bridge	34%	-8%	-14%
St Lucia Bridge	57%	-11%	-13%
W.T. Bridge duplication	12%	1%	-2%
Riverhills Bridge	82%	-19%	-24%
Moggill Bridge	40%	-8%	-9%
Non-croissing	-1%	0%	0%
All river crossings	12%	-3%	-4%
Total	0.1%	1%	1%

Note: Direct is the trip distance as the "crow flies".

6.7. Economic Analysis

In order to more completely understand the benefits gained by adding the additional bridges, an economic analysis using Consumer Surplus was performed. The total benefits are composed of Travel Time Savings, Vehicle Operation Costs (VOC), Accidents and Emissions and are expressed in monetary units [$]. The Table 8 shows the benefits of the Option I (All Bridges) and Options II (individual bridges) in comparison to the Base. It is no surprise that the Option I provides the biggest total benefits of almost $706,200 thousand a week day. From the individual new bridges, the biggest benefits are provided by St Lucia Bridge followed by Eleanor Schonell Bridge. Interestingly, Hamilton Bridge has the second lowest total benefits (after duplication of Walter Taylor Bridge), although it carries the highest volume of all the new bridges.

Table 8: Economic Analysis of Option I and Options II to Base (Dollar Benefits, per week day)

		All Bridges	Hamilton Bridge	Bulimba Bridge	West End Bridge	Montague Rd Bridge	Boundary St Bridge	E. Schonell Bridge	St Lucia Bridge	W.T. Bridge duplication	Riverhills Bridge	Moggill Bridge
Consumer surplus [h]	Travel time savings | car	28,300	3,100	3,900	3,700	4,000	5,000	6,500	8,000	2,300	4,500	3,800
	Travel time savings | CV	1,700	300	200	300	200	300	400	500	100	200	200
	Total [h]	***30,000***	***3,400***	***4,100***	***4,000***	***4,200***	***5,300***	***6,900***	***8,500***	***2,400***	***4,700***	***4,000***
Consumer surplus [$]	Travel time savings | car	372,700	40,800	51,400	48,700	52,700	65,900	85,600	105,400	30,300	59,300	50,000
	Travel time savings | CV	71,700	12,600	8,400	12,600	8,400	12,600	16,900	21,100	4,200	8,400	8,400
	Total [$]	***444,400***	***53,400***	***59,800***	***61,300***	***61,100***	***78,500***	***102,500***	***126,500***	***34,500***	***67,700***	***58,400***
VOC [$]	Benefits | Car | Freeway	63,200	20,800	9,800	8,500	10,800	9,200	12,500	20,100	4,800	4,000	2,000
	Benefits | Car | Non-freeway	70,600	-8,400	14,500	12,100	13,400	21,200	24,200	14,000	1,700	12,000	10,800
	Benefits | CV | Freeway	37,800	17,400	3,000	2,400	4,000	3,100	5,100	8,400	3,200	2,300	1,700
	Benefits | CV | Non-freeway	44,200	-2,200	10,100	10,600	9,100	10,700	13,600	12,600	2,100	6,000	5,300
	Total [$]	***215,800***	***27,600***	***37,500***	***33,600***	***37,200***	***44,200***	***55,500***	***55,000***	***11,800***	***24,300***	***19,800***
Accidents [$]	Benefits | Car	17,700	-1,900	4,400	3,000	3,500	5,500	6,400	4,200	600	3,600	2,000
	Benefits | CV	1,700	200	300	300	300	300	400	400	100	300	200
	Total [$]	***19,300***	***-1,700***	***4,700***	***3,300***	***3,800***	***5,800***	***6,900***	***4,500***	***600***	***3,800***	***2,200***
Emissions [$]	Benefits | Car	17,300	2,000	2,600	2,400	2,700	3,300	4,200	4,800	1,200	2,500	2,200
	Benefits | CV	9,300	1,700	1,400	1,600	1,500	1,600	2,200	2,500	600	800	800
	Total [$]	**26,700**	**3,800**	**4,000**	**4,000**	**4,200**	**4,900**	**6,400**	**7,400**	**1,800**	**3,300**	**3,000**
	Total benefits [$]	**706,200**	**83,100**	**106,000**	**102,200**	**106,300**	**133,400**	**171,300**	**193,400**	**48,700**	**99,100**	**83,400**

The results of the economic analysis for Option II were not provided in the interests of brevity.

7. Discussion

7.1. Limitations of this study

This study has two major limitations. The first is its use of a single city as a case study, the second is that it lacks comparisons with other infrastructure projects.

Brisbane provides an excellent case study for the comparison of conglomerated verses well-spaced river crossings, due to the prominence of the river in the city, the spread of the city on both sides of the river, and the positioning of its current crossings. However, the focus on only one city as a case study limits the generalizability of this paper's findings.

It must be recognised that the river crossings proposed here would have a significant cost, and would only be considered in comparison to other possible projects. However, this paper does not seek to make specific recommendations as to future infrastructure projects, and hence an analysis of the potential cost of the projects presented here is considered out of the scope of this paper

7.2. Topics for further study

It would be beneficial to further test the theory presented here, in other cities that are separated by a mobility barrier. This could be done using the same methodology on a similar city or by removing bridges in a city with many well-spaced bridges. Such research would considerably improve the generalizability of the findings presented in this study.

This research could also easily be continued in more detail in Brisbane City. This could include further research into the feasibility of the bridges presented here or the study of other similar projects. This would allow for comparison with other infrastructure projects, which was lacking in this study.

8. Conclusions

The purpose of this paper is to analyse the benefit gained from providing well-spaced crossings over mobility barriers, such as rivers, in cities.

Brisbane City was chosen as a case study due to the highly conglomerated nature of its river crossing capacity, and the authors' familiarity with the area. The findings of this study are consistent with Braid, R. (1989) and are applicable to any city that is divided by a mobility barrier, such as the rivers in many Australian and international cities.

As part of the study, ten new spatially separated bridges were tested and evaluated using the Zenith strategic transport model. The modelling results presented above suggest that the conglomeration of bridges around Brisbane's CBD is resulting in inefficient use of the road network.

The criteria used to evaluate the benefit gained from the new bridges were actual daily traffic, travelled distance and time loss, and Economic analysis using Consumer Surplus.

Based on the outcome, the St Lucia Bridge provides daily total benefits of $193,400, saving of 6,500 vehicle hours and is used by 26,600 vehicles. The Boundary St Bridge provides total daily benefits of $133,400 a day, saving of 98,900 vehicle kilometres and is used by 20,300 vehicles. On the other side, the modelling indicates that the Hamilton Bridge only provides daily total benefit of $83,100, but carries about 31,200 vehicles which is the highest volume of all tested bridges.

These results show that the addition of the new bridges resulted in considerable benefit for road users. These benefits resulted partly from increased capacity, but, as this paper shows, also from optimising the network, and how it is used. This means that while the bridges are Brisbane specific, the principle that providing well-spaced crossings, to mobility barriers, improves network efficiency is generally applicable.

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